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Ship design-knowledge in early modern Europe:

Royal yachts and the shared knowledge of ship-designers and common shipwrights.

by

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Thesis for the degree of Doctor of Philosophy

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ABSTRACT

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SHIP DESIGN-KNOWLEDGE IN EARLY MODERN EUROPE:

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The initial objective of this thesis aimed at comparing the performance characteristics of two yachts belonging to King Charles II of England during the latter years of the 17th century. This goal, which called for accurate modelling of the shape of each yacht, was extended to investigate the design processes used by Dutch and English shipwrights of the period. It was soon decided that, instead of focusing on the performance of each ship or, more precisely, of their theoretical – therefore questionable– reconstruction, this research would focus on the design knowledge of the early modern period used to design the different yachts and contemporary ships. This was necessary, firstly, as a means of helping with the theoretical reconstruction which was one of the initial aims of the research. But, most importantly, it was necessary to produce a picture of the knowledge-space in which ships of this period were designed and built. Consequently, this research offers an overview of the current narrative that describes ship design knowledge of the early modern period and criticises some aspects of it. Moreover, as the current understanding of such knowledge is included within a longer narrative that describes ship design knowledge of shipwrights from the earliest known examples of ships to the present, this research also looks into the manner in which ship design knowledge is understood within such a long narrative. This research provides arguments to show that ship design knowledge could be re-defined. It provides a more nuanced description of the design knowledge of traditional shipwrights and includes the knowledge of early modern shipwrights within this re-modelled narrative.

Table of Contents

List of Tables

- The tables mentioned in this volume are all included in Volume 2

List of Figures

- The figures mentioned in this volume are all included in Volume 2

List of Abbreviations

CSPD	Calendar of State Papers Domestic

List of Accompanying Materials

- Attached to Volume 1 of this thesis, the reader will find a DVD containing ship design treatises of the 17^{th} and 18^{th} century which have been used in this research. It should allow the reader to contrast the contents of the treatises with their interpretation in this thesis.

DECLARATION OF AUTHORSHIP

I, Juan-Pablo Olaberria, declare that this thesis and the work presented in it are my own and has been generated by me as the result of my own original research.

Ship design-knowledge in early modern Europe: Royal yachts and the shared knowledge of ship-designers and common shipwrights.

I confirm that:

1. This work was done wholly or mainly while in candidature for a research degree at this University;
2. Where any part of this thesis has previously been submitted for a degree or any other qualification at this University or any other institution, this has been clearly stated;
3. Where I have consulted the published work of others, this is always clearly attributed;
4. Where I have quoted from the work of others, the source is always given. With the exception of such quotations, this thesis is entirely my own work;
5. I have acknowledged all main sources of help;
6. Where the thesis is based on work done by myself jointly with others, I have made clear exactly what was done by others and what I have contributed myself;
7. None of this work has been published before submission

Signed: ....

Date: ....

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Next I must express my gratitude to my colleague Thomas Dhoop for his always constructive input and enlightening discussions during the five years that we have shared our common interest in ships. His comments and suggestions to an earlier draft of this thesis have also been very helpful. Other colleagues at the university deserve to be thanked as well. Rodigo Ortiz for his help in obtaining documents from the Naval Museum in Madrid, Spain. Felix Pedrotti for his translation of several sections of Furttenbach's treatise from the original German. I should also thank Jaap Luiting for translating a whole chapter of Van Yk's treatise from the original Dutch and for the productive exchange of ideas that followed our first communication by email. Also, Rolf Warming helped by providing a quick translation of 18th century Danish documents used in this research. Also, I must thank Pat Tanner. It is during the week-long meeting of maritime archaeologists organised by Pat in Baltimore, Ireland, that some of the ideas which have seen the light in these thesis took shape.

I would also like to express my gratitude to Iñaki Olaizola who has inspired me and encouraged me to pursue this research.

Finally, I would like to dedicate this work to my wife, Ana, and our children, Amaia, Mikel and Helene. I must thank them for their support and patience, and for allowing me to spend endless hours at my desk when my attention should have been directed to them.

Chapter 1: Introduction

One of the most repeated ideas in studies of past shipbuilding traditions is that ships and boats are one of the most complex artefacts ever built.[1] One reason for such complexity would be the medium in which ships and boats are used: the water. In contrast to a building or other human-made structures that perform in a relatively stable environment, ships must survive in a medium that constantly changes due to the weather and other environmental conditions. If practical requirements are taken into account, the first requirement for a ship is that it must have sufficient buoyancy to support its own weight and any additional load carried by it. Until the adoption of mechanical propulsion ships, mainly, relied on sails as a means of propulsion. This brings with it a second requirement: the ship has to be able to remain upright in opposition to the forces created by the sails that try to capsize it. To further increase the complexity of the ship as a technological artefact, it must be made strong enough to survive the variable and often unpredictable environment. But not too strong or else the weight of the over-engineered structure could render it useless. In summary, in order for this complex human-made artefact, the ship, to be of any use, it must be made in such a way that it performs in a suitable manner. It must float, it must stay upright and it must be strong enough to survive the forces imposed by wind and waves during its operation. There are, obviously, more requirements from a ship. For example, it must move through the water efficiently, or at least in an expected manner with the rigs and/or manpower available.

However, ships are not just floating platforms with a purely practical goal. Therefore, in addition to the techno-practical complexities mentioned above, ships present other aspects that add to their complexity and increase their interest as a means to gaze into the minds of past societies responsible for their construction. For example, ships are often built with an economic goal. This makes them a suitable material of study to learn about socio-economic relations in the past.[2] Also, ships can be understood as the materialisation of the aspirations of a society working within physical and metaphysical constraints,[3] thus, they are useful to study technological development

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[1] Adams, J. 2013. *A Maritime Archaeology of Ships. Innovation and Social Change in Medieval and Early Modern Europe.* Oxford: Oxbow books, p. 11; Maarleveld, T.J. 1995. Type or technique. Some thoughts on boat and ship finds as indicative of cultural traditions. *International Journal of Nautical Archaeology*, 24(1), p. 3; Muckelroy, K. 1978. *Maritime Archaeology*. Cambridge: Cambridge University Press, p. 3.

[2] Unger, R. W. 1980. *The Ship in the Medieval Economy 600-1600*. London: Croom Helm.

[3] Adams. *A Maritime Archaeology of Ships*, p. 23.

as part of wider processes of social change.[4] Lastly, due to their relatively small size, the social divisions and social relations on board may be different to those of land-based societies. Thus, the study of interior arrangements within ships can be used to learn about such social interactions on board which, in turn, can help define the social landscape in land.[5] These examples illustrate that far from being a sailing machine that can be studied from a practical point of view only, ships can be used to explain wider aspects of human nature. However, this research started with a strong techno-practical outlook.

The initial goal set for this research aimed at evaluating the differences in performance of Charles II's (King of England from 1660 to 1685) royal yachts with special emphasis on two of his yachts, both called *Mary*.[6] In general, Royal yachts were built and equipped for the King. As ships of high status, it could be expected that they would have been built by trusted shipwrights following up-to-date design methods. The original *Mary* was Dutch while its replacement was English. Hence, they would have been shaped and made following different design criteria (see chapters 4 to 7). These yachts were built for racing, or at least that is the prevalent idea in the literature. The idea of racing suggests images of sophisticated sailing machines competing for speed and manoeuvrability, designed by ship-designers applying specialised knowledge in the pursuit of the ultimate goal: winning at the race course.

From a scholar's point of view, it might be interesting to know if there are differences in performance between the different yachts (Dutch and English) and if those could be linked to their design. This, in turn, could be used to look into their design traditions (Dutch and English). Contemporaries of both ships wrote that Charles II ordered the design and construction of a yacht to beat his first yacht, the *Mary*, which had been a gift from the Dutch. Consequently, the idea that the new ship had been built with a design brief aimed at surpassing the Dutch *Mary* on the racecourse was considered worthy of investigation utilizing tools available to modern naval architects. However, this mainly technical approach was soon considered unsatisfactory.

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4 For a discussion about the relation between technological innovation and social change in early-modern Europe see: Adams. *A Maritime Archaeology of Ships.*

5 For example: Eriksson, N. 2014. *Urbanism Under Sail: An Archaeology of Fluit Ships in Early Modern Everyday Life*. Huddinge (SE): Södertörn University.

6 This project grew out of an existing collaboration between the History, Ship Science and Archaeology departments at the University of Southampton. The initial aim of the project was to compare how the two versions of the *Mary* handled, sailed, and how suited they were to British waters. The results would allow an exploration into the significance of the first royal yacht and how both forms of the vessel were used politically and socially; how competition with the Dutch may have driven the decision to reform the second ship's hull. The initial project fitted in the maritime studies research strategy within History, extending it more firmly into the early-modern period.

Very soon in the research it was considered that a study of performance could not provide a meaningful insight into the society responsible for the construction and use of the yachts. Yes, a ship may be faster or more weatherly than another; it may be more capacious; more stable; stronger; etc. But very soon it was realised that these differences could not inform about the people responsible for their construction. The study of each yacht may provide an indication of what shape they were and how they were built and rigged, for example. But it would provide little insight into the reasons behind the technological choices that resulted in a particular configuration. Such choices would not have been made in a vacuum of individual ship-designers or shipwrights each with their own set of beliefs and technological knowledge. On the contrary, the choices that led to the construction of the yachts were taken within a shared knowledge-space and technological-landscape. This research has focused on these. By characterising the knowledge of early modern shipwrights, it was expected that it would be possible to produce a better description of the social and technological-landscape in which ship-designers and shipwrights of the period performed. By extension, one of the goals of this research became to study and criticise the manner in which this knowledge-space is defined in the current scholarship.

Charles II's yachts provided a good opportunity to explore the knowledge-space of ship-designers and shipwrights of the end of the 17th century in two shipbuilding traditions which, often, are considered to be exemplars of two opposite ways of approaching the conception and construction of ships (Chapter 2). However, these yachts, and the English and Dutch building traditions were used as a pretext to look into the wider picture in order to understand the processes of hull design in these two traditions, and more widely, by extension –both geographically and in time–, they can be used to better understand and define the knowledge-space and technological-landscape of ship-designers and shipwrights of the early modern period. This led to a further extension in the time limits in order to re-define the manner in which shipwrights of different building traditions are understood to visualise three-dimensional shape. In doing so, a proposal will be made to suggest that shipwrights since the ancient Mediterranean to the mid-19th century shared a common paradigm which helped them define and, most importantly, store and transmit three-dimensional shape.

In order to research the technological-landscape of the period ship design treatises from the 15th to the early 19th centuries have been studied (tables 1-2). They are described in their respective subheadings in chapters 4-5. This will help understand the outlook of this research, hence its outcome. But, it will mainly help highlight one of the shortcomings of the current scholarship. That is, the over-representation of a few selected treatises, and the apparent disregard to the abundant additional literature. Additionally, a new source of evidence, Arrospide's design 'instructions', is brought to the attention of scholars for the first time. The method is described in detail in Appendix B, where the 'instructions' are also translated into English. These 'instructions' provide a unique method of hull design used in the construction of commercial ships, for which no parallel has been described in the literature. They should help describe the technological-landscape of late 18th century Spain and, by extension, Europe.

During this research there has been an especial emphasis in keeping a constant awareness of the outlook of the present author. First, as a naval architect since 1995, the present author has tried to always approach the subject from a techno-practical stance. This has made it possible to search for the ultimate goals of the different design-strategies studied in this research and to understand them as the means available in the period to guarantee certain performance characteristics of ships. As a boat builder, building and repairing wooden boats for more than 12 years, the outlook of this researcher had always in mind the realities of wooden boat- or ship-building. Thus, the design-recipes and design-strategies analysed were read through the lens of the shipwright who had to not only find a way of building a ship but, more importantly, the shipwright had to find a way of storing and transmitting such knowledge in order for it to survive. Finally, having done an MA in Maritime Archaeology in 2012-3 this researcher became aware that there is a body of literature, which studies ships as a means of understanding past societies, that is grounded on ideas about the shipbuilders' design-paradigms that require to be revised. Central to this is the manner in which shipwrights are understood to visualise hull-shape and hence create their knowledge around this paradigm. Design treatises of the early modern period form one of the pillars on which this current narrative is founded on. Therefore by re-analysing the treatises, keeping these three different but complementary outlooks, this research will try to re-define, or at least define in a more nuanced manner the knowledge-space and technological-landscape of pre-19th century shipwrights.

Finally, this research started by looking at the particular case of Charles II's yachts and, specifically, at their performance. This precise focus of interest opened up a wider field of research. The yachts provided the excuse to justify looking into the wider picture, so to speak. Thus, the research could not focus only on the shipwrights responsible for the construction of the yachts or their contemporaries. The results of this thesis would like to help portray the nature and knowledge of shipwrights building planked ships[7] since at least the ancient Mediterranean into the mid-19th century and, therefore, extended its temporal and geographical limits to those

7 This thesis has focused on planked boats and ships without consideration to other type of floating vessels whose shapes may be the result of a different set of design choices available to the shipwrights. For example, logboats which are constrained by the shape and size of available trees.

periods. Obviously, the research focused mainly on the early modern period. It is hoped that the following chapters will justify the opening of the scope and outlook of the research which in turn, should provide the opportunity to address some of the limitations of the current scholarship and provide a more nuanced picture of ship-designers and shipwrights and their knowledge.

1.1 Development of the aims of the thesis

The aim of this thesis evolved during the process of research. The original aim of the thesis was to investigate and compare the royal yacht *Mary* and its replacement, also called *Mary*, both of which belonged to King Charles II of England in the latter part of the 17th century. One of the initial objectives of the thesis was to investigate the possible differences in performance of both *Mary*-s, and to relate these differences to their hull shapes. The first *Mary* was of Dutch construction and, therefore, had a typical Dutch shape. The second *Mary* was built in England and had an English shape. Hull-shape and ship performance are interrelated aspects.[8] Therefore, this research would try to establish how ship performance was affected by their respective hull-shapes, and how these shapes might have been adapted to particular sea conditions or to the different uses of the yachts during their service in the navy and as personal ships of the King.

The initial goal of the research, the analysis of hull performance, required an approach based on modern naval architecture. Consequently, the analysis of the performance of both *Mary*-s and the rest of Charles II's yachts required that their shape had to be modelled as precisely as possible, as the definition of the 'correct' shape of the hulls is a prerequisite for any hydrodynamic analysis. However, there are no archaeological remains that can help with the modelling of any of the royal yachts, hence their shape had to be modelled from other forms of evidence.[9] In the case of the second *Mary* and the rest of the English yachts there are near contemporary plans supplemented by official records, paintings, and shipbuilding treatises to allow a theoretical reconstruction of their shape. However, this was not the case for the original *Mary*, for which no plans existed, and only the principal dimensions of the hull and paintings existed. This required that, in order to

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[8] Marchaj, C.A. 1986. *Seaworthiness: the forgotten factor*. Camden, Maine, USA: International Publishing Company, p. 10. For reference books on ship-design understood as the relation between hull shape and ship performance see, for example: Saunders, H.E. 1957. *Hydrodynamics in Ship Design. Volumes I and II*. New York: Society of Naval Architects and Marine Engineers (SNAME); Watson, D.G.M. 1998. *Practical Ship Design*. London: Elsevier.

[9] There are some archaeological remains of the original *Mary* of Dutch origin. However, very limited hull material survived and, as a result, a reconstruction of its shape from the archaeological remains is not possible (e.g. Tanner, M. 2008. *Royal Yacht Mary. The Discovery of the First Royal Yacht*. Board of Trustees of the National Museums and Galleries on Merseyside).

model its theoretical shape, the design practices followed by 17th century Dutch shipwright had to be applied during the process of digital modelling (appendix C).

This prompted an analysis of the literature describing Dutch shipbuilding of the 17th century. It was soon found out that in the body of literature written since the middle of the 20th century there is a wide acceptance of the idea that Dutch builders of the period built their ships '*by-eye'* (chapter 2). If this were correct it would be impossible to really propose a hull shape that could be said to resemble the shape of the original *Mary* with confidence as it would be impossible to recreate the eye of the original builder.

In order to really understand how Dutch shipwrights designed the shape of their hulls primary and secondary sources had to be compared and analysed in a critical manner. As a result of this, the research into Dutch and English ship design procedures followed during the 17th century became a point of interest. Similarly, the manner in which English shipwrights of the 17th century shipwrights are said to understand the process of designing their ships was researched and found to be lacking in certain respects. This prompted the investigation to centre on the specific area of scholarship that deals with the design-knowledge and design strategies of early modern shipwrights. Although, later the temporal limits were extended to include (briefly in chapter 7) the ancient Mediterranean period.

As a result of this process, the initial research questions were modified from a particular focus on the performance of a few individual ships, to a wider look into the knowledge-space and technological-landscape of early modern shipbuilders. The yachts, which initially were the 'narrow' goal of the research, became the excuse to open the gate into a new, 'wider', field that represented the knowledge used by shipwrights of the period. By widening the scope it became possible to look at how shipwrights of the period designed the shape of their hulls and provided a better understanding of the ultimate reasons behind those design-strategies.

1.2 Research questions

This research has maintained two parallel lines of enquiry around which the research questions can be grouped. The first line of enquiry focuses on the knowledge of early modern ship-designers and shipwrights. The second line of research focuses on the manner in which this knowledge is described in the currently scholarship.

- With respect to the knowledge of early modern ship-designers and shipwrights:
    - What is the design-paradigm of early modern ship designers and shipwrights?

  - Do they share a common design-knowledge or, on the contrary, do they have different design-paradigms?
  - What is the real purpose of the seemingly different design-strategies? Are they means of obtaining new shapes, or on the contrary are they just strategies for the storage and transfer of knowledge?

- With respect to the manner in which the knowledge of early modern ship designers and shipwrights is portrayed in the current narrative:
  - Is the knowledge of early modern ship-designers and shipwrights characterised correctly?
  - Can the current narrative be reviewed to offer a modified account that helps characterise the knowledge of early modern ship designers and shipwrights?

1.3 Methodology and sources

Defining this research from a methodological point of view is not an easy task, as the project is a collaborative effort that involves three different departments of the University of Southampton – History, Ship Science and Archaeology– each with specific methodologies. Consequently, the project needed an initial approach that required an understanding of 17th century shipbuilding, a practical understanding of ship design processes and the ability to tackle the challenging engineering analysis.[10]

This research required the analysis of a large body of primary and secondary literature. The references to historical sources –both primary and secondary– are described in chapters 2, 4-5 of this document. These sources include original 17th century shipbuilding treatises (chapters 4 to 5;

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[10] As a PhD candidate engaged in this research the present author's personal skills allowed this author to tackle it with the necessary wide skill-set. Thus, I brought a practical focus to the research, as a result of having more than 12 years practical experience working as a shipwright building, repairing and restoring wooden boats. Also having obtained an MA in Maritime Archaeology provided this author with a grasp of the theoretical challenges ahead and, especially, helped identify aspects of the research which can contribute to the creation of new knowledge. Also, being naval architect has allowed this author to tackle the complex engineering analysis and understand its limitations. Finally, this author's command of Spanish and written French has made it possible to access original 17th century manuscripts. As it will be shown, this has facilitated a critical review of established theories that, as a result, have produce new knowledge with regard to the real methods followed by 17th century shipwrights to shape their ships. Finally, fluency in the Basque language has allowed this author to understand and translate *Arrospide's 'instructions'* which, although were written in Spanish, it was done in the style of a Basque speaker with relatively poor grasp of Spanish grammar and syntax.

appendix B; tables 1-2), original accounts describing 17th century shipbuilding in the Netherlands (chapter 4; appendix A), and original near contemporary plans for the second *Mary* and other royal yachts (appendix C). The body of literature that describes the modelling and engineering analysis of ships of this period is more limited. Some authors have successfully argued for a digital reconstruction and analysis of the performance of early ships from limited archaeological material. For example, Jon Adams effectively used limited archaeological remains to reproduce the shape of the 17th century *Sea Venture.* By combining manual and computerized procedures Adams estimated some basic performance characteristics of the hull from a technically rigorous perspective.[11] Other authors have also analysed ships of this historical period by using an interdisciplinary methodology that combines historical and engineering approaches. Most notably the theoretical reconstruction of 17th century Portuguese *naus*[12] by Filipe Castro *et al.* shows the level of detail that such an effort may produce when historic and engineering approaches are combined.[13] However, there are also authors that have approached the analysis of the performance of ships of the period from a purely engineering approach.

In the early 1990s two reproductions of a mid-18th century Dutch cargo ship called *Amsterdam* were built in the Netherlands. Based on one of them, and with a purely engineering approach, A.H. Hubregtse calculated the performance of the ship using scale models in a towing tank and computer velocity predictions for the sailing rig.[14] The results may represent closely a ship with the geometry of the 1990s reconstruction. However there was no attempt to check if the forces

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[11] Adams. *A Maritime Archaeology of Ships,* pp. 130-147.

[12] A *nau* is a type of ship used by sailors of the Iberian Peninsula (Portugal and Spain) around the time of their maritime expansion in the Americas and Asia.

[13] The process of theoretical reconstruction, which is based on a combination of historic material, modern naval architecture and 3D modelling software is described in the following series of papers: Castro, F. 2005. Rigging the Pepper Wreck. Part I—Masts and Yards. *International Journal of Nautical Archaeology*, 34(1), pp. 110–122; Castro, F. 2009. Rigging the Pepper Wreck. Part 2—Sails. *International Journal of Nautical Archaeology*, 38(1), pp. 105–115; Castro, F., Fonseca, N. and Wells, A. 2010. Outfitting the Pepper Wreck. *Historical Archaeology*, pp. 14–34; Fonseca, N., Santos, T. and Castro, F. 2005. Study of the intact stability of a Portuguese Nau from the early XVII century. *Maritime Transportation and Exploitation of Ocean and Coastal Resources*, 1, pp. 893–900; Santos, T.A., Fonseca, N. and Castro, F. 2006. Stability characteristics of an early XVII century Portuguese Nau. In *Proceedings of the 9th International Conference on Stability of Ships and Ocean Vehicles (STAB 2006)*, pp. 69–80; Santos, T., Fonseca, N. and Castro, F. 2007. Naval Architecture Applied to the Reconstruction of an Early 17th Century Portuguese Nau. *Marine Technology*, 44(4), pp. 254–267; Santos,T.A, Fonseca, N., Castro, F., and Vacasa, T. 2012. Loading and stability of a late 16th century Portuguese Indiaman. *Journal of Archaeological Science*, 39(9), pp. 2835–2844.

[14] Hubregtse, A.H. 1990. The V.O.C. ship Amsterdam: A velocity prediction. In J. Gerritsma (ed.), *11th International Symposium on Yacht Design and Yacht Construction*. Amsterdam, 13 and 14 November 1990, pp. 160-179.

calculated in the analysis could be admissible for a 17th century rig and materials[15]. Therefore, it is possible that the forces calculated may have resulted in rig loadings that were too large for the materials of the 17th century. Without consideration for this and other aspect of the analysis, the validity of the results may be questioned. As it will be described in appendix C, this research encountered difficulties with the theoretical analysis of the performance of the hulls, which raised doubts about the validity of the results. Thus, this avenue of research was not pursued further. Instead, it put the focus on the design-knowledge of early modern shipwrights which should help enlighten this period of history.

Finally, a note must be made here about the usefulness that this research may have for someone interested in the archaeology of ships. After all, no original archaeological material has been used directly in this research, and hence, it cannot be argued that materials directly originating from original archaeological enquiry have been used for this research. However, much of the discussion about the conception of hull shape has been based on works of reference and secondary material which are used regularly by maritime archaeologists in their analysis and interpretation of archaeological remains, as well as on primary sources that are regularly referred to in the archaeological literature. It is felt that the use of this material, their critique, and the relevance that this critique may have in the interpretation of past shipbuilding by maritime archaeologists justifies the archaeological scope of this research.

1.4 Structure of the thesis

The thesis is divided in nine chapters grouped in three parts. Chapters 1 to 3 present the research to the reader and introduce key ideas which establish the boundaries of the research and the current scholarship on the subject. The methodology and aims of the research are also described. This is followed by the middle part of the thesis, made up of chapters 4 and 5, where the main material used in this research is described. It consists of an analysis of ship-design treatises dating from the 15th to the late 18th century.[16] Finally, chapters 6 to 9 provide a critique to current scholarship (chapter 6). This is followed by chapters 7 and 8, where a series of ideas are offered to describe the ship-design knowledge of traditional shipwrights – including the early modern period. The last chapter of this group, chapter 9, summarises and concludes the thesis. Several additional appendices provide supporting material that could not be included in the main body of

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15 Hubregtse. The V.O.C. ship Amsterdam, p. 160.

16 The thesis is accompanied by a DVD where the treatises used in this research are included. This will allow the reader access to the original ship-design treatises.

the thesis. Appendix A deals with Arnoul's account of Dutch shipbuilding written in 1670 and the manner in which its mistranslation has helped maintain a description of Dutch design methods which is not supported by its contents. Appendix B describes Arrospide's 1789-90 ship design instructions which describe in detail a new method of hull design not described up to now in the literature. Finally, appendix C contains a short glossary of technical terms used in this thesis.

Chapter 2: Contextualisation: Ship-design in the early modern period

This chapter describes the context that has framed this research. The first part of the chapter describes the yachts of Charles II in order to give an overview of these ships and how they were used by the King and additional users. This will be useful to understand the nature of these ships. Were they specialised ship types, hence with their own design solutions and design methods? Or, on the contrary, were they general ship types used for a variety of purposes, and, therefore, of a general form and without particular design solutions and design methods? The answer to these questions will open, in subsequent chapters, a window into the design-knowledge of early modern shipwrights. The second part of the chapter discusses the current understanding of the wider technological context in which these ships were designed, built and used. The main focus will be placed in the conceptual approach used by ship-designers/ shipwrights to conceive the shape of their hulls. This will provide the reader with the background knowledge required to understand the approach followed in this research in order to answer the main research questions which were centred on two lines of enquiry. One focusing on the design-knowledge of early modern shipwrights and ship designers and another on the manner in which such knowledge is characterised in the current academic literature.

2.1 The royal yachts of Charles II. A specialised or generic type of ship?

During the 17th century England suffered a civil war (1642-1651) in which the ruling monarch, Charles I (1600-1649) was beheaded on the block. His son, who was later to become King Charles II (1630-1685), had to flee to exile, where he remained until monarchy was restored in 1660. The civil war was followed by periods of political and religious unrest which were not fully settled with the restoration of the monarchy.[17] Within this backdrop, the figure of Charles II stands as a ruler who, according to one view, indulged in his own pleasures, who 'prefer[ed] the racecourses [...] and brothels [...] to the day-to-day tedium of government'.[18] He had a cosmopolitan personality that contrasted with the common personality of his English subjects.[19]

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17 Coward, B. 1980. *The Stuart Age. England 1603-1714*. London: Pearsons Education, p. 283.

18 Coward. *The Stuart Age,* p. 291.

19 Holmes, G. 1993. *The Making of a Great Power. Late Stuart and Early Georgian Britain 1660-1722.* London: Longman, p. 86.

For some of his contemporaries ‘King Charles was a young Prince more inclined to taste the pleasures of power than willing to feel its weight’.[20]

One of his favourite pastimes, was sailing and racing sailing yachts. The nature of these races is not clear, as there are few original references to actual races, however, the origins of the interest seem to be clearer. The first yacht that Charles II had was a present from the city of Amsterdam to celebrate the restoration of the English monarchy in 1660, which he used for his personal use for a short period of time.[21] This prompted the King to order a series of new yachts (table 3). It is generally accepted that these new yachts were designed and built in order to be superior to the Dutch gift in every aspect.[22] Contemporary accounts by Samuel Pepys (1633-1703)[23] seem to corroborate this.[24]

The yacht gifted by the city of Amsterdam, the *Mary,* had been originally built for the Dutch East India Company.[25] Although, as it will be described, the word yacht did not refer to a homogeneous type of ship, it has been suggested that its appearance could have been similar to other Dutch yachts of the period like the yacht depicted in figure 1 extracted from Nicolaes Witsen’s (1641-

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[20] Charles Davenat. 1699. in Holmes. *The Making of a Great Power*, p. 92.

[21] t' Hooft, C.G. 1919. The First English Yachts, 1660. *The Mariner's Mirror* 5: 4, p. 109.

[22] McGowan, A.P. 1953. *Royal Yachts*. Greenwich: The National Maritime Museum, p. 2; t' Hooft. The First English Yachts, p. 120.

[23] C. S. Knighton, ‘Pepys, Samuel (1633–1703)’, *Oxford Dictionary of National Biography*, Oxford University Press, 2004; online edn, Sept 2015 [http://www.oxforddnb.com/view/article/21906, accessed 18 Aug 2017].

[24] Pepys, S. 1660-9. *The Diary of Samuel Pepys*. Latham, R. and Matthews, W. 1970-83 (eds). London: Bell & Hyman, Vol.1, pp. 286-287.

This is how Pepys described it:

> In the afternoon Commissioner Pett and I went on board the Yaght; which endeed is one of the finest things that ever I saw for neatness and room in so small a vessel. **Mr. Pett is to make one to out-do this for the Honour of his country** [...]. (Highlights by JPO)

Similarly, in 13 January 1661 Pepys comments that the new yacht that Commissioner Pett is building ‘will be a pretty thing, and much beyond the Dutchman's’ (Pepys. *The Diary of Samuel Pepys*, Vol.2, p. 12).

[25] t' Hooft. The First English Yachts, p. 109.

1717)[26] shipbuilding treatise published at the end of the 17th century in the Netherlands.[27] Clearly, yachts of this period would be very different from the fast racing machines that the word ‘yacht’ conveys in the present.

Yachts were commonly used in the 17th century in the Netherlands as transports for the Colleges of State and the Admiralty and for persons of rank and nobility who used them as convenient means of transport.[28] However, transport duties and business were not their only purpose and yachts built for sport and pleasure, *speeljaghten*, (Figure 2) were common.[29] Yachts varied in size according to their use. They often had a pavilion at their stern where the passengers could be protected from the elements while enjoying their outing. *Paviljoen* yachts, as they were known, were around 69 Amsterdam *voet*[30] (feet) in length (c.19.5m), while the *speeljaghten* (or racing yachts) were shorter, being around 42 *voet* long (c.11.9m).[31] The *Mary* was of the larger type being 72 *voet* in length (c.20.4m), 19 *voet* (c.5.7m) in breadth to the inside of the planking and 8 *voet* (c.2.3m) deep within the hull.[32]

The *Mary*, in common with subsequent royal yachts, was richly decorated.[33] Its elegance and uniqueness were noticed in England where praises to its beauty are found in contemporary documents. For example, Pepys commented that it was ‘one of the finest things that [he] ever saw’.[34] In his first year of reign Charles II was already the owner of three yachts: the *Mary*, the

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26 Peters, M. 1989. Nicolaes Witsen and Gijsbert Cuper: two seventeenth-century Dutch burgomasters and their Gordian knot. *LIAS: Sources and Documents Relating to the Early History of Ideas*, Vol. 16/1 (Amsterdam / Maarssen 1989), pp. 11-151 (p. 112).

27 t' Hooft. The First English Yachts, p. 118.

28 The internal body of water which occupied much of what nowadays constitutes dry land, the Zuiderzee, has been compared to a highway which provided a route of easy communication by water.(For example: Van Holk, A.F.L.,2017. The Zuiderzee (the Netherlands). Highway, fishing ground and power landscape. In J. Gawronski, A. van Holk and J Schokkenbroek, *Ships And Maritime Landscapes. Proceedings of the Thirteenth International Symposium on Boat and Ship Archaeology, Amsterdam 2012*, p. 73).

29 Tanner. *Royal Yacht Mary*, p. 8; t' Hooft. The First English Yachts, p. 108.

30 One *voet*, or Amsterdam foot is equivalent to 0.285m (t' Hooft. The First English Yachts, p. 109).

31 t' Hooft. The First English Yachts, p. 109.

32 Tanner. *Royal Yacht Mary*, p. 7; t' Hooft. The First English Yachts, p. 110.

33 Crabtree, R. 1975. *Royal Yachts of Europe. From the Seventeenth to Twentieth Century.* London: David and Charles, p. 7.

34 Pepys. *The Diary of Samuel Pepys*. Vol.1, pp. 286-287.

Bezan and the *Royal Escape*. The first two were of Dutch construction.[35] The *Royal Escape*, on the other hand, was a converted fishing boat built in England, formerly known as *Surprise,* which the King had used to escape to the Channel Islands in 1651 on his way to exile. He purchased it and renamed it after his return to the throne in 1660.[36]

One year after receiving the *Mary* from the Dutch, Pepys in 1661 recorded that the King ordered two new yachts to be built to beat the *Mary.*[37] They were the *Katherine* built for the King, and the *Anne* built for his brother James, the Duke of York (1633-1701). Their decorations were of the same standards as the original *Mary* as was noted by William Schellinks (1627–1678) in 1661.[38] Some 20th century authors like Madge considered that the *Katherine* was a near copy of the *Mary* with the exception of its deeper draught, which was seven feet (c.2.1m).[39] Others, like 'tHooft and Endsor, on the other hand, considered that these ships were not copies or modifications of the original *Mary* type. According to them the new designs, with English hull shapes, would have been better adapted to local conditions.[40]

It is believed that Charles II had sufficient technical knowledge to take part in the process of yacht design and decision-making.[41] Interestingly, William Sutherland (1668-1740),[42] writer of several shipbuilding treatises analysed in chapters 4 and 5, wrote that Charles II 'had much appreciation about the art of the shipwright, and could discourse at length with the principal ship builders of the time',[43] therefore, corroborating this idea. Numerous contemporary references show that during the construction of the yachts, the King often visited the yards and took personal interest

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35 t' Hooft. The First English Yachts, p. 119.

36 McGowan. *Royal Yachts*, p. 2.

37 Pepys. *The Diary of Samuel Pepys*. Vol.1, pp. 286-287; Pepys. *The Diary of Samuel Pepys*. Vol.2, p. 12.

38 Schellinks compares the finishes of the *Mary* of Dutch origin and the *Katherine*, made in England (Schellinks, W. 1627-1678. (1993). *The journal of William Schellinks' travels in England, 1661-1663.* London: Royal Historical Society, p. 62).

39 Madge, T. 1997. *Royal Yachts of the World*. East Molesey (Surrey): Thomas Reed Publications, p. 31.

40 McGowan. *Royal Yachts*, p. 2; t' Hooft. The First English Yachts, p. 120.

41 Endsor, R. 2009. *The Restoration Warship. The Design, Construction and Career of a Third Rate of Charles II's Navy*. London: Conway Maritime Press, p. 10; Naish, G.P.B. n.d. *Royal Yachts*. Greenwich: National Maritime Museum, p. 3.

42 For an account on Sunderland's life see: Mallagh, C. 2014. Some Aspects of the Life and Career of William Sutherland. *The Mariner's Mirror*, 100(1), pp. 17–28.

43 Sutherland's M.S. c. 1720: f.45. SPB/50/1 and SPB/50/2, Archive Collection of the Caird Library, National Maritime Museum, Greenwich.

in construction details.[44] This interest in ship-design fits well with the personality of Charles II who was interested in scientific development and in 1662 issued a charter for the approval of the Royal Society of London for Improving Natural Knowledge which, to this day, survives as one of the leading promoters of scientific research.[45]

Contemporaries of the King and his brother, the Duke of York, were aware of their love for sailing and navigation.[46] John Sheffield, Earl of Mulgrave, warship commander in the Third Dutch War, described Charles II as talented in matters related to the sea and shipping. A talent that was based on his first-hand knowledge and inclination towards such matters.[47] As noted on the Calendar of State Papers dated 21 July 1671, Charles II was not a fair weather sailor. On the contrary, he enjoyed sailing in adverse conditions. That day, the *Cleveland* yacht, with the King on board, is described as facing strong contrary winds on its return trip from Torbay. Such conditions would result in a long trip. This, which for others could be seen as a disadvantage, was actually seen as a pleasurable outcome by the King: ‘The wind blowing contrary will make his passage long, though not tedious, out of the great pleasure his Majesty takes to be at sea’.[48]

As a result of Charles II's love for sailing he is often regarded as the father of yachting for sport and recreation.[49] However, although it is evident that Charles II must have played a role in the popularisation of sailing for sport and recreation, it is also true that yachts such as Queen Elizabeth I's *Rat of Wight* built in 1588 and a yacht that Prince Henry had built in 1601[50] were known before the *Mary* was brought to England.

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44 For example, in May 19 1663, Charles II visited the shipyard at Woowich, where a new yacht was being built, expressing his interest in the keel for the new yacht (CSPD Charles II, 1663, p. 145). Another example of the Kings interest can be seen on a series of entries in the Calendar of State Papers from June 27 to July 16 1671. They refer to the launch of a new yacht built for Charles II, the *Cleveland*, and the subsequent sea trials conducted with the King on board. A number of other yachts were ordered to attend the sea trials so that the performance of the *Cleveland* could be compared with them (CSPD Charles II, 1671, pp. 312-385).

45 https://royalsociety.org (Last accessed 10 January 2018)

46 e.g. Grenville 1693, in Naish, G. 1956. Hydrographic Surveys by Officers of the Navy under the later Stuarts. *Journal of Navigation*, 9(01), p. 47.

47 Endsor. *The Restoration Warship*, p. 10.

48 CSPD Charles II, 1671, p. 391.

49 Crabtree. *Royal Yachts of Europe*, pp. 7, 18; Lavery, B. 1981. *Deane's Doctrine of Naval architecture, 1670. Edited and introduced by Brian Lavery*. London: Conway Marine Press, p. 16; Naish. *Royal Yachts*, p. 2.

50 McGowan. *Royal Yachts*, p. 2; Tanner. *Royal Yacht Mary*, p. 9.

Even if Charles II had over 20 yachts built (table 3) it is considered that the *Jamie* (25 tons) and the *Bezan* (35 tons), his smallest yachts, were used most often for racing.[51] The nature of these races is unclear, as most mentions about racing in the literature refer to a single race that took place between the King and the Duke of York, each on their own yachts, on the 1st October 1661. This race was for a wager of £100, and the course was from Greenwich to Gravesend, at the Thames estuary, and back. Diverse authors use an original entry in John Evelyn's diaries to illustrate the King's racing activities.[52] There is also mention of a second race, with the same setting and course, between the *Bezan* and the *Jamie*, won by the *Bezan*.[53] During these outings the King was often followed by his barge and *Kitchen* yacht where the royal cooks prepared the meals for the King's party.[54] After the death of Charles II, his successors lost interest in owning yachts, and if Charles II had kept an average of 15 yachts in commission, by the early 18th century there remained only nine royal yachts in service.[55]

By the mid-1670s English shipwrights had learnt to design and build yachts of such quality[56] that Charles II offered two yachts built by Anthony Deane (1638–1721) [57] as a present to the French king. They were destined for the pond built at the Palace of Versailles, where there was a fleet of 60 ships and boats of diverse types.[58]

Although the idea of yachts as pleasure craft is strong, hence leading to ideas about a specialised ship type, designed for racing and pleasure sailing, numerous accounts indicate that Royal yachts

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51 Crabtree. *Royal Yachts of Europe*, p. 18.

52 Naish. *Royal Yachts*, p. 2; Tanner. *Royal Yacht Mary*, p. 11; t' Hooft. The First English Yachts, p. 119.

53 t' Hooft. The First English Yachts, p. 120.

54 Naish. *Royal Yachts*, p. 11; t' Hooft. The First English Yachts, p. 119.

55 Naish. *Royal Yachts*, pp. 3-4.

56 For example, internally fitted with gilded leather decorations, luxurious lanterns and marble fireplaces (CSPD Charles II, 1663, pp. 160, 261, 271). Another example of the quality of construction can be seen in the choice of ballast material. Instead of using stones for internal ballast as was customary on naval vessels, the internal ballast of the royal yachts was made up of iron shot and musket shot. This took up less room inside the ship, thus, provided more comfortable interior accommodations. However, the use of such large amounts of ammunition as ballast led to a complaint by the Ordnance Officers who feared that their stocks of ammunition were being reduced to an alarming low level as they were being used to ballast the King's yachts (CSPD Charles II, 1663, pp. 275, 277, 285).

57 Walker, F.M. 2010. S*hips and Shipbuilders: Pioneers of Design and Construction*. Barnsley (UK): Seaforth Publishing, p. 20.

58 Ferreiro, L.D. 2007. *Ships and Science. The Birth of Naval Architecture in the Scientific Revolution, 1600-1800*. Cambridge (Ma): The MIT Press, p. 68; Lavery. Deane's Doctrine of Naval Architecture, p. 16.

were not used exclusively for pleasure. On the contrary, these vessels were armed and on the duty list of the Royal Navy (figure 3) and, within the navy, they performed a multitude of roles suited to their characteristics.[59] With time yachts evolved into the ship type known as the 'sloop of war'.[60]

The original *Mary* was used as the private yacht of the King only for one year. In September 1661 it left the Thames and was sent to Dublin where it performed ferry duties, engaged in the transport of persons of rank and in the transport of bullion. Its services included trips across the Irish Channel, where, according to modern authors, the shape of its hull was suitable for the short seas commonly found there.[61] It is said that the design of the *Mary* was so well suited to the local sea conditions that the navy had difficulties in finding a suitable replacement after it sunk in 1675.[62]

Other Royal yachts were also used in official missions. For example, they were used for the transport of dignitaries on cross channel trips.[63] However, longer trips were also common. On the 11 April 1670 the royal yacht *Katherine* transported the new Consul to Hamburg from England. In Hamburg, the Earl of Essex came on board to be transported to the Court of Denmark.[64] In fact, the use of royal yachts for the transport of dignitaries was so common that, as a result, the number of passengers available for other cross-channel ferry services was reduced.[65] As well as

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59 Tanner. *Royal Yacht Mary*, p. 13.

60 McLaughlan, I. 2014. *The Sloop of War*. Barnsley (UK): Seaforth Publishing, p. 70.

61 Mc Bride, P.W.J. 1973. The *Mary*, Charles II's yacht. *International Journal of Nautical Archaeology*, 2, p. 63.

62 Tanner. *Royal Yacht Mary*, p. 14.

63 Numerous entries in the Calendar of State Papers refer to such use. A few examples:

> Crossing to England with 'Spanish ambassador and lady' (CSPD Charles II, 1667, p. 533.);
> Crossing to France with Lord Douglas on board (CSPD Charles II, 1667-8, p. 362);
> Crossing to England with: 'Royal Highness's daughter, the Lady Anne, and her retinue'(CSPD Charles II, 1667-8, p. 476);
> Crossing to England with: 'Lord Ailesbury, and his lady and son' (CSPD Charles II, 1670 With Addenda 1660-70, p. 148).

64 CSPD Charles II, 1670 With Addenda 1660-70, pp. 158, 185.

65 This is how it is noted in the Calendar of State Papers:

> 'The number of passengers between Calais and Dover is much lessened by weather and by the King's pleasure yachts, which are constantly conveying lords to and fro, and carry all by reason of their gallant accommodation.'(CSPD Charles II, 1663-4, p. 52)

passengers, yachts were also used as secure means of transporting large sums of money. For instance, the five million *livres* paid by the king of France for the purchase of Dunkirk in 1662.[66] The money was distributed in four yachts and a frigate.[67]

Although transport and ferry duties were common for royal yachts there are other instances when they were used for different purposes. For example, in 1662 Robert Hooke (1635-1703) carried out scientific experiments on board the *Mary* to test the accuracy of the new clock made by Huygens aimed at solving the problem of longitude.[68] Another duty that royal yachts performed were coastal hydrographic surveys aimed at improving the quality of maritime charts. To improve these, the royal yachts *Merlin* and *Monmouth* were ordered to perform a survey of the coasts around the British Isles in 1681 that lasted until 1688. The results, published in 1693, remained in use for the next 100 years.[69] However, surveys were not always part of organised surveying expeditions. Often, trips with different purposes were used by the captains of the yachts to chart areas of interest, even with important dignitaries on board.[70]

As part of the Royal Navy, yachts were not kept away from danger as illustrated by the capture of the *Katherine* by the Dutch in 1673 while carrying a doctor to the English fleet, at war with the

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66 Grose, C.L. 1933. The Dunkirk Money, 1662. *The Journal of Modern History, 5.1*, p. 10; Tanner. *Royal Yacht Mary*, p. 13.

67 This is how Pepys noted it in his diary on Friday 21 November 1662:

> 'This day come the King's pleasure-boats from Calis, with the Dunkirke money, being 400000 pistolls' (Pepys. *The Diary of Samuel Pepys*. Vol. 3, p. 262).

Interestingly, although at this instance these yachts were not performing as pleasure boats, they were still seen as the King´s pleasure craft.

68 T Taylor, E.G, 1937. The geographical ideas of Robert Hooke. *The Geographical Journal*, 89.6, p. 526.

69 McGowan. *Royal Yachts*, p. 2; Naish. Hydrographic Surveys, p. 48; Naish. *Royal Yachts*, p. 3.

70 Thus, the *Anne*, used by the Duke of York, surveyed a shoal in Dover in 1670. Likewise, in 1680 the second *Mary* was used to survey the Channel Islands while on a mission to carry dignitaries to the Islands. The presence of a royal passenger was not an impediment for a survey to be carried out, as was the case of the survey of the Harwich area carried out by the captain of the second *Mary* while carrying the King (Naish. Hydrographic Surveys, pp. 48, 49, 52).

Dutch; or the sinking of the *Henrietta* by the Dutch in the battle of Texel.[71] Under such circumstances yachts could be used to transport important passengers[72] or common troops.[73]

It has been shown that the *Mary* and other royal yachts played roles that were far from specialised. Often, they served for the leisure of the King and persons of rank.[74] This could suggest the idea of a specialised ship type built to be fast and comfortable to their users, manned by skilled crews. Obviously, high quality luxurious finishes would be expected from such a ship. On other occasions they were used for the transportation of prestigious dignitaries, thus representing the King and England. Again, this would require that the ships were built, kept and sailed to a high standard as befitting a symbol of Royal power. However, it has been shown that on other occasions royal yachts performed utilitarian, but no less important, tasks such as surveying. Also, in times of war, they successfully took part in the conflict in roles suitable for their relative small size and manoeuvrability. Thus, these uses would suggest that yachts were not necessarily fast, elegant, vessels built for racing and fun with little use for other pursuits. On the contrary, they suggests that yachts were strong, reliable and seaworthy ships, which could be used, successfully, in a variety of roles.

As a result of this variety of roles, and especially, of the different origin of the original *Mary* (Dutch) and the rest of the yachts (English), an interesting question arises about the design procedures followed by the shipwrights who built these yachts. According to some modern authors, yachts built by the English would have been better suited to local English conditions than yachts built by the Dutch would.[75] However, this statement can be questioned. What do these modern authors consider English conditions? Or indeed, is there such a thing as typical English waters? It has been shown that the *Mary* and other royal yachts were included in the navy's list and, as a result, they played a variety of roles that required sailing into every possible sea and

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71 Boxer, C.R. 1969. Some Second Thoughts on the Third Anglo-Dutch War, 1672-1674. *Transactions of the Royal Historical Society (Fifth Series)*, 19, p. 89; McGowan. *Royal Yachts*, p. 2; t' Hooft. The First English Yachts, p. 116.

72 Tanner. *Royal Yacht Mary*, p. 15.

73 Described by Pepys on 2nd June 1666 (Pepys. *The Diary of Samuel Pepys*. Vol.7, pp. 140-141). Also, the *Calendar of State Papers Domestic: Charles II* provides numerous entries where royal yachts are shown to be carrying common troops. For example: CSPD Charles II, 1667, p. 4; CSPD Charles II, 1670 With Addenda 1660-70, p. 77; CSPD Charles II, 1677-8, p. 628.

74 There are numerous entries in Pepy's diaries that mention dignitaries and high officials using the royal yachts for their personal use. For example: November 27th 1663; August 17th 1665 (Pepys. *The Diary of Samuel Pepys*. Vol. 4, p. 399 and Vol. 6, p. 193).

75 McGowan. *Royal Yachts*, p. 2; t' Hooft. The First English Yachts, p. 120.

weather conditions in which an English naval ship of that size was expected to sail.[76] Thus, the real interest for the researcher would be to ask if the technical knowledge of Dutch and English shipwrights of the period allowed them to design ships for specific areas and sea conditions or, on the contrary, such a precise design approach was not possible.

Additionally, another question can be asked about the manner in which these ships were designed. The idea of a yacht built to provide enjoyment for the King in the racecourse, thus built with specific performance parameters in mind, may seem tantalizing. However, the numerous roles played by these ships, apparently successfully, seems to suggest otherwise. Indeed, it would appear that these yachts were not the result of some design procedure aimed at optimising their shape and configuration to a specific set of requirements (racing and pleasure). On the contrary, it would appear that they were generic naval ship types, designed following generic design methods, adapted for the occasional royal use by way of lavish decorations and quality of construction and finishes.

These thoughts helped shape this research which extended beyond the initial scope to focus on the design procedures of the period and what they can tell us about the technical knowledge of the period and the craftsmen who used this knowledge to design and build ships. It is obvious that not everyone would have been trusted with the design and construction of a royal yacht. However, the basis of this trust may have depended more on the ability of the shipwright to produce beautiful and stylish ships built with care and top quality finishes, other than based on specific technical knowledge that enabled the shipwright to produce ships of superior performance. As chapters 4 to 7 will show, the state of the design-knowledge of the period severely limited the ability of shipwrights' to produce ships with specific performance characteristics.

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[76] The Calendar of State Papers provide numerous entries which show that these yachts were used on any weather and sea conditions and that they were not reserved for fair weather. For example:

> In storm conditions (CSPD Charles II, 1667-8, p. 482); Long distance crossing to Stockholm (CSPD Charles II, 1668-9, p. 445); At sea in bad weather conditions (CSPD Charles II,1670 With Addenda 1660-70, p. 37); Beating to windward for three days with a round-trip from Portsmouth to Guernsey, to Plymouth and back to Portsmouth planned ahead (CSPD Charles, 1670 With Addenda 1660-70, p. 439); Yachts seen past Weymouth sailing with a gale from behind thus expected to arrive in Plymouth early (CSPD Charles II, 1671, p. 385).

Also, in *Gloria Britannica*, yachts are listed alongside other naval ships, with no distinction to suggest their use as leisure boats (A. B. 1689. *Gloria Britannica, or the Boast of the British Sea*, p. 7-8).

2.2 Literature review

This section will offer a literature review of the previous work that has studied the manner in which shipwrights of different periods and traditions have tackled the complex process of building a ship. It will place an especial emphasis on the conceptualisation of hull-shape which is fundamental in ship-design. This will provide the necessary background information for the analysis and critique in subsequent chapters which will try to establish the nature of ship design-knowledge of early modern shipwrights and the manner in which such knowledge is described in the current literature.

2.2.1 The conceptual approach to ship design in the literature

Generally, the construction of a complex structure like a ship requires a coordinated effort of a group of people. This idea was well put forward by Patrice Pomey:

> The construction of a ship […] represents for the society that undertakes the endeavour a considerable effort in terms of *savoir faire*, technical means, supply, and development of materials. And in terms of social and political organization, it implies the conjunction, coordination, and application of the necessary means (emphasis in original).[77]

Building a ship is, then, an endeavour that extends beyond the shipyard and the mere practical aspects of ship construction and should be studied as such. The way in which a ship is built has been used to infer ideas about the social interactions that are followed during its construction. These interactions are not limited to the actual construction itself. Valuable information about the social mechanisms leading to its construction and the manner in which knowledge is shared among builders have been inferred from the analysis of different shipbuilding traditions. Therefore, in order to clarify some basic concepts, the following pages will highlight the main concepts around ship design and construction which help modern scholars interpret the social arrangement of past societies. These ideas will be discussed in chapters 6 to 8 of this thesis.

Different cultural groups may display different approaches to designing and building ships which are often described in techno-practical terms. Thus, environmental conditions, technological developments, availability of materials, and other constraints are often considered to be behind

[77] Pomey, P. 2011. Defining a Ship: Architecture, Function, and Human Space- In A. Catsambis, B. Ford, and D.L. Hamilton (eds), *The Oxford Handbook of Maritime Archaeology*, p. 27.

the different practical approaches to ship design and construction.[78] However, besides these techno-practical reasons, differences in the approach followed to obtain hull-shapes are often taken as indicative of differences in mentality of the cultures responsible for the particular ship design/construction method being studied. They are considered to be the particularities that define a 'building tradition'.[79]

In wooden-planked shipbuilding Olof Hasslöf defined two main 'building traditions': 'shell-first' and 'frame-first'.[80] Both traditions follow a reverse hull assembly sequence and are said to be the product of two opposing ideas about how a ship should be built.[81] The following paragraphs will define these two building traditions, and how the idea of these two paradigmatic opposite building traditions has evolved from when they were first proposed by Hasslöf in 1957 to our current times. This will be relevant later in order to analyse, criticise and review the currently accepted theories describing the opposite manner in which 17th-century Dutch and English shipwrights approached the conception of hull shape, and by extension of the knowledge used by shipwrights throughout history to store and communicate fundamental design-knowledge on how to shape a ship's hull (chapters 4, 7 and 8).

2.2.2 ***Shell-first*** **and** ***frame-first*** **ship construction. Two opposing world views**

In 1946 James Hornell published his study of the different means of water transport used by different human societies, where he attempted to describe the origin and evolution of ships, boats, and other means of floating transport from their origin to the mid-20th century. [82] In order to do so he recorded and classified traditional watercraft still being used around the globe by non-industrialised societies. In general terms, Hornell described the 'anatomy' of a wooden boat or ship as an inner structure of transversal frames covered by a skin of planks running longitudinally,

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78 McGrail, S. 1998. *Ancient Boats of North-West Europe. The Archaeology of Water Transport to AD 1500.* London: Longman, p. 5.

79 Crumlin-Pedersen, O. 2004. Nordic Clinker Construction. In F.M. Hocker and C.H. Ward (eds.). *The Philosophy of Shipbuilding. Conceptual approaches to the study of wooden ships.* College Station: Texas A and M University Press, pp. 37-64 (p. 49).

80 Hasslöf, O. 1957-8. Carvel Construction Technique, Nature and Origin. *Folkliv*, 21-22: 49-60; McGrail, S. 2001-a. *Boats of the World. From the Stone Age to Medieval Times*. Oxford: Oxford University Press, p. 8.

81 For the most up to date study on this subject see: Hocker, F. M., and Ward, C. H. 2004. *The Philosophy of Shipbuilding. Conceptual approaches to the study of wooden ships.* College Station: Texas A and M University Press.

82 Hornell, J. 1946. *Water Transport. Origins and Early Evolution*. Newton Abbot: David and Charles.

at roughly 90° to the frames. However, among his observations, he noticed that there were two opposite ways in which a wooden boat or ship could be constructed. These two opposite methods depended on the order in which the skin of wooden planks and the frames were erected with respect to each other. Generally, the construction of a ship would start with the erection of the backbone, composed of a keel, a stem and a sternpost. However, some builders would continue by erecting the outer skin of planks first while others would continue by erecting the internal framework prior to the external planking (figure 4).

The oldest method seemed to be one in which the construction process started by building the planked skin of the hull first. In order to do so adjacent planks would be attached to each other, using different types of mechanical fixings, thus creating the 'skin' of a watertight vessel (figure 5). Normally, the skin would then be reinforced internally by the addition of transversal frames. The opposite, apparently more modern, method consisted in erecting a framework first, which was later covered by the skin made up of planks (figure 6). In this second case, the planks would be attached to the framing only. These two methods would represent opposite paradigms with respect to the approach followed to build a hull, and Hornell could not imagine a possible evolution from one into the other.[83]

In 1957 Olof Hasslöf proposed a theoretical framework to classify these two conceptually different traditions initially described by Hornell. Hasslöf's theoretical framework can still be considered to be one of the basic paradigms that guide and constrain the study of different shipbuilding traditions.[84] Based on ethnographic research, Hasslöf extended Hornell's work and studied the processes followed by shipwrights to build their hulls. In particular he focused on the

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83 Hornell. *Water Transport. Origins and Early Evolution*, pp. 193-4.

Others authors also expressed their difficulties in understanding a possible origin of frame-first construction as a transition from shell-first construction. For example: Martino considered that such a transition was surrounded by mystery (Martino, S. 2011. Sulle origini della carpenteria moderna. In W. V. Harris and K. Iara (eds) *Maritime Technology in the Ancient Economy: Ship-Design and Navigation. Journal of Roman Archaeology. JRA Supplementary Series Number 84*, p. 113-131. Portsmouth, Rhode Island, p. 113). Sarsfield found this transition to be an intriguing step (Sarsfield, J. P. 1991, Master Frame and Ribbands: a Brazilian case study with overview of this widespread traditional carvel design and building system, in R. Reindeers and K. Paul (eds), *Carvel Construction Technique. Skeleton-first Shell-first. Fifth International Symposium on Boat and Ship Archaeology, Amsterdam 1988.* Oxbow Monograph 12, Oxford, p. 137). Hasslöf found it conceivable that such transition could take part. However, his observations referred to the Nordic case, where frame-first building approach was 'borrowed' from an outside culture arriving, ultimately, from southern Europe. Thus, his observations did not explain a transition from a shell-first tradition into a frame-first tradition without outside influence. (Hasslöf, O. 1963. Wrecks, Archives and Living Tradition. Topical Problems in Marine-Historical Research. *The Mariner's Mirror* 49(3), p. 172).

84 Hasslöf. Carvel Construction Technique, Nature and Origin.

process followed to shape the hull. In this influential publication, Hasslöf defined the main ideas that have influenced the conceptual framework of scholars since. According to Hasslöf, ships are essentially a 'watertight shell' or a 'waterproofed frame'. Thus, ships whose construction process starts with the skin could be seen as a 'watertight shell' and would be known as *shell-first* hulls. On the other hand, ships where frames are erected first and the outside planking is installed after could be considered a 'waterproofed frame' and would be called *frame-first*.[85] Although this view has been criticised as being too restrictive by some scholars,[86] it remains very influential in current interpretations of the variety of hull shapes that can be found in the archaeological, historical and ethnographic record.[87]

One of the outcomes of Hasslöf's classification –which remains relevant today– refers to the idea that both *shell-first* and *frame-first* builders followed opposite ways of conceiving hull-shape. Shell-first builders started the construction process by laying the outside planking of the hull first which led to the conclusion that they could shape the three-dimensional shape of the hull based on the shape of the planks.[88] This led to the widely circulated theory that states that shell-first builders visualised hull-shape longitudinally, as an ensemble of longitudinal planks that defined

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85 McGrail. *Boats of the World*, p. 8.

86 This division in such clear lines has been criticised for not being able to consider ships and boats that are built using other methods which appear to use certain aspects of each approach. For example, see: Arnold B. 1991. The Gallo-Roman Boat of Bevaix and the Bottom-based Construction. In: R. Reinders, and K. Paul, (eds), *Carvel Construction Technique. Skeleton-first, Shell-first. Fifth International Symposium on Boat and Ship Archae*ology, Amsterdam 1988. Oxford: Oxbow monograph, p. 22; Basch, L. 1972. Ancient wrecks and the archaeology of ships. *International Journal of nautical archaeology*, 1(1), p. 17; Hocker, F. M. 1991. *The Development of a Bottom-Based Shipbuilding Tradition in Northwestern Europe and the New Worl*d. PhD Dissertation Texas A & M University, p. 12.

87 For example, in the following works of reference: Crumlin-Pedersen, O. 1997, *Viking Age Ships and Shipbuilding in Hedeby/Haithabu and Schleswig. Ships and Boats of the North Vol. 2.* Schleswig and Roskilde; Crumlin-Pedersen, O. and Olsen, O. 2002, *The Skuldelev Ships I. Ships and Boats of the North Vol. 4.1*. Roskilde; Rieth, E (dir). 1998. Concevoir et construire les navires. De la trière au picoteux. Technologies, Idéologies, Pretiques. *Revue d'anthropologie des connaissances*. Vol XIII-1; *Steffy, R. 1994. Wooden Ship Building and the Interpretation of Shipwrecks.* College Station: Texas A & M University Press; Pomey, P., Kahanov, Y. and Rieth, E. 2012. Transition from Shell to Skeleton in Ancient Mediterranean Ship-construction: analysis, problems and future research. *International Journal of Nautical Archaeology* 41.2: 235-314.

88 Harpster, M. 2009, Designing the 9th-Century-AD Vessel from Bozburun, Turkey. *International Journal of Nautical Archaeology* 38.2, p. 300; Steffy, J.R. 1995. Ancient Scantlings: The Projection and Control of Mediterranean hull-shapes. In H. Tzalas (Ed.). *Tropis III. 3rd International Symposium on Ship Construction in Antiquity. Athens 1989*. Athens: Hellenic Institute for the Preservation of Nautical Tradition, p. 422; Pomey et al. Transition from Shell to Skeleton, p. 2; Wilson, A. 2011. The economic influence of development in maritime technology in antiquity. In W.V. Harris and K. Iara (eds). *Maritime Technology in the Ancient Economy: ship-design and navigation. Journal of Roman Archaeology Supplementary Series Number Eighty-Four*, p. 218.

three-dimensional hull-shape.[89] A consequence of this view is that in shell construction there was no process of pre-design of the transversal shapes of the hull, and, most crucially, that hull-shape was created and conceived as the ship was being assembled in a simultaneous process of design and construction.[90] Frame-first builders, on the other hand, needed to erect the frames first, and therefore had to make them following some means of pre-design. Consequently frame-first builders are considered to have a method of pre-designing their hulls before the process of construction begins.[91] A further refinement of this view would state that frame-first builders visualised hull-shape as a series of transverse sections and the three-dimensional shape of the hull would not materialise until the planking had been fixed onto the pre-erected frames.[92]

These early ideas have been re-visited by certain scholars whose aim has been to go beyond the material construction of the ship and have attempted to explore the cognitive aspects of ship construction; how a shipwright manages to convert the idea of building a ship into the finished object.[93] Most notably Frederick Hocker broke down this process in three distinct phases that he

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89 Although not every scholar considers longitudinal and transversal approaches, they are very relevant on some influential authors, especially on studies of the transition from shell-first to frame-first construction during the first millennium in the Mediterranean. For example: Steffy. *Wooden Ship Building and the Interpretation of Shipwrecks*, p. 85; Pomey, P. 2004. Principles and Methods of Construction in Ancient Naval Architecture. In F.M., Hocker and C.H. Ward (eds). *The Philosophy of Shipbuilding. Conceptual approaches to the study of wooden ships*. College Station: Texas A and M University Press, p. 27; Pomey, P. 2009. On the Use of Design in Ancient Mediterranean Ship Construction. In H. Nowacki and W. Lefèvre (eds), *Creating Shapes in Civil and Naval Architecture. A Cross-Disciplinary Comparison*. Boston: Brill, p. 49; Pomey *et al.* Transition from Shell to Skeleton in Ancient Mediterranean Ship-construction, p. 236; Rieth, E. 2016. *Navires et Construction Navale au Moyen Age: archéologie nautique de la Baltique à la Méditerranée*. Paris, pp. 45, 99.

90 Hoving. *Nicolaes Witsen and Shipbuilding in the Dutch Golden Age*. College Station (Texas): Texas A and M University Press, p. 15; Pomey. Principles and Methods of Construction in Ancient Naval Architecture, p. 27.

91 Hasslöf. Carvel Construction Technique, Nature and Origin, p. 58; Hocker, F. M. 2004-a. Shipbuilding: philosophy, practice, and research. In F.M. Hocker and C.H. Ward (eds). *The Philosophy of Shipbuilding. Conceptual approaches to the study of wooden ships.* College Station: Texas A and M University Press, p. 6; Pomey. Principles and Methods of Construction in Ancient Naval Architecture, p. 27; Pomey *et al.* Transition from Shell to Skeleton in Ancient Mediterranean Ship-construction, p. 236; Van Duivenvoorde, W. 2015. *Dutch East India Company Shipbuilding. The archaeological study of Batavia and other seventeenth-century VOC ships*. College Station. USA, p. 22.

92 Hasslöf. Main Principles in the Technology of Ship-Building. In O. Hasslöf, H. Henningsen and A. E. Christensen (eds.) *Ships and Shipyards – Sailors and Fishermen*. Copenhagen, pp. 27-59 (p. 58); Pomey. Principles and Methods of Construction in Ancient Naval Architecture, p. 27.

93 For example: Basch. Ancient wrecks and the archaeology of ships; Steffy. *Wooden Ship Building and the Interpretation of Shipwrecks*, p. 85.

called: *conception*, *assembly* and *structural philosophy.*[94] *Conception* would represent the mental process by which the ship is imagined in the mind of the shipwright. At a later stage it must be converted into the real ship. This would be done by following a process of *assembly* of the different structural members of the hull. Finally, the way in which these structural elements are arranged in order to take the loads on the hull would be a consequence of the *structural philosophy* of the shipwright. These three phases are a convenient manner of studying the process of building a ship although, in reality, all of them would probably be considered simultaneously by the shipwright.

When one tries to understand the mindset of past shipwrights from studying a ship or its archaeological remains, it is often possible to analyse the way the structural members are arranged. From this, the *structural philosophy* of the shipwrights may be inferred.[95] Similarly, the *assembly sequence* can generally be established by careful examination of the physical fabric of the ship. This can be achieved by studying the manner in which the hull planking is fixed to the ship's internal structure, or by establishing the presence of construction features hidden behind structural members which indicate the order in which these different parts must have been assembled. However, trying to establish the mental process followed to *conceive* the shape of the hull is not always possible as it is an abstract process that leaves no physical evidence and it is not possible to interrogate the original shipwright. For this reason, this most crucial aspect of the construction of a ship, how the shipwright shaped the hull, is generally interpreted based on the assembly sequence.[96] Accordingly, when a ship is found to have been built (or *assembled*) on the shell-first principle it is normally assumed that it was built with no process of pre-design. It is assumed that it was built based on the eye and sculptural capacity of the shipwright. The existence of rules-of-thumb and design aids are commonly accepted in shell-first traditions but, normally, only as a means to assist the eye of the shipwright,[97] without exploring the significance of such design aids which contradict the idea that identifies shell-first construction with no pre-

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[94] Hocker. Shipbuilding: philosophy, practice, and research, p. 6.

[95] This should help establish if the shipwright relied on the shell or on the internal transversal structure as their main load bearing elements (Hocker. Shipbuilding: philosophy, practice, and research, p. 6).

[96] McGrail. S. 2015. Hornell, Hasslöf and Boatbuilding Sequences. *International Journal of Nautical Archaeology*, 44:2, pp. 382–387 (p. 385); Pomey. Principles and Methods of Construction in Ancient Naval Architecture, p. 27.

[97] Crumlin-Pedersen. Nordic Clinker Construction, pp. 40-41; Hasslöf. Carvel Construction Technique, p. 50; Pomey. Principles and Methods of Construction in Ancient Naval Architecture, p. 27; Westerdahl, C. 2008. Boats Apart. Building and Equipping an Iron-Age and Early-Medieval Ship in Northern Europe. *International Journal of Nautical Archaeology*, 37(1), p. 18.

design (chapter 7). On the other hand, when a ship is interpreted as having been built in a frame-first principle, it must be concluded that it was built following a previous process of pre-design, as the frames must be made beforehand, therefore, suggesting that these must have been made following some method to determine their shape.[98] This forms the core of currently accepted knowledge and can be clearly illustrated by the following recent quote by Seàn McGrail in which the procedures followed by shipwrights to conceive the shape of their hulls are summarised:

> Furthermore, [the choice of a shell-first or frame-first approach] indicates how the builder obtained the hull shape he wanted:
>
> [Shell-first]: **by-eye, based on personal experience and inherited wisdom**, and possibly using some 'rules-of-thumb' (highlights JPO).
>
> 'Frame-first': hull shape was encapsulated in a framework 'designed' by 'rule-of-thumb' or by building a small-scale model. Where frame-first techniques were used to extend an existing [shell-first] lower hull, such design work would be minimal.[99]

This idea of two opposing design paradigms, one building to a pre-determined design and another building mostly '*by-eye'* distorts our current interpretation of traditional shipbuilding, in general, and of 17th century Dutch shipbuilding, in particular, which was based on a particular form of shell-building that Hocker defined as *bottom-based*.[100] And, most crucially, this idea of two opposing design paradigms complicates the interpretation of the processes of transition from shell-first to frame-first construction that happened, independently, in the ancient Mediterranean and post-medieval Northern Europe.[101]

2.2.3 Technological context of the royal yacht *Mary*: 17th-century ship design

In order to understand the technological context of the early modern period, this section will give an overview of ship design practices as followed in English and Dutch shipyards of the period. It

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98 Hasslöf. Carvel Construction Technique, Nature and Origin; Hocker. Shipbuilding: philosophy, practice, and research, p. 6; Pomey. Principles and Methods of Construction in Ancient Naval Architecture, p. 27; Pomey *et al.* Transition from Shell to Skeleton in Ancient Mediterranean Ship-construction, p. 236; Van Duivenvoorde. *Dutch East India Company Shipbuilding*, p. 22.

99 McGrail. Hornell, Hasslöf and Boatbuilding Sequences, p. 385.

100 Hocker. *The Development of a Bottom-Based Shipbuilding Tradition in Northwestern Europe and the New World*; Hocker, F. M. 2004-b. Bottom-based Shipbuilding in North Western Europe. In F. M. Hocker and C. H. Ward (eds) *The Philosophy of Shipbuilding. Conceptual approaches to the study of wooden ships.* College Station: Texas A and M University Press.

101 Hocker. Shipbuilding: philosophy, practice, and research, p. 6.

should be pointed out, however, that the ideas reflected in this section are what could be described as 'currently accepted knowledge' in historic ship studies. Chapters 6 and 7 will argue that some of the ideas currently accepted as correct are not, in fact, a true reflection of shipbuilding practices followed in the period under study. Moreover it will be suggested that an alternative interpretation of the evidence is possible that will help describe the ship-design knowledge of early modern shipwrights of the frame-first (English) tradition and the bottom-based Dutch tradition in a more nuanced manner. The section will start by defining what *design* and *ship design knowledge* are, followed by a description of the current understanding of the procedures followed by English and Dutch shipwrights to design, or conceive, the shape of their hulls.

2.2.3.1 What is understood by design in this research?

Christopher Alexander defined the process of design as a 'process of inventing physical things which display new physical order, organisation, form, in response to function'.[102] He added that designers can create a form as they wish, keeping in mind that the context puts some demands on the form of the object being designed. The aim of the designer would be to 'satisfy the mutual demands which the two [form and context] make on one another'.[103] By context, it would be easy to understand the physical context of wind and water in which the ship must perform. However, such a simplistic analysis would overlook the most important aspect that determines the context defining the shape of a ship: the social context.

The study of ships (or any other human production for that matter) cannot be studied in isolation from the social surroundings that have led to its conception. The ship is a product of a society working within a '*craft tradition*' within a '*knowledge-space*'[104]. The craft tradition defines the concepts and methodologies needed to produce an object. These are not particular of individual craftsmen. They are shared by the different craftsmen that belong to that particular craft tradition and it is shared in a coded ideological framework.[105] In such a coded ideological framework, the manner in which the shape is conceived, by applying design-knowledge which is known and used

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[102] Alexander, C. 1964. *Notes on the Synthesis of Form.* Cambridge (Ma): Harvard University Press, p. 1.

[103] Alexander. *Notes on the Synthesis of Form*, p. 19.

[104] David Turnbull described 'knowledge-spaces' as collective spaces where knowledge is made possible by a combination of people, local knowledge and equipment which are inter-connected by shared strategies and technical devices (Turnbull, D. 1997. Reframing science and other local knowledge traditions. *Futures*, 29(6), p. 553).

[105] Adams. *A Maritime Archaeology of Ships.* p 197.

by the community of shipwrights who shared the same building tradition, becomes of paramount interest.

2.2.3.2 17th century ship-design knowledge in the academic literature

Shipbuilding and ship design have always been a craft in which experienced shipwrights did not pass on their knowledge openly. However, the knowledge had to be passed on to the next generation, and thus it was shared with a selected number of apprentices.[106] There are sufficient sources to show that by the 16th century, shipwrights did not build and design their ships '*by-eye'*, but after a careful process of design.[107] Chapters 4 and 5 will describe such design processes.

In modern naval architecture, most design decisions are based on scientific understanding and empirical tools developed in engineering.[108] In contrast, during the 17th century, there was a limited understanding of the scientific principles that explained the behaviour of complex technological devices. Hence, shipwrights of the period, in common with other crafts, had to base their design methods on practical procedures.[109] As chapters 4 and 5 will show, geometry and proportion were the basis of the procedures they followed to guarantee that the ships were shaped according to tradition, thus, meeting certain attributes of speed, stability, capacity, etc.[110] Shipwrights of the period had not yet developed the ability to explain in scientific terms the behaviour of a ship. This, however, did not prevent from elaborating complex theories that helped them in their processes of design. Although, in most cases, these theories were flawed from a modern, scientific, point of view.[111]

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[106] Lavery, B. 1993. *Marine Architecture Directions for Carrying on a Ship (1739).* New York: Scholars' Facsimiles and Reprints, p. 11.

[107] Barker, R. 1988. Many May Peruse Us. Ribband, Moulds and Models in the Dockyards. *Revista da Universidade de Coimbra. Vol. XXXIV*, p. 4.

[108] For example: Ferreiro. *Ships and Science. The Birth of Naval Architecture*; Kemp, J. and Young, P. 2001. *Ship Stability Notes and Example*s. Third Edition. Oxford; Marchaj. *Seaworthiness: the forgotten factor*; Rawson, K.J and Tupper E.C. 2001. *Basic Ship Theory. (Fifth edition. Vols 1 and 2).* Oxford: Butterworth-Heinemann.

[109] Hall, A.R. 1961. Engineering and the Scientific Revolution. *Technology and Culture*, 2(4), p. 333.

[110] Roberts, O.T.P. 1998. An exercise in hull reconstruction arising from the Alderney Elizabethan wreck. *International Journal of Nautical Archaeology* 27.1, p. 32.

[111] Ferreiro's *Ships and Science* provides a very interesting study of the development of the modern discipline of naval architecture throughout the early-modern period. It shows that the academic pursuit of a theoretical understanding which could help explain the behaviour of a ship as a floating body lagged behind the practical achievements of ship-constructors of the period.

One such theory described the optimum underwater hull shape by using the expression *cod's head mackerel's tail*. This would seem to suggest that the forward half of the hull should be shaped like the head of a cod, while the after half of the hull should resemble the shape of a mackerel's tail (figure 7).[112] However, figure 8 shows a superposition of two figures drawn by M. Baker (chapter 4) which seem to suggest that, perhaps, the expression *cod's head mackerel's tail* could be referring to the shape of the rising line, which at the time was considered one of the fundamental lines which determined the shape of the hull and, therefore, its performance (chapters 4-5). Irrespective of this, from a modern naval architect's perspective there is no scientific reason to sustain this or other similar theories in vogue at the time. Consequently, one could be tempted to say that in their pursuit of the *cod's head mackerel's tail* shape, or similar theories like the *body of least resistance*[113] shipwrights of the period followed 'flawed' rules. And, having no real justification behind them, it could be concluded that they could not be useful to create ships of adequate shape and, hence, satisfactory performance. This, however, would be a mistake. The fact that these theories are flawed from a scientific point of view did not prevent shipwrights of the 17th and, indeed, other periods from building satisfactory ships. Thousands of ships built and used before engineering calculations were developed are proof of the success of pre-engineering design methods. Thus, these often seemingly absurd theories and practical rules-of-thumb provided a framework, gained through experience, where decisions could be made within the boundaries set by the rules, thus making successful, repeatable, designs possible.

From a modern perspective the boundaries set by the design rules might be arbitrary and technically flawed. However, by limiting the amount of possible choices available to the designer, to the ones acceptable within the boundaries of the rule, the designer and the ultimate user of the ship knew what to expect at the end of the design and construction process. Following a set design procedure the basic *performance*[114] of the outcome of the design process (a ship) could be

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112 This interpretation of the expression 'cod's head mackerel's tail' is common. For example: Adams. *A Maritime Archaeology of Ships.* p 195; Edwards, C.R. 1992. The impact of European overseas discoveries on ship design and construction during the sixteenth century. *GeoJournal*, 26(4), p. 447; Jong, J. 2010. Standvastigheid and verwachting: a historical and philosophical inquiry into standardization and innovation in design and production of the VOC retourschip during the 18th century, p. 87.

113 Even great scientists like Sir Isaac Newton, one of the pillars of modern science, developed theories that later science has proved to be wrong. For example the theory of the 'Body of Least Resistance' which proposed the existence of a three-dimensional shape which would have the least resistance when moving thorough a fluid. This theory was based on an erroneous understanding of the phenomena that determine the resistance experienced by a body moving through a fluid. See: Solid of least Resistance in Chambers, 1740, Cyclopaedia (Vol II).

114 For this research performance has been defined in very broad and simple terms. This research has focused on certain aspects of the ship's behaviour in the water which shipwrights of the period seem to

estimated. Of course, this estimation would be a far cry from the precision expected from any modern design procedure. However, when compared to the other possibility, that of not having any method or limitations at all, it is obvious that the arbitrary sets of rules and procedures available at the time provided a great advantage. The design-methods and rules-of-thumb enabled the storage and transmission of knowledge in a successful manner, hence, reducing the uncertainties of the ship design/building process to within acceptable limits.[115]

The previous paragraph would seem to indicate that, although 17th century shipwrights followed complex design procedures that made uncertainties manageable, their efforts could often lead to ships with unsatisfactory characteristics. It could be concluded, then, that these methods were unreliable and, by extension, unsatisfactory. However this analysis and conclusion, which perhaps would be correct if applied to a modern, engineering-based process of design, is flawed when viewed through a 17th-century perspective as the following example will illustrate. In 1673 Anthony Deane (1638–1721) [116] built The *Royal Charles* which after construction proved to be relatively unstable. That is, under operating conditions it heeled dangerously. There was a solution to this problem that was relatively common at the time. It was called *girdling*, and consisted on adding an exterior layer of thick planking to the hull around the waterline area. This increased the beam of the hull which has a direct influence on its stability,[117] thus it could be used as a practical solution in certain cases. A similar procedure followed to solve the problem of insufficient stability was called *furring* and consisted in removing some of the hull's planking in order to supplement the frames of the hull. This way a new underwater shape was defined which was planked again, hopefully solving the problems of stability.[118]

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be trying to control from the earliest stages of the conception phase. These basic *performance characteristics* for which the shipwrights of the period seemed to have a practical mechanism of control are: (1) that the ship must float at a given waterline, (2) that it must remain upright during normal service conditions and (3) that it must be made strong enough to resist the strains of normal service.

115 Gorman, M.E. 2002. Types of knowledge and their roles in technology transfer. *The Journal of Technology Transfer,* 27(3), p. 222; King. Technology and the course of shipping. *Ocean and coastal management*, 44(9), pp. 567–577 (p. 570); Taylor. *Boat Building in Winterton*, *Trinity Bay, Newfoundland*. National Museums of Canada (2006 edition), pp. 50-51.

116 Walker. S*hips and Shipbuilders*, p. 20.

117 The effect would be in relation to the increase in beam squared. Thus, a relatively small change in beam, like adding a thick layer of planking around the waterline, would had a positive effect for ships whose stability problems were not too severe.

118 Wagstaffe, C. 2014. Furring in the light of 16th-century ship design. In J.Auer and T. Maarleveld, (eds), *The Gresham Ship Project. A 16th-Century Merchantman Wrecked in the Princes Channel, Thames Estuary. Volume I: Excavation and Hull Studies. NAS Monograph 5. BAR British Series 602.* Archaeopress, p. 75; For a thorough archaeological analysis and theoretical reconstruction of a 16th century English

Few modern naval architects, or their clients, would be happy with the idea of having to widen the ship after launching it in order to solve stability problems that resulted from flaws in the design and construction process. Therefore, from a modern perspective these methods of hull design followed by 17th-century shipwrights could appear unsatisfactory. However, the conclusion is different if girdling is viewed through the eyes of a 17th-century observer. Shortly after launching the ship, Charles II reflected on the stability problems of the ship in a letter written to Prince Rupert on the 4th of August 1673. He wrote:

> I am very glad the *Charles* does so well; a gerdeling this winter when she comes it will make her the best ship in England.[119]

It is evident from Charles II's words that, although the ship had to be girdled, it was considered a very satisfactory and apt ship. So much that, with the girdling, it was hoped that it would become the 'best ship in England'. For 17th-century shipwrights girdling was an acceptable solution to the many unknowns within their knowledge-space.

A more detailed description of Early Modern English and Dutch ship design will be discussed further in 2.3.4 and 2.3.5.

2.2.3.3 Ship design treatises as sources of knowledge

There are no written records that explain the design procedures followed by shipwrights prior to the 15th century when the first surviving ship design treaties where written in Venice. These shipbuilding practices and Mediterranean shipbuilding practices spread to the Iberian Peninsula.[120] It has been established that during the 15th century there was a gradual change in the approach to build a ship in North West Europe. Thus English shipwrights abandoned (gradually) their traditional shell-first construction in order to adopt new methods imported from southern Europe.[121] The manner in which those techniques arrived to Northern Europe is still unclear, although the main influence seems to have come from Iberian Atlantic regions (Portuguese, Basque) and bordering regions of the South-Western French coast (Bordeaux,

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ship with evidences of furring see: Auer, J and Maarleveld, T., (eds) .2014. *The Gresham Ship Project. A 16th-Century Merchantman Wrecked in the Princes Channel.*

119 Creuze, A.F.B. 1840. *Treatise on the Theory and Practice of Naval Architecture: being the article "ship-building" in the Encyclopaedia Britannica, seventh edition*. Edinburgh: Adam and Charles Black, p. 18.

120 Steffy, R. 2001. The development of ancient and medieval shipbuilding techniques. In *Proceedings. International Symposium on Archaeology of Medieval and Modern Ships*, p. 60.

121 Adams. *A Maritime Archaeology of Ships.* Chapter 6.

Gascoigne).[122] However, a direct route by which these techniques could have been transmitted by itinerant workers following the Iberian model is also considered a possible route of technological transmission.[123] Independently of the way in which shipbuilding knowledge could have travelled, the fact is that by the 16th century English shipwrights and those of other Northern European nations were adopting frame-first shipbuilding, at least for the construction of large, prestigious, ships.[124]

There are a number of manuscript and printed treatises on ship design written during the 16th and 17th centuries which describe the practical procedures followed in order to design the shape of a ship (see chapters 4-5). They describe different methods of design. However, in general terms, they all share conceptual similarities. The procedures described in 16th and 17th century shipbuilding treatises were based on geometry, and proportion. The design of a ship would be based on a master frame obtained by following a geometrical construction and a significant (variable) number of sections of the hull would be derived by a controlled transformation of the master section shape.[125] As it will become clear in chapters 4-5, and was also stated by contemporaries of these ship design procedures, these rules and proportions were not based on science. [126] Instead, they were based on accumulated empirical knowledge, transmitted from generation to generation.

The study of these treatises has allowed modern scholars to describe the knowledge-space of ship designers of this period and the manner in which such knowledge was put to use. This has helped create an image of the societies using such knowledge in the frame-first traditions of early modern Europe. This image, in turn, has been used to create a mirror image which, by contrast, has been used to describe the social arrangements in the shell-first traditions still practised during the early modern period in Europe. Most notably in the Netherlands and northern European Baltic regions. These perceived differences in social arrangements will be described in section 2.2.3.6. The manner in which the knowledge contained in the treatises – and used by frame-first builders

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[122] Hocker. Bottom-based Shipbuilding in North Western Europe, p. 80.

[123] Adams. *A Maritime Archaeology of Ships*, p. 71.

[124] Adams. *A Maritime Archaeology of Ships*, p. 71.

[125] For a discussion of these methods –as used in different periods and areas of Europe–, see: Castro, F. 2007. Rising and Narrowing: 16th-Century Geometric Algorithms used to Design the Bottom of Ships in Portugal. *International Journal of Nautical Archaeology*, 36.1, pp. 148-154; Rieth, E. 1996, *Le Maître-Gabarit la Tablette et le Trébuchet: essai sur la conception non-graphique des carènes, du Moyen Âge au XXe siècle*. Paris : Comité des travaux historiques et scientifiques.

[126] Ferreiro. *Ships and Science*, pp. 46-49.

– is interpreted plays an important role in setting the differences and in explaining the technological trajectory of the early modern period. Thus, the following paragraph will give a brief overview of the manner in which such knowledge is characterised in the literature.

The design methods contained in these early modern ship design treatises are often described as the creation of highly skilled individuals, who Barker defined as highly gifted geometers.[127] Hasslöf –one of the earlier authors who described these treatises as a way of understanding social organisation– considered that the authors of these treatises were not necessarily shipwrights. Instead, their merit was that they knew how to write without any real experience in shipbuilding or ship design.[128] Not only this, Hasslöf concluded that these methods would be of little use to real shipwrights who, instead, would prefer more concrete methods of conceiving hull shape.[129] Following this line of argument, Ditta, Auer and Maarleveld considered that the contents of the treatises would not reflect real practices in the shipyards of the period. Instead, these methods would have been invented by sophisticated scholars who would try to create a type of knowledge based on their world view which at the time contemplated an orderly universe, explicable by geometry.[130] This is in line with Gilmer's opinion who wrote that these methods, which relied on geometry, may have been elegant but had little relation with the performance of the ship.[131] However, this view of the knowledge contained in the treatises is not shared by all. For example it was criticised by Jonathan Adams who realised that these methods might not be able to predict performance as expected from a present-day method, however, they produced ships of known type, therefore of predictable performance based on past experience.[132]

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[127] Barker. Many May Peruse Us, p. 547.

[128] Hasslöf described that the inspiration for the treatises came from the ideas of natural science created by Galileo, Newton and others (Hasslöf. Sources of maritime history and methods of research, p. 141-2).

[129] For example Hasslöf wrote that: 'the complicated arithmetical arguments about the proportions of the various parts of a ship and the use of geometrical figures as aids, [...], seem to belong to the world of the scholar, rather than to that of the illiterate craftsman.' (Hasslöf, O. 1966. Sources of maritime history and methods of research. *The Mariner's Mirror*, 52(2), pp. 127–144 (p. 142).

[130] Ditta, M., Auer, J. and Maarleveld, T. 2014. Albrecht Dürer and Early Modern Merchant ships. A reflection on the spread of ideas and transfer of technology. *Archeologia Postmedievale*, p. 87.

[131] Gillmer, T. 1985. Evolving ship design technology revealed in wrecks of Post Medieval ships. In Cederlund, C.O. (ed.), *Postmedieval Boat and Ship Archaeology: papers based on those presented to an International Symposium on Boat and Ship Archaeology in Stockholm in 1982*. Swedish National Maritime Museum Report 20, Stockholm or BAR International Series 256, Oxford, p. 261.

[132] Adams. *A Maritime Archaeology of Ships*, p. 179.

It can be seen that there is a wide scholarship that considers that these treatises were created by a social group that had little relation with ship design. Such a group would create these written pieces within a climate of intellectual scholarship of the period, for the 'enlightened discussions of learned men'.[133] Going further, some moderns scholars consider that the goal of the authors of these treatises would be to better the public status. For example, Brian Lavery wrote that '[Mathew] Baker, who [wrote *Fragments of Ancient English Shipwrightery* (chapter 4)], seems more interested in showing off his knowledge in arithmetic than in providing information on his principles of ship design'.[134] Similarly, Hocker distinguished between treatises of diverse periods with respect to the reasons which could have prompted the authors to write them. He wrote that '[ship building] treatises produced in the 16th and 17th centuries, unlike those of the 15th century were written to demonstrate their brilliance and worthiness.'[135] With this, however, these authors do not necessarily imply that the contents of these treatises are worthless. After all, one could try to impress their contemporaries and at the same time produce a work of relevance. However, other authors have gone beyond this reasoning. Ab Hoving, for example, analysed Witsen's 17th-century treatise (chapter 4) which contained information that did not fit within the currently accepted narrative. Thus, Hoving justified that, by claiming that one of the reasons that Witsen had for writing parts of the treatise was to try to impress his contemporaries, he could disregard information contained in the treatise which questioned the accepted narrative (chapter 4).[136]

From the previous paragraphs, it can be seen that the manner in which the contents of the treatises have been interpreted initially tended to cast doubts about their usefulness, although it is generally accepted now that these practices became the norm for the construction of larger ships throughout early modern Europe, perhaps with the exception of the Netherlands until the early 18th century (chapter 4). Thus, a narrative has been created which describes the eventual adoption of these design methods, from the earliest methods first written down in Venice, to the

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133 For example, Castro wrote that:

> 'Shipbuilding treatises began appearing in the Iberian Peninsula in the final quarter of the 16th century but were not written by shipwrights and do not seem to have been written for shipwrights. They seem, rather, to be a consequence of a Renaissance taste for collecting and organizing knowledge, and eventually using it in enlightened discussions of learned men.'

Thus, according to this, these treatises would have been of little practical use. (Castro, F. 2008. In search of unique Iberian ship design concepts. *Historical Archaeology*, 42(2), p. 67).

134 Lavery, B. 1988. *The Colonial Merchantman Susan Constant 1605*. London: Conway Maritime Press, p. 8.

135 Hocker. In details remembered, p. 81.

136 Hoving. *Nicolaes Witsen and Shipbuilding in the Dutch Golden Age*, p. 18.

latest methods embracing scientific knowledge of the end of the 18th century. Steffy described such a progression, where mathematics and formalised design procedures, relying in increasingly sophisticated graphical depictions, played an ever-more present role which, eventually leading to the adoption of modern science in the 19th century.[137]

In the following chapters the knowledge contained in early modern treatises will be analysed and interpreted. Most of the available treatises, analysed in chapters 4 and 5, describe shipbuilding and ship-design knowledge as used by shipwrights of the frame-first tradition. However Witsen's treatise, and some aspects of Van Yk's treatise, both written in the Netherlands during the late 17th century, describe Dutch shipwrights building in the Dutch version of shell-first construction, called bottom-based by Hocker.[138] Therefore, the following sections will offer a simple description of the conceptual approach to hull design in both traditions, useful to understand the analysis and discussion in the following chapters.

2.2.3.4 Frame-first process of hull design. A conceptually common approach.

This section describes in general terms the process followed by shipwrights building in the frame-first traditions of the period to derive the shape of their hulls. The methods described in the following paragraphs could refer to English practices as well as those of other nations like, for example, France, Spain, Sweden and Portugal, where conceptually similar procedures were followed at least for the construction of large ships.[139] The notable exception would be the Dutch, who followed a different approach to the construction of their ships (see 2.2.3.5).

Shipwrights of the time were not necessarily educated people, and often, even highly esteemed individuals were incapable of reading or writing,[140] therefore, the rules of ship design were, in general, simple and easy to remember and transmit (see chapters 4-5). However, as literacy levels and formal education increased during the 18th century, although the conceptual approach to hull design remained unchanged, the actual practical methods became more complex.[141] During this

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[137] Steffy. *Wooden Ship Building and the Interpretation of Shipwrecks*. Chapter 5.

[138] Hocker. *The Development of a Bottom-Based Shipbuilding Tradition in Northwestern Europe and the New World*; Hocker. Bottom-based Shipbuilding in North Western Europe.

[139] See chapters 4 and 5 to see the conceptual similarities between the design methods in use in England, Spain and France.

[140] Ferreiro. *Ships and Science*, p. 24.

[141] Ferreiro. *Ships and Science*, p. 80.

time, the knowledge which had historically been passed on orally was recorded on written notebooks, first, and more organised treatises, later (see chapters 4-5).

The process of hull design as practised in the 17th century was generally described in a 'recipe' that defined the shape in such a way that, by defining a few parameters, the three-dimensional shape of the hull was established (see chapters 4-5). First, the shipwright decided on the main dimensions of the hull such as its length, beam and depth. Then, the shape of the backbone – stem, keel and sternpost– was decided. Following this, the shipwright would define the three-dimensional shape of the hull based on the shape of the master section and on its gradual transformation to obtain the shape of the reminder of the transversal sections of the hull. In general, the shape of the master section consisted of a series of arcs of circle and straight lines that could be drawn following some geometrical rules based on a proportional relation between its elements.[142] This could be easily defined by simple rules-of-thumb (chapters 4-5).

The shape of the master frame could be used to obtain the shape of the transverse sections or frames of the hull. Thus, let us imagine the process of designing the shape of a frame (figure 9). The first step would be to narrow the master frame template by a predetermined value which was decided by simple geometrical constructions that produced a series of incremental values, appropriate for each individual frame. This movement is termed the *narrowing*. If a ship were to be designed by narrowing alone, its bottom would be too *full* in the ends, therefore the shipwrights of the time had an extra transformation they could apply to the template of the master frame. Shipwrights would raise the template, by a predetermined amount. This movement is the *rising*. Finally, different methods would be used to fill the 'gap' that resulted from rising the template above the keel level. Initially, this process would be done using templates shaped as the master frame, on a loft floor or directly over the framing stock (figure 10), without the need for drafted plans.[143] In larger ships, the template of the master section would be divided in several parts. Later, the same process was used to draw the shape of the hull on paper.[144]

The values of narrowing and rising were predetermined using a variety of methods that varies from treatise to treatise, and from shipwright to shipwright (chapters 4-5). As a general rule, the

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[142] For example: Adams. *A Maritime Archaeology of Ships*, p. 116; Barker, R. 1985. Fragments from the Pepysian Library. *Revista da Universidade de Coimbra*, 32, pp.161-178 (p. 165); Endsor. *The Restoration Warship*, p. 34; Rieth. *Le Maître-Gabarit la Tablette et le Trébuchet*, p. 57.

[143] Castro. Rising and Narrowing: 16th-Century Geometric Algorithms, pp. 148–154.

[144] Olaberria, J. P. and Olaizola, I. 2013, A Basque Shipyard Design Method of the Late 19th and Early 20th Centuries and its Relationship to Non-graphic Hull Design of the 15th Century. *International Journal of Nautical Archaeology*. 42.2, 358–64.

designer would choose the maximum values of rising and narrowing at the extreme sections of the hull where the method would be applicable, and by following simple geometrical constructions, numerical methods, mathematical curves, or fully graphical methods, the values of rising and narrowing for each intermediate sections within the hull could be obtained.[145] These systems of hull design, which did not make use of drafted plans, could not solve very well the shapes of the hull at their most extreme ends: the bow and stern. Hence these areas had to be solved by the shipwright *in situ*, as the construction proceeded, based on their personal experience and wisdom. As a result, two identical ships could not be built.[146]

These procedures became more complex with time, but conceptually similar methods of hull design remained in use until they were abandoned, in general, during the 19th century.[147] However, they did not disappear completely, and have remained in use until our present times for the construction of workboats and fishing boats in traditional shipyards in different areas of the Mediterranean basin and in regions of the world influenced by colonial European shipbuilding traditions (chapter 7).[148]

Change in hull form during the 17th century was gradual and slow.[149] Similarly, the design procedures changed during that time, but remained, in essence, the same: based on a master frame described by a geometric construction which was transformed in a controlled manner to

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[145] For example: Castro. Rising and Narrowing: 16th-Century Geometric Algorithms, p. 149.

[146] Barker, R. 1991. Design in the Dockyards, About 1600. In R. Reinders and P. Kees (eds), *Carvel Construction Technique. Skeleton First, Shell First. Fifth International Symposium on Boat and Ship Archaeology, Amsterdam 1988*. Oxford: Oxbow Monograph 12, p, p. 64; Lavery. *Deane's Doctrine of Naval Architecture*, p. 26. Treatises of the time recognised another reasons for the somewhat unreliable results of the design-construction process. For example the c.1620 anonymous treatise identifies the lack of geometric and arithmetic skills of English shipwrights who relied on small scale plans, as one of the reasons why shipwrights could build very fine ships which too often did not match the shape of the intended ship represented in the drafted plans (Salisbury, W. and Anderson, R.C. (eds), 1958. *A Treatise on Shipbuilding and A Treatise on Rigging, Written About 1620-1625*, p. 32).

[147] For a contemporary (early 19th century) account of these methods, see: Morgan, W. and Creuze, A. 1829. Article I: On Mechanical Methods of designing Ships' Bodies. In *Papers on Naval Architecture and other subjects connected with Naval Science*, Volume II. London: G.B. Whitaker.

[148] Castro, F. and Gomes-Dias, D. 2015. Moulds, Graminhos and Ribbands: a pilot study of the construction of saveiros in Valença and the Baía de Todos os Santos area, Brazil. *International Journal of Nautical Archaeology,* 44(2), pp. 410–422; McGrail, S. 2001-b. Portuguese-derived ship design methods in southern India? *Proceedings International Symposium on Archaeology of Medieval and Modern Ships of Iberian Tradition. (Trabalhos de Arqueologia nº 18)*. Lisbon, pp. 119-129; Rieth. *Le Maître-Gabarit la Tablette et le Trébuchet*, p. 191; Rieth. *Navires et Construction Navale au Moyen Age*, pp. 256-261; Taylor. *Boat Building in Winterton*, p. 5.

[149] Adams. *A Maritime Archaeology of Ships*, pp. 179-180; Endsor. *The Restoration Warship,* p. 7.

obtain the shape of the rest of the transversal sections of the hull (see chapters 4-5).[150] By the 1670s naval architecture is said to be changing from a medieval shipwright's craft to a modern scientific discipline. Thus, the use of drafted plans, the definition of rising and narrowing curves by numeric calculation, logarithms as aids for calculations, and other similar signs of sophistication in shipbuilding treatises are considered a sign of an increasing scientific approach to hull design during the 17th century.[151] Mathematical knowledge is generally considered to be an important aspect of early-modern ship design.[152] Eric Rieth considered that by 1740-1745 the cultural rupture with medieval methods of ship design had been completed.[153]

2.2.3.5 Dutch methods of ship design. A particular case

Although, the design procedures described above were used across Europe during the 17th century, the Dutch had a different approach to hull design.

Dutch shipbuilding of the 17th century is often considered one of the most sophisticated in Europe at the time.[154] The social organisation of Dutch shipwrights in Guilds is said to have provided the Dutch with an advantage when compared to their closest competitors of the time: England and France. Moreover, it would have provided Dutch shipwrights with an efficient way of guaranteeing that shipwrights were properly trained, resulting in an efficient process of storing and transmitting their accumulated knowledge from one generation to the next.[155]

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150 Adams. *A Maritime Archaeology of Ships,* pp. 179-180.

151 Adams. *A Maritime Archaeology of Ships*, p. 148; Barker. Design in the Dockyards, p. 61; Ditta, M., Auer, J. and Maarleveld, T. 2014. Albrecht Dürer and Early Modern Merchant ships. A reflection on the spread of ideas and transfer of technology. *Archeologia Postmedievale*, p. 87; Lavery. *Deane's Doctrine of Naval Architecture*, p. 21.

152 Ditta et al. Albrecht Dürer and Early Modern Merchant ships, p. 95; Rose, S. 2011. Digs and Documents: Gaps in our knowledge of medieval shipping. *The Mariner's Mirror*, 97(1), pp. 63–76 (p. 72); Johnson, S. 1994. *'Making mathematical practice: gentlemen, practitioners and artisans in Elizabethan England*. Ph.D. Thesis. Cambridge, p. 108.

153 Rieth, E. 2003. A Similar Atlantic and Mediterranean Ship Design Method: The Case of the French Royal Dockyards at the End of the XVIIth Century. In H. Nowacki and M. Valleriani (eds) *Shipbuilding Practice and Ship Design Methods From the Renaissance to the 18th Century.* Max Planck Institute for the History of Science, preprint 245, p. 80.

154 Unger, R. W. 1997. Dutch ship carpenters' guilds, c.1400 to c.1600. In: R.W.Unger, *Ships and shipping in the North Sea and Atlantic*, p. 5; Unger, R.W. 1985. Dutch design. Specialization and building methods in the seventeenth century. In: C. O. Cederlund (ed.), *Postmedieval boat and ship archaeology. Papers based on those presented to an International Symposium on Boat and Ship Archaeology in Stockholm in 1982*. British Archaeological Reports, International Series 256, Oxford, p. 154.

155 Unger, R. W. 1976. Wooden shipbuilding in Zeeland. *First Transactions of 'Houten Scheepsbow in Zeeland'*, Zeeurus Tijdschrift 26, 4/5, p. 133.

For a student of ship design in the early modern period, and of ship-design in general, the Dutch case poses interesting challenges as, during the 17th century, the Dutch had two distinct shipbuilding traditions. One, centred on the area of Rotterdam and the other centred on Amsterdam. In Rotterdam ships were built frame-first and in Amsterdam ships were built in the Dutch version of shell-first construction.[156] Thus, two distinct traditions, said to represent different ways of organising knowledge and society were practised in the same region, within the same cultural context, and within a very short distance from each other.[157]

Contemporary treatises written by Van Yk and Witsen during the second half of the 17th century describe their particularities in detail.[158] Witsen described the bottom-based procedure followed in Amsterdam, although he also mentioned that ships were built differently (frame-first) in other areas of the Dutch Republic.[159] However, when modern scholars refer to Dutch shipbuilding practices of the 17th century they refer mostly to shipbuilding as practised in Amsterdam and described by Witsen.[160]

The process of ship construction followed by the Dutch in Amsterdam during the 17th century was initially termed as *Dutch-flush* by Maarleveld.[161] The process of hull construction started as a *shell-first* process, where the skin of the bottom of the ship was erected without any internal framing or other support elements such as provisional moulds that could serve as a means of guaranteeing the shape of the hull. Based on this particularity, that seems to indicate that the shape of the bottom constitutes the basis of the conceptual approach to the conception of hull

[156] Barker, R. 2003. 'Cradles Of Navigation' Re-Visited. In H. Nowacki and M. Valleriani (eds), *Shipbuilding Practice and Ship Design Methods from the Renaissance to the 18th Century.* Max Planck Institute for the History of Science. Preprint 245, p. 103; Hocker. *The Development of a Bottom-Based Shipbuilding Tradition*. p176; Hoving, A. 1988. A 17th-century Dutch 134-foot pinas, Part 1. *International Journal of Nautical Archaeology*, 17(3), p. 212; Hoving. *Nicolaes Witsen and Shipbuilding in the Dutch Golden Age*, p. 7.

[157] Rieth. *Navires et Construction Navale au Moyen Age*, p. 47.

[158] Van Yk, C. 1697. *De Nederlandse Scheeps-bouw-konst. Open Gestelt.* Amsterdam: Ian Ten Hoorn; Witsen, N. 1671. *Aeloude en Hedendaegse Scheeps-bouw en Bestier*. Amsterdam: Casparus Commelijn.

[159] Witsen 1671 in Hoving. *Nicolaes Witsen and Shipbuilding in the Dutch Golden Age*, p. 57.

[160] For example: Hoving. *Nicolaes Witsen and Shipbuilding in the Dutch Golden Age*; Maarleveld, T.J. 2013. Early Modern Merchant Ships, Nicolaes Witsen and a Dutch-Flush Index. *International Journal of Nautical Archaeology,* 42(2), pp. 348–357.

[161] Maarleveld. Archaeology and early modern merchant ships.

shape, Hocker adopted the term '*bottom-based*' to refer to this particular approach to ship construction.[162]

To our current mind this construction process seems a counter-intuitive process, and one fraught with many difficulties, but the Dutch had previous experience in building the bottoms of a medieval ship type called cog before erecting the internal framework.[163] In order to build ships from the bottom up, the Dutch had developed different techniques and tools that allowed them to proceed in this manner. As they lacked any pre-erected internal structure (frames or provisional moulds), the planking was fixed by numerous short wooden cleats that joined provisionally each plank to adjacent planks (figure 11). The cleats were nailed to each of the planks, bridging the joints between them. Once the bottom of the ship was finished, or at least sufficiently planked up, interior framing was installed inside, planks were fixed permanently to the frames, and the cleats, having become redundant, were removed.[164] After the framing had been inserted to stiffen the bottom of the hull, additional framing for the sides was fixed to it and was left protruding upwards, thus offering a structure to which the planking of the sides could be attached in a frame-first manner (figure 12). This second phase of the ship's construction did not differ in essence of the procedures followed by English shipwrights of the period where the planking was attached to a pre-erected framework of transversal frames.[165]

In the Dutch method of ship construction, the bottom of the ship was built without pre-erected frames or moulds to guide the construction of the bottom's planking, in a shell-first fashion. As a result it is described as a method in which there is no pre-design of the hull shape. Rather, Dutch shipwrights designed and built in a simultaneous process where there was no distinction between conception of hull shape and its construction.[166] However, there is also evidence that suggest the

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[162] Hocker. Bottom-based Shipbuilding in North Western Europe, p. 66.

[163] Unger, R.W. 1985. Dutch design. Specialization and building methods in the seventeenth century. In: C. O. Cederlund (ed.), *Postmedieval boat and ship archaeology. Papers based on those presented to an International Symposium on Boat and Ship Archaeology in Stockholm in 1982*. British Archaeological Reports, International Series 256, Oxford, p. 156.

[164] Hocker. Bottom-based Shipbuilding in North Western Europe, p. 82; Lemée, C.P.P. 2006. *The Renaissance Shipwrecks from Christianshavn. An archaeological and architectural study of large carvel vessels in Danish waters, 1580-1640*.Roskilde, Denmark: The Viking Ship Museum, pp. 218-227.

[165] Hocker. Bottom-based Shipbuilding in North Western Europe, p. 82.

[166] Hoving. *Nicolaes Witsen and Shipbuilding in the Dutch Golden Age*, p. 9, 15; Maarleveld. Archaeology and early modern merchant ship, p. 167; Verweij, J., Waldus, W., Van Holk, A. 2012. Continuity and change in Dutch shipbuilding in the Early Modern period. The case of VAL7 and the watership in general. *Journal of Archaeology in the Low Countries*, 4, pp. 65–93 (p. 86).

contrary. For example, Witsen's treatise and other contemporary accounts such as Arnoul's (chapter 4) indicate that Dutch shipwrights of the period used certain design procedures which may have helped them in the conception of hull shape. These design procedures were not based on drafted plans, but on traditional formulae of proportions and simple geometry that were used by the master shipwright during the building process.[167]

Some scholars have studied how these formulae and recipes could have been used by the shipwright to shape the hull. By analysing 16-17th century Dutch shipwrecks found in Denmark, Christian Lemée suggested that Dutch shipwrights of the period did not rely on their 'eye' to shape their hulls. Lemée argued convincingly that methods of pre-design and shape control could have been used for the constructions of Dutch ships of the period. The method would be based around the provisional cleats that shipwrights used to fix adjacent planks to each other (figure 13). By cutting the cleats with a pre-determined angle, it was possible for the shipwright to control the bevel angle between adjacent planks. [168] Thus, in a gradual process, plank by plank, the transversal shape of the hull could be built to a pre-determined shape. Similarly, Kelby Rose's analysis of the remains of the 17th-century Vasa –built by Dutch shipwrights in the Dutch tradition–allowed him to suggest that simple geometry might have been used to design the turn of the bilges of the master section of the Vasa.[169] Kroum Batcharov found further evidences which pointed towards the existence of pre-erected control frames in the bottom of the Vasa which could have been used by the shipwrights to determine the shape of the bottom of the ship before it was built. [170] There is additional archaeological evidence that shows that actual frames were pre-erected before the planking of the bilge and sides was erected. Thus, André van Holk's study of the early 17th century OE 34 wreck of Dutch construction found in the Netherlands, showed that at least two frames had been erected before the bilge and sides of the hull had been planked.[171] Consequently, the archaeological evidence identified by Lemée, Rose, Batcharov and Van Holk , above, suggests that control mechanisms of the transversal shape of the hull in line with the ones described by Witsen's treatise (chapter 4) were being used for the control of the transversal shapes of seagoing Dutch ships built on the bottom-based tradition.

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[167] Hoving. *Nicolaes Witsen and Shipbuilding in the Dutch Golden Age*, p. 9.

[168] Lemée. *The Renaissance Shipwrecks from Christianshavn,* p. 140.

[169] Rose, K. 2014. *The Naval Architecture of Vasa. A 17th-century Swedish Warship*. Phd Dissertation. Texas A and M University, p. 292.

[170] Fred Hocker, personal comment (January, 2017).

[171] Van Holk, A.F. 2014. Maritime archaeology, mind-set and money, the IFMAF and the Zuiderzee: Education, research, awareness and management, p. 46.

The traditional design formulae, the geometric method described by Witsen to define the shape of the master section in the 17th (chapter 4) together with the archaeological evidence should have led to re-considering the idea of Dutch shipbuilding as a process that was based on the 'eye' of the shipwright; where ships were built in a simultaneous process of design and construction; with no method to pre-determine the shape of the hull. However, this is not generally the case, and the formulae and simple geometric procedures are described as a secondary tool, used to aid the 'eye' of the shipwright in the shaping process, as the following quotation by Ditta, Auer and Maarleveld shows:

> In fact, both the historical, the archaeological and the anthropological evidence shows that Dutch ship- building – or more specifically building ships in the Dutch Flush manner – comprises a whole toolbox of skills-based rules and techniques that could be drawn upon to **support the builder's eye in shaping the hull and assisting him in control of symmetry** along the main axis (Highlights not in the original). [172]

Consequently, the role of these rules and techniques as a means to store information about three-dimensional shape, thus allowing this knowledge to circulate, is downplayed to the role of mere control of symmetry. In chapter 6, this and other shortcomings of the currently accepted narrative will be discussed.

2.2.3.6 Social arrangements in English and Dutch shipwright communities according to the current narrative

One of the consequences of the current narrative that describes frame-first hull design and construction methods –as the ones used in England– and shell-first methods –as the ones used to make the bottom by Dutch bottom-based shipwrights– is the perception that those different approaches resulted in different social arrangements. The study of design treatises has influenced these ideas about the social climate in which the knowledge was created (Dutch republic vs English kingdom). The following paragraphs will provide a general description of the social climate, as currently described, in the English and Dutch cases. These ideas will be criticised in chapter 6.

English ship design: an activity divided by social hierarchy

It is generally accepted that with the adoption of frame-first ship construction during the 15th to 16th centuries a social transformation took place which contrasted with the social arrangement

[172] Ditta, M., et al. Albrecht Dürer and Early Modern Merchant ships, p. 90.

prior to the adoption of frame-first design/construction methods. According to this, as a consequence of the adoption of frame-first design and building process, where frames were made at the early stages of the construction process, ship design and ship construction became separate endeavours.[173] This brought with it a transformation of the social structure involved in shipbuilding. The design process became the responsibility of master shipwrights who became ship-designers. Their status grew and rose on the hierarchical ladder to a position above that of shipwrights taking part in the actual construction of the ship. [174] The geometric design methods, described in treatises, were imposed upon the practical shipwrights by theoretically minded designers with no practical craft-experience.[175] Moreover, these methods would respond to the world view of these theoretically minded ship-designers who were inclined to create complex geometric design methods which, in effect, had no relation to the performance of the ship.[176] Thus, shipwrights lost the ability to influence in the design of the ship and became craftsmen who followed orders and decisions issued by the ship-designer.[177] However, these methods, imposed by learned men which led to a hierarchical division of knowledge and practice in English shipyards is considered by some to be responsible for remarkable failures in ship design. Thus, for some, English ship design of this period was 'bogged down on theoretical dogma' with pernicious effects.[178] As a result of such flawed design methods English ships would suffer from an unusually high number of failures that would result in the need for girdling and furring to correct such faulty performance.[179]

It is generally accepted that, as the 17th century neared its end, design methods became more complex by the use of numerical methods and mathematical devices –such as logarithms– and drafted plans, the use of which have been interpreted as the first signs towards a scientific

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173 Adams. *A Maritime Archaeology of Ships,* p. 148.

174 Adams. *A Maritime Archaeology of Ships,* p. 148.

175 Auer, J. and Maarleveld, T. 2014. In Conclusion: Looking Back and Looking Forward. In J.Auer and T. Maarleveld, (eds), *The Gresham Ship Project. A 16th-Century Merchantman Wrecked in the Princes Channel*, p. 86.

176 Gillmer. Evolving ship design technology revealed in wrecks of Post Medieval ships, p. 261; Auer and Maarleveld. In Conclusion: Looking Back and Looking Forward, p. 86.

177 Ditta et al. Albrecht Dürer and Early Modern Merchant ships, p. 84.

178 Bellamy, M. 2006. David Balfour and early modern Danish ship design. *The Mariner's Mirror*, 92(1), p. 15.

179 Auer and Maarleveld. In Conclusion: Looking Back and Looking Forward, p. 86; Wagstaffe. Furring in the light of 16th-century ship design, p. 80. It should be noted, however, that this opinion is not supported by the archaeological record where evidences of furring or girdling are scarce.

approach to ship design.[180] By then the social division between designer and shipwrights is considered complete, leading from the early attempts by Mathew Baker to extend the limits of contemporary knowledge towards the full scientific approaches by Swedish Naval Architect Chapman in the latter years of the 18th century.[181]

Dutch shipwrights

The manner in which Dutch shipwrights of the period designed and built their ships has led to depictions of the social climate around Dutch shipyards which contrast to those of their English contemporaries. Therefore, based on the partially shell-first approach followed by Dutch shipwrights, it is often considered that Dutch shipwrights of the period would not need a method of design.[182] Rather, they would shape their hulls in a simultaneous process of design and construction, creating the shape of the hull while it was built (see section 2.2.3.5 below).[183] According to Richard Unger, Dutch ship designers did not have a method of design based on geometry or mathematics. As a result they would be easier to train as they did not need to learn theory or mathematics. Consequently, it is considered that Dutch shipwrights knew, by way of experience and skill, how to shape a hull to guarantee a successful performance without requiring any method of design. [184]

The way in which Dutch ship construction is generally understood as a process in which the ship is built and designed simultaneously, without a process of pre-design, has resulted in a definition of Dutch shipyards that is markedly different to those of contemporary shipyards of other European nations. In Maarleveld's view, contrary to the geometrical pre-design methods used in frame-first England and other European nations–known to a relatively learned elite while the majority of the workforce would be left to follow orders–, Dutch shipwrights had only a set of simple rules of proportion which, by their own nature, would be easy to transmit and, therefore, harder to keep secret from the workforce. The ship would be built and shaped in full view, following methods

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[180] Tebeaux, E. 2008. Technical writing in English Renaissance shipwrightery: Breaching the shoals of orality. *Journal of Technical Writing and Communication*, 38(1), pp. 3–25 (p. 18); Adams. *A Maritime Archaeology of Ships*, p. 148; Barker. Design in the Dockyards, p. 61; Ditta et al. Albrecht Dürer and Early Modern Merchant ships, p. 87.

[181] Barker. Fragments from the Pepysian Library, p. 174.

[182] Verweij et al. Continuity and change in Dutch shipbuilding in the Early Modern period, p. 86.

[183] Hoving. *Nicolaes Witsen and Shipbuilding in the Dutch Golden Age*, p. 9; Maarleveld. Archaeology and early modern merchant ships, p. 167.

[184] Unger. Dutch design. Specialization and building methods in the seventeenth century, p. 161; Maarleveld, T.J. 1992. Archaeology and early modern merchant ships, p. 167.

that everyone could see as it happened straight in front of their eyes. This would result in a social organisation which contrasted with the hierarchical, bureaucratic description of English shipwrights above. Instead, Dutch shipwrights would constitute a more egalitarian social group with a limited hierarchical and bureaucratic organisation.[185] Thus, the manner in which Dutch shipwrights are understood to organise their ship-design knowledge and the way in which it is shared by the community of shipwrights is a contrast to that of English shipyards.

2.3 Closing remarks

In this chapter the Royal yachts have been described as a ship type that does not appear to be specifically designed to fulfil any particular role. On the contrary, they have been shown to be able to play numerous roles within the Royal Navy which, in principle, would seem to require different performance characteristics. This leads to questioning the ability of designers of the period, to create ships with special requirements in mind. The following chapters will analyse how shipwrights of the period designed the three-dimensional shape of their hulls. Therefore, the chapter has introduced the current scholarship that describes this matter, which, as this thesis will discuss in chapter 6 is based on a flawed understanding of the contents of the treatises and of the procedures followed by early modern shipwrights to design the shape of their hulls. It will be argued that shortcomings in the current narrative which describes shipbuilding knowledge go beyond the particular cases of English and Dutch ship design. Consequently, the research and analysis of written sources of evidence will broaden its temporal limits to include the early modern period, from the 15th century to the mid-19th century when a change in the design paradigm can be shown. But first, in order to understand the outlook of this researcher, the theoretical approach of the thesis will be introduced in the following chapter.

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[185] Maarleveld. Archaeology and early modern merchant ships, p. 169; Adams, J. 2003. *Ships, Innovation and Social Change*, p. 190; Verweij, J. et al. Continuity and change in Dutch shipbuilding in the Early Modern period, p. 84; Ditta et al. Albrecht Dürer and Early Modern Merchant ships, p. 100.

Chapter 3: Theoretical approach of the thesis: In search of the design knowledge contained in shipbuilding treatises

One of the objectives of this thesis is to discuss and establish the nature of the knowledge contained in the different early modern shipbuilding treatises and to establish whether the variety of methods of conception and recording of shape among the different treatises, represent a true technological development; whether the current understanding of these design methods is correct or can they be defined in a different light. In order to do so, chapters 4 and 5 will describe a number of early modern ship design treatises. Therefore this chapter will describe the manner in which knowledge is defined in this research which, in turn, will allow the reader to understand the outlook of this researcher.

3.1 Technology as a window to observe past societies

Human societies, often, enjoy different *scenarios of technological development*.[186] As a result, the manner in which technology is made, put to use, learned and taught will be different. There is much to be said for the study of particular technologies of different societies: their application, tools of implementation, materials and processes available, etc. These aspects may inform us of the knowledge-space in which a society makes their technological choices. This knowledge-space sets the boundaries that envelope the possible number of choices available for the development and implementation of technological processes and devices. Consequently, by knowing these boundaries one can start to describe a picture of the particular technology used by a social group with possible justifications for their choices. However, this approach ignores that, probably, the limiting factor that determines the technological choices available to a social group may not be practical (in a physical sense of materials and tools, for example), but they may cognitive.[187]

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186 The reason for using the term scenarios instead of levels is to avoid suggestions of any kind of technological evolutionary path in which the technologies of different social groups fit. It does not always follow that a group will adopt the most advanced technology available to them. In practice, each group will choose the technology that suits them best, regardless of it being the most advanced technology or not.

187 There is an extensive body of literature that studies how different social groups tackle the problem of ‘design’ when the knowledge is partial (as it was the case of ship designers described in this document). In cases where the design problem is ill defined, designers must base their design decisions on modes of design based on practice, rules of thumb and accumulated tacit knowledge. For example, see: Ahmed,

There are many studies that try to comprehend the historical development of technology and especially technological changes.[188] Often, those studies of technology are based on particular technological objects or practices which are seen as a valuable means of observing past individuals and social groups. However, it has been suggested that research should avoid concentrating on the particularities of individual objects or it would result in an over-particularistic and distorted view. Instead, researchers should widen their focus, with a view to understanding the general 'landscape' in which particular technologies or technological device were used.[189]

The idea of technology as a dynamic element of society, and not of particular individuals, is very much present in the numerous studies that try to understand technological changes throughout history.[190] In those studies, the definition of technological paradigms is crucial as it helps understand what is really being researched. In that respect, this research has been shaped by the following definition of technological paradigm proposed by Giovanni Dosi:

> A 'technological paradigm' [is defined] as an 'outlook', a set of procedures, a definition of the ''relevant' problems and of the specific knowledge related to their solution.[191]

Thus, in the study of a particular technological paradigm and what it tells us about the practitioners and their knowledge-space, the outlook with which the practitioners tackle a particular technological problem becomes of primary interest. To solve such problems practitioners must, first, identify the relevant aspects of the problem to, then, create and apply

S., Wallace, K.M. and Blessing, L.T. 2003. Understanding the differences between how novice and experienced designers approach design tasks. *Research in engineering design*, 14(1), pp. 1–11; Cross, N. 2001. Designerly ways of knowing: Design discipline versus design science *Design issues*, 17(3), pp. 49–55; Dorst, K. 2006. Design problems and design paradoxes. *Design issues*, 22(3), pp. 4–17; Dym, C.L. et al. 2005. Engineering design thinking, teaching, and learning. *Journal of Engineering Education*, 94(1), pp. 103–120; Eilouti, B.H. 2009. Design knowledge recycling using precedent-based analysis and synthesis models. Design Studies, 30(4), pp. 340–368; Jiang, Y. and Chun, M.M. 2001. Selective attention modulates implicit learning. *The Quarterly Journal of Experimental Psychology: Section A.* 54(4), pp. 1105-1124.

[188] For example: Kuhn, S. 2004. Evolutionary perspectives on technology and technological change. *World Archaeology*, 36(4), pp. 561–570; Schiffer, M.B. 2004. Studying technological change: A behavioral perspective. *World Archaeology*, 36(4), pp. 579–585.

[189] For example: Martin, C. 2001. De-particularizing the particular: approaches to the investigation of well-documented post-medieval shipwrecks. *World archaeology*, 32(3), pp. 383–399.

[190] For example: Smith, P.H., Meyers A.R.W. and Cook H.J. 2014. *Ways of Making and Knowing: The Material Culture of Empirical Knowledge.* University of Michigan Press.

[191] Dosi, G. 1982. Technological paradigms and technological trajectories: a suggested interpretation of the determinants and directions of technical change. *Research policy*, 11(3), pp. 147–162 (p. 148).

appropriate knowledge. Hence, the goal of the researcher should be to identify what the problem is, as understood by the practitioner. Once the problem is identified, it should become possible to better understand the knowledge created and the technological solutions to which such knowledge leads. The final goal should be to understand the particular world view of the social group responsible for the technology being researched.

One of the challenges of studying the design paradigm of traditional shipwrights is the well-established theory that relates the assembly sequence of the hull with design-paradigm and by extension with a particular world view and social arrangement (chapter 2). Following Dosi's definition of paradigm, this research attempts to define the outlook of early modern pre-engineering shipwrights towards the technologically challenging task of designing a ship. In particular, what aspects of ship design were perceived as relevant by shipwrights as reflected in the knowledge they created to solve the challenge.

In the field of architecture and the craft of the stonemason the role of geometry and practical tools as a means of facilitating the storage and transmission of knowledge leading to the construction of buildings and other structures is well established.[192] If traditional craftsmen did not find a way of recording past experience –which memory alone cannot do– to use it as the basis of future technological devices, the need to *re-invent the wheel* would present itself time and time again. Thus, rules-of-thumb based on geometry and proportion made it possible to store and transmit the knowledge in the stonemason's craft and other crafts, such as the construction of machines or musical instruments, for example.[193] Similarly, shipwrights willing to create ships, by building on past experience, would have required a means to store information about past design. By analysing the basic needs of such a method from the perspective of the present author – a modern naval architect–, for such a storage method to be successful, it would have to provide the means to store two very different aspects of a ship. These are, the physical configuration of the ship on the one hand, and its three-dimensional shape on the other. Each, in turn, pose distinct challenges with respect to how such information can be stored and transmitted.

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192 Salas, J.F. 1996. Geometría y función estructural en cantería. La cantería y la estereotomía de la piedra en el aprendizaje del arte de construir y otras consideraciones. In *Actas del Primer Congreso Nacional de Historia de la Construcción*, p. 21; Turnbull, D. 1993. The ad hoc collective work of building Gothic cathedrals with templates, string, and geometry. *Science, Technology and Human Values*, 18(3), p. 317.

193 Birkett, S. and Jurgenson, W. 2001. Why Didn't Historical Makers Need Drawings? Part I-Practical Geometry and Proportion. *The Galpin Society Journa*l, p. 244; Birkett, S. and Jurgenson, W. 2002. Why Didn't Historical Makers Need Drawings? Part II: Modular Dimensions and the Builder's Werkzoll. *The Galpin Society Journal*, p. 184; Guzzomi, A.L., Maraldi, M. and Molari, P.G. 2012. A historical review of the modulus concept and its relevance to mechanical engineering design today. *Mechanism and Machine Theory*, 50, p. 7.

The physical configuration would contain information about the actual physical ship itself. Most prevalent would be information about the structure of the ship (arrangement and sizing of elements), of its rigging (arrangement and sizing of elements) and other necessary fittings and technological devices required for the ship to function correctly (e.g. control devices such as rudders or steering oars; installations such as galleys or living quarters). All these can be touched, felt, measured or weighed by the shipwright. Hence, the information can be specified and stored in templates, story-sticks,[194] traditional recipes, complex design functions which can be committed to memory or recorded in documents and books. The information contained in these storage methods can be recalled by the shipwright in order to create a new design.

However, the other important aspect of ship design, three-dimensional hull shape, poses very different challenges, especially at a period when methods to record three-dimensional shape on drafted plans had not been developed yet (chapters 4-5). Shape is abstract in nature and hence, not easy to measure and specify. However, shape is seldom arbitrary and most human made artefacts conform to a certain typological order where objects share common characteristics of physical features and form. In shipbuilding, basic performance characteristics of the ship such as buoyancy and stability are influenced by hull-form. As a result, the control of hull shape must become one of the principal preoccupations of any shipwright. Moreover, in a context where shipwrights lacks the analytical means to predict the performance of the ship being built, the only way of guaranteeing a certain level of performance comes from repeating past designs or, at least, on basing the new design on previous known examples. Thus, in parallel to the storage of the physical fabric of the ship (above) the shipwright must find a way of storing the three-dimensional shape of the hull. Developing such a storage method which allows three-dimensional shape to be remembered, in order to provide a common method of communication with others, must be necessary for most, if not all, shipwrights.[195]

This research has approached the problem of defining the three-dimensional shape of hulls by early modern shipwrights with two premises. One which assumes that all shipwrights, irrespective of their building traditions, must be aware of the importance of hull shape in the performance characteristics of the ship. A second premise would be that one does not require any inherent cognitive superiority in order to be able to design the shape of a ship. In other words, there is no

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[194] A story stick is a piece of wood or similar material in which the worker inscribes the principal dimensions of an object and its features for future reference (Walker, G. R. and Tolpin, J. 2013. *By Hand and Eye*. Fort Mitchell, KY (USA): Lost Art Press, p. 4).

[195] See chapters 4, 5 and 7 for a discussion in the different mechanisms used to store information regarding hull shape.

reason to suspect that the cognitive abilities of shipwrights would be above those of other craftsmen. Certainly, it is possible that extremely skilful shipwrights might have built successful ships based only on their inherent ability for the job. However, without a means to store the information devised by such a genius, it is not possible to transmit it to others or future generations. Thus, it would die out. Based on these premises, this research has approached the design methods of the early modern period by assuming that, in common with similar strategies used in other crafts, the main motive for the existence of these methods must be to serve as storage devices for three-dimensional shape. Thus, allowing shipwrights to accumulate the complex three-dimensional shape of a hull on a simple device, a design recipe, which can be stated in a few words, and can be stored and, most importantly, transmitted by recording a relatively small number of parameters.

Another important outlook of this research is that the contents of the treatises that will be analysed do not imply, necessarily, a constant improvement of technology and technological knowledge; one that is based on optimum and efficient solutions. Technological practice rarely behaves in this manner. It often follows paths which may lead to sub-optimal solutions, or to the survival of theoretically obsolete solutions, that may be satisfactory to its users.[196] As a researcher, the study of these design-tools and technological choices becomes a primary goal as a means of studying the cultural landscape.[197] The treatises analysed in chapters 4-5 have been approached from a practical point of view, focusing on the potentially practical value of the information contained in them.

3.2 Shipbuilding treatises. A window into past practical knowledge

In chapter 2.2.3.3, shipbuilding treatises have been described as sources that could be used to characterise the knowledge of early modern shipwrights engaged in the design of ships. This section will give a brief overview of the type of knowledge that is contained in these treatises and the methodology followed in this research to extract the knowledge from them.

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[196] Baumol, W.J. and Quandt, R.E. 1964. Rules of thumb and optimally imperfect decisions. *The American economic review*, 54(2), p. 23; Harley, C.K. 1973. On the persistence of old techniques: the case of North American wooden shipbuilding. *The Journal of Economic History*, 33(2), p. 398; Wright, G. 1997. Towards a More Historical Approach to Technological Change. *The Economic Journal*, 107(444), pp. 1560–1566 (p. 1564).

[197] Sillar, B. and Tite, M.S. 2000. The Challenge of 'Technological Coices' for Materials Science Approaches in Archaeology. *Archaeometry*, 42(1), pp. 2–20.

In 1578 William Bourne wrote his treatise called *A booke called the treasure for travellers* (figure 14).[198] At the end of the Third Book he enumerated the ideal characteristics required from a ship in order to be of practical use and the manner in which the shipwright could ensure that the ship had those features (figure 14). He wrote:

> Wherefore thus much I have sayde as touchinge the moulde[199] of Shippes, as concerning theyr qualyties, as thus: a Shippe that hath Tucke or Runne ynough, wyl steare well:[200] a Shippe, that doth hange well of on the nayle above the water, wyll beare a good sayle[201]: a Shippe that doth draw a reasonable good drafte of Water, and well wayed forwardes, wyll sayle well by the winde:[202] and beinge well bowed and not to fatte buttocked, [203] wyll goe well a head the sea, and also ryde well at rode, and also wyll hold well at the

[198] Bourne. *A booke called the Treasure for traveilers*. Third book 21-22.

[199] *Moulde:* mould or more generally –in the context of Bourne's text– shape.

[200] Tucke and Runne: Tuck and run.

The tuck and the run are the extreme forward and aft areas of the bottom of the hull respectively. Both have an influence on the flow of water around the hull and, consequently, on its performance; in this case on how the ships steers.

[201] *a Shippe, that doth hange well of on the nayle above the water, wyll beare a good sayle:* With this expression Bourne seems to be suggesting a ship that is stable enough when floating in the water (by imagining it to be hanging of a nail; like a pendulum perhaps?), can carry its sails properly, or as Bourne says *beare a good sayle,* as it will be able to counteract the heeling forces imposed by the sails.

[202] *Drafte:* draught. The draught of a ship is the dimension that measures its depth below the water.

In this sentence Bourne is describing that, in order to sail by the wind, a ship requires to have sufficient draught and also should be well *wayed,* or shaped, forward. It is unclear to what point of sail he may be referring to, although it would seem reasonable to assume that he is referring to sailing into the wind, or upwind.

[203] *well bowed and not to fatte buttocked:* well bowed and not too fat buttocked.

These are references to the shape of the hull at the forward end of the ship, the bow.

In this sentence Bourne indicates that the ship should be shaped in such a manner that it is sufficiently full (or fat) forward, at the bow. However, he warns that a shape that is too full (or fat buttocked) can be counterproductive.

> Sea loose.[204] and floty Shippes that steere well and wyll beare a good sayle, wyll sayle well,[205] then ynde beyng large .etc. And thus I doe ende this thyrde Booke.etc.[206]

Bourne had a clear idea of what characteristics were desirable in a ship and, most importantly, that all these characteristics were dependant on the three-dimensional shape of the hull. However, the text also points at the limitations of the technological knowledge of the period. Although the ideas expressed by Bourne are correct in qualitative terms –as abstract ideas of general trends and concepts– they fail to provide quantitative information that may be used by the shipwright. The reader is told that ships should have *enough* tuck or run; they should have a *reasonable* draught; they should be *well shaped*, *well bowed* and with buttocks that are *not too fat*. In conclusion, they should be shaped and proportioned correctly so that the result is a ship that sails well. Unfortunately for the reader the text gives no indication of how much tuck or run is considered enough; or, what constitutes a reasonable draught; what is considered by the author to be the shape of a good bow or buttocks that are not too fat. Unfortunately for Bourne and contemporary shipwrights and scholars, the development of theoretical knowledge of the period did not allow more precision. However, lacking a theoretical framework that explained the performance[207] of a ship in the water did not prevent the development of practical procedures

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[204] If the ship is made with the right amount of fullness, it will sail well into a head sea. Although Bourne does not explain why this would be the case, it is clearly a consequence of the fact that when a ship with a very full bow is driven against incoming waves it tends to slam hard. On the other hand, a finer ship will have a softer ride as it will not tend to pound so hard if driven against incoming waves. However, if the bow should be made too fine, it would not provide sufficient buoyancy to lift to incoming waves and it would tend to plunge, dangerously, into them.

Similarly, when a ship is at anchor –the rode Bourne refers to is the anchor rode or the line (rope) that attaches the ship to the anchor– the ship normally lies facing the wind and oncoming waves. Thus, if the bow is too full the waves and wind will exert higher forces against the ship than if it were to be shaped with a finer bow. These high forces could make the anchor drag or put too much strain on the rode, deck gear etc. In general, it is a circumstance that should be avoided.

Finally, another reason to shape the hull with a sufficiently full bow is given by Bourne who says that such a shape will *hold well at the Sea loose*. This could very well refer to the practise of letting the ship run the storm, without sails, or with very limited sail area, often by dragging lines (ropes) and objects behind the ship. The combined drag of the lines being towed and the wind and wave pressure result in the ship travelling (in a more or less controlled manner) in the general direction of the wind and waves, whilst taking the waves by the stern.

[205] In this final sentence Bourne summarises all. If the term *floty* is understood as floaty or buoyant ships, Bourne is simply saying that buoyant ships that steer well and have enough stability to be capable of bearing sufficient sail area will be good sailors. In other words, they will be good ships.

[206] Bourne. *A booke called the Treasure for traveilers*. Third book 21-22.

[207] In the context of this document the term performance will be used to refer to the most basic behaviour of a ship in the water: its ability to float and its ability to stay upright or stability.

that allowed shipwrights to produce ships that behaved in a satisfactory manner as it will be shown.

At the time when Bourne's treatise was printed, Mathew Baker wrote his famous manuscript, known as *Fragments of Ancient English Shipwrightry* (c. 1580)[208] which is said to be one of the first works where it is possible to see the incipient application of science and mathematics in ship design.[209] Shortly after Diego García de Palacio published his *Instrucción Nautica* in Spanish (1587), a treatise that is generally considered the first example of a treatise where the method followed to shape the hull is shown in printed form.[210]

These manuscripts and printed treatises had been preceded by unpublished manuscripts, of Italian (15th century) and Portuguese origin (16th century), which have been used to create a narrative of the development of the knowledge required to design a ship in post-medieval Europe. The first written accounts are of Venetian origin, thus suggesting that the ship design methods described in them might have originated there.[211] However, others have suggested that these methods may have an earlier Greek origin.[212] This knowledge would have made its way to the Iberian Peninsula from where it could have expanded to northern Europe,[213] although a direct route from Venice to northern Europe has also been considered.[214]

Eventually, new treatises were published during the 17th and 18th centuries in all major European languages, some of which will be analysed in chapters 4-5.

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[208] Baker. *Fragments of Ancient English Shipwrightry.* Pepys Library MS 2820. Magdalene College, Cambridge.

[209] For example: Ditta et al. Albrecht Dürer and Early Modern Merchant ships, p. 95; Johnson. *Making mathematical practice: gentlemen, practitioners and artisans in Elizabethan England*, p. 108; Rose. Digs and Documents: Gaps in our knowledge of medieval shipping, p. 72.

[210] Rieth, E. and Burlet, R. 1988. Essai de restitution d'un bâtiment de 400 toneladas, d'après Diego García de Palacio (1587). *Histoire and Mesure*, 3(4), pp. 463–489 (p. 466); Rivera, F.T. 2009. El libro y los saberes prácticos: instrucción náutica de Diego García de Palacio (1587). Mexico: Universidad Nacional Autónoma de México, p. 82.

[211] Alertz,U. 1995. The Naval Architecture and Oar Systems of Medieval and Later Galleys In R. Gardiner (ed), *The Age of the Galley. Mediterranean Oared Vessels since Pre-classical times*. London: Conway, pp. 142–62; Rieth. *Le Maître-Gabarit la Tablette et le Trébuchet*, pp. 133-148; *Steffy. Wooden Ship Building and the Interpretation of Shipwrecks*, pp. 93–100.

[212] Hocker, F.M. and McManamon, J.M. 2006. Mediaeval shipbuilding in the Mediterranean and written culture at Venice. *Mediterranean Historical Review*, 21(1), p. 3.

[213] Adams. *A Maritime Archaeology of Ships*, p. 74.

[214] Adams. *A Maritime Archaeology of Ships*, p. 71.

3.2.1 Methodological approach to identify the knowledge contained in the treatises

Traditionally, the main investigative methodology used to document changes in ship design approaches during this period has been to analyse the different methods described on some of the treatises published during this time.[215] Archaeological material, where available, has been used to corroborate the use of the methods described in the treatises.[216] The analysis and interpretations of these treatises is not always easy. Not all treatises are complete and most were written for a readership that was already familiar with the matter being described. As a result, many concepts and ideas are not described fully. Despite these difficulties, the idea of a linear transformation of the design methods following logical pathways of ever increasing complexity and sophistication, which must have resulted in better ships, has taken hold.[217] However, this research approaches the evidence differently in order to provide a more nuanced view of the technological background in which early modern shipwrights designed their ships. The main premise that drives this research is the belief that, often, the analysis of these treatises has been conducted following a flawed methodology (see chapter 6).

The conclusions one gets from analysing data set is, very often, determined by the (metaphorical) lenses one wears to look at the data. In this particular case, arguably, this matter has been approached with a set of lenses that focus on particularities that mark differences between the contents of the treatises (chapter 6). Thus, a complex account of the development of ideas and knowledge has emerged that explains the stepwise progression from one set of ideas, from one body of knowledge, to the next; where complex methods substitute more simple and less sophisticated methods. This research would like to approach the treatises with a different set of lenses which focuses on the common traits, rather than the particularities, in search of the knowledge underlying the design approach. In order to do so, a number of primary sources have been analysed producing a more nuanced view of the knowledge used by early modern shipwrights to shape their ships and the development, or stasis, of such knowledge over time.

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[215] Steffy. *Wooden Ship Building and the Interpretation of Shipwrecks*, p. 93.

[216] Adams. *A Maritime Archaeology of Ships*, p. 141; Bojakowski, P. and Custer-Bojakowski, K. 2017. Warwick: report on the excavation of an early 17th-century English shipwreck in Castle Harbour, Bermuda. *International Journal of Nautical Archaeology*, 46(2), p. 290; Loewen, B. 1998. Ships and Shipbuilding, p. 47.

[217] For example: Steffy. *Wooden Ship Building and the Interpretation of Shipwrecks.*

Following the same logic, it was felt that limiting this research to the 17th century created an artificial boundary that could not be justified. Consequently, it was decided that this research had to analyse treatises and shipbuilding traditions where the same conceptual approach had been followed. For this reason, this research includes historic and archaeological materials that extend from late antiquity to the 19th century supported by 20th-century ethnographic research. Most of the research, however, will be centred on the early modern period.

If one focuses on the particularities of the methods described in the treatises, no two of the treatises analysed describe the same ship design method. Some methods use simple geometry to define the shape of the hull; others use mathematical approaches. The methods described in some treatises are fully graphical, while full non-graphical approaches are also defined in others (chapters 4-5; tables 1-2).[218] Their approach is often, seemingly, so different in the details as to suggest that different cognitive processes have been followed by their writers. For example, some methods appear highly practical, only needing a simple tool like a compass to develop the shape of a hull. On the other hand, others appear highly mathematical, needing numerical dexterity to develop the shape of a hull. Thus, this research tries to identify the commonalities or differences in the design paradigms of the treatises in order to identify the possible development or stasis of ship design knowledge during the period under consideration.

As a methodological approach it was felt that focusing on the particularities of each of the treatises acts as a distraction from the common knowledge contained in them. Consequently, this research would focus on the conceptual approach to ship design described in the treatises, leaving aside the particularistic minutiae of the treatises. This simple idea –that minutiae must be ignored in order to concentrate on the core abstract knowledge– is simple to state. However, what constitutes a core idea or an irrelevant detail is, necessarily, a subjective concept that requires some clarification. Therefore, the following example –which compares two cooking recipes supplied by two individual bakers– will be useful to help understand what is meant by irrelevant minutiae and what is meant by relevant knowledge in the context of this research.

3.2.1.1 The knowledge contained in a recipe

Let us imagine that two different bakers supply us, each with a recipe for making bread. In the recipe the two different bakers describe a process that starts by kneading a ball of dough made up of, mainly, flour, water and yeast in certain proportions. After kneading it to a given consistency

[218] The methods of ship design shown in the different treatises will be discussed in chapters 4-5 of this document.

the dough is left aside for a certain time before being introduced in an oven to bake at a given temperature and for a specified amount of time. However, one of the bakers uses a tin mould to hold the dough while it is baked. Meanwhile, the other places the ball of dough directly on the bottom of the oven without any external mould. Other differences would also be described in the written recipes: for example, type of flour, amount of salt, oil/fat content; proportions between the main ingredients; other additives; baking temperature and time; or the type and design of the oven.

Having read and compared both recipes, one could ask the following questions:

1. Are both recipes the same or are they different?
2. What sort of knowledge is contained in the recipes? Is it a common knowledge or does each baker have a different knowledge?

To the first answer most would answer that both recipes are different, after all, one describes how to bake bread in a tin mould, while the other describes how to bake a loaf of bread without a tin mould. Also, there are numerous differences in the ingredients and processes described. Hence, it could be safe to assume that both recipes were, in detail, different from each other. Additionally, if the two recipes originated from bakers from different time periods and geographical origins, the idea of distinctive recipes transmitting distinctive knowledge, a different paradigm, would be strengthened.

However, if one analyses the recipes in order to answer the second set of questions, the result would be different. Both recipes are clearly recipes for the same thing: bread. Moreover, if one looks at the knowledge contained in both recipes one has to conclude that the knowledge is, in essence, the same: in order to make bread, one needs to mix flour, water and yeast (other additives being optional). The mixture must be kneaded and left to prove in order for biochemical processes of fermentation to start (although the bakers may not know that such a biochemical process is happening and all they see –and observe as important– is the ball of dough growing in size). And, after a period of rest, the dough must be baked in an oven for the process to end. Both bakers share what is, in essence, a common knowledge or paradigm.

From the example above it might be appreciated that, depending on the focus of attention, two different pictures might be obtained. On the one hand, it could be argued that each baker had distinctive knowledge that represented a different paradigm on how to make bread. On the other hand, it could also be said that both shared a common paradigm. Which of those pictures is a correct representation of the real knowledge of the bakers becomes relevant if one is to interpret a hypothetical exchange of information between them.

Let us imagine that each baker tries to make bread in the style of the other baker and that the idea of two distinct paradigms was considered to be correct. In this case, the researcher would conclude that in order to reproduce the other baker's recipe it would require to make a large mental adjustment as it would require to learn a new recipe, which is said to represent a different paradigm. Such a change in paradigm would require a very precise set of instructions. Every ingredient should be described and specified and the process would have to be specified with precision (temperatures, times, consistencies of mixtures and so on) if the process were to be successful. The exchange of information would require complex levels of information exchange.

Our understanding of the process of information exchange would be very different if the idea of a common paradigm is assumed to be correct. In that case, it would be very easy for one of the bakers to ask the other about his/her process of making bread. The exchange of information from one to the other would have to be minimal as both shared a common paradigm as described above, where the differences would be in the details and not in the core conceptual knowledge. As a result, with minor adjustments, it would be easy for one baker to reproduce the recipe of the other baker. Both being proficient and having the same paradigm or knowledge base would help them in the exchange and acquisition of new knowledge, so much, that it is not difficult to imagine that such an exchange of information could happen without the need for words or a common spoken language. Careful observation of the other baker whilst making the bread would suffice for any of the two bakers, as they would already have the knowledge and they would only have to make adjustments to their manner of making bread. The differences in their respective recipes do not represent any real difference in the knowledge, thus, the exchange of information does not require any change of paradigm.

3.2.1.2 The relevance of the researcher's focus of attention

The examples above serve to illustrate how the outlook of the research –focusing on details or in general concepts– leads to a different interpretation when, for example, the exchange of ideas between different practitioners of a craft is studied. This research will suggest that a particularistic approach that focuses on the differences is not a satisfactory way of analysing a particular technological paradigm like ship design.[219] Interestingly, this particularistic approach, has been

[219] This does not mean that details should always be ignored in favour of general concepts. Often what may seem like an over-particularistic focus on a seemingly unimportant feature may open the way to understanding the adoption of a new technology with the social changes that this brings (Adams. *A Maritime Archaeology of Ships*, p. 89).

used most prevalently to analyse the contents of shipbuilding treatises. Such particularistic approach seems to lead to an erroneous conclusions that will be discussed in chapter 6.

This research has focused on the abstract conceptual approach to hull design. Each treatise has been approached with an objective in mind: to identify the cognitive mechanism by which shipwrights of the period ensured that the ship would have a certain shape. What was the form of such a cognitive mechanism? How was it used and transmitted? In essence what was the knowledge required to design[220] a ship and how was it described in each of the treatises? Understanding the essence of this knowledge would provide an insight in the technological transformations that happened during the period of interest.

3.2.2 Authors, users and purpose of the treatises?

In the following chapters a number of design treatises will be analysed to provide information about the design-knowledge described in them and the development of such knowledge over time. However there is another interesting aspect that the research will focus upon. This focus will try identify the social groups who wrote and read these treatises. Several questions come to mind (see chapter 2). Is it true that these treatises were written for the self-aggrandisement of their writers as it has often been said? Similarly, does it hold true that these treatises were of no real use for the practical shipwright? Did science and higher mathematics play any role in the development of the knowledge stored in the treatises? Did those treatises describe a type of knowledge that was prescriptive and thus reduced the liberty of action of the practitioner? In other words, who wrote these books and what and who were their objectives.

When reading these early treatises, it must be remembered that the complex information contained in them –as is the case of shipbuilding treatises– might not have been interpreted or understood equally by all readers or users of those treatises, or that the contents of the treatise might have been written in such a manner as to make them more useful for the intended readership. Thus, a treatise with simple information would not necessarily be indicative of the knowledge of the writer. It could be indicative of the manner in which the writer tried to transmit the message successfully to a particular readership.[221]

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[220] In the context of this research, design does not mean a graphical representation. It is understood in more general and abstract terms as the idea in the shipwright's (or naval architect's) mind, who defines it in such a way that, by the use of tools, materials, and a series of practical actions, results in the construction of a ship. (Hocker. Shipbuilding: philosophy, practice, and research, p. 4.)

[221] This problem was put forward very clearly in the introductory pages of the *Ashley Book of Knots*, written in 1944, which describes graphically and in text how to tie and use more than 3800 knots:

Early treatises can be compared to two types of modern publication. They are 'how-to' manuals and reference books. There are marked differences between both types of publication, both in style and in content. How-to manuals usually give a basic understanding of a problem and, as the name implies, the manner in which the reader can solve the challenge (figure 15). The information is given, generally, in different media (e.g. text and images) so that readers may extract it using their preferred means. However, the most noteworthy aspect of a how-to manual is that the information is given in a step-by-step manner, without theoretical disquisitions, so that, by following a series of steps, the reader can accomplish the result that the manual promises. Reference books, on the other hand, describe knowledge in a deeper and abstract manner, defining general concepts from which the reader can extract the information required for a practical application. Thus, generally, reference books are written for very specific readers with a degree of assumed knowledge and expertise.[222]

Chapters 4-5 will show clearly that the treatises that will be analysed can be compared to modern how-to manuals and not to reference books. Their contents are arranged in such a manner that the material can be read and applied in a step-by-step fashion, without theoretical discourses. It will become apparent that their aim is not to introduce theoretical knowledge. On the contrary their aim is to explain, normally by way of a particular example, a practical method that will produce a ship shape.

> 'Methods of tying will be demonstrated with progressive diagrams in such a manner that it is hoped they can be followed without recourse to the text.
>
> This, however, may not suit all readers, for there are some people to whom diagrams are an annoyance. There are others to whom an arrow or the printed letters *A* and *B* savor of higher mathematics. On the other hand there are some who are irked by written or printed directions of any sort. Sometimes, with the latter, it is possible to have another person read aloud the directions. This alters the situation for them, since they can follow oral directions with ease. Apparently it is only the printed pages that balk them.' Ashley, C.W. 1944. *The Ashley Book of Knots.* London: Faber and Faber, p. 9.

[222] For example, in the opening paragraph of one of the most important mid-20th century references in hydrodynamics:

> 'It is taken for granted that one who reads or uses this book possesses a background of knowledge comprising those phases of mechanics and hydrodynamics that are taught in undergraduate college courses or that are adequately covered in standard textbooks and other works of reference, readily available to all naval architects and marine engineers.' (Saunders. *Hydrodynamics in Ship Design. Volume 1*, p. xxii.)

3.3 Closing remarks

The purpose of this chapter was to present the theoretical boundaries that have guided this present research. By using Dosi's definition of technological paradigm this research attempts to define the outlook of early modern shipwrights towards the technologically challenging task of designing a ship and, most crucially, define the knowledge created towards guaranteeing a successful process of conception of hull shape. It has been argued that in the search of the shared knowledge of pre-engineering shipwrights, the focus must be placed on the common traits of each of the treatises and not on their differences. This, which is a personal choice of the researcher, will produce different results when interpreting the processes transmission of knowledge that took part during the early modern period.

Chapter 4: 16th and 17th century treatises

Chapters 2 and 3 served to establish the nature of ship design processes and paradigms against the backdrop of maritime archaeological/historical study. In doing so, a number of key themes were raised around the manner in which the ideas about methods of conception and construction of hull shape have been linked directly to social organisation. Some of these ideas will be criticised on chapter 6. However, in order to fully appreciate the justification for these criticisms –and bearing in mind that the reader may not be familiar with the contents of the treatises– the focus must now turn to the treatises themselves in chapters 4 and 5.[223] The analysis of the treatises will be used to set the scene for chapters 6 to 8 where the prevalent narrative will be criticised and new ideas will be offered to provide a nuanced description of the knowledge of early modern shipwrights.

Chapters 4 and 5 will cover ship design treatises and written accounts from the earliest manuscripts to the late-19th century, when the last of the treatises written following a pre-engineering design paradigm where produced (tables 1-2). The treatises are shown in chronological order with the exception of the treatises that discuss Dutch ship design which describe a different approach to design. They are included in a separate section at the end of the chapter.

4.1 Italian treatises

This short description of Italian ship design treatises is based on secondary information. However, it is included as it provides the starting point for the chapter as the first known written treatises are of Italian origin.[224]

Early Venetian treatises do not describe the process in as much detail as the treatises that will be analysed in subsequent sections. However, they provide sufficient detail to extract from them the

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[223] Most of the treatises analysed in chapters 4-5 are included in the accompanying DVD.

[224] Alertz. The Naval Architecture and Oar Systems of Medieval and Later Galleys, pp. 142–62; Anderson, R. C. 1925. Italian Naval Architecture about 1445. *The Mariner's Mirror* Vol. 11 (2); Bellabarba, S. 1996. The Origins of the Ancient Methods of Designing Hulls: a hypothesis, *The Mariner's Mirror* 82.3, pp. 259–68; Lane, F.C. 1934. Venetian naval architecture about 1550. *The Mariner's Mirror*, 20(1), pp. 24–49; *Steffy. Wooden Ship Building and the Interpretation of Shipwrecks*, pp. 93–100; Rieth. *Le Maître-Gabarit la Tablette et le Trébuchet*, pp. 133-148.

approach to shaping the hull followed by Venetian shipwrights of the period.[225] The method to shape the hull is conceptually simple. In order to produce the shape of the hull the shipwright determined the shape of the master section, as well as the shape of the stem and sternpost. With a template made to the shape of the master section, the shipwright could obtain the shape of a large portion of the frames in the hull by a process of transformation of the template regulated by narrowings and risings.[226]The conceptual process of shaping the hull has been explained in section 2.2.3.4.

This manner of designing the shape of the hull by rising and narrowing a master template will be constant throughout the treatises analysed in this document. Venetian design practices are no different in this respect. However, the manner in which the Venetian manuscripts define the shape of the master frame and other curved elements of the hull differs when compared to subsequent treatises. Venetian treatises describe their shape as a series of coordinates or offsets whereas in later treatises these elements are described as a series of geometrical constructions. There are two views to the significance of this particularity of Venetian practices. Some scholars interpret that the Venetian method of design was based on geometry and the offsets were just a manner of storing the shape of the hull.[227] Others, on the other hand, consider that these design methods were based on some mathematical rules that defined offsets, without geometric constructions based on arcs of circles.[228]

In his study of the 15th-century manuscript known as *The Book of Michael of Rhodes*, Mauro Bondoli concludes that the information contained in this treatise should not be considered a description of the design methods and additional information regarding navigation or mathematics contained in the treatise. Rather, it should be interpreted as a compilation of knowledge, obtained from different sources. Thus, with respect to the shapes of hulls shown in

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225 Steffy. *Wooden Ship Building and the Interpretation of Shipwrecks*, pp. 96-7.

226 Alertz. The Naval Architecture and Oar Systems, p. 146; Lane. Venetian naval architecture about 1550, p. 29; Hocker, F.M. and McManamon, J.M. 2006. Mediaeval shipbuilding in the Mediterranean and written culture at Venice, p. 2; Steffy. *Wooden Ship Building and the Interpretation of Shipwrecks*, p. 97.

227 Barker, R. 2003. Whole-moulding: a preliminary study of early English and other sources. H. Nowacki and M. Valleriani (eds), *Shipbuilding Practice and Ship Design Methods from the Renaissance to the 18th Century.* Max Planck Institute for the History of Science. Preprint 245, p. 43

228 Steffy. *Wooden Ship Building and the Interpretation of Shipwrecks*, p. 97; Lane. Venetian naval architecture about 1550, p. 28; Alertz. The Naval Architecture and Oar Systems p. 144; Barker, R. 1998. Sources for Lusitanian shipbuilding. In *Proceedings of the International Symposium "Archaeology of Medieval and Modern Ships of Iberian-Atlantic Tradition", Lisbon*, p. 220; McGrail. *Boats of the World*, p. 164.

the treatise, Bondoli concludes that the offsets used to describe the shape of the different curved elements of the ships shown in the treatise, should be understood as a record of a shape –which would have been obtained following an unidentified design procedure– and not as a graphical description of the design method.[229]

Thus, in order to take a stand on these two different views a quick check was conducted on the geometry of two structural elements of the 15th century Flanders galley. The sternpost of the Flanders galley described in *Regioni antique* (2nd half of the 15th century) is analysed in figure 16, which is based on the offsets obtained from the original manuscripts by Bondioli.[230] A grid with the offsets was drawn in AutoCAD and a series of arcs were tried to find out if the offsets could have been derived following a geometric construction based on arcs of a circle. A two-arc construction (figure 16) matches very closely the offsets given in the text. The errors are small and can be assumed to be acceptable with the tolerances of the measurements of the period and the manner in which these measurements were probably recorded. A similar analysis of the figure that describes the sternpost of the Flanders galley illustrated in The Book of Michael of Rhodes as reconstructed by Bondioli shows, again, that a simple arc can be used to describe the figure with great accuracy (figure 17). This would suggest that both elements could have been designed following simple geometrical rules and constructions for which only a compass or a piece of string was needed. The analysis of the master sections, on the other hand, produced inconclusive results. Although, it could be reasonable to assume that the master frames of the hulls, could have been designed following similar geometric constructions.

To summarise, Venetian ships were built after a process of design where geometry played a leading role in the shaping of the main elements used to design the shape of the hulls. These are: the shape of the end posts (stem and stern), possibly the master section, and the rising and narrowing lines which controlled the transformation of the shape of the hull from amidships towards the ends (figure 18-19).

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229 Bondioli, M. 2009. Early Shipbuilding Records and the Book of Michael of Rhodes. In P.O. Long, D. McGee and M. Stahl (eds), *The Book of Michael of Rhodes. Volume 3: Studies.* Cambridge, Massachusetts, pp. 244-280 (p. 251).

230 Bondioli, M. 2009. Early Shipbuilding Records and the Book of Michael of Rhodes. In P.O. Long, D. McGee and M. Stahl (eds), *The Book of Michael of Rhodes. Volume 3: Studies.* Cambridge, Massachusetts, pp. 244-280 (p. 253).

4.2 A booke called the Treasure for traveilers (William Bourne, 1578)

Full title: A booke called the Treasure for traveilers, devided into five Bookes or partes, contaynyng very necessary matters, for all sortes of Travailers, either by Sea or by Lande, written by William Bourne.

Author: William Bourne

Type of book: Printed

Year and place of publication: 1578, London.

Edition consulted: 1578

Language: English

Section 3.2 started with a quotation from *A Booke called the Treasure for Traveilers* which shows that its author, William Bourne (c.1535–1582),[231] had a well formed opinion of what characteristics a good performing ship should have. In the preface, Bourne also specifies who the intended reader of the treatise is. It was written to instruct those who were 'simple and unlearned'. [232]

Treasure for Traveilers describes in five sections, called books, a body of knowledge of interest for *traveillers.* This term identifies workers who travel and settle abroad and later return, bringing with them great benefits to England.[233] Among other subjects, the book discusses: celestial navigation, surveying techniques, ship construction and navigation, and geography.

The section on shipbuilding deals with conceptual aspects of ship design. Although it does not discuss the actual process of designing a ship, the treatise shows that during this period there was a good understanding of basic hydrostatics –why bodies floated in water– and how this knowledge could be applied to shipbuilding.

The author describes that a body will sink in the water until it has displaced the same amount of water (in weight) as the weight of the body itself. [234] Based on this idea, which is none other than

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[231] G. L'E. Turner, 'Bourne, William (c.1535–1582)', Oxford Dictionary of National Biography, Oxford University Press, 2004 [http://www.oxforddnb.com/view/article/3011, accessed 7 Aug 2017]

[232] Bourne. *A Book called the Treasure for Traveilers,* The preface: to the reader (pages unnumbered). Bourne himself had not received his education through university as other contemporary authors writing about mathematics. Instead, he acquired his mathematical knowledge through reading, self-study and the daily contact with practitioners who used mathematical knowledge, such as seamen, and gunners (G. L'E. Turner, 'Bourne, William (c.1535–1582)', Oxford Dictionary of National Biography, Oxford University Press, 2004 [http://www.oxforddnb.com/view/article/3011, accessed 7 Aug 2017]).

[233] Bourne. *A Book called the Treasure for Traveilers.* The preface: to the reader (pages unnumbered).

[234] Bourne. A Book called the Treasure for Traveilers : Book4, p. 3-r.

Archimedes' principle, the conceptual approach to establishing the weight of a ship is clear to the author:

> Looke what quantitie of the Ship is buryed in the water, that is to say, from the edge of the water downwards: then if there were a vessell or great thing made of the proportion of the moulde of a Shyppe, as much as is buried in the water, if that were filled with that water that the ship were in, the water shoulde be of iust equall waight, that the Ship were of, with all her tackle and implements in her. [235]

Bourne continues by observing that whether the ship is floating in fresh or salt water has an effect on how deep it will sink. He is correct in his observation and, also, when he observes that the reason for this is the differences in weight –we would call it density– of the two types of water.

Bourne's interest is not only theoretical and, consequently, he describes three methods by which the weight of a ship may be found. These methods are correct from a conceptual point of view. However, they would only be useful to know the displacement of an existing ship and not as a means of designing a ship with a certain displacement.[236]

The importance of shape control in ship design is clear for Bourne:

> [...] in the buildyng of Ships, the one of the pryncipal poyntes is this, the flowring and quarteryng[237] of them [...][238]

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[235] Bourne. A Book called the Treasure for Traveilers : Book4, p. 3-v.

[236] Two of the methods are based on the same idea. The shipwright would measure the cross-sectional area of certain sections of the hull below the waterline for which the ship had to be taken out of the water. The next step would be to assess the distance in which this shape remains fairly constant and, consequently, by multiplying the cross-sectional area by this length, the volume of this portion of the hull could be found. The same approach could be followed for the rest of the hull by dividing it in as many vertical planes as possible. Always treating the hull as a series of prisms for which the volume could be calculated relatively simply. By adding the volume of all the prisms the true volume of the submerged part of the hull could be found. The third method was a fully practical approach. The process started by making a scale model of the ship as accurately as possible in solid wood. Following this, the solid model would be wrapped by a sheet of malleable metal such as lead. Then, the lead shape could be removed from the solid model and could be used as a container to be filled with water. Bourne argued, correctly, that the weight of this water could be used to calculate the weight of the full sized ship by applying the correct scaling factor.

[237] The 'flowering' refers to the floors, or the bottom area of the hull close to the keel. This could be related to the modern term called deadrise angle which describes the fullness or sharpness of the transversal sections of the hull. 'Quartering' refers to the quarters, or ends of the ship. Both aspects of a ship's hull-form will have an effect on the hydrostatic and hydrodynamic characteristics of the ship.

[238] Bourne. *A Book called the Treasure for Traveilers*. Book 4, p. 4-r

... or in modern terms: one of the principal points on building a ship is how its bottom is shaped.

Bourne is aware that not all hull forms are suitable for all circumstances, thus explains –in very general terms– that ships should be shaped according to their intended use. It is during these explanations that the author concedes that he is not ‘a ship carpenter, neither usual Sea man’. [239] However, his lack of practical experience in the actual construction of ships does not decrease the importance of this treatise as a testimony of certain theoretical knowledge and practical procedures that were possible at the time. Bourne does not give the impression of describing new knowledge or some obscure knowledge that was not known at the time. Hence, it would seem that Archimedes' principles which describes why ships float were well known at the time, and that they had not been lying dormant for two millennia –as stated by Nowacki– until it was rediscovered by Flemish/Dutch mechanicist and engineer Simon Stevin in the late 1500s.[240]

Although Bourne considers that it is easy to estimate the weight of a ship by calculation or the practical methods he describes, in reality, his methods would have had very limited practical use. This will be a constant through history, as the analysis of subsequent treatises will show.

4.3 Fragments of Ancient English Shipwrightry (Mathew Baker, c.1580)

Full title: Fragments of Ancient English Shipwrightry

Author: Mathew Baker

Type of book: Unpublished manuscript.

Year: c.1580

Edition consulted: Original manuscript (MS 2820) and transcript in the Pepys Library, Magdalene College, Cambridge

Language: English

Fragments of Ancient English Shipwrightry –written at the end of the 16th century– is considered to be the first shipbuilding treatises written in English that shows hull design methods. It is attributed to Mathew Baker (1529/30–1613),[241] although parts of it were written by a second

[239] Bourne. *A Book called the Treasure for Traveilers*. Book 3, p. 19-r.

[240] Nowacki, H. 2006. *Developments in fluid mechanics theory and ship design before Trafalgar*. Max Planck Institute for the History of Science. Preprint 308, p. 9.

[241] James McDermott, ‘Baker, Matthew (1529/30–1613)’, Oxford Dictionary of National Biography, Oxford University Press, 2004; online edn, Jan 2008 [http://www.oxforddnb.com/view/article/45684, accessed 7 Aug 2017].

author, most probably John Wells, in the early years of the 17th century.[242] In contrast to the treatises analysed below there is no facsimile or edited version available for consultation, therefore, in order to check its contents the original of the manuscript was consulted.

Richard Steffy wrote that M. Baker applied superior mathematical skill in his designs.[243] This idea would sit well in the current description of the technological trajectory from a craftsman's approach to ship design to that of a modern naval architect, with ever increasing use of mathematics and science. However, an analysis of the text shows that M. Baker described procedures that could be beneficial to mathematically skilled shipwrights as well as to those who did not have a knowledge of mathematics. Thus on folio 21 of the original, M. Baker proposes a method to plot a ship of a certain burden based on the scaling up or down of a previous design. It was a method that required basic knowledge in arithmetic which, according to him, would be useful to the learned shipwright, or to quote the original, 'to him that has the use of the pen'. However, in order to aid readers who may not be skilled in the arithmetic required, he provides some graphical scales where the ratios and transformations can be read directly.

A second example of these two types of readership he might have been aiming at can be seen in folio 33 of the original where M. Baker proposes methods to calculate the rising and narrowing of the frames.

The method he describes, is defined as:

> [a] mechanical demonstration [...] devised for the workman unskilled in mathematics and geometry.[244]

Thus it can be seen that the knowledge described in the manuscript could also be destined for shipwrights who were not skilled in either geometry or mathematics (multiplication and division).

The manuscript is beautifully illustrated. However, it lacks a coherent order and a clear line of argument within the text. It does not provide a description of the method of ship design that M. Baker himself followed, or proposed others to follow, without a high level of interpretation from

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[242] Barker. Fragments from the Pepysian Library, p. 161.

[243] For example, on this subject Steffy wrote that 'Mathew Baker must have used his mathematical dexterity to produce more accurate formulas for tonnage.' (Steffy. *Wooden Ship Building and the Interpretation of Shipwrecks*, p. 145). However, the formula used to justify the 'mathematical dexterity' of Mathew Baker was just as arbitrary as any of the many formulae for tonnage in vogue at the time (see figure 41).

[244] Baker. *Fragments of Ancient English Shipwrightery*. f33.

the modern reader. However, from the drawings and some explanations within the text the general approach to hull design can be established. The process is shown graphically in several instances (figure 23).

The method relied on geometry and proportion. To design a ship, the designer would decide the principal dimensions (length, beam, depth). With these he could shape the midship frame following different graphic design methods based on simple geometry (figure 24). The shape of the transversal frames of the hull could be obtained from the transformation of the shape of the master section following some simple transformation rules. These rules were controlled by several rising and narrowing lines that determined how the shape of the hull tapered as it approached the ends of the hull. The shape of the rising and narrowing lines are based on arcs of circle of a large radius, and folio 23 shows an example of the method that the designer could follow to calculate the radius of the rising line from the distance from midship to the tuck and the rising at the tuck. In common with the rest of the methods analysed in this document, the shape of the hull depended directly on the shape of the master section and the rising and narrowing lines that controlled its transformation. The ‘goodness’ of the hull depended on the ‘perfectness’ of the midship mould.[245]

The manuscript was never completed. As a result, it does not explain the reasons behind the variety of geometric methods used to define the shapes of the master frames shown in the treatise (figure 24). However, this variety of midship frame shapes has focused the attention of many scholars who, by a few references to dates and geographical references given by Mathew Baker, or inferred from the text, use them to link geographic origins to certain midship frame shapes,[246] or to describe an evolution in shapes and design methods from the middle of the 16th century to the early years of the 17th century.[247]

Although *Fragments of Ancient English Shipwrightry* represents an invaluable document and a necessary source of information, it lacks the coherence and clarity of text that other treatises

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245 Baker. *Fragments of Ancient English Shipwrightery*. f. 34.

246 For example, in a discussion about a Venetian drawing showing a master frame drafted in 1619, Barker hypothesises about the possible influence of English design practices based, solely, on the similarities with one of the master sections shown in Mathew Baker’s manuscript (Barker, R. 2003. A Venetian Ship Drawing of 1619. In H. Nowacki and M. Valleriani (eds) *Shipbuilding Practice and Ship Design Methods From the Renaissance to the 18th Century. Max Planck Institute for the History of Science, preprint 245*, p. 72).

247 Barker, R. 1998. English shipbuilding in the sixteenth century: evidence for the processes of conception and construction, In E. Rieth (dir), *Concevoir et construire les navires. De la trière au picoteux*, p. 117.

have. Despite these important shortcomings it is one of the key documents on which the current narrative is based, and there is hardly any study of the trajectory of shipbuilding or ship design technology that does not include a reference to it. However, it is worth bearing in mind that this was an uncompleted manuscript and, as such, it may have had less influence at the time it was written as opposed to its influence in more recent study.

4.4 Instrucción Nautica (García de Palacio, 1587)

Full title: Instrucion (sic) Navthica, Para el Buen Uso, y regimiento de las Naos, su traça, y y gouierno conforme à la altura de Mexico

Author: Diego García de Palacio

Type of book: Printed

Year and place of publication: 1587, Mexico

Edition consulted: 1587

Language: Spanish

Instrucción Nautica[248] –written by Diego García de Palacio in 1587– is considered to be the first treatise in which the method followed by shipwrights to shape their hulls is described in printed form in any language.[249] It covers, in 313 pages, all aspects required for navigating, sailing, designing and building ships suitable for the waters around Mexico.[250] The treatise is written for the information and benefit of the ‘common person’.[251] Thus, although it covers themes like astronomy and celestial navigation, the author provides methods that are suitable for the practical person who might not be accustomed to written communications or may lack previous formal education (figure 20). This paragraph illustrates García de Palacio's intended readership:

> Let us not confound the understanding of those who know no philosophy, nor letters, who are the ones we have to work for, as they are the ones who most commonly practice this art [of shipbuilding]. As I have promised above I shall describe the *nao,* [252] its parts, and people, and trades [involved in its construction and running], by the

[248] This title is normally shown in a form which corrects the grammatical error in ‘*Instrucion’* as well as by adopting current Spanish spelling rules. Thus, in this document it will be referred to as *Instrucción Nautica*, in its correct spelling and shortened version.

[249] Rieth and Burlet. Essai de restitution d’un bâtiment de 400 toneladas, p. 466.

[250] García de Palacio. *Instrucción Nautica* . Title page.

[251] García de Palacio. *Instrucción Nautica* , p. 1.

[252] *Nao:* a type of sea going vessel from the Iberian peninsula of the period.

> clearest method of which I am capable.[253] (Translation from the Spanish original JPO. Some punctuation has been altered for clarity).

With this readership in mind, 'those who know no philosophy, nor letters, who [...] are the ones who most commonly practice this art' García de Palacio writes in a clear language the conceptual method of shaping the hull. In common with other treatises of the period, the text presents the information in the style of a conversation between two participants. The design method is based on knowledge accumulated from past experience. This knowledge is stored in a series of proportional relations, or ratios, among the principal dimensions of the hull. The author is aware that these proportions are not immutable and that they often respond to the environment where the ship is to be used. For example, he cites that ships destined for the shallow harbours of New Spain, from Cozumel to Pánuco (in modern day Mexico), require ships with fuller and flatter floors than ships destined for areas with deeper waters.[254] He is also aware that ultimately, when it comes to deciding the proportions and shape of a ship, the shipwright's personal choice and individual opinion play a decisive role in the process of designing a ship.[255]

García de Palacio does not provide any method to aid the shipwright in the choice of proportional ratios relating the principal dimensions of the hull and its components. Instead, the text describes the design method based on a single example of ship of 400 tonnes that illustrates the conceptual approach used by shipwrights of the time. The design process is described in schematic form where many of the details are omitted. Despite the description's shortcomings, a shipwright with knowledge of the general principles that were followed at the time would have had no difficulties building a hull, provided that they had sufficient knowledge to fill in the numerous gaps left in García de Palacio's schematic description.[256]

The design process is centred around a master section that is transformed to obtain most of the frames on the central part of the hull. The master frame is described as being based on an arc of large radius (specified) and a flat floor (given as a proportion of the keel's length). In order to control the transformation of the master frame into the other frames the author 'rises' and 'narrows' the shape of the master section. Interestingly, he makes no mention of the manner in

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[253] García de Palacio. *Instrucción Nautica* , p. 89-v.

[254] García de Palacio. *Instrucción Nautica* , p. 91-v.

[255] García de Palacio. *Instrucción Nautica* , pp. 91-v, 92-r.

[256] This was corroborated by Rieth and Burlet who reconstructed the shape of the *nao* of 400 tons from the information given by García de Palacio in: Rieth and Burlet. Essai de restitution d'un bâtiment de 400 toneladas, p. 585.

which the values of rising and narrowing of the individual frame stations are obtained. However, suitable maximum values of rising and narrowing at the tail-frames[257] are specified. The positions of the tail-frames are also described in the text although with some imprecision.

The explanation continues by describing that once the central part of the ship has been framed up, three strong ribbands should be placed at specified heights, bent around the erected frames, and taken all the way to the ends of the hull (the stem and sternpost). Thus, the ribbands would define the shape of the ends of the hull, which have not yet been framed at this stage. These ribbands would be used to obtain from them the shape of the frames on those areas. Following this, some other considerations about the placement of the master section and its relevance to its effect on the ship's trim and steering are given. To finish the process of shaping the ship of 400 tons, its heights at different parts as well as the manner in which the rudder must be made and attached to the ship are described.[258] The method described by García de Palacio to shape the hull occupies only three pages of a small 20x15 cm book.

One relevant feature of the method described in the treatise is that it does not require any drawings to be made of the ship. The method described is entirely non graphic. However, the text contains some illustrations (figures 21 and 22) which have led some authors to conclude that García de Palacio was describing a method of design based on the erection of three frames and ribbands bent around them.[259]

This interpretation, however, is doubtful as the purpose of the illustrations are stated clearly by García de Palacio.

> **With the purpose that the method** [of shaping the hull] **and measurements** [included in the text] **are understood better, I shall draw the following figure** of the body of the *nao*, in profile. [the text is followed by figure 21]. [260] (Translation JPO. Some punctuation has been altered for clarity. Highlights by JPO.)

Thus, it is stated that the figure is just an illustration to help the reader follow the text, it is not intended as a design aid, nor is it hinted in the text that such an aid was necessary or, indeed,

[257] The tail-frames were the two extreme frames (forward and aft) were the method of rising and narrowing was applied. Beyond those frames the shipwright had to find an alternative means of finding the shape of the frames. García de Palacio describes that ribbands were used for this (see main text).

[258] García de Palacio. *Instrucción Nautica* , pp. 92-v, 93-v.

[259] Hasslöf. Sources of maritime history and methods of research, p. 136.

[260] García de Palacio. *Instrucción Nautica* , p. 93-v.

used to build ships. The building procedure would have been, in common with other methods of the period, fully non-graphic.[261]

This section of the treatise is finished by providing a second drawing of a smaller ship which, again, is shown for illustration purposes only by the author (figure 22). This second drawing provides more information about certain dimensions of the ship yet, unless the reader had a working knowledge of the methods being described, there would not be sufficient information to define the shape of the ship. However, if the shipwright was familiar with the method, the dimensions given would have provided a framework to aid the shipwright in making design decisions.

The next chapter of the treatise discusses the manner in which the large ship should be rigged. García de Palacio does not describe how to rig the smaller ship, giving the following reasons for it:

> The following explanations [on how to rig a ship] correspond to the first of the ships. From them, it will be possible to reduce [in size] and to design correctly, the masts, yards, booms, rigging, and other tackle which might be needed [for the smaller ship] following the good directions of the master, who will have to determine **many things which, for their complexity, cannot be said in the figure and which are common to the practitioners of this art**.[262] (Translation JPO. Some punctuation has been altered for clarity. Highlights by JPO.)

Again, García de Palacio made it clear that the readers should have no trouble filling up the gaps left by his schematic explanations. Moreover, the text highlights where the real difficulty lies. The technical knowledge shared by shipwrights is, seemingly, so complex that García de Palacio cannot find a way of conveying it in a written text or in figures. This difficulty of putting in words or figures the knowledge used by shipwrights is a common characteristic of the treatises analysed in subsequent sections.

This brief analysis of *Instrucción Nautica* by García de Palacio will finish by summarizing the design method in the treatise:

The design method is a non-graphic approach to ship design based on the transformation of the master frame into the other frames of the central part of the hull. The transformation is

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[261] Barker and Rieth identified correctly the method used by García de Palacio as being based on a master section and rising and narrowing lines, pointing at Hasslöf's error in: Barker. Many May Peruse Us, p. 542; Rieth and Burlet. Essai de restitution d'un bâtiment de 400 toneladas, p. 485.

[262] García de Palacio. *Instrucción Nautica* , p. 95-v.

controlled by a series of risings and narrowings, although, no rationale is given that explains how their values are calculated.

The design method is not prescriptive as it does not give specific, precise, normative, instructions of any of the dimensions of the hull and its constituent parts. All dimensions and measurements given are merely descriptive in nature. These, provide information that gives a sense of proportion to the design. Moreover, the author is clear in several instances,[263] that the shipwright is free to choose the proportions and dimensions of the ship that he considers best.

The readership is clear in intent and content. The treatise does not describe theoretical knowledge that may seem irrelevant, or incomprehensible to the practical shipwright. On the contrary, the contents may be of use to shipwrights with the appropriate shipbuilding skill, who, by their own experience have the ability and knowledge required to fill in the gaps left by the general nature of the description given in the treatise. By following the general proportions given in the treatise the experienced shipwright may be confident to try to build a ship to a set of proportions which he may have not experienced before.[264] A ship built to a design based on the general proportions given in *Instrucción Nautica* would be, in the opinion of García de Palacio, suitable for the particular conditions of the waters around New Spain, or present-day Mexico.

4.5 A Treatise on Shipbuilding, c.1620: Admiralty Library Ms.9 (anonymous, c.1620)

Full title: A Treatise on Shipbuilding, c.1620[265]
Author: Anonymous
Type of book: Unpublished manuscript.
Year: c. 1620
Edition consulted: 1958 edited version by Salisbury and Anderson
Language: English

This anonymous manuscript identified as Ms.9 in the British Admiralty Library was edited and published by Salisbury and Anderson in 1958. After correcting the spelling, editing obvious

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263 For example: García de Palacio. *Instrucción Nautica* , pp. 91-v and 92-r.

264 For example, from the information contained in the treatise and personal knowledge on these design and construction methods Rieth reconstructed the shape of the nao of 400 toneladas described by García de Palacio in: Rieth and Burlet. Essai de restitution d'un bâtiment de 400 toneladas.

265 Salisbury, W. and Anderson, R.C. (eds), 1958. *A Treatise on Shipbuilding and A Treatise on Rigging, Written About 1620-1625.* Society for Nautical Research

mistakes and re-drawing the missing figures from the instructions given in the text, it was published under the title: *A Treatise on Shipbuilding, c.1620.* [266] Salisbury and Anderson dated this treatise to the 1620s and suggested that it may have been written by John Wells, storekeeper at Deptford Yard.[267]

The treatise covers in detail the procedure to follow in order to define the three-dimensional shape of a ship's hull very similar to the ideal proportions described in the last page of *Fragments of Ancient Shipwrightry*. It does not touch any other aspects of ship design such as stability or ship resistance. In contrast to previous treatises analysed, *Treatise on Shipbuilding c.1620* provides sufficient information to be able to reproduce a similar ship to the one chosen as an example. However, the author does not attempt to justify the choices he makes to establish dimensions and proportions other than past experience. At most, he suggests intervals of maximum and minimum values for certain parameters of the hull's geometry.[268]

The process of design is based on simple geometry and arithmetic, and requires, in principle, little mathematical skills.[269] Most dimensions are related by ratios and proportions so that, as the anonymous author states, most dimensions can be obtained from one of the principal dimensions.[270]

In common with the design treatises described before (*Instrucción Nautica* and *Fragments of Ancient English Shipwrightry*) the shape of the ship's hull is obtained in the following manner: a master frame is defined by following a series of simple geometrical constructions based on arcs and straight lines. After the master frame has been formed in this manner, the shape of the other

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[266] Salisbury and Anderson. *A Treatise on Shipbuilding c. 1620*, p. 3. The present analysis is based on Salisbury and Anderson's edited version. However, as the edited version also specifies the original pagination, page numbers will refer to both, with original page numbers shown in brackets.

[267] Salisbury and Anderson. *A Treatise on Shipbuilding c. 1620*, p. 2.

[268] One example of the manner in which upper and lower limits are suggested for certain dimensions of the hull would be the following:

> '[...] the depth must never be more than half nor less [than] 1/3 [of the beam of the hull]' (Salisbury and Anderson. *A Treatise on Shipbuilding c. 1620*, p. 14 (84-v)).

[269] Although some of the procedures shown in the treatise appear to be highly mathematical, at most they require that the reader knows multiplication and division.

[270] This is what the author wrote:

> if only the breadth be given the rest [of the ship's dimensions] may be drawn out of that by the rules afore-going (Salisbury and Anderson. *A Treatise on Shipbuilding c. 1620*, p. 14 (84-v).

frames of the hull are obtained by transforming its shape in a regulated manner. Several longitudinal curves, called rising and narrowing curves,[271] are used to regulate the transformation.

The anonymous author states that the qualities of the ship depend upon the choice of rising and narrowing lines which 'must neither be too high nor too low, nor [...] too lank nor too full.'[272] These general statements are followed by specifying different types of curves that would be most appropriate for each of the rising and narrowing curves. However, the author cannot justify from a theoretical point of view what is considered too high or too low, or too lank or too full, or too round or too straight. Most importantly, the author does not explain how these characteristics of the rising and narrowing lines affect the performance of the ship. The suitability of different curve shapes and their proportions can only be justified based on what has worked in the past.

The different types of rising and narrowing curves recommended by the anonymous author can be obtained by simple arithmetic. The designer specifies a maximum rising at the end of the line. This is done as a proportion of other dimension of the ship.[273] The variation in rising from one frame to the next would be determined by the shape of the rising line which, for the anonymous author, depends on the n^{th} power of the longitudinal position of the frame. The value of n used in the definition of the n^{th} power of the curve, in turn, defines its curvature and, thus, how the shape of the hull varies as it gets away from the ship's centre and closer to the ends. Figure 25 shows a comparison in the curvature of the different methods proposed in *A Treatise on Shipbuilding, c.1620*. From the figure it is clear that the author is trying to control the shape of the curves, so that they have the right fullness, although no rationale is given for each of the particular choices.

The author also specifies the geometrical construction to follow in order to obtain the shape of the master section. It is based on three arcs of circle that can be up to four (figure 26).[274] Their radii are given as a proportion of the principal dimensions of the hull (depth and beam).[275]

The manner in which the treatise is written, using the imperative mood, might give the impression that the method described is rigid and prescriptive. For example:

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[271] The method described in the treatise defines narrowing lines at the floor and at the maximum breadth. Similarly the rising lines used are one at the floor area and an additional rising line at the maximum breadth area.

[272] Salisbury and Anderson. *A Treatise on Shipbuilding c. 1620*, p. 15 (58-r).

[273] Salisbury and Anderson. *A Treatise on Shipbuilding c. 1620*, p. 23 (88-v).

[274] Salisbury and Anderson. *A Treatise on Shipbuilding c. 1620*, pp. 16-17 (85-v, 86-r).

[275] Salisbury and Anderson. *A Treatise on Shipbuilding c. 1620*, p. 16 (85-v).

> The several lines being concluded we **must** begin with the midship bend, ...
>
> ... the **centre** thereof **must always be** upon a perpendicular raised to the extreme of the floor.....(Highlights JPO) [276]

However, although the method appears to be rigid the text provides sufficient clues to show that designers need not follow the instructions so rigidly, for example:

> ... The radius [of the middle sweep][277] must ever be greater than half the breadth and less than the whole breadth, and **may be longer or shorter as you desire** to have the futtock righter or rounder (Highlights JPO). [278]

Another example:

> The breadth of the ship [...] you may make more or less with a longer or shorter radius [...][279]

Therefore, what may seem to be a prescriptive method may only be a direct consequence of the fact that the method is described by using a particular example with a given set of dimensions and proportions. Trying to describe the geometric procedures and conceptual approach to hull design without a practical example, only in abstract terms, would have made the writing of the treatise a more complicated effort.[280]

One interesting feature of this treatise is that it describes the process of design based on a small scale drawing and the procedure that must be followed in order to scale up the design on paper to the full size ship.[281] However, in order to reduce scaling errors the treatise provided an alternative numerical method that would allow the shipwright the means of deriving the shape of

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[276] Salisbury and Anderson. *A Treatise on Shipbuilding c. 1620*, pp. 15, 16 (85-r, 85-v).

[277] One of the arcs of circle that define the shape of the master frame in figure 26.

[278] Salisbury and Anderson. *A Treatise on Shipbuilding c. 1620*, p. 17 (86-r).

[279] Salisbury and Anderson. *A Treatise on Shipbuilding c. 1620*, p. 17 (86-r).

[280] For a modern example of the use of the imperative mood in an instruction manual see figure 15. The use of the imperative is not identified in this case with a prescriptive manner of instruction on a particular procedure. It is just a convenient way of transmitting information which the reader will identify and interpret according to the particular needs and capabilities.

[281] The drawings shown in figure 26 give a sense of the three-dimensional shape of the hull. However, their ultimate purpose is to provide information about the values of rising and narrowing at particular positions of the hull so that the shipwright can transform the shape of the master frame into the other frames of the hull.

the transversal sections of the hull aided by mathematical knowledge. The process would start by designing the master section following the geometrical method described in the treatise. From the construction the shipwright could obtain the coordinates of the centres of each individual arc by simple numerical calculations. The positions of all the centres were, then, recorded in tabular form. From this table the shape of the frames could be drawn, full size, in a suitably flat floor, as the centre of each arc would be known, from the table, and the radii would be lifted from the plot of the midship bend.[282] By this method all the frames could be drawn full size on the mould floor.

To follow the method described above the shipwright would only require to have a working knowledge of multiplication and division. These are not higher mathematical skills. However, the method required the shipwright to perform numerous long multiplications and divisions, always leaving room for possible mistakes. To reduce this risk of error, the author suggests the use of logarithms, which had been invented only recently in the 1610s as a means of assisting with the numerical calculations.[283] The use of logarithms did not change in any manner the shape of the rising and narrowing curves, hence the ship. The rules used to derive the shape of each of the curves remained unaltered. The use of logarithms provided a tool by which calculation errors could be reduced.[284]

The treatise finishes by describing the process of making each of the frames from a set of moulds obtained in the mould floor from the full size plot described above, with additional details of other aspects of framing a ship, such as regarding bevelling.

An immediate reaction to reading this treatise is that one gets the impression of being in front of a well-thought out document. The process of design is described in the same order in which a shipwright would design the ship. The information is given in an as-needed basis, facilitating its comprehension by the reader. It is given in sufficient detail to be able to follow it from the contents of the text. This is a contrast to the treatises described before which are not so well organised or did not provide all the information that is required to follow the design process. The manner in which this document is organised would remain constant in most of the treatises that followed it.

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[282] Salisbury and Anderson. *A Treatise on Shipbuilding c. 1620*, p. 33 (94-r).

[283] Salisbury and Anderson. *A Treatise on Shipbuilding c. 1620*, p. 33 (94-r).

[284] Ferreiro. *Ships and Science*, p. 43. The use of logarithms to aid in numerical calculations survived well into the 20th century –mostly in the form of the logarithmic sliding-rule so common in the desk of pre-1970s engineers– and was only abandoned with the introduction of calculators.

Unfortunately, the original manuscript is missing and only a manuscript copy made during the late 17th century survives. The original has been dated to c.1620.[285] The author of the 20th century edited transcription, Salisbury, considered that the original manuscript 'does not follow the usual format of a work written for the instruction of shipwrights'.[286] He justifies this idea with the fact that the usual introduction to geometry and mathematics common in other treatises destined to practical shipwrights are missing from the copy. However, he also explains that these pages could have been omitted by the late 17th-century copyist.[287] Therefore, there is no real reason to justify that the treatise was not destined for shipwrights. The clarity of the text and the thoroughness of the explanations would seem to suggest that, indeed, this text would have been very suitable and beneficial to shipwrights.

The anonymous writer does not embark on theoretical disquisitions that would not have been of practical use to a shipwright. The design process is based –in common with the other treatises analysed– on simple geometry and arithmetic, with no use of scientific methods. Logarithms, which might be seen as a sign of sophisticated design methods, are only used as an aid in calculations, much like a modern draughtsman may use a calculator, having no influence in the outcome of the design process. In fact, the method can be followed just as well without the use of logarithms by doing all the numerical calculations by multiplication and long division, or even by scaling up the values of risings and narrowings from the scale drawing.

4.6 Hydrographie (Georges Fournier, 1643)

Full title: Hydrographie contenent la Theorie et la Practique de Toutes les Parties de la Navigation

Author: Georges Fournier

Type of book: Printed.

Year and place of publication: 1643, Paris

Edition consulted: 1643

Language: French

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[285] Salisbury and Anderson. *A Treatise on Shipbuilding c. 1620*, p. 1.

[286] Salisbury and Anderson. *A Treatise on Shipbuilding c. 1620*, p. 1.

[287] Salisbury and Anderson. *A Treatise on Shipbuilding c. 1620*, p. 1.

Georges Fournier (1595-1652)[288] was a French Jesuit priest who had been ‘employed in the French Royal Fleet according to his condition’[289] thus his knowledge was eminently theoretical and often incomplete as he was not a practising shipwright nor a ship designer. *Hydrographie* is a large format publication of 922 pages which is divided in twenty sections, called books. The first book (58 pages) deals with ship design and ship construction. The rest of the books describe an array of subjects related to sailing, navigation and naval matters: harbours and harbour installations; the navies of several countries; the role and responsibilities of each crew member by rank; the different manners in which a ship can be used; naval history; the history of France and the French admiralty; sailing and navigation.

This brief description of the contents of the treatise shows that ship design has a relatively small importance in this treatise (58 pages in a book of 922 pages). It contains, however, a description of ship design methods which are often referred to in the modern literature, in the context of the development of hull-design methods of the period. Hence, it will be described in this section.

The design methods are described in pages 15 to 26. Fournier's methods are based on proportional ratios between the principal dimensions of the ship, and provides a table with the principal dimensions for ships of diverse type to aid in the process of design.[290] The process of ship design is conceptually identical to all the other treatises in this section. The designer started by determining the shape of the backbone of the ship (keel, stem and sternpost/transom) (figure 27). Next, Fournier tells the reader that the designer also chooses the shape of the master section (figure 28) whose main dimensions (breadth and depth) were related proportionally to the ships service but were also very heavily influenced by the shipbuilding tradition of the ship's country of origin.[291] Finally, by modifying the master section in a controlled manner, the shipwright could obtain the shape of the rest of the frames in a large area of the hull.

Fournier described two different geometrical methods to shape the master section. The first, he called *‘selon l'ancienne façon’*[292] or ‘according to the ancient fashion’ (figure 29). The second

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288 http://catalogue.bnf.fr/ark:/12148/cb12138420w.public (last accessed 11 January 2018)

289 Fournier, G. 1643. *Hydrographie contenent la Theorie et la Practique de Toutes les Parties de la Navigation*. p: To the King (unnumbered) (Translated from the original by JPO).

290 Fournier. *Hydrographie*, p. 13.

291 Fournier. *Hydrographie*, p. 20.

292 Fournier. *Hydrographie*, p. 20.

method of defining the shape is also shown in figure 29 and was called by Fournier *'à la moderne'*[293] or 'in the modern fashion'.

The names ancient and modern have been used to identify rounder shapes, as shown in the 'ancient' method, with archaic ships. This has been used by some authors to identify certain shipbuilding treatises as out-dated based on the idea that their hull shapes had a certain resemblance to the ones shown by Fournier as the ancient method.[294] However, Fournier was clear that the method he called *'selon l'ancienne façon'* was, still, very much in use at the time he wrote his treatise. According to him, this method produced ships with round sections and, as a result, ships tended to roll heavily at sea. The flatter floors produced by the second method, *'à la moderne'*, would solve the problem by reducing the ship's rolling.[295]

Interestingly, the process of defining the rest of the frames of the ship from the master frame is described in the text and it is illustrated using a master section that is neither 'ancient' nor 'modern' (figure 30).

In common to the other methods described in this section the transformation of the master section into the other frames of the hull is controlled by rising and narrowing the sections in gradual increments the further they are from the master section. The values of rising and narrowing at each specific frame position is obtained from a simple quadrant and it is applied to the line of maximum breadth of the hull (figure 31). This is a distinct particularity which sets Fournier's method apart from the rest of the treatises analysed in chapters 4-5, with the exception of the plans drafted by Arrospide in the late 18th century, discussed in chapter 5 and appendix B. Fournier's method does not require a drafted scale plan, and it would be entirely possible to build the ship by drawing the sections full-size on the loft floor directly.

Fournier's text was obviously destined to a segment of society that did not have a direct involvement with ship design. Consequently, the superficial and incomplete description of ship design methods seems to be justified, as they are sufficient to inform the reader of the conceptual approach to ship design.

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293 Fournier. *Hydrographie*, p. 24.

294 For example, Richard Barker identifies single arc methods, like the ones shown in the *'l'ancienne' method* with archaic practices, consequently, inferring that the shapes shown in Sutherland's treatise (below) may be obsolete as they are drawn using a similar one-arch method (Barker. Whole-moulding: a preliminary study of early English and other sources, p. 33).

295 Fournier. *Hydrographie*, p. 24.

One of the main interest of the treatise has generally been that it has helped create a narrative that explains the transformation of shape with time from the ancient method (round) to the modern method (with a flatter floor). However, it has been shown that such names are misleading as Fournier clearly stated that the ancient method was still in common use. Moreover, plans drafted one century later show that rounder shapes were not necessarily a sign of archaic methods (figure 32).

4.7 The Compleat Ship-Wright (Edmund Bushnell, 1664)

Full title: The Compleat Ship-Wright (The Complete Ship-Wright)[296]
Author: Edmund Bushnell
Type of book: Printed
Year and place of publication: 1664, London
Editions consulted: 1664, 1669 (Two editions), 1678, 1688
Language: English

The Compleat Ship-Wright –written by Edmund Bushnell and first printed in 1664– describes the process of designing the hull of a ship by a method which does not differ with the other methods described in this section. The treatise is directed to the practical craftsman who requires simple, practical instruction. It was printed in five separate editions (1664, two editions in 1669, 1678 and 1688) (figure 33). Later, it was included nearly *verbatim*[297] in three other editions of a treatise called *Marine Architecture* published in London in 1736, 1739 and 1748.[298] It is the first printed treatise which describes ship design in English. Consequently, it should be considered an invaluable element in the shaping of the current narrative that describes the development of shipbuilding knowledge in the early modern period. However, as it is discussed in chapter 6, it has remained largely ignored.

The title page of the book states the intention of the writer:

[296] This treatise was published with two alternative spellings for the word Complete.

[297] With the exception of the short section on how to row a ship in a calm.

[298] *Marine Architecture* included a literal copy of Bushnell's *The Compleat Ship-Wright,* and a combination of Miller's *The Compleat Modellist and Bond's The Boatswayn's Art.*

> Plainly and Demonstratively Teaching the **Proportions used by Experienced Ship-Wrights, according to their Custome of Building; both *Geometrically* and *Arithmetically* performed** (Italics in the original. Highlights JPO).[299]

Bushnell's title does not leave room for doubt. His intention is not to transmit new knowledge. His intention is to transmit the knowledge used by experienced shipwrights following their customary methods of designing the shape of ships geometrically and arithmetically. Being a description of the customary practices of shipwrights, Bushnell does not engage in any theoretical discourse.

The treatise starts ––without the usual dedication to a patron– with a section called *To the Reader* where the writer gives explicit reasons for writing the treatise and the intended readership. It also provides a critique to the method of transmission of knowledge by apprenticeship common of the time and the opportunities available to the shipwright who could learn to design the shape of a ship.[300]

Bushnell is clear in this introduction that the method he describes is directed to practising shipwrights with little or no knowledge on how to define the shape of a ship. This lack of knowledge could be the result of not having had sufficient instruction from their masters, who Bushnell accuses of trying to keep the secret of the trades to themselves or, at most, within a small circle of chosen craftsmen. What most shipwrights learn from their masters –as the introduction says– is to hew, to dub and to fay pieces of wood which the master shipwright has

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[299] Bushnell, E. 1664. T*he Compleat Ship-Wright*, p. 'Title page'.

[300] This is how Bushnell justifies the writing of treatise:

> [T]his treatise, is written only for the good and profit of my Countrymen, [who] are ignorant in their *Trades*, and desire Instruction; not that I presume to teach those long experienced *Ship-Wrights*, whose actions hath declared their Abilities to the whole World.[...] yet the knowledge they desire to keep to themselves, or at least among so small a number as they can, for although some of them have many Servants[300], and by Indenture (I suppose) bound to Teach them all alike the same *Art* and *Mystery* that he himself useth; Yet it may be he may Teach some one, and the rest must be kept ignorant, so that those *Ship Wrights*, although bred by such knowing Men, yet they are able to teach their Servants nothing, more then *(sic)* to Hew, or Dub, to Fay a Piece when it is Moulded to his place assigned, or the like: but if occasion require, that the greatest part of these Men, by being *Carpenters* of Ships, or the like, may be removed from *England* to *Virginia*, or *New-England*, or the like Countries, where Timber is plenty for their use, yet through their ignorance, they durst not undertake such a Work: **For their sakes I have written this *Book***, wherein the *Reader* shall finde instructions sufficient for Moulding of any *Ship*, or *Vessell* whatever, with the Masting of them, drawing of *Draughts*, and all in a very plain and exact Method, which I am confident will be understood by the meanest capacities, if they can but read English, and have the benefit of a little Arithmetick, as Adition, Substraction, Multiplication, Division: be diligent, and I shall be thereby incouraged, if need be, to help thee farther in the Art. (Bushnell. T*he Compleat Ship-Wright*, p. 'To The Reader' (Italics in the original. Highlights by JPO.)).

decided where they should be placed. This arrangement of the work where master shipwrights direct the work of common shipwrights who execute the manual work of crafting and adjusting the pieces, thus building the hull, is not to the liking of Bushnell as it may not help shipwrights transmit their knowledge successfully in times of rapid expansion and colonisation as the ones he was experiencing. This organisation of the workforce and of the process of designing and building a ship may work in the shipyards of England where the organisation of the workforce had developed over the years. However, the situation of the colonies –'Virginia, or New-England, or the like Countries'– presented shipwrights with new opportunities that would not be possible in England.[301] If shipwrights –whose ability to hew, dub and fay was taken for granted– learned how to design ships, then, the construction of ships in those places would be possible.[302] This would obviously benefit England's interests in the colonies, but also, it would benefit those shipwrights who would see that, by way of knowing how to design a ship, new opportunities of social progress were available for them. Thus, *The Compleat Ship-wright* can be read as a true how-to manual aimed at transmitting useful knowledge, to readers who already had the necessary ability and background knowledge.

The language, structure and content of the treatise reflects the readership which Bushnell is writing for: those shipwrights who 'desire Instruction'. Bushnell, who in the title page informs the reader that he is a shipwright himself, does not make any observations about the extent of the knowledge he is describing. Therefore, it is not clear if he decided to leave other, more advanced, types of knowledge out of the book so as not to confuse his intended readership. His style is clear without introducing an unduly number of examples that could confuse the reader. He states that one single example is sufficient to convey a conceptual idea.[303] By reading the treatise it must be concluded that it fulfils the intended goal successfully. This is achieved by writing in a style that is

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301 Ships were so necessary in the colonies that the General assembly of Virginia encouraged the construction of ships. This went against the policies of England that discouraged the manufacture of goods in the colonies. However, it was allowed in order to respond to the real need for ships in the colony (Evans, C. W. 1957. *Some Notes on Shipbuilding and Shipping in Colonial Virginia. Issue 22 of Jamestown 350th anniversary historical booklets.* Virginia: 350th Anniversary Celebration Corporation, p. 20).

302 This idea is similar to the general concept of García de Palacio's treatise who wrote it for the benefit of those who were building ships in the New World. Obviously, in the new colonies the number of skilful shipwrights with the ability to design new ships would be limited. Anything that could be done to provide knowledge would be greatly beneficial for the colony.

303 Bushnell. T*he Compleat Ship-Wright*, p. 11.

easy to understand and by following a very well organised order which helps in the transmission of the information in an efficient manner.[304]

Bushnell's design method requires that the shipwright produces a basic drawing of certain features of the ship to scale. To enable this, Bushnell proposes that the shipwright should learn to draw a graphic scale which he will use, then, to reduce full size dimensions into scaled dimensions (figure 34). Conversely, the graphic scale could be used to pick up dimensions from the drawing to convert them into full size dimensions. Following this, Bushnell introduces the main body of the treatise in which the manner of designing a ship is described. It is divided in several short chapters. The longest chapter describes how to define the three-dimensional shape of the hull. This is followed by an additional chapter on how to measure ships in order to know their interior capacity. A shorter chapter on masting follows. Finally, the treatise ends with a chapter in which Bushnell describes a method of rowing ships in a calm.

The design procedure is, in principle, very similar to the methods described up to now, and can be described in general terms as follows: The shape of the hull is obtained from the shape of the backbone (stem, keel and sternpost/transom), the shape of the master section, and several longitudinal curves (rising and narrowing). Geometry determines the shape of these elements. The shape of most of the frames on the hull can be obtained from the transformation of the shape of the master frame in a process regulated by the rising and narrowing curves.[305]

The process is based on a simple drafted plan, to scale, in which the backbone, the rising and narrowing curves, and the master frame are drawn (figures 35 and 36). The construction of the master section is different to the one proposed in the previous treatises but, in common with them, it is based on very simple geometric constructions that are easy to remember and if needed could be modified (figure 36). In this particular case the master section was derived from two arcs of circles and a straight line.[306] However, Bushnell explains that other alternative ways are possible. The rising and narrowing lines are made of arcs of circles (figure 37). These lines control the shaping of the three-dimensional shape of the hull by guiding the transformation of the

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[304] The order in which the contents of the treatise are described is similar to the anonymous treatise described in Salisbury, W. and Anderson, R.C. (eds), 1958. *A Treatise on Shipbuilding and A Treatise on Rigging, Written About 1620-1625.*

[305] The method described in the treatise defines narrowing lines at the floor and at the maximum breadth. Similarly the rising lines used are one at the floor area and an additional rising line at the maximum breadth area.

[306] The particular process of drafting the shape of the master section is not relevant for this analysis. In common with the rest of the treatises analysed it will not be described here.

master frame mould into the other transversal frames of the hull and, therefore, are central to the process of shaping the hull. However, in common with others treatises analysed for this research there is no clear indication as to how to choose the values of maximum rising and narrowing that will determine the final shape of the curves and, hence, the hull. The treatise also provides an alternative method by which curves with fuller ends can be defined at the will of the designer (figure 37). Again, no rationale is given to explain why a shipwright should desire to have fuller or finer ends, or what degree of fullness could be desirable.

The shipwrights for whom Bushnell is writing are expected to have enough experience in shipbuilding, although not in design. Therefore, it is expected that they might have a feel for what shapes they desire even if they do not have the means –prior to reading the treatise– to guarantee that they will build the ship to the desired shape. Consequently, although Bushnell gives precise dimensions for many of the ship's geometric parameters they must be taken as illustrative. The text provides a sufficient number of examples to show that the method described is not prescriptive, or normative, and that the shipwright can divert from it, or from the proportions and shapes shown on it, if he so desires. For example:

> If any be desirous to have a Rising line rounder [...] [307]
>
> Herein any may do as they please, give more or less [breadth to the floor]; my Judgement is, rather more than less [...][308]

Clearly the dimensions and proportions given in the text can be varied by the shipwright to suit their particular goals.

The process of obtaining the shape of each individual frame is, again, explained very clearly by Bushnell. Following the method of design described in the *Compleat Ship-Wright*, the only transversal sections of the hull that the designer must draw on the drafted plan is the master frame. The finished plot would be one similar to a combination of figures 35 and 36. Although it is a close precursor to the modern lines plan, it cannot be considered equivalent to a lines plan yet.[309]

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[307] Bushnell. T*he Compleat Ship-Wright*, p. 41.

[308] Bushnell. T*he Compleat Ship-Wright*, p. 11.

[309] The purpose of these plans was to obtain from them the values of rising and narrowing at each individual frame. Thus their objective was not to provide a visual representation of the three-dimensional shape of the hull as is the main purpose of a modern lines plan.

In order to obtain the shape of the transversal frames, Bushnell proposes that they should be drawn full size directly on the mould floor using for this a mould made of three parts which, when joined, reproduced the shape of the master frame.[310] This is a very simple process that he explained in the text using an illustration as an aid (figure 38). First the shipwright would choose the values of rising and narrowing for each individual frame from the scale plan shown in figure 25 or from direct calculation following the alternative arithmetic method given.[311] These values indicated by how much the shipwright had to rise and narrow the three parts of the mould of the master section in order to obtain the shape of the new frame (figure 38). With the mould in place, the shape could be scribed into the mould floor. This process would be repeated for each frame. Later, these shapes drawn in the floor would be used to make the frames of the hull.[312]

The process described by Bushnell is conceptually simple but, as it requires that measurements are scaled up from a relatively small drawing to the full size plot, there was a real possibility of introducing scaling errors. Aiming at avoiding such errors, the treatise, proposes to use the alternative arithmetic method. It is, in essence, the same as the one described in *A treatise on Shipbuilding (1620-1625)*, described before. It is based on Pythagoras's theorem and, therefore, requires knowledge on how to calculate the squares and square roots of numbers. Bushnell acknowledges that not all practising shipwrights may be comfortable performing square roots.[313] Thus, he provides a table of squares and square roots that solves the problem as the shipwright could use it to read the values directly (figure 39 and 40).

One further interesting feature of this treatise is that it shows an early attempt of providing a method to calculate the true displacement of a ship. Formulae to calculate the tonnage of ships were used at the time. They were a rough measurement of the volume within a hull which in turn served as an estimate of the capacity to accommodate cargo within a hull. However, Bushnell knew that this ‘tonnage’ had no relation to the real weight of the ship or the shape of its under-body (figure 41).[314] He explains that unless the volume of the underwater part of the hull is measured accurately, the shipwright will have no means of knowing the real weight of the ship. Bushnell continues by describing a method of calculating the underwater volume of the hull

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[310] Bushnell. T*he Compleat Ship-Wright*, pp. 15-18.

[311] Bushnell. T*he Compleat Ship-Wright*, p. 22.

[312] Bushnell. T*he Compleat Ship-Wright*, pp. 15-22.

[313] Bushnell. T*he Compleat Ship-Wright*, p. 25.

[314] Bushnell. T*he Compleat Ship-Wright*, p. 59.

following a method that divides the ship in a series of prisms, delimited by vertical sections, in a manner which is conceptually close to the method described in *A Book called the Treasure for Traveilers* discussed above. The main difference would be that Bushnell's approach calculates the volume of the hull from the drafted plan as opposed to the real ship. This method, however, can only be used as a check of the weight of the ship, were it to float at the theoretical design-waterline. It cannot be used to design a ship to a previously specified weight.

The design method described in this treatise requires very limited geometry and mathematical knowledge which, together with the clarity of the explanations and simple text, would have made it very suitable for the education of shipwrights. The treatise is totally devoid of any theoretical discussions or conceptual description that may indicate any use of science or scientific thought in its conception. Nor is it prescriptive. In numerous instances the reader is told to freely change parameters to suit personal needs or ideas.

4.8 The Compleat Modellist (Thomas Miller, 1676)

Full title: The Compleat Modellist: Shewing The true and exact way of Raising the Model of any Ship or Vessel, small or great, either in Proportion, or out of Proportion

Author: Thomas Miller

Type of book: Printed

Year and place of publication: 1676, London.

Editions consulted: 1676, 1684

Language: English

Although this book does not describe hull design, it describes the rigging of ships based on drawing a simple plot of the ship, to scale, which is used by the rigger to specify the different parts of the rig: masts, lines, and so on. (figure 42).

This short treatise contains a paragraph that illustrates the mindset of the period and the importance of past experience in technological processes. The knowledge that could be obtained from past practice was considered so important by Miller that he recommended that it should be recorded in a ‘Book of large and good Paper Royal’.[315] In that book one should write down the dimensions of as many ships as one could. These dimensions could be obtained from the master carpenters of the ships, or by measuring them oneself. Once those dimensions were recorded, the

[315] Miller, T. 1676. *The Compleat Modellist*, p. 6.

ship should be drafted in the book, so that in the future, when one was asked to rig a ship of similar dimensions 'there you have a Model raised to your hand.'[316]

The author is only interested in representing a simplified view of the ship in profile. He is not interested in elaborate plots, unlike others in the past who, as the author criticises, 'were so affected with the draught of the Ship, they minded that more than the substance that belonged to it.'[317] In the illustration the author purposefully distorted the ship represented on it in order to simplify the drafting process. Decks are shown as straight lines when in reality would have had long curving shapes. The drawing is, therefore, a simple tool to be used to store basic information required for the definition of rigging elements. However, the author, justifies the reasons behind this simplification of the drawing and consequently shows that basic drawings are not necessarily a consequence of bad printing or drawing capabilities, and that often authors purposefully produced drawings that represent a simplified, schematic, depiction of the real object.

Without this past experience, and in the absence of suitable theories, the readers of this book, and any other craftsman of the period, would have been lost. Thus, any means that served to record the experience, such as templates, notebooks, drawings or rules of proportions, were a great aid for the riggers for whom the treatise was written, but would be just as applicable to any practical craftsman.

4.9 Deane's Doctrine (Anthony Deane, 1670)

Full title: Doctrine of Naval Architecture

Author: Anthony Deane

Type of book: Unpublished manuscript (MS PL2910) in the Pepys Library, Magdalene College, Cambridge

Year: 1670

Editions consulted: 1981 edited version, by Brian Lavery[318]

Language: English

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316 Miller. *The Compleat Modellist*, p. 6.

317 Miller. *The Compleat Modellist*, p. 'To the Reader'.

318 Lavery, B. 1981. *Deane's Doctrine of Naval architecture, 1670. Edited and introduced by Brian Lavery*. London: Conway Marine Press. The present analysis is based on Lavery's edited version. However, as the edited version also specifies the original pagination, page numbers will refer to both, with original page numbers shown in brackets.

Anthony Deane (1638–1721) [319] is one of the most renowned English shipwrights of the 17th century. He is often mentioned as being one of the first shipwrights to use a scientific approach to ship design.[320] However, even if the quality of his work and calculations appear to be superior to the ones shown in the previous ship design treatises, his approach to hull design was based on the same principles.

Deane's method of ship design remained rooted in tradition and was based on geometry and proportion. His method, like the ones before and after him, were not capable of predicting the performance of a ship. They were methods that had to be followed in a mechanical manner, step by step, within a certain set of boundaries, which produced a ship with acceptable characteristics. In the text Deane writes in a manner that he seems to be talking to the reader, in an almost conversational style. For example:

> To let you know from whence I derive my breadth, I take 3/10 of the length of the keel [...][321]
>
> And then, when you have done that, sweep another of the same form.[322]

On several instances Deane hints at the possible readership he was writing for:

> [...] and therefore I shall learn the **young artist** a sure way which shall not fail of shaping such a body as I hope may retain no blame by the reader [...]. This much I thought a good hint, to fortify the **young artist** against any fanatic doctrine, [...].[323] (Highlights JPO.)

The design method described by Deane in *Deane's Doctrine* is described in enough detail to be able to follow the procedure.[324] However, similarly to the other methods, the choice of the design parameters of the ship is not justified in any objective way by relating it to some scientific or theoretical principle. Thus, it is not always clear if the actual proportions or dimensions chosen for a particular feature reflect a general principle or a particular case of the ship used as an example.

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[319] Walker. S*hips and Shipbuilders*, p. 20.

[320] Lavery. *Deane's Doctrine of Naval Architecture*, p. 21.

[321] Deane in Lavery. *Deane's Doctrine of Naval Architecture*, p. 52 (37).

[322] Deane in Lavery. *Deane's Doctrine of Naval Architecture*, p. 54 (43).

[323] Deane in Lavery. *Deane's Doctrine of Naval Architecture*, p. 61 (53).

[324] In common with other treatises analysed there the method is not described to its full details. Thus Deane performs an additional transformation to the radii of the frames which is not described in the text.

The design method does not differ in essence from any of the other methods described in this section and can be summarized as follows:

The shipwright draws, carefully and to scale, a profile view of the ship where all the dimensions are related proportionally to the length of the keel.[325] Next the rising and narrowing curves are drawn, in profile and plan view according to certain proportional and geometrical rules (figure 43).[326] Following this, the midship frame shape is drawn as a series of tangential arcs of circle (figure 44).[327] Again, the arcs of the radii and the positions of the centres are related proportionally. Based on the midship frame shape and the rising and narrowing curves, the shipwright could draw all the frames in the ship. One important difference to Deane´s method and the previous cases is in the definition of the shape of the rest of the frames from the shape of the master section. Where before, the shape of the frames was not drawn on the scale plan and was obtained directly in the full size mould floor, Deane draws the frames on the scale plan. The process is the same, but the level and graphical quality of the information shown in the plan differs.[328]

Deane stresses the importance of the rising line of the floor as the main line which determines hull-shape and, consequently, the good or bad characteristics of the ship. He writes:

> For to lay down [the rising line] as it ought to be is great worth and advantage on every man-of-war, which, if it had been thoroughly understood, we had never had such mistakes in the navy as we have found [...].[329]

This quotation can be used to characterise the knowledge of the period. From a conceptual point of view, the knowledge of the period was right. Shape and performance are related, and hence an unsuitable shape will result in an unsatisfactory ship. But, due to the limitations of the knowledge of the period, shipwrights did not have any means of relating form and performance in an objective manner. Thus, although Deane describes what is, in his opinion, the most suitable shape for the rising line he could not provide any theoretical justification for his choice.

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325 Deane in Lavery. *Deane's Doctrine of Naval Architecture*, pp. 54-56 (43-46).

326 Deane in Lavery. *Deane's Doctrine of Naval Architecture*, pp. 57-62 (47-58).

327 Deane in Lavery. *Deane's Doctrine of Naval Architecture*, pp. 67-9(65-66).

328 Deane's scale plan gives a superior sense of shape when it is compared to the plans shown in previous treatises. One immediate advantage of this is that the designer has a convenient manner of seeing the shape of the hull at a very early stage.

329 Deane in Lavery. *Deane's Doctrine of Naval Architecture*, p. 55 (45).

For the rising he favours true arcs of circle, although he writes that he has tried elliptical or diminishing lines in the past.[330] To save the new artist (designer) from making the many mistakes of others, Deane details how to obtain the shape of the rising curve by drawing it in the plan, or by calculating its centre by numerical methods.[331] With the shape of the curve drawn in the plan, the individual values of rising at any position along the hull can be obtained by scaling from the plan at each frame position or, alternatively, a fully numerical method is provided.[332] It is noteworthy that Deane uses the same method for defining the shape of his rising and narrowing lines –arcs of circle– which is the geometric construction used by Bushnell in *The Compleat Ship-Wright,* by the anonymous author of *A Treatise on Shipbuilding* for some of the longitudinal lines and Mathew Baker in *Fragments*.

One important feature in the design of a ship according to Deane is the position of the waterline. He argues that the real ship must never sink below the waterline marked in the plan, or else the gun ports will be too close to the water which would render the lower gun ports dangerous or unusable at sea. He describes, correctly, that in order for the ship to float at this waterline, the weight of the ship and the weight of the water displaced by the underwater portion of the hull must be equal.[333] Again, we can see a correct understanding of the Archimedes principle that explains why bodies float on a fluid. Expanding on this idea, Deane stresses the importance of placing the waterline on the drafted plan after a careful consideration.[334] Thus, to assist the designer, the treatise describes a method by which the volume of the underwater portion of the hull and consequently its weight can be established from the theoretical drafted plan following a relatively simple method.[335]

[330] Deane in Lavery. *Deane's Doctrine of Naval Architecture*, p. 60(53).

[331] Deane in Lavery. *Deane's Doctrine of Naval Architecture*, p. 57(47).

[332] Deane in Lavery. *Deane's Doctrine of Naval Architecture*, p. 65(62).

[333] Deane in Lavery. *Deane's Doctrine of Naval Architecture*, p. 71 (69).

[334] Deane in Lavery. *Deane's Doctrine of Naval Architecture*, p. 56 (45).

[335] Pepys credited Deane with being the first shipwright to develop a procedure to calculate ship displacement (Creuze 1840: 18) However, it has been shown that the authors of *A Book called the Treasure for Travellers* and *The Compleate Ship-Wright* described methods to calculate displacement which, in principle, are all correct. In common with the other methods, Deane's approach to calculating the weight of the ship is based on calculating first the underwater volume of the hull which, when multiplied by the water's density, provides the weight of the ship. To calculate the underwater volume of the hull Deane slices the hull in vertical sections for which he calculates the area. In contrast to the methods described in the treatises above, that did not specify how to calculate these areas, Deane gives two alternative, approximate, methods.

However, how could the designer ensure that the weight of the real ship, once it was built, matched the weight calculated for the theoretical drafted plan? Deane's treatise shows the method followed by shipwrights of the period to control the weight of their ships. This was done by following a set of pre-established scantlings (size) of the ship's constituent elements which would give as a result a ship of a certain total weight. Consequently, the tool available to the ship designer to ensure that a ship performed[336] in a successful manner was based on a combination of two mutually dependant tools. The first tool would be the method followed to shape the hull which, in turn, determined the volume of its underwater portion and, hence, its hydrostatic characteristics. The second tool available to the designer would be, a specification or scantling rule –not necessarily written– that controlled scantlings of the constituent parts of the hull and rig (hence the weight of the ship) in a manner that matched the weight of the underwater portion of the hull defined by the shape design rule. In Deane's words:

> A good proportion for the ship [as described], with the assignment of every part of a ship with the scantlings herein mentioned shall not exceed in draught of water here declared [...].[337]

In other words, if the reader shaped the hull following Deane's proportion and method, and built it according to the scantlings given, the ship would float in the waterline specified in Deane's example. Moreover, the original text continues by saying that the combination of hull-shape design method and specification of scantlings provided in the treatise produced ships that would not require future alteration to correct any problem that may result as a consequence of insufficient stability.[338] The design-recipe and its companion, the scantling rule, provided a design route which guaranteed –to a certain extent– that hull shape, hull weight and its centre of gravity would match in a harmonious manner.

To summarize Deane's treatise briefly, it would suffice to say that, in common with all the treatises analysed up to now, the design method is based on the transformation of a master section which is shaped after a geometric method for which no justification is given. The transformation is guided by pre-established longitudinal rising and narrowing lines which, although considered vital for the performance of the ship, are shaped following equally unjustified methods. Deane states how shipwrights guarantee that the ship floated as expected.

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336 At this period, the most basic performance characteristics that a ship had to meet was that it floated at its design waterline and that it had sufficient stability to carry sail.

337 Deane in Lavery. *Deane's Doctrine of Naval Architecture*, p. 76(73).

338 Deane in Lavery. *Deane's Doctrine of Naval Architecture*, p. 76(73).

This came necessarily from a mutually dependant hull-shape design-recipe and specification of scantlings.

A few final comments about the readership and the writer. The tone of the text, and references within, show that this text would have been very accessible to shipwrights who were literate and had a very basic mathematical knowledge. However, it is a manuscript which remained in the private collection of Samuel Pepys which does not appear to have been copied or printed at a later date. Therefore, its influence on other shipwrights cannot be known. Deane's drawings are precise and beautifully decorated. However, there is nothing in the design method that prevents it from being used in a simpler manner, with less visual flourish, perhaps by shipwrights engaged in the design of more utilitarian ships.

4.10 Dutch ship design: Arnoul, Witsen and Van Yk

The procedure which Dutch shipwrights of the 17th century followed to shape their hulls has been described in chapter 2. The current narrative is based mainly, on the interpretation of documents written during the 17th century which play a central role in any description of 17th-century Dutch shipbuilding and, therefore, they will be described here. The first document is a short description by a French observer called Arnoul, the second is Witsen's printed treatise on shipbuilding and, finally, the third document is Van Yk's printed treatise on shipbuilding. The manner in which these documents have been approached by some modern scholars, in what appears to be a subjective manner, will also be exposed.

4.10.1 *Remarques Faites par le Sieur Arnoul* (Arnoul, 1670)

Full title: *Remarques faictes par le sieur Arnoul sur la marine d'Hollande et d'Angleterre dans le voyage qu'il fit en l'année 1670, par ordre de Monseigneur Colbert.*

Author: Pierre Arnoul

Type of publication: Manuscript

Year: 1670

Editions consulted: Microfilm of original manuscript, MF 16520. Bibliothèque nationale de France, Paris

Language: French

In 1670 a Frenchman, Mr. Arnoul, was sent by the then Minister Colbert to observe the shipbuilding procedures followed in Dutch and English shipyards. He wrote an account that has been used to interpret how Dutch shipyards of the period built their hulls.[339] According to Arnoul's manuscript Dutch shipwrights started by building the bottom shell-first (figure 45) and once it had been planked up internal reinforcements (floors and frames) were introduced. The topsides were planked in a frame-first fashion by attaching planking to these pre-erected frames.

Arnoul's text is one of the few contemporary accounts of the process and was used by Hasslöf in support of his shell-first versus frame-first paradigm. Its importance as a clue to define Dutch shipbuilding of the 17th century can be understood when it is realised that in numerous publications in which the particularities of Dutch shipbuilding are discussed references to Arnoul's manuscript are included.[340] However, often references seem to have been obtained from Hasslöf's publication and not from the unpublished manuscript. Additionally, it would appear that it is the English translation of the text by Hasslöf that is referred to, instead of the original French text, which was included in one of his publications.[341]

Tellingly, Hasslöf used different translations of Arnoul's text when he developed his ideas.[342] For unknown reasons, the latter translations, convey a different idea to that of the original text. This faulty translation provided the evidentiary support to the idea defended by Hasslöf that the Dutch shipwrights of the period did not have a method of pre-design and that they designed and built simultaneously, making design decisions during the process of construction.[343] Unfortunately, this distorted message has been adopted within current scholarship, thus, not taking full advantage of Arnoul's original text. Appendix A shows the different translations used by Hasslöf and the distorted message that the latter versions seem to convey. It is an interesting portray of the manner in which the evidence is interpreted in line with a pre-established narrative, instead of shaping the narrative according to the evidence (appendix A).

This is what Arnoul had to say about the manner in which the Dutch built and shaped their hulls:

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339 *Arnoul. 1670. Remarques faictes par le sieur Arnoul sur la marine d'Hollande et d'Angleterre dans le voyage qu'il fit en l'année 1670, par ordre de Monseigneur Colbert..*

340 Basch. Ancient wrecks and the archaeology of ships, p. 40; Hocker. Bottom-based Shipbuilding in North Western Europe, p. 83; Lemée. *The Renaissance Shipwrecks from Christianshavn*, p. 42; Unger. Dutch design. Specialization and building methods in the seventeenth century, p. 155; Van Duivenvoorde. *Dutch East India Company Shipbuilding*, p. 31.

341 Hasslöf. *Carvel Construction Technique, Nature and Origin*, p. 54.

342 An analysis of the original text and its translations is shown in appendix A.

343 Hasslöf. Main Principles in the Technology of Ship-Building, pp. 59-60.

> The first thing I have noticed is that as a rule in France one begins to place the floors immediately after laying the keel. In Holland, on the contrary, they begin with the planking and do not shape the floors until they have fitted as many as ten or twelve strakes. **They know the width they should give [to the bottom] forward, aft and amidships,** and thus they get the form of their ship by-eye, shaping it in whichever manner they wish, since they have the same facility of working inside as outside. This also ensures that the planks fit much better against one another. And as to the floors, they then cut them according to the [shape of the] planking [...] (highlights JPO).[344]

Reading this account written by Arnoul in 1670, it could be concluded that Dutch shipwrights building in the Dutch bottom-based tradition had a clear idea of the shape of the hull before its construction began. The shipwright knew the breadths of the bottom of the hull at three key pre-decided positions (forward, midship and aft). Therefore, the shipwright had a clear idea of the shape of the bottom of the hull before the construction started (figure 46). This may not seem like much in way of pre-design. However, if it is assumed that the method described by Arnoul is necessarily incomplete, as his description only amounts to a few sentences, and that much detail must evidently be lost due to the brevity of the account, the conclusion that it is a method that describes construction by-eye, with no idea of pre-design, where the shipwright is building and designing simultaneously, cannot be necessarily inferred as Hasslöf did (see appendix A for a longer analysis). When Arnoul's text is read in conjunction with Witsen's 1671 text –analysed in the following section– a picture will emerge that shows that 17th century Dutch shipwrights had methods of pre-design of the bottom of their ships. In these methods the pre-established idea of the breadths and deadrise angles of the bottom of the ship at several pre-established positions along the ship's length played a leading role.[345] However, the transversal section of the hull through its widest point, the master frame, would also play a relevant role, and, not necessarily a secondary role (chapter 7).

4.10.2 Aeloude en hedendaegsche scheepsbouw en bestier (Nicolaes Witsen, 1671)

Full title: *Aeloude en hedendaegsche scheepsbouw en bestier*
Author: Nicolaes Witsen
Type of publication: Printed treatise
Year and place of publication: 1671, 1690, Amsterdam

344 Hasslöf. Wrecks, Archives and Living Tradition, p. 170.

345 As clearly stated by Arnoul and Witsen below.

Editions consulted: 1671, 1690 and Hoving's 2012 edited version: *Nicolaes Witsen and Shipbuilding in the Dutch Golden Age*

Language: Dutch (English translation by Hoving)

Nicolaes Witsen was the Director of the West India Company and a member of the Admiralty of Amsterdam. He was not a professional shipwright. Based on this, different authors interpret the validity of the contents of his treatise differently. Unger, for example, thought that he knew little of practical shipbuilding and reported only what others told him.[346] Basch and Hoving, on the other hand, considered him a man with a deep knowledge of the practices followed in Dutch shipyards of the period.[347] Similarly, his contemporary, Aubin, described Witsen as the most illustrious author who had ever written about shipbuilding.[348] In all probability it will never be possible to state beyond any doubt which of those two opposing opinions reflects Witsen's true knowledge. However, based on the present author's personal study of Witsen's treatise, Ab Hoving's opinion is followed and it will be argued that the treatise is a good source of valuable information with regards to the practicalities of Dutch shell-first ship construction during the second half of the 17th century. The original is written in Dutch, therefore, incomprehensible for the present author. However, in 2012 it was translated into English by Ab Hoving which has made it accessible to a wider readership.

Hoving's 2012 edition of Witsen's treatise gives a direct translation of most of Witsen's text related to ship design and construction which has been rearranged in order to describe the construction and design process in a more orderly manner than in the original document. Other themes like sail theory or navigation are not reflected in the edited text. Alongside the translation of Witsen's original text –but readable as a totally independent text–, Hoving gives his own interpretation of the original text.

[346] Maarleveld, T.J. 2013. Early Modern Merchant Ships, Nicolaes Witsen and a Dutch-Flush Index. *International Journal of Nautical Archaeology*, 42(2), p. 349; Unger. Dutch design. Specialization and building methods in the seventeenth century, p. 156.

[347] Basch. Ancient wrecks and the archaeology of ships, p. 5; Hoving. *Nicolaes Witsen and Shipbuilding in the Dutch Golden Age*, p. 70.

[348] Aubin. 1702. *Dictionaire de Marine*, p. 2-v.

Aubin translated the contents of Witsen's treatise into French as a French–Dutch dictionary. The author informs that most of the information was translated from Witsen's dictionary although other sources had been consulted as well. Translations from Witsen's treatise are distinguished by using quotation marks. Thus, it could be used as a contemporary source of information about the contents of Witsen's treatise.

Such a profound and detailed analysis of the text could have produced a nuanced description of the whole design and construction process as defined by Witsen in his treatise. However, although the translation by Hoving is truthful to the original content,[349] the interpretation of the construction procedures can be critiqued. The text could have been used to try to learn from it what design procedure Dutch shipwrights of the period may have used to shape their hulls. But, instead of taking this opportunity, the analysis starts with Hasslöf's theoretical work as a premise and the text is approached with the pre-established idea that there was no pre-conceived method of conception. Thus, what should have been a conclusion drawn from Hoving's careful study of Witsen's treatise, is stated as premises instead. The danger of starting from the point one tries to establish was put forward by Gould:

> For archaeologists, the most serious potential pitfall is what historians of science call the *fallacy of affirming the consequent,* that is, assuming the very thing you should be trying to find out. [350](Emphasis in original)

Cases of subjective interpretation will be highlighted and Witsen's text will be interpreted in a, hopefully, objective manner. This will result in a clearer picture of the practical procedures followed by 17th-century Dutch shipwrights to conceive the shape of their hulls.

A critical reading of Witsen's treatise

In the introductory sections of his modern edition of Witsen's text, Hoving set the groundwork by making clear what is the currently accepted theory regarding hull-shape conception by 17th-century Dutch shipwrights. He does it by introducing the key ideas as facts, as accepted wisdom. This sets the reader into the right frame of mind in order to understand the text, and, more importantly, it highlights the frame of mind of Hoving in order to understand why certain passages of the book are interpreted the way they are. This most enlightening passage in the introduction of the book reads:

> [In Dutch shipbuilding of the 17th century] **there was no distinction between design and execution. The shape** was not designed on the drawing board but **was shaped during the building process**, not on the basis of an engineer's calculations but through the

[349] I have to thank my colleague Thomas Dhoop for his assistance in comparing the original text with Hoving's translation.

[350] Gould, R.A. 2001. From sail to steam in the late nineteenth century. In M.B. Schiffer (ed), *Anthropological Perspectives on Technology*. Albuquerque. University of New Mexico Press, p. 194.

> master builder's active engagement in the building process in the yard (Highlights by JPO).[351]

Thus, Hoving starts by setting the premise that there is no process of pre-design of the ship. Further on, he continues: 'The design came into being in the yard through the actual construction of the ship itself'.[352] It is this idea that there is no difference between design and execution, that the ship is built and shaped (or designed) at the same time, which leads Hoving's reading and interpretation of the text. It is not an idea that is inferred from the contents of the text. It is a premise accepted without discussion, previous to the reading of the text.

However, in a previous publication Hoving acknowledged that there were many rules and proportions in place that 'produced the measurements of all the parts that had to be worked out into the ship'. These rules were codified in such a way that they could be recorded into written specifications, which 'provided the master builder with the limits within which he had to build the ship'.[353] Therefore, although the idea of pre-design is not accepted readily, the existence of written specifications detailing important limits to the construction of the ship is acknowledged. Such specifications did not refer to physical elements of the hull and rigging only. They also described certain dimensions which show that before construction began shipwrights had a series of control dimensions that guided the shaping of the hull (figure 47).

The shaping/building process according to Witsen:

The process of ship construction according to Witsen can be described in the following steps. They are well described in the original text which is illustrated with numerous drawings and diagrams. All the references below are taken from Hoving's edition of Witsen's treatise, and unless otherwise stated they represent Witsen's original ideas and not Hoving's modern interpretations.

In order to build a ship, shipwrights could follow different rules of proportion that allowed them to work out the dimensions of the different parts of the ship. These rules were not to be followed strictly. They acted as guidelines which could be modified at will but at the same time gave assurance that as long as one followed the rules closely the results would be satisfactory.[354]

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351 Hoving. *Nicolaes Witsen and Shipbuilding in the Dutch Golden Age*, p. 9.

352 Hoving. *Nicolaes Witsen and Shipbuilding in the Dutch Golden Age*, p. 9.

353 Hoving. A 17th-century Dutch 134-foot pinas, Part 1, p. 212.

354 Hoving. *Nicolaes Witsen and Shipbuilding in the Dutch Golden Age*, p. 9.

Once the main proportions and dimensions of the different structural members had been established, based on rules-of-thumb, the backbone of the ship could be erected (figure 48). This consisted of the stem sternpost-transom assembly, and keel. Next, the first planks of the bottom could be installed in place against the keel. This first plank (the garboard) was placed at a specific angle (deadrise angle) with respect to the keel, held in position by a series of pre-made provisional transversal floor-cleats (figure 49). Once the garboards fitted snugly against the keel they could be fixed to it and to the provisional floor-cleats. The next row of planks could then be fixed against previously laid planks. However, as there was no internal framing to guide this work, long clamps held the planking provisionally (figure 49). In order to fix planks to each other, short pieces of wood, cleats, bridging the seams between planks were nailed in place (figure 49).

Witsen's description matches very well with Arnoul's description above. They both agree that shipwrights knew the breadths of the bottom of the ship at specific positions along the ship's length before the process of planking started. Witsen supplies further detail by informing that in addition to the breadths, shipwrights also had a preconceived idea of the deadrise angle at those specific positions. Witsen does not specify a rule by which deadrise could be chosen. However, he gives examples of deadrise angles at different longitudinal positions for several types of ships.[355] Therefore, it is evident that at this early stage shipwrights had a very clear idea in their mind of the shape of the bottom they wished to obtain. Three widths and deadrise angles, plus, the self-fairing effect of a smooth planked bottom was all the information required to store the three-dimensional shape of the bottom (figure 50).

Hoving acknowledges that 'together with the width of the bottom, setting the deadrise was another of the typical design moments in which the properties of the vessel were determined.'[356] However, his acknowledgement of this fact is not sufficient for him to accept that there could be a degree of pre-determined design in the shaping of the hull. The setting up of the deadrise seems to be an impromptu decision of the shipwrights rather than a preconceived idea.

Following Witsen's account, once the bottom had been planked up, internal floors were introduced and the bottom planks were fixed permanently to them. These floors gave cohesion

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This freedom to change the rule as desired is pointed out as a uniqueness of Dutch flush construction. However, a careful reading of contemporary 'frame-first' treatises in this chapter shows that the same can be said for the procedures described in them. The authors of these treatises described practical methods, with specific rules of proportion and geometric constructions, which could be altered by shipwrights according to their particular needs or ideas.

355 Witsen in Hoving. *Nicolaes Witsen and Shipbuilding in the Dutch Golden Age*, p. 59.

356 Hoving. *Nicolaes Witsen and Shipbuilding in the Dutch Golden Age*, p. 62.

and structural integrity to the bottom, therefore, the short cleats bridging the seams could be removed at this stage. The next step –and probably the most important step in the definition of the transversal shape of the hull– was the erection of the master frame. This master frame –or part of a master frame– consisted of the floor and two bilge-futtocks bolted to it (figure 51).[357] The next step consisted in planking the bilges of the ship that, amidships, would be fixed to the mainframe as far as the pre-erected bilge-futtock.[358]

At this stage, the bottom would be fully planked-up and one main frame, or a few frames would have been erected. In order to obtain the shape of the rest of the frames, ribbands[359] were installed longitudinally from stern to transom (figure 52). These defined the external shape of the hull, and were used to obtain the transversal frames at any convenient location of the hull using different devices specific for the job (figure 53). Following this, planks were fixed to the pre-erected protruding frames.

It could be argued that the shape of the master frame inserted above could have been defined by-eye. However, just as likely it could be argued that shipwright must have followed some pre-established procedure to shape the master frame of the hull, in the same manner that it is argued that frame-first builders who make the frames before the planking must have been in possession of a pre-design method in order to shape those frames. Interestingly Witsen describes in words and images a geometrical construction followed to derive the shape of the master frame of the ship he uses as an example throughout his book (figure 54).[360] The original text does not mention that this method is Witsen's invention, or that it is something he wishes to propose as an innovation. On the contrary, it is shown as part of an illustration and description in the main text showing all the steps followed by Dutch shipwrights to shape and build their ships, as described in the previous paragraphs. The figure is shown in its original configuration in figure 55.

Witsen's description of a geometrical method to derive the shape of the master section would seem to confirm that Dutch shipwrights of the 17th century had indeed methods that allowed them to pre-define the shape of their hulls before construction. It must be remembered that this is the main contemporary source of information, and thus, it should carry some weight in the current narrative. However, in his interpretation Hoving considers –without any supporting

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[357] Witsen in Hoving. *Nicolaes Witsen and Shipbuilding in the Dutch Golden Age*, p. 63.

[358] Witsen in Hoving. *Nicolaes Witsen and Shipbuilding in the Dutch Golden Age*, p. 64.

[359] Long flexible battens bent around frames to assist the shipwright in defining a fair shape (see figure 52).

[360] Witsen in Hoving. *Nicolaes Witsen and Shipbuilding in the Dutch Golden Age*, p. 17-figure 1.11.

evidence– that the method of designing the shape of the master section described by Witsen is a method devised by Witsen himself to 'raise the status of the building method he advertised.'[361] This idea is echoed in other works describing 17th century Dutch shipbuilding.[362] Following this, Hoving adds:

> If Witsen's geometrical method was used by shipbuilders after all, it can only have been used to design a frame on paper. In the yard it would have been useless, for with the shell-first method, no entire frame was ever assembled to be raised on the keel; instead, section after section was fitted in the hull, following the building stages.[363]

This idea that 'with the shell-first method, no entire frame was ever assembled to be raised on the keel' was proven to be wrong by Van Holk who found archaeological evidence which shows that ships of this tradition, some at least, were built with fully pre-erected master frames.[364] Furthermore, figures drawn by Witsen (Figures 54 and 55) and Hoving himself (figure 52) show that full frames were erected as a matter of practice in Dutch ship construction. Additionally, a contemporary illustration by Swedish author Rålamb (1691) shows a ship being built in the Dutch tradition, showing again that full master frames could be erected in the early stages of building a ship (figure 56).[365] Therefore, if the existence of pre-erected master frames have been proven in the archaeological record, and there are contemporary depictions that show them being used, there is no objective reason to claim that the idea described by Witsen must be an invention to raise his status. On the contrary, Witsen's account should be taken as valid and accept that the frame arrangement shown in figures 51 and 55 could have been built by following a geometrical construction similar in concept to the one drawn by Witsen, shown here in figure 54 and 55. It is notable that, despite the description and figure by Witsen, the drawing by Rålamb and archaeological evidence described by Van Holk, Lemée, Rose and Batcharov, Dutch shipbuilding has been forced into the category of 'shell-construction' and is still interpreted as 'built by-eye' according to no pre-conceived design or ruleset.

Final evidence in favour of the proposed idea that current interpretations of Witsen's treatise have been influenced by the pre-conceived theories of shell- and skeleton-construction as

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361 Hoving. *Nicolaes Witsen and Shipbuilding in the Dutch Golden Age*, p. 18.

362 Ditta et al. Albrecht Dürer and Early Modern Merchant ships, p. 93.

363 Hoving. *Nicolaes Witsen and Shipbuilding in the Dutch Golden Age*, p. 18.

364 Van Holk. Maritime archaeology, mind-set and money, p. 46.

365 Rålamb, A. 1691. *Skeps Byggerij Eller Adelig Öfnings Tionde Tom*.

outlined by Hasslöf come from the analysis of figure 55. In Witsen's original text this figure is shown as a unit next to figure 49. These figures illustrate the text in pages 168 and 169 of Witsen's (1690) original text, where the process of shaping, framing, and planking the hull is described. If the figures and accompanying text are read as Witsen meant, as a coherent unit, it is easy to conclude that in order to make the frame shown in figure 55-V the shipwright must have followed a method which could be the method illustrated above it and expressed in the text, or any other similar method. However, when the image is split and reproduced in different parts of the book, as is the case in Hoving's edition, the coherence of the method and the link between a method of pre-design and the making of the frame is broken. It is easier for a modern reader to accept that the geometrical construction shown in figures 54 and 55-W responds to Witsen's wishes to impress when it is reproduced in the introduction of Hoving's edited text (in page 17), separated from the rest of the original figure and text (in pages 61 to 72), than when the full figure and original text are shown in their original composition.

In a final example that shows the difficulties of reconciling established theories describing the procedures to shape hulls in 17^{th} century Dutch shipyards with the detailed account given by Witsen, Hoving writes:

> We do have assurance that ships built [following Hoving's instructions based on Witsen] will have the right proportions and characteristic features [...]. The shape of the bow and stern of a hull thus reconstructed can of course be questioned for these depended directly on the talent and experience of the individual shipwrights. But their secrets have accompanied them to their graves.[366]

Therefore, in previous paragraphs, Hoving expresses that the shape of the bottom of the hull had to be ‘left to the eye of the master-[shipwright]’,[367] as the shaping process did not follow a pre-established design process.[368] While, in the quotation above, Hoving acknowledges that by following the steps described by Witsen precisely it is possible to reproduce a ship with the right characteristics, with the exception of the shape at the ends that were normally faired *‘by-eye’* by

[366] Hoving. *Nicolaes Witsen and Shipbuilding in the Dutch Golden Age*, p. 204.

[367] Hoving. *Nicolaes Witsen and Shipbuilding in the Dutch Golden Age*, p. 62.

[368] Hoving. *Nicolaes Witsen and Shipbuilding in the Dutch Golden Age*, p. 9.

the builders. This shows the difficulty of reflecting the contents of Witsen's treatise in a way that fully agrees with the currently accepted theories.[369] [370]

4.10.3 De Nederlandse Scheeps-bouw-konst. Open Gestelt (Cornelis van Yk, 1697)

Full title: *De Nederlandse Scheeps-bouw-konst*. *Open Gestelt*
Author: Cornelis van Yk
Type of publication: printed treatise
Year and place of publication: 1697, Amsterdam
Editions consulted: 1697

Language: Dutch

Van Yk's treatise will be addressed briefly. It has not been translated, therefore, this author has had limited access to its 357 pages. Still, with a few translated pages it was possible to obtain some information which complements Arnoul's and Witsen's accounts above. On the introductory pages the reader is informed that Van Yk had had twelve years' experience as a shipwright under the orders of his uncle from whom he inherited his builder's notes with information regarding past ships. From those Van Yk believed he could extract some general rules. While describing this, Van Yk referred to Witsen´s treatise above, and although he had not read it, he mentioned the opinion of his colleague who praised Wisten's work.[371]

Besides highlighting the importance of Witsen's work, Van Yk's treatise provides a very interesting section in which he discusses how to control the shape of a hull, and shows the tools used in the process. Some of those tools enrich Witsen's and Arnoul's accounts.

The treatise describes the manner of shaping the hull for different types of ship, each on their heading. The first of the design 'tools' available to the shipwright of the period is the knowledge of the deadrise angles at two specific positions on the hull for different types of ship, forward and aft of amidships. This is clearly shown in a figure and is also referred to within the text. The bevel angle at the master section is given in another section of the treatise where the making of the

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[369] Some authors have identified evidences in their archaeological research which may be used to argue in favour of methods of control of hull shape and design in Dutch shipbuilding. Most notably, see, Lemée, Rose, Batcharov and Van Holk (chapter 2.2.3.5).

[370] Lemée. *The Renaissance Shipwrecks from Christianshavn.*

[371] Van Yk. *De Nederlandse Scheeps-bouw-konst.* Opdragt (unnumbered pages). I have to thank my colleague Thomas Dhoop, and Jaap Luiting for translating the relevant passages of the book.

keel is discussed (figure 57).[372] Therefore, the idea described by Arnoul and Witsen is repeated again, in a different contemporary source. In addition to this tool, the shipwright stored the longitudinal curvature of widest point of the hull, the breadth line. This information was stored in a wooden staff, as a series of marks which indicated the height of the breadth line at specific positions of the hull (figure 58).[373]

This very brief description of Van Yk's work should reinforce the idea that, indeed, Dutch shipwrights of the period had design methods which helped them shape their bottoms, and with the aid of simple recording staff, they could also store and reproduce the perimeter of the hull along its point of maximum breadth.

4.10.4 Conclusion: early modern, bottom-based, Dutch ship design

This section should conclude by remarking that there is a clear discrepancy between the contemporary information regarding early modern, bottom-based, Dutch ship-design practices and the manner in which they are described and interpreted in the literature.

With respect to the latter, the idea that Dutch shipwrights of the period built and conceived the shape of their ships simultaneously, without a preconceived idea of design, where the eye played a leading role, seems to be heavily influenced by the theoretical framework established by Hasslöf. This framework seems to distort the interpretation of the design-paradigm of Dutch shipwrights. The contemporary sources of evidence, on the other hand, point clearly that there were design methods in place. Evidences of some of these methods had been recognised in the archaeological record. Most notably, Lemée's research and analysis of 17th century Dutch ship-wrecks helped identify some control tools that may towards methods of pre-design on Dutch ships.[374] Similarly, Kelby Rose's analysis of the remains of the 17th-century Vasa allowed him to suggest that simple geometry might have been used to design the turn of the bilges of the master section of the Vasa.[375] In addition to those, possible evidences of pre-erected control frames were identified in the bottom of the Vasa by Kroum Batcharov,[376] Further evidence of the use of pre-

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[372] Van Yk. *De Nederlandse Scheeps-bouw-konst*, p. 72.

[373] Van Yk. *De Nederlandse Scheeps-bouw-konst*, p. 72.

[374] Lemée. *The Renaissance Shipwrecks from Christianshavn,* p. 140.

[375] Rose, K. 2014. *The Naval Architecture of Vasa. A 17th-century Swedish Warship*. Phd Dissertation. Texas A and M University, p. 292.

[376] Fred Hocker, personal comment (January, 2017).

erected main frames by Dutch shipwrights was identified by André van Holk in his study of the early 17th century OE 34 wreck of Dutch construction.[377] Thus, the archaeological evidence provides compelling evidence to suggest that Dutch shipwrights of the period had concrete methods of pre-design and of control of three-dimensional hull shape. However, the significance of these methods of pre-determining shape and their role in the storage and transmission of hull shape has not been fully recognised, generally, in the current scholarship.

4.11 Closing remarks: 16th and 17th century treatises.

In the previous sections, a total of 12 treatises have been described dating from the 15th century to the end of the 17th century. From the analysis of each treatise a picture emerges which shows that all treatises –with the exception of the Dutch treatises– share a common design paradigm based on simple geometric and transformation rules. These can be described in very general terms in the following manner:

a) The shape of the hull is defined by a series of lines which are used to generate its three-dimensional shape based on a few control parameters. The shape of these lines is obtained by a series of graphical, geometric or mathematical procedures.

b) The lines used to generate the three-dimensional shape of the hull are:

   - The ship's profile shape; made up of the keel, sternpost and stem.
   - The master frame which determines the transversal shapes of the frames of the hull.
   - Several rising and narrowing lines which determine how the shape of the frames change as they near the ends and 'move' further away from amidships.

c) The method could be used directly on a full size loft floor, or by drafting a simple plan previously where the lines mentioned in point *(b)* were drawn.

d) The lines shown in the drafted plans do not inform of the surface of the hull. Instead, they show the lines defined in point *(b)*. Sutherland (chapter 5) aptly called these lines 'the

[377] Van Holk, A.F. 2014. Maritime archaeology, mind-set and money, the IFMAF and the Zuiderzee: Education, research, awareness and management, p. 46.

> Lines that shape the Body'.[378] With the exception of the plans drawn by Deane, they provide little additional information about the real shape of the surface of the hull.

The analysis of the Dutch treatises and the contemporary texts that refer to them, has highlighted the disparity between the manner in which Dutch shipwrights are understood to conceive the shape of their hulls and the original description in contemporary texts. Thus, whilst modern scholars define Dutch methods of conceiving hulls as a process in which the hull was built and shaped simultaneously, without a process of design (chapter 2), the analysis of the treatises and texts, and supporting archaeological material, has shown that, contrary to this, Dutch shipwrights designed key elements of the hulls before the construction began. This allowed them to establish the shape of the hull prior to the construction process. The repercussions of this will be discussed in chapters 6.

In the following chapter a series of treatises will be analysed which describe methods of ship design which function in the same principles as the ones analysed up to the moment. However, as it will be shown, the quality of the drafted plans will change during the 18th century.

[378] Sutherland. *Britain's Glory: or Ship-Building Unvail'd*, p. 25.

Chapter 5: 18th century treatises

This chapter will continue the analysis of early modern ship design treatises written in the 18th century in order to identify the conceptual approach to ship design and its relation with previous modes of hull design. These treatises show a more sophisticated use of graphical representation than the ones analysed in the previous chapter. However, although the visual representation of the hull and its design methods appear to be different it will be shown that in essence the conceptual approach to hull design remained unaltered. At the end of the period analysed here (early 19th century) these methods lost favour and new methods based on ‘science’ took their place, at least for the construction of larger ships within an industrial, technologically developed, environment. This analysis will lead into the discussion in chapters 6 to 8 where some of the shortcomings of the current narrative will be highlighted and a more nuanced description will be provided of the realities of the knowledge contained in these treatises and of the knowledge-space and social realities of early modern shipwrights.

5.1 The Accomplish'd Ship-Wright and Mariner (John Hardingham, 1706)

Full title: The Accomplish'd Ship-Wright and Mariner
Author: John Hardingham
Type of book: Printed
Year and place of publication: 1706, London
Edition consulted: 1706
Language: English

This treatise has remained largely ignored in the literature that describes the development of shipbuilding knowledge of the early modern period. This makes it particularly interesting. The author, John Hardingham, describes the design process followed to design cargo ships which would have been built on commercial yards, not necessarily influenced by the construction and design practices of yards involved in the design and construction of state sponsored warships. The following extract of the introduction clearly sets out that the contents are intended for the practical carpenter.

> The design of this Tract is Principally to Instruct the **Practical Carpenter** and Mariner how to Build a Ship for Burthen and Sailing; and by the Rules of Proportion to Mast her, and fix her with Sails and Guns, and Equip her fit for the Sea, by those Proportions and

> Rules mentioned therein; and last of all, by easy Rules and Methods, Safely to Navigate her.[379](Highlights JPO.)

This intended readership may not be versed on mathematical and theoretical knowledge, thus, the book was written in a practical and simple style:

> I have endeavoured in as plain a method as possible I can, to be understood by the meanest Capacity, in these parts of my Labour and Study, to level at the mark so near as at last, the Industrious, may come to hit the white.[380]

Despite Hardingham's appeal at simplicity the 406 pages of the book cover a very extensive array of topics in six chapters. Basic geometry, basic mathematics, ship design and rigging, gunnery, astronomical navigation, trigonometry, and so on.

Hardingham's signature, at the end of the section called *to the Reader* gives a final glimpse of the author and of the treatise itself (figure 59). By signing as *Your Mathematical Friend*, Hardingham is declaring his interest in a knowledge based on sound foundations. However, when Hardingham signs as a *Lover of Arts and Honest Artists*, he is highlighting the reality of the technological background of the period which was firmly rooted in the practices of traditional craftsmen.

The chapter on ship design does not deal with any theoretical knowledge and it is written in a language that is easy to understand and at the same time follows a very well ordered structure. The method followed to design and shape a hull is described in detail by Hardingham and, in common with all the other treatises seen above, it is based on the design of a master section and several rising and narrowing lines following geometrical procedures. The shape of the hull at different transversal positions is defined by the transformation of the shape of the master section guided by the pre-determined rising and narrowing lines.[381]

The material contained in Hardingham's treatise shows similarities with Bushnell's treatise (figures 60). However, Hardingham section dedicated to ship design provides more detail and, especially, more worked examples than Bushnell's.

[379] Hardingham. *The Accomplish'd Ship-Wright and Mariner*, p. 'To the reader' (unnumbered).

[380] Hardingham. *The Accomplish'd Ship-Wright and Mariner*, p. 'To the reader' (unnumbered).

[381] These include the maximum breadth line which was shaped using similar principles.

The process of design is described with an example of a ship of 65 feet on the keel.[382] Once the keel length has been decided, the rest of the dimensions of the hull, the shape of the master frame, the shape of the rising and narrowing lines and other features can be specified from proportional relations.

Hardingham's method of obtaining the shape of his master section is identical to the one proposed by Bushnell, although Hardingham describes how it could be modified to obtain ships suited to specific needs. This is shown in figure 61. The general method is shown at the top and the possible modifications for ships for burthen or for sail are shown at the bottom. The construction of the rising and narrowing lines and their proportional relations are also discussed in detail (figure 62) and they are based on arcs of circle. The design process is identical to the one described by Bushnell in 1664 and requires that the shipwright draws the shapes of the frames on a mould floor, using for this a three-part template in the same manner as described by Bushnell above.[383] To illustrate the explanation Hardingham shows the shapes of the different sections as they would appear on a drafted plan (figure 63), although in reality the process would be done directly on the loft-floor. Hardingham provides a numerical method like the one described by Bushnell to allow the builder to calculate the values of rising and narrowing of intermediate frames without having to scale up from a small drawing.

It is clear for the writer that every shipwright may have different ideas about proportions, and that the dimensions he gives are just for illustration purposes only. This can be seen clearly in expressions like: '[...] set off 8 inches or more if you please [...]',[384] or '[...] a foot more or less, as you please.'[385] The treatise is not to be followed in a prescriptive, manner.

There is no theoretical reasoning or justification behind the proportions chosen for any of the geometric constructions used to determine the shape of the ship other than experience. The knowledge accumulated from past experiences should guide the shipwright in making changes to previous designs 'thus you may proportion any ship as you intend [...] by augmenting to, or lessening these proportions, or any proportions you will begin with [...].'[386]

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[382] Hardingham. *The Accomplish'd Ship-Wright and Mariner*, p. 19.

[383] Hardingham. *The Accomplish'd Ship-Wright and Mariner*, p. 31.

[384] Hardingham. *The Accomplish'd Ship-Wright and Mariner*, p. 20.

[385] Hardingham. *The Accomplish'd Ship-Wright and Mariner*, p. 20.

[386] Hardingham. *The Accomplish'd Ship-Wright and Mariner*, p. 69.

The lack of theoretical discussion is clearly evident in the treatise, and Hardingham feels the need to explain why this is on at least two occasions. The first instance can be read in the section where he discusses the relation between the shape of the master section and characteristics of the ship such as capacity and stabilit. Hardingham treats these fundamental aspects of ship design in a superficial manner. Aware of this, he offers his excuses saying that 'was I to enlarge on this Subject it would be a Volume of it self.'[387]

A second instance where Hardingham excuses himself for not dealing with theoretical aspects of ship design can be found on the section called *Direction how to Build a Ship for Sayling* where he discusses, succinctly, what shape would be most appropriate for a ship so that it would be a good sailing ship. According to Hardingham such a shape could be obtained by studying the shape of certain fish.[388] Following this, he concluded, however, that the ships whose design were based on the aforementioned fish would only be suitable for certain services and that they would not be suitable for cargo ships. Hardingham, claims to know how to solve this problem, and that he is able to design a ship for the 'Merchant Service' –hence for carrying cargo– whilst retaining her good sailing capabilities so that the ship would be 'capable of escaping her Enemy in the Ocean'[389]. This, obviously, is a complicated matter and, therefore, Hardingham excuses himself for not explaining it in depth. He reasoned that '[s]hould I enter on this Subject, it would be a Volume of it self so only hinted it to you by the way.'[390] This is followed by a brief description on the merits of different water creatures (fish, porpoises) as models to be used in ship design.

Hardingham also proposes a method of calculating the displacement of the hull from a simple plan where a number of frames are shown. The method is simple and uses a grid superimposed

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387 Hardingham. *The Accomplish'd Ship-Wright and Mariner*, p. 23.

388 The idea that fish could be used as models in which to base the shape of ships' hulls had been suggested before by the authors of several of the treatises analysed: e.g. Bourne, M. Baker and Bushnell. However, fish swim under water, therefore their flow characteristics are very different to those of ships that sail on the surface of the water. This is what Hardingham had to say:

> The Dolphin, the Salmond [sic], or the Mackerel, bissected , and their ture *[sic]* Proportions taken with all their Ellipsis, truly Squared and Cubed, and their Area known, are the true Molds for a Sayling Ship, taking them in their length, breadths and depth, carrying their Proportions equally to the Burthen of the Shyp you design to Build (Hardingham. *The Accomplish'd Ship-Wright and Mariner*, p. 69).

389 Hardingham. *The Accomplish'd Ship-Wright and Mariner*, p. 69.

390 Hardingham. *The Accomplish'd Ship-Wright and Mariner*, p. 69.

over the plan (figure 64) which can be used to find the areas at the frame locations.[391] With these areas after a simple calculation the volume of the underwater portion of the hull can be found. However, in common with other treatises that provide methods of calculating the displacement of the ship, the method shown by Hardingham would only be suitable to check the volume under a given waterline. It could not be used to design a ship of a given weight or displacement.

To summarize, Hardingham's method is conceptually similar to all the treatises described. A master section is drawn based on an arbitrary geometrical construction. This shape is used to obtain the shape of the other frames by a controlled transformation based on longitudinal rising and narrowing lines which are also shaped based on arbitrary rules which can be justified only on past experience. Based on Hardingham's words, the tone of the text and the contents, the intended readership is clearly composed of practical shipwrights. The treatise is not to be followed strictly and shipwrights are expected to vary the dimensions and proportions given to suit their particular ideas. None of the dimensions, proportions or design methods is justified on theoretical grounds.

5.2 The Ship-builders Assistant (William Sutherland, W. 1711)

Full title: The Ship-builders Assistant: or, some Essays Towards Compleating the Art of Marine Architecture

Author: William Sutherland

Type of book: Printed

Year and place of publication: 1711, London

Edition consulted: 1711

Language: English

This is the first of four treatises written by William Sutherland (1668-1740)[392] that will be analysed in this document. They provide complementary information about ship design and construction during the period. Sutherland's *The Ship-Builders Assistant* was republished four times (1755, 1766, 1784 and 1794). However, there are some appreciable differences between the original 1711 edition and its latter reeditions. Therefore, they will be described jointly in section 5.7.

[391] Each of the squares on the grid has a known area. Therefore, by counting the number of squares the area of each of the sections can be found.

[392] For an account on Sunderland's life see: Mallagh, C. 2014. Some Aspects of the Life and Career of William Sutherland. *The Mariner's Mirror*, 100(1), pp. 17–28.

Sutherland gave a variety of motives for writing the treatise. On the one hand as a critique to previous, unnamed experts, who despite not having any experience on the matter pretended to be experts on shipbuilding. He also pretended to instruct theoreticians who may lack the practical experience on ship design. And finally, probably the real objective of Sutherland's treatise, to instruct young practitioners.[393] Clearly, one aim would be to improve the ability and status of shipwrights who, according to the following quotation, lacked the necessary recognition from other members of society:

> Besides, the proper Business of a Shipwright is counted a very vulgar Imploy, and which a Man of very indifferent Qualification may be Master of. Many have as mean an Opinion of it, as a certain Gentlemen, who told one of our former Master Builders, that he had a **Blockhead of a son uncapable to attain any other Trade unless that of a Ship-carpenter**, for which he design'd him.[394] (Highlights JPO.)

Sutherland, a shipwright himself, could not be pleased with this low perception of the abilities and importance of shipwrights in society.

In comparison with previous treatises that were, mainly, descriptions of the method to shape and build a hull, Sutherland's *The Ship-Builders Assistant* is a more ambitious work based on the extensive experience of the author and his predecessors in ship construction.[395] As the title implies the treatise was written to assist shipwrights in their professional development. Thus, it covers such diverse aspects as economy, structural arrangement and strength, hull design, rigging and aesthetics.[396]

The treatise is ambitious,[397] but acknowledges the great lacunae in the technological knowledge of the period. Thus, on the early discussions about hydrostatics Sutherland describes a future when the ‘Art will be made perfect, that there will be no Occasion for chargeable or fruitless Projects. [In this ideal future] Ships will not by bad Faculties miscarry, since it may be absolutely

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[393] Sutherland, W. 1711. *The Ship-builders Assistant*, pp. 23, 79.

[394] Sutherland, W. 1711. *The Ship-builders Assistant*, p. 38.

[395] Sutherland, W. 1711. *The Ship-builders Assistant*. Preface (unnumbered).

[396] Sutherland, W. 1711. *The Ship-builders Assistant*. Preface (unnumbered).

[397] This is necessarily a subjective opinion of the present author. However, by reading this and the rest of Sutherland’s treatises, one gets the impression that a reader with previous shipbuilding knowledge could greatly benefit from reading them in order to set up their own shipbuilding enterprise.

known whether they are of Service or not [at the design stage].'[398] This ideal future is a stark contrast to the realities of shipbuilding of the period that was, according to Sutherland, 'grounded in no manner of principle.'[399]

The treatise is highly conceptual. The author describes – in well-argued qualitative terms – the merits of different proportions of the hulls and their effect on general performance of the ship.[400] However, knowing the limits of his knowledge Sutherland does not pretend to give any numerical values to the proportions.[401] Sutherland continues by enumerating the problems one may encounter if the ship were to be made disproportionate. However, what constitutes a disproportionate ship is left for the reader to decide.

The process of hull design is described in its own chapter (pages 78 to 84). In tune with the rest of the work it is a highly conceptual text which describes the process but does not give any accurate or guiding proportions or measurements. The design process is based on a drafted plan, preferably at a scale of 1 to 48 (1/4 of an inch equals a foot), in which the general shape of the ship is drafted. From the scale plan a full sized plot of the body plan can be drafted on a mould floor which will be used to make the frames of the ship.[402] In common with all the design processes described up to now, the shape of the frames of the ship are obtained from the shape of the master section which is modified according to several, longitudinal, rising and narrowing lines (figure 65). [403] Sutherland does not mention any particular method of shaping the rising and narrowing lines.

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398 Sutherland, W. 1711. *The Ship-builders Assistant*, p. 4.

399 Sutherland, W. 1711. *The Ship-builders Assistant*, p. 32.

400 Sutherland, W. 1711. *The Ship-builders Assistant*, p. 34.

401 For example:

> 'Hence a ship ought not to be too long for her breadth, or too short for her depth; but her shape and proportion adapted to the use for which the vessel is designed, which also relates to disposition.' (Sutherland. *The Ship-builders Assistant*, p. 34).

In Sutherland's text the term *disposition* describes the harmonious relationship between the physical parts of the hull.

402 Sutherland, W. 1711. *The Ship-builders Assistant*, p. 77.

403 Sutherland, W. 1711. *The Ship-builders Assistant*, p. 8. In common with the other treatises, four longitudinal lines control the shaping of the hull. They are two rising lines (floor and maximum breadth) and two narrowing lines (floor and maximum breadth).

One of the most interesting points about Sutherland's description of the design process is when he describes how to shape the midship frame, which must be remembered is the basis of all the other frames in the hull and, therefore has a strong influence on the ultimate characteristics of the hull. On that subject, Sutherland proposes a master section that is described by a flat floor and a long, single, arc that defines the whole of the underwater part of the hull. This is a contrast to other more complex shapes described in previous treatises, and Sutherland gives a reason for it. He says that such a simple shape:

> [...] will describe a midship bend more agreeable, and less perplexing, than if you was to chalk out 100 segments of circles. This said indeed that the [catenary] line will describe a shape of greater gravity, but I shall leave such nice demonstration at present, and proceed to show an intelligible method to suit forward young beginners.[404]

Clearly, Sutherland sacrifices the complication of describing compound curves (which he considers perplexing) or lines more difficult to represent, but not necessarily inadequate, (like a catenary curve) in search of a more simple conceptual explanation which will suit the young beginner. Based on the shape of the master frame shown in his treatise, which is similar to the Ancient method described by Fournier (above), Richard Barker considered that Sutherland's treatise may be using outdated, or at least not contemporary methods.[405] However, it can be shown that during the second half of the 18th century similar shapes were used in treatises that are described as modern (e.g. figure 33). Thus the idea of a roughly circular shape being old fashioned should be questioned.

It can be said that, in contrast with previous treatises analysed, Sutherland was more interested in transmitting the conceptual aspects of ship building which are defined by ideas rather than concrete quantities and numerical relations. On the other hand, his design method was conceptually equal to previous treatises as it was based on the transformation of a master section, controlled by longitudinal rising and narrowing lines.

One interesting feature of *The Ship-builders Assistant* is that it shows two very different types of drafted plan (figures 65 and 66). The plan in figure 65 describes the conceptual approach to the definition of hull shape showing the control lines thus, do not represent real shapes. They are shown for illustration only as a means of conveying an idea. The plan on figure 66, on the other hand, shows a realistic scale drawing of the body plan of a ship, drawn in great detail, showing the

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404 Sutherland, W. 1711. *The Ship-builders Assistant*, p. 79.

405 Barker. Whole-moulding: a preliminary study of early English and other sources, p. 33.

geometric construction followed to define it. It is interesting to note that Sutherland felt no need to draw a detailed lines plan of the ship where the plan view and profile view are shown in detail. Such a drawing was not necessary. With Sutherland's method the body plan would have been drafted, directly, on the mould floor from the shape of the master frame and its transformation from rising and narrowing values for which Sutherland provides no theoretical justification.[406]

5.3 Britain's Glory: or Ship-Building Unvail'd (William Sutherland, 1717)

Full title: Britain's Glory or Ship-Building Unvaild. Being a General Director for Building and Compleating the Said Machines

Author: William Sutherland

Type of book: Printed

Year and place of publication: 1717, London

Edition consulted: 1717

Language: English

In this treatise Sutherland describes a variety of subjects which are complementary to the contents of *The Ship-builders Assistant.* The treatise starts with a short description of the state of the Royal Navy at the time. Following this, Sutherland discusses, in the preface, his reasons for writing the book. Among those reasons, Sutherland considers that theory and practice must be developed in order to avoid some 'miscarriages that have happened for lack of standards in [ship design]'[407]. One of the causes of those miscarriages, or ships with unsatisfactory behaviour, is that 'it's very rare to see an able shipwright thoroughly skilled in learning'[408].

This treatise describes the proportions, rig, and size of the structure of different types of ships, all based on 'practice, without the help of any theory'. This, in itself, is not a bad thing for Sutherland who did not have a very good opinion of the state of the theoretical knowledge of the period.[409] However, he found that those who engaged in shipbuilding without the proper practical knowledge, or as he says, '[people] who engage to build a ship with little assistance of [the adze]'[410] should be criticised. As an example he cites 'The Royal Catherine [which] was contrived

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406 Sutherland, W. 1711. *The Ship-builders Assistant*, p. 80.

407 Sutherland. *Britain's Glory: or Ship-Building Unvail'd*, p. XXV.

408 Sutherland. *Britain's Glory: or Ship-Building Unvail'd*, p. XXV.

409 Sutherland. *Britain's Glory: or Ship-Building Unvail'd*, p. 2.

410 Sutherland. *Britain's Glory: or Ship-Building Unvail'd*, p. XXV. The adze is a shipwright's tool which, in the right hands it is extremely precise. However, it requires skill to use correctly. It is used to remove large

by [the highest scientific institution of the country,] the Royal Society, and yet [it had to be] girdled' [411] as a results of limited or insufficient stability. [412]

In addition to the sections on rigging and hull design and construction, in the final chapters of the treatise, the author describes how to write a building contract, for which he provides a 22 page long specification, with blank spaces which should be filled to suit the particular case for which the contract would be used.[413]

This section on how to write a specification is undoubtedly of great importance for practical shipwrights who may not have had a formal training or may be starting and thus may not have a previous contract and specification to use as a reference. This aspect only would have made Sutherland's treatise of great interest for any shipwright building a ship for a client requiring a formalised commercial relation. However, in order for the book to be of greater use still, Sutherland dedicates 18 pages to describe practical 'cases which may happen in ship-building and refitting and hiring of ships'[414] For example, Sutherland advises on what to do 'in case a person contracts for building a new ship, [...] and after the [specifications] are drawn, [...] there should happen to be several materials highly necessary to be put in the said ship, left out, and not mentioned in the [specification].'[415] This is a real concern known to anyone who has had any experience in industry, where specifications often happen to be incomplete. Who pays for these materials? Sutherland responds, from his experience, to this and other matters covered in the 18 pages of this section, which must have been highly beneficial for shipwrights in charge of smaller, private yards.

Finally the treatise finishes by discussing how to transform raw timber into finished ship parts, with consideration to economy and structural strength.

This treatise does not discuss in any detail the procedures for designing the hulls. From the contents and how they are described it is clear that the intended reader of the treatise must know

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chunks of timber or, if needed, the finest of shavings. Thus, those engaged in building ships with little assistance of the adze –those with little experience like the experts of the Royal Society– should be criticised.

411 Girdling: Girdling a ship consisted in adding a thick layer of planking around its waterplane, to increase beam and, thus, solve problems of stability.

412 Sutherland. *Britain's Glory: or Ship-Building Unvail'd*, p.XXVI.

413 Sutherland. *Britain's Glory: or Ship-Building Unvail'd*, p. 86.

414 Sutherland. *Britain's Glory: or Ship-Building Unvail'd*, p. 98.

415 Sutherland. *Britain's Glory: or Ship-Building Unvail'd*, p. 98.

how to design a hull, and if this is not the case, Sutherland refers the reader to his other publication on page xxvi of the preface. However, although it does not discuss ship design procedures in detail, it shows in graphical form the information required to shape a ship's hull (figure 67). Notably, only three transversal sections and rising and narrowing lines are used to show each design. The author does not draw a full body plan, as it would have no use for a shipwright. In practice, the shipwright would draw the full-sized body plan in the mould loft by the transformation of the master section using values of rising and narrowing from the plans. Sutherland refers to these lines as 'the Lines that shape the Body' of the ship[416]. The treatise includes similar drawings for six ships of different sizes for which the scantlings and rigging details are also supplied.

If this figure is compared with figure 23 taken from *Fragments of Ancient English Shipwrightry*, it becomes apparent that despite the more than a century that sets them apart, the information required to shape the hulls, as indicated by the plans, has not changed substantially. In fact, all the treatises analysed show figures very similar to this one (see figures 21-22; 27; 35-36; 43-44; 61-62; 65). A master frame, and rising and narrowing lines for the floor and maximum breadth and sometimes the two tail-frames are sufficient to form the shape of the body of the hull.

5.4 The Prices of the Labour (William Sutherland, 1717)

Full title: The Prices of the Labour in Ship-Building Adjusted: or, the Mystery of Ship-Building Unveiled. Being, A Brief Explanation of the Value of the Labouring part in Ship-building; from a ship of the biggest Magnitude to a small Boat. First, Shewing the Working the whole Ship, according to the Length, Breadth, Depth, Girt: and then by Sub-divisions shews the Value of every particular Part.

Author: William Sutherland

Type of book: printed book

Year and place of publication: 1717, London

Edition consulted: 1717

Language: English

Sutherland's *The Prices of the Labour* was written for the benefit of 'able workmen', who Sutherland specifies are shipwrights who had served a seven year apprenticeship.[417] It is a complement to the previous treatises where he dealt with the design and construction of ships. In *The Prices of the Labour* Sunderland details the economic aspects of ship construction. The book

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416 Sutherland. *Britain's Glory: or Ship-Building Unvail'd*, p. 25.

417 Sutherland. *The Prices of the Labour*. To the Able and Experienced Shipwrights (unnumbered).

analyses the costing of a ship starting from the timbers of the main structure and how different approaches to building the ship can affect its cost. It also describes the economic relation with other trades involved in the shipbuilding process. Thus, the book describes how to deal with sawyers, iron-smiths, caulkers, painters, mast makers and riggers, sailmakers, glaziers and rope makers. Each trade is treated separately and Sutherland explains in very extensive detail, with numerous examples and tables, how to calculate the costs involved and the manner of writing contracts for each of the particular trades, according to their custom.

The Prices of the Labour is not a treatise on ship-design in the strict sense. But, as a complement to Sutherland's previous treatises, it is a good example of the type of written work that was being produced aimed at shipwrights with good technical abilities but not enough experience at leading a ship-building project. The knowledge contained in this treatise would not make every shipwright into a shipbuilding tycoon. However, in the right hands, it would open new opportunities for those who had sufficient technical skills and entrepreneurial drive.

5.5 Action and Reaction equal on a Fluid (William Sutherland, c.1719-24)[418]

Full title: Action and Reaction equal on a Fluid

Author: William Sutherland

Type of book: Unpublished manuscript (Caird SPB/50/1, and SPB/50/2). Archive Collection of the Caird Library, National Maritime Museum, Greenwich

Year: c.1719-24

Edition consulted: transcription of manuscript: http://crismallagh.org/SuthMS/SutherlandMS.html (last accessed 10 September 2017)

Language: English

In the three treatises analysed above Sutherland describes his ideas about shipbuilding and ship-design without the support of any theoretical framework. However, it would appear that these treatises received some criticism which prompted Sutherland to write a fully theoretical manuscript entitled *Action and Reaction equal on a Fluid*.[419]

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[418] The full title of the manuscript is: Action and Reaction equal in a Fluid or a Specimen toward removing some Untoward Approved of Maxims in Building and Equiping Ships. c.1719-24. Caird SPB/50/1, and SPB/50/2.

[419] This is how Sutherland refers to the criticisms which prompted him to write the manuscript: 'And because several persons have intimated that my former Volumes have not enough in them to inform a man to build a Ship, I shall now Follow the examples of Elderly divines leaving perplexed discourses about predestination, and transubstantiation, and so preach Faith, and good works, Neighbourly Love

In this manuscript Sutherland describes his personal theories about ship resistance and ship stability and the general knowledge required to design a ship. Those theories are mostly grounded on Sutherland's personal observations and ideas previously published by other authors.[420] Although the text is full of many theoretical and 'scientific' references, it fails to produce any useful outcome.[421] However, Sutherland's manuscript was written in a very opinionated style, which presents an opportunity to look into the realities of shipbuilding as experienced by practical ship builders during the period, and how design knowledge was being shared among them.

Sutherland started by denouncing the lack of communication between different ship builders with regards to their theories and procedures. This prevented debate and, therefore, did not facilitate the development of the art of shipbuilding unlike other arts.[422] Following this Sutherland justified the use of geometry on ship building which, as the analysis of the previous treatises has shown, is not based on any scientific theory. Sutherland wrote:

> In [designing the shape of the ship], **Geometry** [...] will be absolutely Necessary **by which means the Artist will be able to Inform himself what regular figure he hath built, that so finding a defect he may the easier know how to make an Advantageous alteration**.[423] (Highlights JPO.)

This statement shows clearly that, for Sutherland, the objective of using geometry in this period was just to have a means of controlling and, most crucially, knowing the shape being produced. By controlling shape, through a relatively small number of easy-to-remember parameters, hull-shape and ship's performance could be related –albeit only in qualitative terms– by the ship builder. Therefore if the performance was satisfactory, or on the contrary was not as expected, shipwrights had a means of knowing what shape they had built and, hence, had a way of trying to

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and charity, or doing as they would be done unto But I proceed to shew what I have considered in the following work' (Sutherland. *Action and Reaction equal in a Fluid*. f. 15).

[420] He mentions among others, John Wallis (mathematician), Newton and Bernoulli (scientists). (Sutherland. *Action and Reaction equal in a Fluid*. f. 8V).

[421] In this author's opinion the treatise does not produce any information which could be used by this author as a shipwright. In addition, reading this treatise as a naval architect, none of the seemingly technical information shown in it would be practical in the process of designing a ship.

[422] This is what Sutherland wrote:

> '[...] if we were as generous as the Ancient Astronomers and publish our Opinions, was wee positively sure to be Confronted by the Next Author [...].' (Sutherland. *Action and Reaction equal in a Fluid*. f. 6v).

[423] Sutherland. *Action and Reaction equal in a Fluid*. f. 7.

learn from the experience and apply the changes that they thought appropriate for the next design.

Unfortunately for the ship builders of the period they could not use scientific knowledge to relate shape and performance and, as a result, the opinions of shipwrights were often contradicted by the real performance of ships, as Sutherland wrote:

> And altho' divers trials has been made by our own Master-builders, as well as in other nations to build ships so extreamly clean, **that only to look on before they were launched and Equiped for use, one would believe they would run swift without assistance of impulsion, yet it has been otherwise found in diverse trials**.[424]

The manuscript continues by explaining that the opposite case –when ships that looked as if they would perform badly happened to be very good ships– was also often true. This highlights the difficulty of relating shape and performance based on a visual judgement alone, unaided but what would be considered modern scientific understanding. As a result of the difficulties of relating visual appreciation of shape with ship performance, in Sutherland's opinion, the debate among expert ship-builders was 'fit for little [more] than table talk'.[425] In order to improve their understanding so that discussions could raise above the category of simple table talk, Sutherland engaged in theoretical disquisitions that, unfortunately, would be of little use for ship builders or scientists of the period.[426]

Sutherland dedicated a rather lengthy part of his manuscript to describe the most important master-builders of his period and their successes and failures. At the end of this section Sutherland provided a paragraph that condenses the real approach to ship design and construction during this period. This interesting paragraph will be analysed below in three parts that have been numbered [1], [2] and [3]:

> The way and means to unite every good Faculty in a Ship, is to embrace every good precedent, Since it is possible to build one good Ship by the pattern of another, if that good Ship can be mended in the Judgment of Knowing men Such alterations may be made [1]. But if the new projects are Started they ought to be well examined before they are followed [2]. But I shall proceed, and Finish this observation with Shewing

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424 Sutherland. *Action and Reaction equal in a Fluid*. f 7.v.

425 Sutherland. *Action and Reaction equal in a Fluid*. f.7.v.

426 See footnote 421 above.

> proper lines to Form a Ship's body, which may be made Universal, Especially for Such Ships as are designed for swiftness [3].[427]

According to the first part of the paragraph [1], the design of a new ship ought to be based – whenever possible– on a previous design of known good performance. This manner of approaching a new design is still very much favoured by modern-day naval architects who use the term 'base ship' or 'parent ship' for the ship in which the new design will be based.[428] Obviously the design brief of new ship might not be identical to the base ship and, hence, Sutherland recommends that the modifications are based on the 'Judgment of Knowing men'. Unfortunately, such judgement could not be backed by scientific principles or modern analytical tools.[429]

In the case of a totally new design unrelated to past experience [2], the designer cannot base the design decisions on any previously successful ship and hence it is required that the designer proceeds with caution. Again, ship designers of the period would have no way of supporting their decision making process. Consequently the success of novel designs would be uncertain.

Finally on the third part of the paragraph Sutherland shows a relevant characteristic of pre mid-19th century ship design. The text promises to show the 'proper lines to Form a Ship's body' that could be made 'universal' for ships designed for speed. Again, the lack of scientific understanding of the period leads Sutherland to conclude that a shape can be made general for a certain application. This manner of designing ships which is based on traditional methods of pre-determined shape control was swiftly abandoned when scientific principles and empirical principles –supported by the general scientific principles and analytical tools– became the basis of ship design in the mid-19th century.[430]

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[427] Sutherland. *Action and Reaction equal in a Fluid*, p. 50.v.

[428] Saunders. *Hydrodynamics in Ship Design. Volume II*, p. 457.

[429] For example: Ferreiro, L.D. 2009. *The Aristotelian heritage in early naval architecture, from the Venetian Arsenal to the French navy, 1500-1700*. Max Planck Institute for the History of Science. Pre Print 371, p. 45.

[430] This is how an early 19th century commentator asked for the adoption of design principles based on mathematical analysis:

> The object of the naval architect, therefore, should be to accumulate and make a methodical arrangement of the experience of ages, so that the knowledge of many may be attainable by one ; and then, by means of mathematics and the method of induction, to establish true principles to proceed upon. That would be the way to find a cause for every effect, and a reason for every inference; instead of making use of that " guess-work knowledge which is the creature of habit, not of reason—ever liable to the errors of custom and the prejudice of ignorance." ([Annon], 1833. *An*

The main ideas that can be concluded from the brief analysis of Sutherland's manuscript –*Action and Reaction equal on a Fluid*– is that, once again it, becomes clear that although there was a drive to try to understand the laws of nature and how they could be applied to ship design this endeavour produced little results that could be applied to practical cases of ship design. Also, it can be concluded that practical ship builders like Sutherland also tried to investigate, learn, and apply such knowledge;[431] that this drive for the theoretical aspects of knowledge was not only an objective for learned individuals.

5.6 Oservaziones que se Pratican para la Delineacion de Navios (Gerónimo de Aizpurua, c. 1732)

Full title: Oservaziones que se Pratican para la Delineacion de Navios en las Costas de Cantabria, son las siguientes.

Author: Gerónimo de Aizpurua

Type of publication: Manuscript

Year and place of publication: 1732-33

Edition consulted: Edited facscimile: by Lourdes Odriozola Oyarbide and Sagrario Arrizabalaga Marín, 2004.

Language: Spanish

Geronimo de Aizpurua[432] wrote this treatise which describes in a very well organised way the procedure followed to build an 80-gun warship in Spain. The structure of the text follows the process of construction of the ship and is divided in the following sections entitled:[433]

- **Proportions and rules** to build an 80 gun warship
- **Proportions** of the materials used for the construction of the ship

Apology for Ship-builders: Showing that it is not necessary that the country should look to the navy for naval architects. London, p. 47).

431 Mallagh. Some Aspects of the Life and Career of William Sutherland., p. 18.

432 Geronimo de Aizpurua was born in a family with a long tradition in shipbuilding. He had a 31 year long career working in state-run shipyards building warships for the Spanish navy employed as a highly qualified shipwright playing a series of supervisory and management roles until he retired aged 53. After retirement from shipbuilding Aizpurua occupied a series of public office posts in his hometown (Aizpurua, J. 1732-33. Oservaziones que se Pratican para la Delineacion de Navios en las Costas de Cantabria. L, Odriozola Oyarbide and S. Arrizabalaga Marín (eds) 2004. Fundación Oceanográfica de Guipúzcoa. p 38).

433 The long titles have been simplified.

- **Rules** for the method of fixing the structural elements of the ship and the materials to be used
- Specification of the number of structural items used to build the ship
- **Proportions and general rules** used to make the rigging elements of any type of ship
- **[Proportions and rules]** for any auxiliary rigging elements in the ship
- **Rules** for rigging any type of ship
- Tonnage rule as approved by the King in 1613
- Index of the contents by terms in alphabetical order

The highlighted words show that the author considers that every element of the ship must be designed according to a proportion or a rule.

The process of designing a ship is described in the first section of the treatise with a ship of 92 $\frac{2}{3}$ *codos* (c.53m)[434] as an example. The ship's dimensions which define its shape are given as a proportion to its length. Central among these are the beam of the hull, its depth, measured amidships, and the breadth of the floor at the master frame.

The treatise does not specify how the master section should be shaped. However, it does indicate that the central part of the hull amidships should be shaped with sections which are equal to the master section. The rest of the hull should be shaped by a process of rising and narrowing which is defined by certain values given as a proportion of the breadth of the stern, which in turn was defined in proportion to the length of the ship. It is said that the rising and narrowing should be applied to the ends of the floors gently.[435] However, the author does not indicate any curve, or geometric construction used to control the values of rising and narrowing. Similarly the treatise describes the manner in which the maximum breadth line must be determined in a process that would require drawing a simple plan view of this line.[436]

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[434] One *codo* was the equivalent of 0.575m (Loewen, B. 2001. The structures of Atlantic shipbuilding in the 16th century. An archaeological perspective. In *Proceedings of the International Symposium on Archaeology of Medieval and Modern Ships of Iberian-Atlantic Tradition*, p. 243).

[435] Aizpurua. *Oservaziones que se Pratican para la Delineacion de Navios, p.* 4r.

[436] Aizpurua. *Oservaziones que se Pratican para la Delineacion de Navios*, pp. 5v-6r.

The method is easy to follow and, although the proportions given do not appear to be very flexible, there are instances where the author shows that, in common with all the other treatises analysed, the proportions and rules given should not be taken as fixed values. The reader would be expected to alter them to suit particular needs. For example when describing the way of drawing the maximum breadth line the author says:

> [Then], a compass will be opened to two thirds of the breadth of the ship (or more if [the reader] fancies, five eights [...]).(translated from the original JPO)[437]

Someone with sufficient knowledge could easily use the treatise as a guide book which would lead to a hull shape. All that prospective designers would require was a previous knowledge of the shape of the master section which they required and some choice of method to distribute the values of rising and narrowing in a gradual manner. The rest is fully specified in the treatise in a step-by-step manner.

The rest of the treatise deals with scantlings of structural elements and rigging. Interestingly, all of these are given, again, as proportions to some element of the hull which ultimately is related proportionally to the length of the hull.[438] For the author definite dimensions were not the goal. In his view a harmonious relationship of all the elements of the hull would result in a ship which would show a harmonious relation between its size, weight, weight distribution and ultimately strength.[439]

Aizpurua does not pretend to give a full detailed account of the design process. The reader will have to provide previous knowledge if they are to design successful ships. This is clearly written by the author when discussing the all-important positioning of the waterline of the ship with respect to the maximum breadth of the hull. The author warns that the waterline should never be above the maximum breadth of the hull. If placed correctly, the ship should behave in a satisfactory manner in waves and should have sufficient stability to carry its sails in safety. Crucially, the lower gunports would be useable in any kind of weather.[440] However, the treatise does not explain how to guarantee that the underwater volume of the hull provides sufficient buoyancy to support the

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[437] Aizpurua. *Oservaziones que se Pratican para la Delineacion de Navios*, p. 6r.

[438] Thus, for example, the siding (thickness) of the frames should be three times the thickness of the planking. The planking thickness had been defined, in turn, as one quarter of the breadth of the keel which was related, by proportion, to its length and hence to that of the ship. Aizpurua. *Oservaziones que se Pratican para la Delineacion de Navios*, p. 12v.

[439] Aizpurua. *Oservaziones que se Pratican para la Delineacion de Navios*, p. 3r.

[440] Aizpurua. *Oservaziones que se Pratican para la Delineacion de Navios*, p. 3r.

weight of the ship. This problem is left to the judgement of the shipwright who must 'apply all his knowledge so that the ship, being level in the water' must float with the waterline always below the maximum breadth line.[441]

It is not possible to identify the intended readership from the text as the author never addresses the reader directly and the treatise lacks an introduction which could help define the intended readership or the reasons for writing the book. However, based on the title which could be translated as 'Procedures used to draw ships in the coasts of Cantabria'[442] it could be assumed that the treatise is a record of the design practices of the northern region of Spain in that period, in the shipyards where the author, Aizpurua, served his time as master shipwright.

5.7 The Ship Builder's Assistant or Marine Architecture (William Sutherland, 1755)

Full title: The Ship Builder's Assistant or Marine Architecture
Author: William Sutherland
Type of book: Printed
Year and place of publication: 1755, 1766, 1784, 1794
Editions consulted: 1755, 1766, 1784, 1794
Language: English

In 1755 Sutherland's *The Ship Builders Assistant* (written in 1711) was re-edited with numerous changes to its contents and internal arrangement. The 1755 edition includes several additions, being chapter V of particular interest. However, it must be realised that Sutherland died in 1740, thus, it is not clear if the changes in this edition were made by Sutherland himself or by the unnamed editor.[443] From the point of view of this research, the most interesting changes in the 1755 edition are to chapter V which is called *Of Delineating the Forms or Models of the Timbers of Ships*. The 1755 edition was later reedited in 1766 with some additional changes to chapter V in which the text discusses the manner of designing the shape of a hull on paper. The reeditions in 1784 and 1794 did not see further changes.

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[441] Aizpurua, J. 1732-33. *Oservaziones que se Pratican para la Delineacion de Navios*, p. 3r.

[442] The Cantabrian Sea (Mar Cantábrico in Spanish) extends to what an English speaker would call South-West Bay of Biscay. It is not limited to the present-day region called Cantabria.

[443] Independently of the identity author of this particular edition, the fact that the treatise was republished at this date and reedited several times until its final edition in 1794 shows that Sutherlands original text was widely circulated and worthy of consecutive reeditions.

The design method described in the new version of Sutherland's treatise does not change substantially from the original version. The quality and type of graphical representation, on the other hand, experience important changes. The conceptual explanation of the process is explained using the same figures and illustrations as in the original treatise which are sufficient to describe in graphical form the manner of conceiving the shape of the hull, and the main lines that take part on the process (figure 68 (c)). However, in the 1766, 1784 and 1794 editions of the present treatise, for the first time the author discusses the method of drawing sections through the surface of the ship, such as waterlines. These are lines which do not take part in the actual process of shaping the hull. They are a consequence of it. By showing them in the plan Sutherland is showing in graphical form the shape of the surface of the hull in a manner that previous editions of his treatises had not (figures 68 (a) and (b)). Thus, in this period of time, the purpose of the plan shifted from being a tool to show the lines that shape the body of the hull, to being a tool that shows the shape of the surface of the hull. Albeit, still, the manner of obtaining the three-dimensional shape of the hull remained constant.

This treatise gives a valuable testimony of the validity of Sutherland's text which had been written in the early 18th century which by the end of the 18th century it was still valid for a reedition. However, the treatise gives another important piece of information about the use and re-use of information among authors for which often there was no indication in the text. Large parts of the explanation regarding the shaping of the hull following the whole-moulding method are identical to Mungo Murray's treatise described below in 5.9:

- Sutherland (1766, 1784, 1794): By this Way of forming the Frame, it is plain the Centers and Radii of the Sweeps are arbitrary.[444]

- Mungo Murray (1764): By this way of forming the frame, it is plain the centers and radii of the sweeps are arbitrary.[445]

Similarly, whole paragraphs of the text are identical to texts in Mungo Murray's treatise.

The main interest of this version of the 1711 text is as testimony of the changes in representation technique during this period. The design techniques, as shown by the conceptual recipes shown in

444 Sutherland, W. 1766. *The Ship Builder's Assistant or Marine Architecture*, p. 67; Sutherland, W. 1784. *The Ship Builder's Assistant or Marine Architecture*, p. 62; Sutherland, W. 1794. *The Ship Builder's Assistant or Marine Architecture*, p. 57.

445 Murray, M. 1764. *A Treatise on Ship-Building and Navigation*, p. 135.

both versions saw little change, however the manner of representing the ship on paper, as a finished shape, transformed the quality and level of the information provided to the reader.

5.8 Élémens de l'Architecture Navale (Duhamel du Monceau, 1758)

> ***Full title:*** Élémens de l'Architecture Navale ou Traité Pratique de la Construction des Vaisseaux
>
> ***Author:*** Henri-Louis Duhamel du Monceau
>
> ***Type of book:*** Printed
>
> ***Year and place of publication:*** 1758 (Second edition), Paris
>
> ***Editions consulted:*** 1758
>
> ***Language:*** French

This treatise of 484 pages was written by Duhamel du Monceau who in the title page is described as a member of the Royal Academy of Sciences of France, of the Royal Society of London, an Honorary Member of the Society of Edinburgh, member of the Naval Academy of France and the Inspector General of the French Navy. Besides these credentials, in the preface the reader is also informed that the author had practical experience in the construction of ships. It is during this period that Duhamel du Monceau put to paper his knowledge in the form of personal notebooks in order to preserve the knowledge and to organise his ideas.[446] Based on those personal notebooks which were never intended for publication, after re-arranging them and correcting them Duhamel du Monceau wrote *Elémens de l'Architecture Navale*.

The purpose of the treatise was stated in the preface:

> [The treatise is for] the education of young people. A [treatise] of this type was entirely necessary [...]. The treatise I am presenting is thus purely practical, and elementary [...].[447] (Translated from the original by JPO.)

The next paragraphs of the preface define, in an almost apologetic style, the real value of the knowledge contained in the treatise and provides an informed and well-argued contemporary opinion of the limitations of the knowledge of the period.

> I shall not engage in trying to find out if it is possible to give ships a different shape, from the one they currently have, a shape which would allow them to satisfy their

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[446] Duhamel du Monceau. 1758. *Élémens de l'Arrchitecture Navale ou Traité Pratique de la Construction des Vaisseaux*. Paris, p. v.

[447] Duhamel du Monceau. *Élémens de l'Arrchitecture Navale*, p. vi.

> requirements better. I have adopted the shapes in use, and all that I endeavour is to take those shapes, which I presume to be near perfect, as best as I can. I shall not try to show new methods to make better ships than those that are in use. I only desire to show to those that study ship construction[448] with my treatise, a manner of building ships that do not have any fundamental defects, and which can be equal to ships which have become reputable.[449] (Translated from the original by JPO.)

It is clear, then, that the treatise is aimed at transmitting existing knowledge to readers who desire to learn the practical knowledge required to design a ship. Most relevant is the statement made by the author that he will not attempt to improve upon existing knowledge, as the limitations of the general knowledge prevents him from trying. It is noteworthy that the goal is to teach the reader 'a manner of building ships that do not have any fundamental defects.' [450]

The author is aware of the limitations of the knowledge of the period and as a results his style is not prescriptive. Duhamel du Monceau apologises to those that:

> [...] may blame [him] for the indecision that [is abundant] in his work. Instead of giving various dimensions that have been used in different times by different builders, would it not be more proper to refer only to those that are preferable above the others? Instead of engaging on a discussion of the reasons that would justify following one or the other practices which [the author] has described without [indicating which one he favours]; would it not be better [if he decided] these questions?[451] (Translated from the original by JPO).

He answers to these questions by saying that he has no way of knowing which opinion is the best and, consequently, a prescriptive tone, would not be appropriate as it would impose false principles onto the young men for whom this treatise is directed.[452] The structure of the treatise is true to this spirit and many of the sections were a certain practice or example are described are followed by a section called 'Remarque' –remark– where often the author provides counter-arguments that contradict the ideas expressed in the section, or gives examples of

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448 Although the author refers to construction, in common with the treatises analysed, the treatise is mainly about design aspects of shipbuilding.

449 Duhamel du Monceau. *Élémens de l'Arrchitecture Navale*, p. vii.

450 Duhamel du Monceau. *Élémens de l'Arrchitecture Navale*, p. vii.

451 Duhamel du Monceau. *Élémens de l'Arrchitecture Navale*, p. vii.

452 Duhamel du Monceau. *Élémens de l'Arrchitecture Navale*, p. vii.

alternative practices followed by other ship builders with results that are, in practice, just as valid (figure 69).

The treatise is divided in ten chapters. The first chapter describes in detail the structural arrangements and scantlings of all the structural elements used in the construction of a ship. In chapters 2 to 6 ship design methods are described. And, in chapters 7 to 10 the author discusses some aspects of ship construction, resistance and stability.

The process of ship design is, again, based on proportional relationships among the principal dimensions of the hull, chapter 2 being fully dedicated to this matter. Duhamel du Monceau wrote that there was no consensus among practising shipwrights on the best proportions. Following on his words in the preface the author does not express any preference for any of the choices and gives examples of the different criteria followed by individual shipwrights.[453] After the main proportions were chosen, shipwrights had to decide on the shape of the master frame. On that important subject Duhamel du Monceau wrote:

> Each builder differs in the shape he gives [to the master frame]. [...] Each builder adopts the [method of drafting the master frame] that he considers superior to the others. [...] We shall describe several methods so that young ship builders can choose [the method] that they consider to be [most appropriate]. These methods differ only in the manner in which the arcs or the contours of the [frame] are drafted.[454] (Translated by JPO.)

The treatise describes four different methods[455] of shaping the master frame, all based on geometric constructions (figure 69). Each of the methods is described in its individual section.[456] These geometric constructions are different from the ones that have been described up to now. However, they are based on rules that must be followed in a mechanical manner and produce a certain shape. By altering the proportional relation of the parameters within the geometric rules

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[453] Duhamel du Monceau. *Élémens de l'Arrchitecture Navale*, p. 82.

[454] Duhamel du Monceau. *Élémens de l'Arrchitecture Navale*, p. 206.

[455] On page 212 the author tells the reader that he could have added numerous other methods to shape the master section because each builder has a method the he has contrived. Interestingly, on a section (page 215) in which Duhamel du Monceau proceeds to describe a different aspect of the design method he '[starts by explaining] how we can draw a master frame, by a different method to those that have already been described'. This gives an idea of how a method or other could be chosen for convenience only.

[456] Duhamel du Monceau. *Élémens de l'Arrchitecture Navale.* Chapter IV: Sections IV, V, VI and VII.

the shape of the frame can be changed. Once again the author does not provide any rationale[457] for the use of any of the methods nor does he express any preference for them. The best method according to the author would be the one that allows the builder to modify the shape of the frame at will. The author finishes the section on master frames by saying that 'nothing could be easier than to imagine other methods [to shape the master frame] that are just as good as those that we have just described'.[458] Obviously, for Duhamel du Monceau, there is nothing especial about the drafting methods. They are just a convenient tool to create a hull shape.

With the shape of the master frame designed, the next step would involve the design of the shape of two additional frames towards the ends of the ship –the tail-frames– using similar geometrical methods.[459] Following this, the ship designer ought to draw the shape of the frames on the body plan by a process of transformation between the shape of the master frame and the shape of the tail-frames. In order to do this the designer would draw the frames between the master frame and the tail-frames by altering the shape of the master frame gradually by a process that the author calls reduction; the frames closer to the master frame would be more influenced by its shape and less by the shape of the tail-frame and vice versa. This gradual transformation was controlled by a series of curves which run on the surface of the hull along diagonal planes (figure 71).[460] The shape of these curves could be obtained by a number of methods based on simple geometric constructions, each ship builder favouring a method over others.[461] Duhamel du Monceau finishes the chapter by writing that '[he] could have [described] many more methods of reduction; however, [he] would [not include them on the treatise] so as not to enlarge the treatise [...].'[462] These methods were just a practical procedure which Duhamel de Monceau calls *'practiques mechaniques'*[463] or mechanical methods that could be followed to control the transformation of the shape of the hull in a practical manner.

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457 On page 213 the author gives his opinion about the effect that shape has on performance. However, his opinions are based on 'feel' and not on 'science'.

458 Duhamel du Monceau. *Élémens de l'Arrchitecture Navale*, p. 214. (Translated from the original by JPO).

459 Duhamel du Monceau. *Élémens de l'Arrchitecture Navale*, p. 221.

460 Duhamel du Monceau. *Élémens de l'Arrchitecture Navale*, p. 231.

461 Duhamel du Monceau. *Élémens de l'Arrchitecture Navale*, p. 256.

462 Duhamel du Monceau. *Élémens de l'Arrchitecture Navale*, p. 260.

463 Duhamel du Monceau. *Élémens de l'Arrchitecture Navale*, p. 256.

The method appears to be a departure from the previous methods of rising and narrowing lines. However, if the method is reduced to its conceptual minimum –to just a few sentences as below– and using only abstract terms it becomes evident that the conceptual approach to defining the shape of a hull is the same. The methods described by Duhamel du Monceau could be described with the following sentences:

> In order to design the shape of the hull, a master frame of arbitrary[464] shape is transformed along the length of the ship, in a transformation that is controlled by several longitudinal curves which are constructed following arbitrary methods based on graphic, geometric or numerical constructions. If these rules are followed in a mechanical manner, they result in a ship shape.

This definition above could be used to define any of the methods that have been described up to this point and in the following sections. From here on, when referring to these methods in general terms the term mechanical methods will be used.

One important difference of the methods shown in *Elémens de l'Architecture Navale* with previous methods analysed in this section is that in *Elémens* the shape of the ship is fully drafted –at the design stage– in a plan that shows all the frames in the body plan and a horizontal projection of the diagonals (figure 72). This is not an intrinsic difference of the shaping methods, as it would have been just as possible with the previous methods. However, it provides extra information about the shape of the hull's surface. According to Duhamel du Monceau this difference had a major advantage:

> Ship builders, having seen the advantages of drafting in a single plan the projection of all the frames of a ship, with the aim of seeing at a single glance the relation that each [frame] had with the others, **[could study] with the compass[465], or by calculation, the properties of the ship's hull from its figure** [...] [466] (Translation from the original by JPO.)

Hence, from the analysis of *Elémens de l'Architecture Navale* it can be concluded that the main change that is reflected in the treatise when compared to previous treatises come from the

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464 By arbitrary it is meant a shape that had no objective justification based on some inherent characteristic of the shape. Its only justification would be that it had worked in the past.

465 The compass was not a tool used for drawing circles only. It could be used to perform mathematical calculations. For example see: Lavery. *Deane's Doctrine of Naval Architecture*, p. 42(29); Walker and Tolpin. *By Hand and Eye*, p. 107.

466 Duhamel du Monceau. *Élémens de l'Arrchitecture Navale*, p. 215.

practise of representing the shape of the ship fully at the design stage, and not on the conceptual approach to hull design.

The graphical representation of the ship's hull allowed the shipwright to build the ship virtually on paper. This facilitated the possibility of analysing some of its characteristics at this stage, what Duhamel du Monceau calls the properties of the ship's hulls, (the most obvious being hydrostatics). Thus, if the result of the analysis was found unsatisfactory by the designer, a new modified shape could be tried. However, other characteristics of the hull –manoeuvrability, ability to sail to windward, balance under sail, response to the helm at any point of sail– could not be judged in objective terms yet and were, therefore, treated in abstract terms on chapter VII of the treatise.

The analysis has shown that the arbitrary nature of the methods described in the treatise was known, and accepted, by the writer. They provided a convenient way of controlling hull shape and of relating it to some performance characteristics of the hull.[467] This was an acceptable reason for the author of the treatise. Science, or scientific arguments are not used or present along the treatise. Although the ideas seem complex when shown on paper, in reality they represent a type of knowledge that could be put into practice with very simple tools and which required no mathematical or scientific knowledge. Most tellingly, the treatise is not prescriptive. On the contrary, the author went to great lengths to try to provide as many examples as possible of alternative hull design methods available to ship designers, all based on conceptually similar principles.

5.9 A Treatise on Ship-building and Navigation in Three Parts (Mungo Murray, 1765)

Full title: A Treatise on Ship-building and Navigation in Three Parts
Author: Mungo Murray
Type of book: Printed
Year and place of publication: 1765, London
Editions consulted: 1765

[467] In addition to these methods oh hull design Chapter I of the treatise provided a comprehensive set of scantlings for most of the structural elements of the hull and rig. By following these scantling rules, it was expected that the weight of the ship and the location of its centre of gravity would, hopefully, be within normal parameters. The combination of scantling rules and hull-shaping rules provided the way in which the ship designer could guarantee that the ship would have sufficient displacement and stability.

Language: English

This treatise written by Mungo Murray (second edition) contains, in addition to his own treatise, abridged translations of contemporary ship-building treatises from French authors, Duhamel du Monceau and M. Bouger. The introduction is dedicated to the Earl of Egmont, First Lord Commissioner of the Admiralty. In his dedication, Mungo Murray describes that the treatise is intended for 'the Benefit and Assistance of young Beginners in His Majesty's Dock Yards.' The aim of the treatise is 'the instruction and improvement of Ship-wrights, in the art of delineating or drawing of ships'.[468] Each of the texts represent separate works and will be described accordingly on separate sub headings. When referring to the text combining the three separate treatises it will be described as the 'compilation'.

5.9.1 A Treatise on Ship-Building and Navigation (Mungo Murray, 1764)

Mungo Murray's own treatise is a long document of 344 pages in which the author describes different methods of designing the shape of a ship's hull in 65 pages. The rest of the treatise is dedicated to geometry, trigonometry, mathematics, geography and navigation. The present analysis will be mostly concerned with part II of the treatise where the different hull design methods are explained.

On first impression, the treatise appears to be directed to people with a certain level of previous mathematical knowledge. However, it would appear that the use of logarithms as a tool to aid in performing simple arithmetic was already extended to practical craftsmen. This is shown in the preface when Mungo Murray states that his treatise will show how to make a logarithmic scale that will allow the reader to make his own sliding-rule. Such a tool '[is] so expeditious and useful that it is universally [used] in measuring all the plank into his Majesty's Yards, and used not only by ship-wrights, but by many other artificers, as joiners, painters andc.'[469]

In his treatise Mungo Murray describes three different methods of hull design: Whole Moulding, forming a body by sweeps and by the sector. Each will be analysed briefly below.

5.9.1.1 Whole Moulding:

The first method is called whole moulding and is in essence equal to some of the previous methods (pre mid-18th century) described above. The shipwright shapes a master section based

[468] Murray, M. 1764. *A Treatise on Ship-Building and Navigation*. To the Right Honourable. (unnumbered).

[469] Murray. *A Treatise on Ship-Building and Navigation*. The preface.

on a series of sweeps (arcs), and uses this shape to obtain the rest of the frames. Once again the transformation is controlled by a rising and narrowing line that works in the same manner as has already been explained above. The explanation is given in both graphic (figure 73) and text form. The process of design itself is less complex than the figure suggests. The complex illustration is a graphical representation of the three-dimensional shaping process, and not of the drawings which the shipwright must perform to design a hull following this method. In practice the method could be carried out without the use of drafted plans.

Mungo Murray describes a master frame based on a simple geometrical construction that uses three arcs of circle. In common with other authors before, Mungo Murray clearly understood the arbitrary nature of this design approach:

> By this way of forming the frame, **it is plain the centres and radii of the sweeps are arbitrary**, but they **must be determined** before any of the other timbers can be formed; **if by no other means, by repeated trials**, till they are made to please the fancy and judgement of the artist.[470] (Highlights JPO.)

What matters is that the shape of the master frame 'please[s] the fancy and judgement of the artist'. The method is irrelevant and, if necessary, a simple method of trial and error, 'by repeated trials' will suffice. Criticisms by contemporary ship designers like Spanish author Aizpurua (chapter 5.6) show that designing the master frame by trial and error in English yards was more common than the treatises which have been described up to this point show.[471]

After defining the master section a lengthy explanation of the design method follows using, as an example, a boat of 29 feet in length. The explanation is all on abstract terms, and apart from the length of the boat, the text does not include any reference to dimensions or proportions. The very detailed explanation must be read together with the illustration shown in figure 73.[472] The comprehension of this process is very much improved by the very efficient use of labels that relate each step of the explanation with features in the drawing.

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[470] Murray. *A Treatise on Ship-Building and Navigation*, p. 135.

[471] This is how Aizpurua put it:

> [with a geometric ship-design method the shape of the master frame] is defined to perfection. There is no doubt that with this method, the infinite trials with which the English draw their plans are avoided (Aizpurua. *Oservaziones que se Pratican para la Delineacion de Navios*. p 19. (Translated by JPO)).

[472] Murray. *A Treatise on Ship-Building and Navigation*, p. 135.

Mungo Murray did not make any reference to the use of this method from which it may be inferred if it was used for large ships or only boats as the one used for the example.

5.9.1.2 Forming a Body by Sweeps

This method has already been explained several times before, being nearly identical in all its general terms to previous design methods. It is interesting to observe that, similarly to the previous case of whole moulding, the text does not specify any of the dimensions or ratios of the geometrical process. The explanation is given in text and graphical form and both text and figure must be read at the same time in order to understand the explanation. Once again this is made simple by the labels that relate the figure and the text (figure 74).

The design method is based on three sections whose form must be pre-determined by the ship builder. The master frame and two additional frames, each towards each end of the ship. The designer is expected to 'shape [the master frame] either by two, three, or more sweeps, as the artist shall think more suitable for the service the ship is designed for'.[473] Or by repeated trials as stated before. Hence it can be seen that the method cannot be considered prescriptive. Shipwrights have the liberty to design as they wish. There are no indications to the method which could be followed to design the shape of the two tail-frames.

A large format plan (figure 74) describes the method in graphical form which is similar to the method proposed by Duhamel du Monceau. The transformation is controlled by curved lines running on the surface of the hull, placed on diagonal planes.

5.9.1.3 By the sector

The third method that Mungo Murray described used a sector to store all the dimensions of the main parameters of the hull (figure 75). The sector was a mathematical instrument that was made up of two hinged legs each one inscribed with a series of markings, which usually represented trigonometrical functions. Helped with this tool and a set of dividers (compass) it was possible to use it as a calculator.[474] However Mungo Murray's sector, stored all the information regarding the parameters required to shape of a hull. In the strict sense the sector was not a design tool. It could only be used to reproduce the shape of the ship which had been used to inscribe the marks on the sector which could be scaled up or down, proportionately, to the dimensions required. However, Mungo Murray provided some guidance which described how to use this tool in order

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473 Murray. *A Treatise on Ship-Building and Navigation*, p. 145.

474 Walker and Tolpin. *By Hand and Eye*, p. 103.

to produce shapes that were slightly different to those stored in the sector.[475] Mungo Murray was the only author who proposed its use for this purpose in a written treatise. Therefore, it was probably never successful method of storing shapes. A table with the dimensions of the main parameters of a ship was much simpler to make and would have had the same use. However, there are other authors who showed sectors in the context of shipbuilding (figure 76), architecture (figure 77) and mathematics. This shows that the sector may have been useful for the storage of information which remained invariable in time, such as the ratios and proportions between features of the different architectural orders, or mathematical functions. However, in shipbuilding, designs were varied to suit the needs of the service thus needed a flexible 'design tool'. The sector did not allow for this readily. Thus, it never became a widely used design tool in shipbuilding.

5.9.1.4 Conclusion

For Mungo Murray it was clear that science or scientific knowledge played no role in the design methods of the period which were based on purely arbitrary –albeit convenient– methods. He wrote:

> Now, [the shape of the hull] thus formed may prove fair, yet neither this method by the sector, nor any other method [of shaping the hull], which has been published, can be established as a certain invariable rule; because the curves by which they are formed have no properties peculiar to themselves to distinguish them from all other curves, as was before observed.'[476]

The treatise shows that there was still no conceptual evolution on the design processes and that the actual design methods remained in essence the same. However, there was a substantial development taking place in the ability to represent the three-dimensional shape of a ship on paper which saw a great improvement during the first half of the 18th century. As a result the illustrations on the treatise convey the information with a higher precision and quality than the illustrations on many of the texts analysed above (figure 74). Interestingly, Mungo Murray shows a very detailed drafted plan, where the information required to describe the shape of a ship is shown reduced to its minimum expression (figure 78) by omitting the central section of the hull from the profile and plan views. This plan is reminiscent of the drawing shown in figures 18 and 19, drawn in the 15th century in the context of Mediterranean shipbuilding.

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[475] Murray. *A Treatise on Ship-Building and Navigation*, p. 176.

[476] Murray. *A Treatise on Ship-Building and Navigation*, p. 177.

5.9.2 The Elememts (sic) of Naval Architecture (Translation of Duhamel du Monceau's 1758 work)

The second text included in Mungo Murray's compilation is *Elememts (sic) of Naval Architecture* which is a short abridged version of the treatise written by Duhamel du Monceau that has been analysed above. The contents have been described in the previous section thus they will not be described here again.

It is noteworthy that, although both Mungo Murray and Duhamel du Monceau describe similar methods of design, Duhamel du Monceau's explanations describe the processes with greater clarity.

5.9.3 Supplement to the treatise on ship-building. Extracts from Traité du Navire. (Bouguer, 1765)

This supplement was included at the end of the compilation and it is and short translation of *Traité du Navire* by French scientist M. Bouguer. The contents of the treatise are highly theoretical and study aspects like ship resistance and ship stability. These are treated in a totally theoretical manner which does not relate those aspects of a ship with a method or recipe of hull design. In fact, it deals with simplified shapes which do not resemble the shape of real ships. Thus, although Bouguer's work is essential to understand the developments which led to modern-day naval architecture, they were not of much use to practising shipwrights and ship designers of the period. Therefore, the supplement will not be described here.

5.10 Delineaciones o figuras de construcción (Manuel de Arrospide, 1789, 1790)

Full title: N/A

Author: Manuel de Arrospide

Type of publication: Two unpublished, manuscript, large-format, labelled plans (835 x 1056 mm and 665 x 1026 mm respectively).

Year and place of publication: 1789, 1790, Portugalete (Biscay, Spain)

Editions consulted: original plans in the Museo Naval of Madrid. Museum catalogue numbers: mnm_pb_0047 and mnm_pb_0048

Language: Spanish

Unlike other documents in this chapter, which are printed treatises or handwritten manuscript books, these two documents (called here *Delineaciones of figuras de construcción*)[477] are two large format plans (figures 79 and 80). They are included for two reasons. Firstly, to show that there are alternative sources of evidence which may help improve our present understanding of ship-design practices and, hence, shipwrights of the period, especially in commercial yards as described by Arrospide. Secondly, they describe a design method that shows a remarkable originality in its practical approach to obtaining hull shape. Of course, always within the same approach to hull design based on a controlled variation of a master section.

This thesis argues that a study of the details distracts from the real knowledge contained in each particular method (chapter 2). Thus, Arrospide's plans are not treated differently. However, bearing in mind the originality of the method, it is described in detail in appendix B which includes a transcription of the original Spanish text and an English translation. The appendix also draws some interesting conclusions with respect to the often obscure syntax used by Arrospide which may have prevented Spanish scholars from properly understanding the contents of this valuable document. This could explain why it has not been studied before.

From the analysis of the text it can be interpreted that the contents of the plans describe the design methods used by commercial shipyards of the late 18th century in Portugalete, Spain. This area, which is close to Bilbao, in the Basque region, was considered a thriving shipbuilding centre in Spain during this and the preceding centuries.[478] A method describing design practices in commercial yards, away from the pressures and regulations of state-sponsored shipyards justifies its inclusion in an appendix of this thesis.

The design method described in these two plans is conceptually similar to the other methods described in this thesis (see for example figures 126-129 and appendix B). A master frame is designed as a series of arcs of circle, reminiscent of the methods described in the treatises analysed in the previous chapter of 16th and 17th century treatises (figures 80-81). The transformation of the master section into the other sections is controlled by a transformation based on simple geometry (figure 81-83 and 129-132). However, when the method described by Arrospide is compared to the other methods in this thesis, an important difference can be identified. In all cases researched –except Fournier's–, the transformation of the shape of the master section into the other sections is controlled by several rising and narrowing lines –or

[477] The title is taken from the first line of plan-1 which can be translated as: *Plots or Construction Figures*.

[478] Zabala, A. 1984, *La Construcción Naval en el País Vasco en el Siglo XIX, Arquitectura Naval en el País Vasco,* Eusko Jaurlaritza-Gobierno Vasco, Vitoria-Gasteiz.

similar devices–, each controlling the shape of a certain area of the hull. By contrast, Arrospide`s method uses a single quadrant to control the manner in which the maximum breadth line narrows and rises as it nears the ends of the ship (figures 82, 126). The rest of the three-dimensional shape of the hull is obtained automatically from the line of maximum breadth. In this respect it is similar to the method described superficially by Fournier. The 'tools' required in Arrospide's method to design the shape of a ship are remarkably few and simple. With just a quadrant, and knowing the breadth and depth of the hull, the main parameters required to design the shape of the hull are determined and the design can be drawn full-size directly on a loft floor. Although the text is rather obscure it is possible to identify the design method with sufficient detail. It is described in appendix B.

Besides the actual design method, the texts give a very interesting description of the tools used in the design process in the shipyard for the design of commercial hulls. The author starts by warning that in the process of designing a ship the sections of the hull must be obtained according to what he calls the 'art of the compass'. By following the 'art of the compass' all builders using the same measurements will produce equal ships. The compass Arrospide refers to is a string-compass[479] or a trammel used to draw on a suitably flat floor the shape of the frames and transversal sections of the hull, full-size .[480] Here he draws a comparison with stonemasons who in their process of designing 'arches and other curved lines [must] plot them full size' on a flat floor in order to obtain the shape of the different stone elements required for their construction.

The design method is based on a body plan, and the profile and plan view drawn in the plans are used by Arrospide to further clarify the drafting method. They are not needed in the real design process. The body plan shown in the first plan (figure 79) represents four different designs to indicate the variable shapes that can be obtained by modifying three design-parameters which are the depth of the ship, its breadth and the line that determines the centre of the bilge arc (appendix B), thus showing that the method is adjustable and non-prescriptive. The author explains that the method is suitable for merchantmen and fast vessels.

Arrospide, describes the design process from the line of maximum breadth down. Although the shape of the frames above the maximum breadth are shown, he does not explain in his text how they were obtained. He is interested in describing the lower portion of the hull, which would correspond loosely to the underwater portion of the hull, thus the part of the ship responsible for

[479] See footnote 19 in appendix B.

[480] See footnote 20 in appendix B.

its behaviour in the water as a floating vehicle. The rest of the hull would be designed by certain geometric methods, not explained in the text.

To conclude, these plans illustrate design methods which, on the one hand, appear modern in their use of well drafted plans to convey information. But, on the other hand, they appear obsolete, if the simple method followed to obtain the shape of the hulls is considered. The design method described in the plans requires far fewer parameters than the methods described in the other treatises. Such methods required very simple tools. Only a string used as a compass or a trammel made up of two pieces of timber fixed to each other (appendix B).Thus, the method would be well suited to commercial yards. Alternative sources of evidence like the plans drafted by Arrospide provide valuable information about the design practices used by commercial yards building large ships and the social landscape of the shipwrights. They provide a counterbalance to the sophisticated methods described in late 18th century treatises, like Chapman's (below).

5.11 Architectura Navalis Mercatoria. (Fredrik Chapman, 1768)

Full title: *Architectura Navalis Mercatoria*
Author: Fredrik Henrik A. F. Chapman
Type of book: Printed
Year and place of publication: 1768, Stockholm
Editions consulted: 2006 edition and English translation[481]
Language: Swedish

[Note: this treatise is not shown in chronological order. Instead, it has been placed at the end of the 18th century treatises, as often Chapman is considered one of the early examples of a modern naval architect. Thus, one of the first examples of a break with the old traditions]

Swedish ship builder Fredrik Chapman (1721-1808) is often considered one of the first, modern, scientific, naval architects, and as such he is often placed at the frontier between traditional ship building and modern, scientific, ship design.[482] This section will analyse his approach to hull design

[481] Chapman, F.H. 1768. *Architectura Navalis Mercatoria*. 2006 edition. Mineola, New York: Dover Publications.

[482] For example: Barker. Fragments from the Pepysian Library, p. 174; Chapman. *Architectura Navalis Mercatoria.* Publisher's Note (no page number); Hasslöf. Sources of maritime history and methods of research, p. 143.

to establish if Chapman broke up with the design paradigm described up to the moment or if, indeed, he belonged to the same design tradition.

This short analysis of Chapman's work is based on *Architectura Navalis Mercatoria*, published in 2006. *Architectura Navalis Mercatoria* combines two of Chapman's published works. It contains 62 plates from the original *Architectura Navalis Mercatoria* published in Stockholm by Chapman in 1768. In addition to the plates, it includes a translation by James Inman –published in 1820– of Chapman's *Tractat om Skepps-Byggeriet* originally published in Swedish in 1775.[483] The plates are so beautifully drafted that they can be considered a work of art. But, the real interest of the work lies in the written work which gives a well-informed opinion on the state of theoretical knowledge as applicable to ship design at the end of the 18th century.

In the preface Chapman describes that ships from different parts of Europe may all seem different at first sight. However, when one considers ships built for the high seas 'even though of different countries, we shall find that being built for the same purposes, they are similar in their essential parts.'[484] He then enumerates the main proportions that define the shape of the hull. These proportions –between length, beam, depth– are not fixed, but vary between minimum and maximum values, which have been arrived at as a 'result of an infinite number of trials and experiments, and of alterations made in consequence thereof, [thus, for a new design], it would be improper to infringe on limits so established'.[485] Once again, in common with all the other treatises analyses, the process of designing a ship is based on inherited proportions which can be changed –within reason– at the judgement of the shipwright.[486]

In this work Chapman writes that 'ships cannot be carried to greater perfection, till a theory has been discovered, which elucidate the [differences in performance of different hulls]'.[487] In that respect, he adds that some theories have been formulated which aid in such a theoretical understanding which must always be accompanied by practical experience. However, the complexities of developing a full theoretical understanding are such that it 'seems to extend the force of the human understanding.'[488]

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483 Chapman. *Architectura Navalis Mercatoria.* Publisher's Note (no page number).

484 Chapman. *Architectura Navalis Mercatoria*, p. 125.

485 Chapman. *Architectura Navalis Mercatoria*, p. 125.

486 Chapman. *Architectura Navalis Mercatoria*, p. 125.

487 Chapman. *Architectura Navalis Mercatoria*, p. 126.

488 Chapman. *Architectura Navalis Mercatoria*, p. 126.

The rest of *Architectura Navalis Mercatoria* deals with hydrodynamics, based on experimental work carried out by Chapman. In those experiments Chapman attempted to explain the hydrodynamic resistance of bodies moving through the water by performing systematic towing experiments of simple 'ship' forms. Chapman's assumptions about fluid flow were based on erroneous concepts which led him to unsatisfactory conclusions.[489] He was aware of the little practical use of his experimental results. He wrote:

> As we cannot conclude any thing from the [towing experiments] concerning the proportions, which ought to place between the length, breadth, and depth of a ship, and since its qualities depend greatly upon these proportions, it is necessary to enumerate those qualities [...] in order thence to determine the proportions most advantageous, and most likely to produce such or such qualities [...]. [490]

He follows by enumerating the qualities that one should seek in a ship and the manner of determining the proportions which will produce such qualities.

According to Chapman, in order to determine the proportions between length, beam and depth of ships 'theory alone is not sufficient [and] it becomes necessary to introduce practice, and to see [...] in what manner different ships answer in different cases.'[491] To do so, he provides a table with the ideal proportions for different types of ships. The table seems complex and highly mathematical, but, in essence it is nothing more than a relation of recommended proportional relations between the length, beam, and depth of different types of ships. The formulae are, certainly, more 'mathematical' than the simple ratios given in previous treatises, thus appear to be more scientific. However, behind this appearance of high mathematics, in fact, they are nothing more than recommended ratios between the main parameters of the hull based on past experience. They are just a collection of empirical data for which no scientific justification is offered.[492]

Chapman's work towards trying to develop a theoretical framework to try to understand the physical phenomena which define the behaviour and performance of a ship allowed him to gain respect from his contemporaries and from modern scholars. However, his method of designing

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[489] Chapman. *Architectura Navalis Mercatoria*, p. 131.

[490] Chapman. *Architectura Navalis Mercatoria*, p. 133.

[491] Chapman. *Architectura Navalis Mercatoria*, p. 135.

[492] The formulae given are not to be taken as absolute values. They should only be used as guidance for approximate dimensions (Chapman. *Architectura Navalis Mercatoria*, p. 136).

the hull of a ship was closer to the methods described in previous sections than the free methods relying on engineering that substituted them.[493] His method relied on an arbitrary rule that determined the manner in which the shape of the master section had to change along the length of the ship. Only this time, the method specified that the area of the frames followed a parabolic distribution. In practice the shape of the master frame was modified by the use of diagonal planes, in a similar fashion to the method described by Duhamel du Monceau above. The main difference would be on the shape of the diagonal curves which for Chapman were segments of parabolas (figure 83).[494]

In essence, although Chapman was trying to break from previous practice, and pointed towards the use of mathematical analysis in ship design, he was aware that such a break was not possible yet. Therefore, his approach to design belonged, in some respects, to the same conceptual approach as the treatises analysed previously. Thus, for Chapman, the shape of the hull was obtained from an arbitrary geometric (mathematical) transformation of a master section along parabolic diagonal curves. However, he developed 'tools' that could be used, for the first time, to guarantee a certain volume under the waterline of a hull during the design stage. Thus, by the invention of the *sectional area curve*, he provided the tool that would free future naval architects from design methods based on design-recipes that produced a three-dimensional shape. Instead, future naval architects would be able to design any shape (without a design recipe), knowing that the hull being drawn would have a given volume, decided prior to the drawing process, under its waterline.[495]

5.12 1800s: Change of paradigm; the beginning of a new era.

By the turn of the 19th century it had become clear that science could begin to provide some answers to the challenges that ship-designers had had throughout history, namely that ships had to float, stay upright and sail in an efficient manner. The advance of science highlighted the fallacies of past theories but also the shortcomings of contemporary scientific understanding. For example, in 1787, Vial de Clairbois wrote in his *Traité Élémentaire de la Construction des Vaisseaux*:

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[493] Morgan and Creuze. *On Mechanical Methods of designing Ships' Bodies*, p. 17.

[494] Creuze. *Treatise on the Theory and Practice of Naval Architecture*, p. 61.

[495] Nowaki, H. 2009. Shape Creation Knowledge in Civil and Naval Architecture. In H Nowacki and W Lefèvre (eds), *Creating Shapes in Civil and Naval Architecture: A Cross-Disciplinary Comparison*. Leiden: Brill, p. 29.

> Hydrodynamics, that deals with the effects [of ships moving through the water] has not provided yet with a satisfying [theory on the subject of ship resistance]. The greatest geometers, lacking the facts, have imagined hypotheses, and upon these bad foundations, have made up great calculations that are more elegant than useful. (Translated from the original by JPO.)[496]

Despite knowing that old theories were not based on sound foundations, it was acknowledged that they had provided a safe environment for centuries by reducing the uncertainties of the design and construction process. Consequently, many were reluctant to abandon those methods and to embrace the new methods, yet unproven, which they feared could 'introduce evils, the nature and extent of which cannot be fully known.'[497] The new methods –which were still being developed– did not guarantee success and it was noted that, very often, as in the case of small vessels built by practical men, ships built using the traditional, unscientific methods, proved to be superior to those built by learned designers following scientific principles.[498] This strengthened the opinion of those who refused to embrace the new methods. Some even doubted that it would ever be possible to find scientific solution to the challenges of ship design.[499]

Eventually, engineering principles became common and ship designers or naval architects, could start to design their ships based on sound engineering principles during the second half of the 19th

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496 Vial de Clairbois. 1787. *Traité Élémentaire de la Construction des Vaisseaux*, p. 253.

497 Atwood, G. 1798. A Disquisition on the Stability of Ships. *Philosophical Transactions of the Royal Society of London*, 88, pp. vi–310 (pp. 201, 204). The writer of these words, George Atwood (1745-1807), was one of the first mathematicians to study ship's stability successfully. Some of his theories and formulae are still used, today, to estimate the stability of ships, especially, at the early stages of design. See for example in: Kemp and Young. *Ship Stability Notes and Examples*. Third Edition, p. 59; Tupper, E.C. 2004. *Introduction to Naval Architecture* (4th edition), p. 104.

King. Technology and the course of shipping, p. 571.

498 Lord Viscount Mandeville. 1829. An Examination into the Form of Ships' Bodies, in connection with the Passage of the Water, with a view to discover a Principle common to Form of all fast-sailing Vessels. In W. Morgan and A. Creuze (eds) *Papers on Naval Architecture and other Subjects Connected with Naval Science. Vol II*. London, p. 67; Finchman, J. 1827. Dimensions, and calculated Elements, of some of the Vessels of the Royal Yacht Club, with a few remarks on their construction. In W. Morgan and A. Creuze (eds) *Papers on Naval Architecture and other Subjects Connected with Naval Science. Vol I*. London, p. 210.

499 Henwood, W. 1865. An Inquiry respecting the Form of least Resistance for a Ship ; the Position of the Centre of Gravity with respect to the Ship's length; and the means of Reducing the Motions of Pitching and Scending to a minimum. (Being a Reprint from the "United Service Journal" for 1833). In W. In Morgan and A. Creuze (eds) *Papers of Naval Architecture and other Subjects Connected with Naval Science.* No. XIV. Vol IV, p. 158.

century.[500] Modern naval architects developed analytical tools which allow them to establish the buoyancy and stability characteristics of ships from its shape as depicted in scale plans, even before they were built. Moreover, they did not follow a method that started from developing a shape and then establishing its characteristics (either by calculation or by a full size test after construction). With the new analytical tools, naval architects developed the capability of designing a hull which met with certain characteristics that had been decided beforehand. The shapes were drawn freely, following no mechanical design methods. Thus, breaking their link to past practices which did not fully disappear but were relegated to traditional yards building boats and small utilitarian ships (see chapter 7).

5.13 Closing remarks: post mid-18th century treatises

The analysis in this chapter of treatises written during the 18th century shows that the manner in which 18th century shipwrights approached the problem of designing a new ship, remained constant during this period. Moreover, the analysis shows that there was no conceptual variation between the methods described in 16-17th century treatises (chapter 4) and 18th-century examples. In all cases, a design-recipe based on geometry and the control of shape by a transformation of a master section remains at the core of the design paradigm. Towards the end of the 18th century, new knowledge based on science became available and 'scientific' design methods began to be used. Fredrik Chapman became one of the most prominent names on this new approach to design.[501] In his case, his method still shared some common ground with past methods. In essence, a recipe was still responsible for the shape of the hull. However, his use of the sectional area curve, as the control mechanism, opened the way to future naval architects who became liberated from design-recipes for hull shapes. Although, as indicated in 5.12, initially these new methods failed to convince everyone. Chapter 8.1.1 will offer a few more examples of this.

The following chapters will come back to the main research questions that referred to the design-paradigm of early modern ship designers and shipwrights and the manner in which the knowledge of early modern ship designers and shipwrights is characterised in the current scholarship. Chapter 6 will offer a criticism to the current scholarship with respect to the manner in which the treatises have been approached. Building on it, chapters 7 and 8 will offer a more nuanced description of the ship-design knowledge of shipwrights in general and early modern shipwrights

500 Saunders. *Hydrodynamics in Ship Design. Volume II*, p. 207.

501 Hasslöf. Sources of maritime history and methods of research, p. 143.

in particular. A summary of the analysis in chapter 4 and 5 at the beginning of chapter 6 will set the scene for the criticism and subsequent chapters.

Chapter 6: Discussion: Criticism to the current narrative

This chapter starts by summarising the main ideas that can be extracted from the treatises analysed in chapters 4 and 5. This is followed by a criticism of the current narrative which explains the technological-landscape of the early-modern shipwright. The criticism highlights some shortcomings of the currently accepted narrative. The main criticism will be that the treatises have generally been approached with an over-particularistic outlook which, in turn, has led to a distorted description of the ship-design knowledge of the early-modern period. The criticism will also highlight the manner in which, sometimes, the evidence is made to fit within the currently accepted narrative, not always easily, instead of shaping the narrative to the available evidence. These criticisms follow one of the research questions which focused on the knowledge contained in the treatises and the manner in which it is portrayed in the current literature.

Following chapters (chapters 7 and 8) will build on these criticisms in order to answer the other set of research questions which focused on the design paradigms of early modern shipwrights. It will do it by re-defining the theoretical framework which is used currently to study the ship design and construction paradigms in different shipbuilding traditions.

6.1 Summary of chapters 4 and 5

Chapters 4-5 of this thesis have described ship design treatises from the 15th century to the late 18th century. It was argued in chapter 2 that, in order to establish the contents of the treatises, irrelevant details had to be ignored and the focus had to be placed on general concepts. By doing so, a picture emerges which suggests that during this period there was a common design paradigm that remained practically unchanged.

From chapters 4 and 5 it can be stated that the design process was simple and common to all treatises. Designers chose the size of ship they desired and the design-recipe produced a shape in an almost automatic manner. In all treatises analysed, with the exception of the Dutch examples, the manner of obtaining the shape was as follows: [502]

[502] The fact that some design-recipes limit the frames which are obtained from the transformation of the master-frame to those in the central part of the hull only, leaving the ends undefined, does not change the essence of the design paradigm.

a) The shipwright knew from tradition, the preferred proportions between length, beam, and depth of the ship.

b) The shape of the hull was defined by a series of lines which were used to generate its three-dimensional shape based on a few control parameters. The shape of these lines was obtained by a series of graphical, geometric or mathematical procedures.

c) The lines used to generate the three-dimensional shape of the hull were:

- The ship's profile shape: made up of the keel, stem and sternpost.
- The master frame which influenced the transversal shapes of the rest of the frames.
- Several lines of longitudinal control which determined how the shape of the frames changed as they neared the ends of the ship and 'moved' further away from amidships.

d) The shape of the transversal frames of the hull were obtained by a transformation of the master section, controlled by the lines of longitudinal control defined in (c)

e) The method could be used directly on a full size loft floor or, alternatively, it could be used to draw a simple plan where the lines mentioned in point *(c)* were shown.

One way of seeing, literally, that the design paradigm remained constant in the treatises is by looking at figure 84. It shows in schematic form the elements for which – according to the authors of each treatise– the designer had a pre-determined design-recipe available. From the figure it becomes apparent that all treatises use the same curves to generate the three-dimensional shape of the ship. The manner of obtaining the shapes of the individual curves may be different, but, the conceptual approach and the design-tools –as defined by the design-recipes– remained constant.

None of the treatises described in chapters 4 and 5 defends, from a theoretical point of view, the choice of a particular method to construct the master frame or the longitudinal control curves. At most, the authors declare their preference for a particular procedure, generally stating that the reader is free to choose any other proportion, design method, or geometric construction which may be considered more appropriate. On this subject, interestingly, the authors do not give any reasons to justify why the reader may decide on such changes. However, most authors agree that changes should be based on the past experience of the shipwright. The analysis of the treatises in chapters 4-5 has also opened a window into the readership of these treatises. The intended readership is explicitly stated on numerous occasions which leads to the idea that, in general, the treatises were written to be accessible to common practitioners. Most importantly, the methods contained in the treatises are conceptually simple and easy to comprehend. Consequently, theories which describe that these treatises were beyond the comprehension of common shipwrights become questionable (see also chapter 7).[503]

One important limitation of the ship-design knowledge of the long period analysed is that, until the first third of the 19th century, ship designers had no practical means of calculating the stability characteristics of a ship at the design stage.[504] Thus, in common with the methods of shaping the hull which guaranteed a certain predictability of the hydrostatic characteristics of the ship –of which stability was an important aspect–, shipbuilders of the period needed methods to try to control the other factors which determine the stability characteristics of a ship. These other factors were, firstly, the weight of the ship and the position of its centre of gravity. The second important factor was the configuration of the sailing rig and its negative influence on the ship's stability. In order to ensure sufficient stability, and to keep the effects of the weights and sailing rig under control, most treatises analysed provided scantling and rigging rules which ensured –within acceptable levels of uncertainty– that the weights of the different structural and rigging elements of the ship and their positions (vertically and horizontally) would conform to normal practice (tables 1-2). Similarly they ensured –again within acceptable levels of uncertainty– that the sailing rig would be proportionate to the size (hence, shape) of the hull. If that was the case, the match between the hydrostatic characteristics of the hull (due to its shape) and the effects of the ship’s weight distribution and sailing rig on its stability would be within common practice and, consequently, the ship would hopefully behave in a satisfactory manner. This aspect is seldom discussed in the current scholarly debate. At present, the main discussion seems to be centred around the geometric methods followed to obtain hull shape obviating that the weight and position of the centre of gravity, on the one hand, and the rig, on the other, have a dramatic influence on the stability characteristics of a ship, hence, on its usability as a floating vehicle.

[503] For example, as described in very influential papers like Hasslöf. Main Principles in the Technology of Ship-Building, p. 66.

[504] Ferreiro. *Ships and Science*, p. 304.

6.2 Criticism of the current approach to understanding the knowledge contained in the treatises: A distorted narrative

Traditional studies of the history of technology have often been criticised for tending to focus on novel ideas and inventions, although, it is known that pre-modern societies rarely developed or used these innovations in isolation from the technologies which they were accustomed to using.[505] As a result, historians have often developed a narrative based, exclusively, on important inventions, thus, creating a 'heroic narrative' where the biographies of leaders and findings of great discoverers played a central role.[506] The trend has changed and, currently, historians of technology and science engaged in the study of past societies realise the importance of studying the way in which technologies were put in practice by their wider users.[507]

Similarly, there has been a gradual transformation in the manner in which shipbuilding traditions from the past have been studied and interpreted. The idea that ship construction evolved from the simplicity of early vessels to the complexities of modern ships, following a linear mode of accumulative development, used to form the main argument line of earlier works. This is what Steffy called the 'steady transition from logs and thick planks to modern steel freighters'.[508] This view observes the archaeological, historical and even modern material record by focusing on certain chosen particular ship types, or particular building techniques. Thus, by extracting the ideal exemplar for each period –admittedly being limited in choice by the scarcity of written records and archaeological remains– one can easily construct a linear path which takes the older, simpler, ship type to a newer, more complex, ship type.[509] Following this view of technological development, each of the steps seem to be self-evident and deterministic in the sense that complex technological development builds upon past simpler models in a logical and

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[505] Long, P.O. 2010. The Craft of Premodern European History of Technology: Past and Future Practice. *Technology and Culture*, 51(3), p. 698.

[506] Büttner, J., Damerow, P. Renn, J. and Schemmel, M. 2003. The Challenging Images of Artillery. In W. Lefèvre, J. Renn and U. Schoepflin (eds), *The Power of Images in Early Modern Science*. Boston: Birkhäuser, p. 3; Long. The Craft of Premodern European History of Technology, p. 703; Smith, P.H. and Schmidt, B. 2007. *Making Knowledge in Early Modern Europe. Practices, Objects and Texts, 1400-1800.* University of Chicago Press, p. 41.

[507] Long. The Craft of Premodern European History of Technology, p. 711.

[508] Steffy. *Wooden Ship Building and the Interpretation of Shipwrecks*, p. 85.

[509] A classic example would be: Landström, B. 1961. *The Ship. A Survey of the History of the Ship from the Primitive Raft to the Nuclear-Powered Submarine with Reconstructions in Words and pictures*. London: Allen & Unwin. A more recent example would be: Lavery, B. 2004. *Ship, 5000 years of Maritime Adventure.* London: National Maritime Museum.

deterministic manner. Human social groups, however, do not follow such deterministic, logical steps. In the particular case of ships and other floating vessels, this was recognised and the evolutionary account of the transformation of shipbuilding technology has been criticised and it is not considered valid as a means of understanding the past. [510]

The picture is less clear, however, if one focuses on the studies which analyse the abstract knowledge contained in shipbuilding treatises and the knowledge used by traditional shipwrights to define the shape of their hulls or, indeed, how this knowledge has changed during history to arrive at our modern ‘scientific’ understanding of ship design. Contrary to the case of shipbuilding technology where evolutionary ideas have been pushed aside by most authors, the idea that the knowledge required to conceive the abstract concept of the ship (form, shape, structural arrangement) evolved in a stepwise manner, building up in a coherent process of increasing mathematical complexity which, as a result, reserved this knowledge to a learned elite, is a relevant line of argument in the current literature.[511] This chapter will argue that the current narrative which describes the knowledge contained in the treatises should be questioned.

6.2.1 Criticism to the particularistic approach

One of the dangers facing archaeologists and other students of the past is that, in general, the sources of evidence are limited. As a result, general trends may be extrapolated from small sample sizes which could lead to inaccurate descriptions of reality. However, although the danger is obvious, this manner of proceeding is common.[512] This is especially poignant in studies of ship-design knowledge.

Shipbuilding treatises are central to the study of past ship-design knowledge, therefore, the manner in which they have been approached in the past, and the narrative that has been built upon their interpretation, deserves critical attention. This section would like to highlight some of

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[510] For example, McGrail stated that ‘Preocupation with the idea of tracing the ‘evolution’ or ‘development’ of the various types of boat has bedevilled many otherwise objective studies [...]’(McGrail. *Ancient Boats of North-West Europe*, p. 1). Hocker also states, that this model is flawed, as ‘technological variation is not random but deliberate’ (Hocker. Shipbuilding: philosophy, practice, and research, p. 8).

[511] Some authors who see complexity increasing in ship-design knowledge often leading to important social changes are: Adams. *A Maritime Archaeology of Ships*, p. 148; Barker. Design in the Dockyards, p. 61; Ditta et al. Albrecht Dürer and Early Modern Merchant ships, p. 21.

[512] Hocker, F.M. 2013. In details remembered: Interpreting the Human Component in Shipbuilding. In J. Adams and J. Rönnby (eds) *Interpreting Shipwrecks. Maritime Archaeological Approaches*. Southampton Monographs in Archaeology, New Series No. 4. Södertörn Academic Studies 56. Southampton: Highfield Press, p. 73.

the main shortcomings of the current narrative. These are, firstly, the relatively small number of treatises that have been used to construct the current narrative. Secondly, the selective focus on particular aspects of the treatises. A third, and crucial, criticism that will be made to traditional studies of ship design technology of the early modern period is that the contents of the treatises are not always used to shape the currently accepted narrative which describes the knowledge shown by these treatises. Instead, often, the contents of the treatises are interpreted in order to make them fit, however uneasily, within the currently accepted narrative.

6.2.1.1 Narrative: based on few, high status, sources of evidence

For reasons of historical development of the discipline, the limited source material available for interpretation has resulted in a narrative that places much emphasis on treatises written by certain sophisticated authors who were not necessarily ship-designers. [513] In his influential early work on shipbuilding written in the 1960s Hasslöf remarked that:

> The authors of these [treatises of the early modern period] were not shipwrights. Their qualifications were that they had received a general education and could write.[514]

Thus, from the earliest attempts to understand the social implications of the different approaches to ship-construction and ship-design, a doubt was cast upon the validity of the treatises as a means to describe the wider society of the period or, at least, as a means of relating the contents of the treatises to the practices followed by common shipwrights.

With reference to the lack of relation between treatises and shipwrights, Hasslöf wrote:

> Thus the complicated arithmetical arguments about the proportions of [...] a ship and the use of geometrical figures as [design] aids, [...] seem to belong to the world of the scholar, rather than to that of the illiterate craftsman.[515]

Thus, in Hasslöf's opinion, ship-building treatises of the early modern era would be of limited use to try to learn about practical shipwrights and their approach to ship design. Although, he conceded that they may be interesting to study the history of politics. He was of the opinion that 'the craftsmen of those days [...] were undoubtedly more at home with concrete, easily

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513 Bellamy. David Balfour and early modern Danish ship design, pp. 7-8.

514 Hasslöf. Sources of maritime history and methods of research, p. 141.

515 Hasslöf. Sources of maritime history and methods of research, pp. 141-142.

understood aids.'[516] Thus, for Hasslöf, the contents of the treatises could not be defined as 'concrete, easily understood aids'.

In a similar vein, the reason for writing some of these treatises would be an attempt of their authors to elevate their status in front of their contemporaries, thus, casting further doubts on the validity of these treatises as a means of learning about shipwrights of the period.[517] Following with the interpretations above, these ship-design treatises are often seen as the product of highly educated individuals written for an educated elite.[518] However, Richard Barker concluded that, contrary to Hasslöf's view, some of these treatises were, indeed, written by knowledgeable ship-designers.[519]

In the current narrative that explains the development of ship design knowledge in England in the latter 16th to early 18th centuries, manuscripts such as *Fragments of Ancient English Shipwrightry*, *A Treatise on Shipbuilding, c.1620*, and *Deane's Doctrine* are often used as the main stepping stones. [520] They were written by high status individuals which led Barker to conclude that the practices shown in these treatises must be a reflection of the idealized world of the most sophisticated shipwrights of the period. These would have been at the forefront of ship design-knowledge, creating and extending new knowledge beyond the limits of contemporary technology in a way that did not happen again until the late 18th century. [521] In contrast, the practices of more humble shipwrights building less sophisticated, utilitarian, ships, do not feature in the current narrative.

The three key documents mentioned above are manuscripts, thus, it is expected that their circulation and influence would have been limited when compared to that of a highly circulated printed treatise. However, these manuscripts are central to the currently accepted narrative

516 Hasslöf. Sources of maritime history and methods of research, p. 142.

517 Lavery. *The Colonial Merchantman Susan Constant 1605*, p. 8; Hocker. In details remembered, p. 81; Hoving. *Nicolaes Witsen and Shipbuilding in the Dutch Golden Age*, p. 18.

518 Hasslöf. Main Principles in the Technology of Ship-Building, p. 67; Rieth. *Navires et Construction Navale au Moyen Age*, p. 10; Steffy. *Wooden Ship Building and the Interpretation of Shipwrecks*, p. 145.

519 Barker. *Many May Peruse Us*, p. 557.

520 For example, in one of the most commonly used reference book on the subject in maritime archaeology studies: Steffy. *Wooden Ship Building and the Interpretation of Shipwrecks.* Similarly, in Jonathan Adams's analysis of the changes in English shipbuilding –associated with the rise in status of ship designers–, the main argument line is based on the following two manuscripts: *Fragments of Ancient English Shipwrightry* and *Deanes' Doctrine* (Adams. *A Maritime Archaeology of Ships*, pp. 132-148).

521 Barker. Design in the Dockyards, p. 61; Barker. Fragments from the Pepysian Library, p. 174.

which, actually, extends beyond English shipbuilding as they are used in the overall description of the development of early modern ship-design technology in Europe. Interestingly, however, there are other sources of evidence described in chapter 4 which could have been used to provide a more nuanced account of the manner in which ship-design knowledge was put in use during this period. Most notable are the treatises written by Bushnell and Hardingham (chapter 4). Surprisingly, these two treatises receive little or no attention in the current narrative when, in fact, they provide an invaluable source of information about the knowledge used by shipwrights in general, and common shipwrights in particular, in a way that the manuscripts described above cannot do.

Bushnell's treatise, printed with the title *The Compleat Ship-Wright,* is the earliest printed treatise that describes in detail ship-design practices in English. In addition, it is the only example printed during the 17th century that discusses this matter in English. Moreover, in the 24 years that followed its first publication, *The Compleat Ship-Wright* was printed in five separate editions (1664, two editions in 1669, 1678 and 1688). Later, it was printed again in three other editions of a treatise called *Marine Architecture*[522] published in London in 1736, 1739 and 1748 where it was included nearly *verbatim*.[523] Thus, in total, Bushnell's *The Compleat Ship-Wright* was re-edited eight times in a period of 84 years. Eight editions in a period of 84 years would suggest that the book was widely circulated, making Bushnell's *The Compleat Ship-Wright* a necessary source of information for students of shipbuilding of the period; especially for the study of shipwrights building utilitarian cargo ships. In 1706, the second printed treatise written in English which described the process of ship-design was published by Hardingham with the title *The Accomplish'd Ship-Wright and Mariner*. It included a section in ship design aimed at a similar readership.

The wide circulation of a treatise like *The Compleat Ship-Wright* by Bushnell, and Hardingham's contemporary *The Accomplish'd Ship-Wright and Mariner*, would suggest that the design methods they described were used among common shipwrights. Moreover, they would be of sufficient interest to justify a total of eight editions of Bushnell's treatise and at least one of Hardingham's. Additionally, these books would show that such printed works of reference were a valuable source of information for shipwrights in their quest for instruction and knowledge. Obviously, not

[522] Full title: *Marine Architecture or, the Ship-Builder's Assistant: Containing Directions for Carrying on a SHIP, from the first laying of the Keel, to the actual Going to Sea*.

[523] *Marine Architecture* included a literal copy of Bushnell's *The Compleat Ship-Wright* from which the last chapter which describes how to row a ship in a calm had been removed. In addition it included extracts from Miller's *The Compleat Modellist* and Bond's *The Boat-Swain's Art.*

all shipwrights would use treatises like this. But, as in the case of other how-to manuals that will be discussed in chapter 7, some shipwrights would be capable of producing and accessing written information through written media.

Any study of the development of shipbuilding knowledge in England, and by extension in Europe, should include these sources of evidence to see how their contents could help shape the current narrative. However, this is not the case and in the current scholarship these treatises remain largely ignored. For example, in Steffy's seminal work that still very much underlies the current narrative, the importance of treatises as a source of information is highlighted, especially due to the limited archaeological evidence available at the time of Steffy's writing.[524] Thus, the main line of argument in which Steffy describes the developments that took part during the early modern period is based on short references to Venetian and Portuguese manuscripts and a lengthier analysis of *Fragments of Ancient English Shipwrightery* and *Deane's manuscript*. Bushnell is only described as 'interesting' without further mention to it, its contents or their significance.[525] Hardingham is ignored. Therefore the only printed treatises in English which could have informed of the design practices of the period do not form part of the narrative which is mostly based on manuscripts whose circulation, hence influence and representativeness, is unknown.[526]

The only time that the present author has seen Hardingham mentioned in the context of this research is in *Shipbuilding Practice and Ship Design Methods from the Renaissance to the 18th Century* which discusses ship design methods from the Renaissance to the 18th century. In such a context, Hardingham's treatise could have been used to provide further sources of evidence to supplement the few printed treatises available for analysis. However, it is mentioned once, by Barker, only to say that he had never read it.[527] Thus, valuable sources of information remain identified but ignored. This, however, does not mean that they have been fully ignored. In fact, Bushnell's treatise, in its 1739 edition, was printed as a facsimile by naval historian Brian Lavery in 1993.[528] From it, a very interesting picture can be extracted which highlights the manner in which

[524] Steffy. *Wooden Ship Building and the Interpretation of Shipwrecks*, p. 93.

[525] Steffy. *Wooden Ship Building and the Interpretation of Shipwrecks*, p. 156.

[526] Two of the manuscripts which are constantly referred to in the current narrative, *Fragments of Ancient English Shipwrightry* and *Deanes' Doctrine*, were held at the private library of Samuel Pepys. There are no contemporary references to copies being made for circulation, thus, their possible influence within the ship-builders community should be questioned.

[527] Barker. Whole-moulding: a preliminary study of early English and other sources, p. 42.

[528] Lavery. *Marine Architecture Directions for Carrying on a Ship (1739).*

the accepted narrative shapes the interpretation of the sources of evidence, instead of letting the evidence shape the accepted narrative.

In the introductory pages of the facsimile Lavery describes the historical context in which this treatise was published and it significance to understand the development of ship-design knowledge through the 17th and 18th centuries. In Lavery's facsimile edition the significance of Bushnell's treatise, and its persistence as a widely published book for more than 80 years, is downplayed. To do so, Lavery starts with a premise which serves as the foundation for his subsequent interpretation. In his view, the design method described in Bushnell's *The Compleat Ship-Wright* was totally obsolete by the early 18th century. This opinion would be based on the following idea: that the method of drawing the master section shown in Bushnell's book was obsolete by the time the treatise was published.[529] From this *a priori* assumption –for which no justification is given–, it is concluded that it is doubtful if this treatise would have been of any relevance to practising shipwrights by the time it was re-edited in the mid-18th century. Thus, following with this argument, Lavery concludes that the survival in print of this outdated treatise for such a long period of time must be an indication of the nature of the nautical book market and of little use for the description of ship-design knowledge of the period. At most, it would be of use to understand the practices in small yards which, as it is implied in Lavery's text, would use such outdated practices.[530]

In the opinion of this author, a more interesting approach would have been to conclude that, in view of the evidence provided by such a widely circulated treatise, Lavery's presumption and the theories that support it would not stand. Furthermore, it could be concluded that the accepted narrative which indicates that this manner of drawing the master section is outdated might be wrong. After all, there are no other contemporary printed documents to contrast this opinion with. Thus, one should begin to question where one should place more weight: in the opinions of late-20th century scholars or on the most widely published source of evidence of the 17th to early 18th centuries. In the opinion of the present author, the disagreement between the current narrative and the printed treatise should have been solved in favour of the treatise. Bearing in mind that Bushnell's treatise is the only printed book in which English methods to design a hull are described in the whole of the 17th century, and only one of three until the middle of the 18th century, it should have led to a re-appraisal of the accepted narrative at the time. Instead, this is

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[529] Lavery. *Marine Architecture Directions for Carrying on a Ship (1739)*, p. 16.

[530] Lavery. *Marine Architecture Directions for Carrying on a Ship (1739)*, p. 19.

an unfortunate example of the evidence being forced to fit in the narrative instead of shaping the narrative according to the evidence.

6.2.1.2 Narrative: based on few, selected, features of the design-recipe

The design methods that have been identified during this period are all based on simple design-recipes which create a three-dimensional surface by a process of controlled transformation of a master curve. In such a process of shaping the hull, the shape of the longitudinal control curves and the shape of the master curve play equally important and complementary roles. From the treatises analysed in chapters 4-5 it is not possible to infer that the master section was regarded as the principal design element and the longitudinal control curves played a secondary role. However, in the current narrative, modern researchers tend to identify the master frame with the central element in the design method, while the longitudinal control lines, built following similarly complex graphical and numerical methods – as equally important in the hull shaping process–, do not receive the same attention.[531] Consequently, the current narrative widely states that shipwrights of the period had a transversal understanding of the geometric shape of the hull.[532]

One of the implications of the status given to the master-frame in ship studies is that for many modern scholars the shape of the master frame and, most importantly, the geometric rule used to derive it become the focus of attention. Consequently, the design-recipes used to shape the master frames become proxies from which certain aspects of the development of shipbuilding technology have been extracted. This often follows the assumption that the individual design methods shown in the treatises are representative of particular geographical regions and time periods. Following this assumption, for example, the variation in the geometric methods of

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[531] For example see the emphasis on the geometry of master sections in: Adams. *A Maritime Archaeology of Ships*; Barker, R. 1998. English shipbuilding in the sixteenth century.

[532] Although not every scholar considers longitudinal and transversal approaches, they are very relevant for some influential authors, especially on studies that investigate the transition from shell-first to frame-first construction during the first millennium in the Mediterranean. For example: Pomey, P. 2004. Principles and Methods of Construction in Ancient Naval Architecture. In F.M., Hocker and C.H. Ward (eds). *The Philosophy of Shipbuilding. Conceptual approaches to the study of wooden ships*. College Station: Texas A and M University Press, p. 27; Pomey, P. 2009. On the Use of Design in Ancient Mediterranean Ship Construction. In H. Nowacki and W. Lefèvre (eds), *Creating Shapes in Civil and Naval Architecture. A Cross-Disciplinary Comparison*. Boston: Brill, p. 49; Pomey *et al.* Transition from Shell to Skeleton in Ancient Mediterranean Ship-construction, p. 236; Rieth, E. 2016. *Navires et Construction Navale au Moyen Age: archéologie nautique de la Baltique à la Méditerranée*. Paris, pp. 45, 99; Rieth, E. 2009. L' architecture navale médievale en Méditerraneé: quelques axes de réflexion. *Arqueologia nàutica mediterrània*, pp. 363–380 (p. 371); Steffy. *Wooden Ship Building and the Interpretation of Shipwrecks*, p. 85.

shaping the frames are used as indicators of the development, in time, of the principal design criteria from which the time of construction of particular wrecks could be established.[533]

Chapters 4-5 have shown that a variety of methods were used to define the shape of the master sections. When all methods are compared as in chapters 4-5 there is no clear path that links them geographically or by period. Moreover, it has been shown that according to the writers there were additional methods of shaping the master section and longitudinal control curves which they could have included in the treatise. Therefore, focusing on the details of each recipe may create a false idea about the importance of certain features of the design-recipe. Instead, if the authors of the treatises had described all the known methods available to them, it is possible that the extra methods and recipes available for study would have produced a different result.

6.2.1.3 Narrative: based on few, geographically isolated, sources

Similarly to the previous criticisms, it could be said that the current narrative tends to have a particularistic approach to the evidence which is broken along national boundaries. Such an approach creates artificial boundaries in a knowledge-space that was common, not only geographically but also temporally. In the literature, it is easy to find references to 'Portuguese', 'English' or 'Iberian' design methods, for example.[534] This creates the impression that there must be some strong evidence to suggest that certain geographical origins may be linked to particular geometric constructions. However, as Hocker suggested, generalisations from limited examples may lead to erroneous interpretations.[535] The analysis in chapters 4-5 has shown that design methods do not differ in their conceptual basis, rather in the ways conceptual tools are accomplished. Linking these differences to national boundaries cannot be justified. Especially, as

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[533] For an example of the use of different geometric constructions as the basis of chronological development see: Adams. *A Maritime Archaeology of Ships*, p. 141; Thomsen, C. and Ditta, M. 2014. Analysing the Model of the Princes Channel Wreck by Christian. In J.Auer and T. Maarleveld, (eds), *The Gresham Ship Project. A 16th-Century Merchantman Wrecked in the Princes Channel*, p. 74.

[534] For example: based on a few master frames in *Fragments of Ancient English Shipwrightry,* a distinct English design method has been defined (e.g. Barker, R. 1998. English shipbuilding in the sixteenth century, p. 117). Another example in which a drawing in a treatise is identified with a regional distinct design method is found in: Castro, F., 2008. In search of unique Iberian ship design concepts. *Historical Archaeology*, pp.63–87 (p. 78). One further example could be found in: Loewen, B., 2001. The structures of Atlantic shipbuilding in the 16th century. An archaeological perspective. In *Proceedings of the International Symposium on Archaeology of Medieval and Modern Ships of Iberian-Atlantic Tradition*. pp. 241–58 (pp. 245-246). Also: Barker, R., Loewen, B. and Dobbs, C. 2009. Hull Design of the Mary Rose. In, P. Mardsen (ed.) *Mary Rose Your Noblest Shippe: anatomy of a Tudor warship (Archaeology of the Mary Rose 2).* Oxford: Oxbow Books, p. 35.

[535] Hocker. In details remembered, p. 73.

the limited nature of the evidence cannot provide a continuous line of information regarding general practices for individual nations. Moreover, the realisation that there were numerous other methods that the authors of the treatises could have shown but, by their own admission, they decided to leave aside, indicates that the methods shown in the treatises are just a limited sample of the many examples which could have been described. However, even if this idea is admittedly accepted by modern scholars, the reality is that in the current narrative such artificially drawn national boundaries still feature strongly.[536]

One of the consequences of this particularistic approach along artificially set national boundaries is that it leads to ignoring valuable sources of evidence, or to distorted views of the historic reality. Two such examples will be described briefly.

Furttenbach's 1629 *Architectura Navalis*

In the study of Venetian and Mediterranean ship design methods, Italian manuscripts form one of the most important sources of evidence. Mediterranean design methods influenced European shipbuilding, therefore, their understanding would help understand better the technological transition and transfer of knowledge that was witnessed in early modern European shipbuilding (chapter 2). The study of these manuscript sources could have been supplemented by *Architectura Navalis* written by Furttenbach at the end of the 16th century[537] and printed in 1629.

Despite being a book which was written in German and published in Germany, *Architectura Navalis* describes the design and construction of Mediterranean ship types with numerous figures showing geometric constructions and detailed explanations within the text (figures 85, 86 and 87). Moreover, although it was written in German, all the technical vocabulary used throughout the text is in Italian (figures 85) thus showing a strong influence of the origin of the material. The subject matter and the strongly Italianized language used throughout the treatise would suggest that *Architectura Navalis* could have been used to provide a richer representation of ship design and construction methods used in the Mediterranean at the end of the 16th century and beginning of the 17th century and their influence in European shipbuilding. However, this treatise rarely features in research papers describing Mediterranean design practices. The possible reason for it

[536] For example, in a discussion about a Venetian drawing showing a master frame drafted in 1619, Barker hypothesises about the possible influence of English design practices based, solely, on the similarities with one of the master sections shown by Mathew Baker (Barker, R. 2003. A Venetian Ship Drawing of 1619. In H. Nowacki and M. Valleriani (eds) *Shipbuilding Practice and Ship Design Methods From the Renaissance to the 18th Century. Max Planck Institute for the History of Science, preprint 245*, p. 72).

[537] Furttenbach, J. 1629. *Architectura Navalis*, p. Title page.

is that *Architecture Navalis* was written in German and was published in Germany, therefore, away from the Mediterranean. But, most importantly, out of the focus of researchers who may be using a geographically over-particularistic focus on their research.

The Album of the Marqués de la Victoria

Another example of a geographically particularistic outlook which results in a distorted interpretation of treatises could be the case of the manuscript written by the Marqués de la Victoria (Spain c. 1780) (figures 88 and 89). This manuscript is often used as a key document by students of the developments in ship design and construction in 18th-century Spain.[538] Accordingly, the manuscript would be a detailed source of information on 18th-century Spanish ship design and construction. The illustrations would show the shape and construction features of a number of common Spanish ship-types of the period.[539] Thus, for students of 18th-century Spanish shipbuilding, this document should be of utmost interest. However, when one widens the scope, in time and geographical area, and this treatise is read alongside other publications from Europe a new picture emerges which shows that a significant proportion of the contents in this manuscript are a direct copy of Witsen's treatise published in the Netherlands more than half a century earlier (chapter 4) (figures 88 and 89).

This example highlights the dangers of having a particularistic outlook which presumes that individual treatises must represent the practices followed at specific locations and time periods. By following a particularistic look, researchers have wrongly assumed that the information contained in the manuscript represents mid-18th-century Spanish practice. A wider look, on the

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[538] Some examples which show the manner in which this manuscript has been used to represent 18th-century Spanish shipbuilding:

By using drawings of a ship shown in the manuscript as being representative of 18th century Spanish ships types: Mendoza, B.M.R. 2008. *Standardization of Spanish Shipbuilding: Ordenanzas para la fábrica de navíos de guerra y mercante-1607, 1613, 1618*. M.A. Thesis. Texas A & M University, p. 56, (fig. 3-4).

By considering the manuscript as a representative source of Spanish shipbuilding matters of the 18th century: Novi, C. 1997. The Marqués de la Victoria and the Advancement of Naval Lexicography in Eighteenth-Century Spain. *The Mariner's Mirror*, 83(2), p. 145.

By considering it a vital bibliographic reference, regardless of the doubts raised by an unnamed author who had suggested that the Marques de la Victoria owned a copy of Witsen's treatise and might have copied some of its contents: Rivera Vaquero, I. 2009. Analisis de las Fuentes Bibliográficas Disponibles Sobre Arboladura y Jarcia Españolas. *Revista de historia naval,* (107), p. 11.

[539] Hamelink, M.P. 2014. Pautas para la identificación de tradiciones navales en pecios de finales del siglo XVII y primera mitad del XVIII. *In Arqueología subacuática española: Actas del I Congreso de Arqueología Naútica y Subacuática Española, Cartagena,* 14, 15 y 16 de marzo de 2013, p. 403

other hand, helps place the treatise in its real context and provides an opportunity to extract valuable information from such a manuscript. It may not inform of actual shipbuilding in Spain in the mid-18th century, however, it may still be valuable to learn about the wider movements of information in Europe at this period. [540]

6.2.2 Criticism to the implications of the current narrative: Technical aspects

During this period there were a number of scientists who were trying to understanding the physical natural phenomena and their influence in ship performance. However, this knowledge – often flawed from a modern scientific perspective– did not seem to find any practical application in ship design.[541] Modern scholars have suggested that an increase in the use of drafted plans, of numerical design-methods and early 'science', eventually lead to naval architecture being a scientifically led discipline by the 18th century.[542] However, the analysis of the treatises above has shown that all the treatises discussed describe the same conceptual approach to ship design which is eminently practical and lacking a theoretical framework to justify it.

It is true that there are several treatises described in chapters 4 and 5 that use numerical methods to derive the shape of the rising and narrowing lines, such as *Fragments of Ancient English Shipwrightery*, *A Treatise on Shipbuilding, c.1620* or *The Compleat Ship-Wright.* But, even in these treatises other methods which required no mathematical knowledge are also described. These alternative methods were not considered inferior by their authors. They were offered for the reader who might prefer practical methods to numerical methods. Just like a modern engineering book may offer a formula to solve some problem or a table from which answers to the same problem can be obtained.

Even in a sophisticated mid-18th-century treatise like *Élémens de l'Architecture Navale (1758)*, developed to instruct students of naval architecture in a formal academic environment, a purely geometrical method is used to derive the shape of the longitudinal fairing diagonals and master

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[540] Sutherland's The Ship Builder's Assistant (Chapter 5.7) and Mungo Murray's A Treatise on Ship-building (chapter 5.9) provide another good example of knowledge being used and reused without proper acknowledgement of the sources)

[541] In *Ships and Science,* Ferreiro provides a very interesting account of the long and arduous route which led to the development of naval architecture as a 'scientific' discipline (Ferreiro. *Ships and Science*).

[542] Adams. *A Maritime Archaeology of Ships*, p. 148; Barker. Design in the Dockyards, p. 61; Ditta et al. Albrecht Dürer and Early Modern Merchant ships, p. 87; Lavery. *Deane's Doctrine of Naval Architecture*, p. 21; Rieth. A Similar Atlantic and Mediterranean Ship Design Method, p. 80; Steffy. *Wooden Ship Building and the Interpretation of Shipwrecks*, p. 144.

curve (chapter 5). In common with other end of the 18th-century methods like Mungo Murray's (chapter 5.9) or Arrospide's (chapter 5.10) , the only tool that is required to draw these shapes is a compass which can be used to create the simple geometric construction used to define the curving lines. Mathematical or numerical methods of shaping a hull are not included in the treatise. Thus, it is apparent that different approaches were in use simultaneously, showing that each ship designer would have chosen to use the methods which suited them most; some would prefer mechanical methods based on simple geometry, other would prefer highly numerical methods based on mathematics. It all boiled down to personal choice.

6.2.3 Criticisms to the social implications of the current narrative.

The current scholarship considers that there are some social implications which can be linked to the manner in which ship-design knowledge is put to use, stored and transmitted in shell-first and frame-first traditions. However, the following sections will argue that some of the social implications assumed in the current scholarship can be criticised.

Early modern frame-first construction

It is generally accepted that the adoption of frame-first construction methods led to changes in the process followed to build a ship. In contrast with previous shell-first processes, where there would be no distinct phases of design and construction, in frame-first construction a design method would be used to shape the frames before erecting them. Therefore, the phases of design and of construction would have become two distinct phases, separate from each other, and put in practice by persons who would have been at different levels in the social hierarchy.[543] The design methods of the period are often perceived as being based on a prescriptive approach to ship design based on relatively strict rules.[544] With respect to this, Maarleveld wrote, for example, that English methods like the one described in Deane's treatise did not describe how things were done. Rather, how Dean believed that a ship should be built.[545] This would be reflected in the title itself of Dean's treatise which was simply called *Doctrine*.[546] Accordingly, the design method would

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[543] Adams. *A Maritime Archaeology of Ships*, p. 148; Alertz. The Naval Architecture and Oar Systems p. 144.

[544] Maarleveld. Early Modern Merchant Ships, pp. 349, 355.

[545] Maarleveld. Early Modern Merchant Ships, p. 349.

[546] Jonathan Adams also finds it noteworthy that the word Doctrine was chosen as the title of Deane's manuscript. Adams. *A Maritime Archaeology of Ships*, p. 148.

be 'imposed' on the designer, as a doctrine to follow, who in turn imposed the design onto the practising shipwright.

As a result of the perceived complex nature of the design-knowledge a hierarchical division between master shipwrights –who later became naval architects–, and common shipwrights appeared or became accentuated.[547] One of the main supports of this view would be that the design methods would require a level of geometric and mathematical knowledge that would have made them incomprehensible to the common shipwright.[548] However, the analysis in chapters 4-5 has shown the opposite to be true. The analysis in chapter 4 and 5 describe a type of knowledge which could be understood and put in practice by shipwrights who did not require sophisticated mathematical or technical knowledge. Additionally, they were not forced to follow strict rules that imposed a shape on them. On the contrary, chapters 4 and 5 have shown that the methods were flexible and adjustable. Most authors of the treatises expressed the idea that shipwrights were free to alter dimensions, ratios, or even geometric recipes of design, according to their particular ideas. The existence of a method did not limit or constrain the liberty of shipwrights. On the contrary, it allowed them to freely experiment with changes, knowing that their actions were guided by the rule (see 8.2 for further discussions on this subject). Ethnographic examples (chapter 8) show further evidence of this.

The Dutch case

In Dutch ship design and construction of the period, it is said that the phases of conception of hull shape and of construction were not as clearly differentiated and the ship was built and designed simultaneously (chapter 2). It is generally considered that the Dutch method was not based on geometry and proportions as the other more common European methods were and it is normally accepted that it was a method where the eye of the builder had a direct role in the definition of hull shape during the construction of the ship.[549]

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[547] Adams. *A Maritime Archaeology of Ships*, p. 148.

It is interesting to note that some authors seem to have assumed the idea that the division of labour in hierarchical levels is a consequence of having a method of design. Thus, according to Maarleveld the contrary is also assumed to be true. That is, that in the absence of a method of pre-design 'it becomes quite clear that very little division of labour can be enforced, especially in earlier stages of building.' (Maarleveld. Archaeology and early modern merchant ships, p. 168).

[548] Hasslöf. Sources of maritime history and methods of research, pp. 141-142.

[549] Maarleveld. Archaeology and early modern merchant ships; Garvey, R. 2001. *To Build a Ship. The VOC replica ship Duyfken*. Melbourne: University of Western Australia, p. 8; Hoving. *Nicolaes Witsen and Shipbuilding in the Dutch Golden Age*, p. 9; Verweij et al. Continuity and change in Dutch shipbuilding in the Early Modern period, p. 86.

However, in chapter 4, it has been shown that there are documents which describe design methods in place for Dutch bottom-based construction. Even if these methods are not identical to frame-first design approaches, they do show the manner in which a few parameters could be used to define the three-dimensional shape of a hull before its construction began. Moreover, some examples of archaeological finds have been cited that show, again, construction features and procedures that, while still confirming that the ships were built on a shell-first, bottom-based, manner, they also show that their shapes were controlled by certain tools and transversal elements that contradict the manner in which shell-first shipwrights are understood to shape their hulls (chapter 4). From this, the manner in which Dutch shipwrights are described as having no design methods, thus being able to design freely, in a more egalitarian approach to the social organisation of knowledge and work practices should be put into question. And, if such an egalitarian arrangement of the shipyards existed, it was a republic after all, other reasons besides the alleged non-existence of a design method should be responsible for it.

Chapter 7: Ship-design knowledge in traditional, pre-engineering, ship construction

This chapter will build on the ideas discussed in the previous chapters in order to describe the ship-design knowledge used by shipwrights building ships before the introduction of analytical tools based on engineering knowledge during the 19th century. The chapter will start by looking at some of the general concepts discussed in chapter 2 with respect to the conception of hull shape by traditional, pre-engineering, shipwrights. It is the opinion of this author that the current understanding of the 'problem' of conceiving the shape of a ship can be improved. Therefore, the following sections will offer a new framework with a more nuanced definition of the idea of *conception*, or the manner in which shipwrights are understood to visualise and store hull shape. Thus, it will be suggested that shipwrights of all traditions share the same basic knowledge with respect to how hull-shape is conceived. Then, it will be suggested that the hull-design strategy of early modern shipwrights described in the treatises could have a direct link with the design strategies in place in the ancient Mediterranean.

This chapter will provide a renewed theoretical framework which will be used to discuss the design-knowledge of early-modern shipwrights in chapter 8.

7.1 The design-paradigm of traditional, pre-engineering, shipwrights

This section will explore the design-paradigm of traditional, pre-engineering, shipwrights. This term is used to refer to shipwrights who engaged in the process of making a ship, from conception to construction, without the aid of scientific principles which would help them predict and guarantee –within acceptable levels of uncertainty– the performance of the ship in the water. They could be pre-mid-19th century shipwrights, thus practicing before modern, scientific, analytical processes were invented, or, they could be present-day shipwrights building boats following customary craft traditions.

When Norman Smith described the difficulties of studying the conceptual approach to design in medieval stone masons –who built complex structures without formal plans, in a craft tradition where complex technological knowledge was transmitted orally–, he wrote:

> A not insignificant feature of the problem [how medieval cathedral structures were designed], I believe, is the **absence from a pre-scientific age of evidence really adequate for properly comprehending the distinctive creative and intellectual activity**

> **which structural engineering comprised**. Nor is the point confined to structures. **Within engineering history generally, design procedures, not to mention the very nature of design thinking, are subjects very difficult of access** and which remain, therefore, devoid of very much serious study (Highlights JPO).[550]

Authors like Basch, Pomey and Hocker studied the idea of design thinking, or conception, in shipbuilding traditions, running into similar difficulties.[551] They realised that before the actual construction started, the builder must have processed the shape of the hull in their minds. Understanding such mental process could inform about the choices made by the builder. However, being an abstract process that left no record[552] scholars generally focus on the assembly sequence of the ship as a means of understanding the cognitive processes that led to its construction (chapter 2).[553]

The order in which the elements of the hull are assembled led to the important distinction in this matter (chapter 2). Thus, frame-first builders make the frames of the hull first, therefore, it is assumed that they may see the need to develop a method of designing them beforehand. Contrary to this, shell-builders built the planking of the vessel first (the outer shell) and, according to the definition, did not make any element of the transversal structure of the hull before construction.[554] Therefore, following a complementary line of argument to the one above, it is

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[550] Smith, N.A. 2001. Cathedral studies: Engineering or history. *Transactions of the Newcomen Society*, 73(1), pp. 95–137 (p. 105).

[551] Basch. Ancient wrecks and the archaeology of ships, p. 17; Hocker. Shipbuilding: philosophy, practice, and research, pp. 6-8; Pomey. Principles and Methods of Construction in Ancient Naval Architecture, p. 27.

[552] Even in modern design processes, where the design is recorded in a drafted plan, very rarely is the abstract design process recorded in detail.

[553] For example in these three reference publications, discussions about conceptual approaches to hull conception are still heavily influence by ideas of assembly sequence: Hocker, F. M. and Ward, C. H. 2004. *The Philosophy of Shipbuilding. Conceptual approaches to the study of wooden ships.* College Station: Texas A & M University Press; Steffy. *Wooden Ship Building and the Interpretation of Shipwrecks;* Pomey *et al*. Transition from Shell to Skeleton in Ancient Mediterranean.

[554] The use of moulds erected before the planking, thus determining the transversal shapes of the hull has been suggested for ancient Mediterranean shell-building based on the analysis of archaeological material. See 7.1.4 and: Olaberria, J.-P. 2014. The Conception of Hull Shape by Shell-builders in the Ancient Mediterranean.

Similarly, cognitive mechanisms used to control the transversal shapes of the hull on Nordic shell-building have been suggested: Dhoop, T. and Olaberria, J.P. 2015. Practical Knowledge in the Viking Age: the use of mental templates in clinker shipbuilding. *International Journal of Nautical Archaeology* 44.1, pp. 95–110.

often assumed that they did not need such method of designing transversal shapes; that the three-dimensional shape of the hull would be defined during the construction of the ship.[555] As a result, the different traditions (shell-first and frame-first) are understood to have opposing solutions to the problem of conceiving hull shape and to the associated problem of storing and transmitting such knowledge. Accordingly, they would have opposite paradigms of ship design/construction. It will be suggested that this is not so.

This research would like to address this matter by using the ideas extracted from the analysis in chapters 4-5 and the criticisms to the current narrative in chapter 6. The aim is to build on previous work that studied the *philosophy of shipbuilding*[556] and defined it into three phases which Hocker called *conception*, *assembly* and *structural philosophy* (chapter 2). However, in this instance, the conceptual phase of ship design is approached without any consideration to assembly sequence or to current theories that suggest a link between assembly sequence and the manner in which the shipwright understands the problem of conceiving and storing hull shape. Instead, the problem is approached from a purely abstract stand, guided by Dosi's definition of *technological paradigm* (chapter 3).[557]

The following paragraphs will try to establish the paradigm or *'outlook'* of different traditions of shipwrights, in order to establish how they understood the *'problem'* of creating a hull shape and the cognitive mechanisms that helped them create and store such shape. This will be done by following a reverse route which starts at the known *'solutions'* adopted by the craftsman. From these *'solutions'* it might be possible to infer what the *'problem'* was according to them. And by understanding the *'problem'* it will be possible to define the paradigm, or *'outlook'*, of the practitioner.

In the case of shipbuilding and ship-design, the matter is technically complex and, therefore, it must be tackled always bearing in mind the complex equilibrium that must be maintained in shipbuilding between the three-dimensional shape of the hull and its physical configuration. Despite claims by Rieth who wrote that the study of ships is not more technically complex than

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[555] Hasslöf. Main Principles in the Technology of Ship-Building, pp. 59-60; Hoving. *Nicolaes Witsen and Shipbuilding in the Dutch Golden Age*, pp. 9, 15; Maarleveld. Archaeology and early modern merchant ship, p. 167; Steffy. *Wooden Ship Building and the Interpretation of Shipwrecks*, p. 85; Verweij et al. Continuity and change in Dutch shipbuilding in the Early Modern period, p. 86.

[556] For a reference book on this subject see: Hocker, F. M. and Ward, C. H. 2004. *The Philosophy of Shipbuilding. Conceptual approaches to the study of wooden ships.* College Station: Texas A & M University Press.

[557] Dosi. Technological paradigms and technological trajectories, p. 148.

other forms of craft and that 'naval architecture is a production activity that does not involve a technical [knowledge which is] more complex or difficult to reach than other forms of production',[558] the reality is that, indeed, ship design remains a technically complex engineering endeavour. Naval architects acknowledge, to this day, that it is a discipline were a significant amount of knowledge still has not been derived from a rigorous understanding of their underlying scientific principles.[559] The modern naval architect can analyse a design and establish its main characteristics (weight, stability, strength, and power requirements) from a purely theoretical approach at the design stage. However, only knowledge gained from past experience can dictate if those characteristics are sufficient for a satisfactory performance during use.[560] Consequently, contrary to the idea expressed by Rieth above, who downplayed the difficulties of ship design, they must be highlighted. Thus, when the design paradigm of past shipwrights is studied the complexities of ship design should be born in mind. Arguably, one of the main difficulties in ship design is to create a hull with a shape that matches the weight and weight distribution of the ship.

7.1.1 A premise: Ship-design is an exercise in shape control

Shipbuilding is an activity that extends beyond the practical construction of the ship. Besides shipwrights, who rarely work in isolation, there are numerous other stakeholders whose requirements influence the process of construction of the ship. As a result, shipbuilding requires a social organisation to guarantee that the building process satisfies the often conflicting expectations of the diverse stakeholders (figure 90). What constitutes a successful ship is a subjective matter. From a techno-practical stance only, one could imagine many ways of measuring the level of success of a ship. For example, economy of construction, speed and strength, to name a few. The possibilities are just as varied as there are shipwrights and ship users. This is complicated further, by the variable roles that the same ship can play depending on the circumstances. This is clearly shown in chapter 2 which highlights the multiple roles played by the royal yachts of Charles II, which were the initial goals of this research. These roles may require conflicting performance characteristics hence, in principle, different criteria of success and, consequently, different design strategies. Thus, what constitutes a successful ship and what a

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[558] He compares shipbuilding with other production processes like mining, metallurgy, glassmaking and pottery. (Rieth. *Navires et Construction Navale au Moyen Age*, p. 10. Translated by JPO).

[559] For example: Marchaj. *Seaworthiness: the forgotten factor*, p. 155.

[560] Rawson and Tupper. *Basic Ship Theory. (Vol. 2)* (Fifth edition). Oxford: Butterworth-Heinemann, p. 2.

failure depends on the outlook of the 'judge'. The shipwright, the user or, indeed, the present-day researcher may have different ways of measuring success.

There are, however, three minimum criteria that all successful ships must meet. The first requirement is that it must float. This, however, is not sufficient. It must do it with sufficient freeboard to make it useable (figures 91, 114). Secondly, the ship must have sufficient stability to remain upright at all times during normal use, when heeling forces due to waves, wind or uneven loading disrupt it from its upright position. And, thirdly, the ship must be strong enough to withstand the stresses of its intended service. It should be safe to assume, as a premise which requires no further justification, that all shipwrights and users of ships would have considered these three basic requirements before they built or used a ship. Similarly, it would be safe to assume that the shipwright's knowledge would be configured in such a manner that its practical application would seek to guarantee –within acceptable levels of uncertainty– that ships met these three minimum criteria which are directly determined by the three-dimensional shape of the hull.

The analysis of the treatises in chapters 4 and 5 shows that early modern ship-designers did not have any objective means of analysing the three basic characteristics described above (buoyancy, stability and strength) before the ship was put in the water.[561] However, lacking the theoretical framework and analytical tools did not prevent them from developing an understanding of the direct relation between three-dimensional hull-shape and the buoyancy and stability characteristics of the ship.[562] Shipwrights would be fully aware that, in order for a ship to perform correctly, the three-dimensional shape of its underwater portion must be in harmony with its weight, its weight distribution and, in the case of a sailing ship, its rig. Lacking theoretical tools of analysis, such harmony could only be guaranteed by basing the new designs on past successful ships (hull shapes). These could be modified, with controlled variations, so that their performance could be predicted –within reason– before the new ship was built.[563] This suggests an immediate

[561] The methods to calculate the displacement of the ship which are described in the treatises could only be used as a check to know the weight of the finished ship or of the ship drawn in the plan. These methods did not provide a means which could be used to design a ship to a specific weight.

[562] For example, see the long quotation from Bourne. *A Book called the Treasure for Travellers* in section 3.2.

[563] This manner of proceeding has been common in modern engineering when new technologies made the creation of novel devices possible, even before the development of theoretical analytical methods which could be used in their design process. For example see: Vincenti, W. G. 1990. *What Engineers Know and How They Know It. Analytical Studies from Aeronautical History.* Baltimore: The Johns Hopkins University Press.

question: How could shipwrights 'remember' the shape of a successful ship in order to base a new design on it?

Shipwrights could try to create the new shape from memory, trying to match the shape of the ship under construction with an image recalled from memory. And, indeed, this idea of building '*by-eye'* is commonplace in the current narrative for the shell-first tradition (chapter 2). But, how could such an endeavour ever be successful? How could the shipwright 'remember' three-dimensional shape of a large ship which he may not be capable of observing from the right perspective while it is being built?[564] Even if that were possible, how could shipwrights store such a shape in their memory and share it or transmit it to future generations? Other questions come to mind. For example, how could shipwrights simultaneously change the shape of the hull and its material fabric, *'by-eye'*, and still manage to somehow produce a match between the new volume properties of the hull and the new weight properties of the physical fabric? The conclusion must be that, with the exception of relatively small boats, or extremely gifted shipwrights, the idea of building *'by-eye'* becomes an unrealistic proposition. Especially, on an artefact that was expensive to build whose failure to perform put lives and livelihoods at risk. Shipwrights, therefore, required a means of storing past experience reliably and effectively in some retrievable manner. Within such a method, the need to store three-dimensional shape would be at its core.

7.1.2 The problem of codifying three-dimensional shape on a 'pre-graphically-literate'[565] world

Storing in a code the information regarding the three-dimensional shape of simple objects like buildings, made up of straight lines and simple curves defined by planar surfaces, is relatively simple. Besides using scale plans, memory, simple sketches and simple geometric constructions may be sufficient. However, the storage of three-dimensional information of curved surfaces such as a ship's hull poses significant challenges. For the modern-day technologist accustomed to the reduction of three-dimensional shapes into two-dimensional scale plans it may be simple. However, during the early modern period methods to represent curved surfaces on flat paper had not been fully developed.[566] Early attempts to represent three-dimensional shape like models and

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564 Barker. Many May Peruse Us, p. 543

565 By pre-graphically-literate it is meant a period, or social group, when it was not possible, or common, to use graphical representations to describe the three-dimensional shape of objects.

566 Methods to represent three-dimensional objects on paper by using orthogonal projection were first codified in the late 18th century (Ceccarelli, M. and Cigola, M. 2001. Trends in the drawing of

fold-up paper models (figure 92),[567] are known to have been used to convey a sense of shape to the observer. However, ingenious as these methods were as a means of storage and transmission of three-dimensional shapes, they were not used to create new hull shapes during the early stages of the design process.[568]

Leaving Dutch shipwrights aside for a moment, the solution adopted by early-modern shipwrights would be to create a code –in practice a recipe– that allowed them to produce a three-dimensional shape from a limited number of parameters (chapters 4-5). The code would be based on geometry and its main advantage, as stated by Sutherland in the 18th century, would be that it allowed the builder to store information regarding the three-dimensional shape of ships which he had built before.[569] Shipwrights did not know how to produce entirely novel shapes, leading to innovative ships, of revolutionary performance. Without the means of mathematical analysis on paper, the code –or recipe– would not allow for that.[570] However, by following a methodology which provided a means to store past shapes on a code, the shipwright could use the code to build new ships of predictable shape, hence, predictable performance.

7.1.3 Design methods based on an innate approach to visualising three-dimensional hull shape: The importance of contours

This research proposes to look at the design-recipes described in chapters 4 and 5 by focusing on their common conceptual approach to ship-design. The aim, to find out if the design paradigm

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mechanisms since the early Middle Ages. *Proceedings of the Institution of Mechanical Engineers, Part C: Journal of Mechanical Engineering Science*, 215(3), p278).

567 Fox, C. 2007. The Ingenious Mr Dummer: Rationalizing the Royal Navy in Late Seventeenth-Century England, *Electronic British Library Journal*, p. 21.

568 There is ample evidence of models being used in the 19th century for the design of ships. For example, a hull would be carved in wood and, then, it could be sliced in order to obtain the shape of the waterlines or sections (Hasslöf. *Carvel Construction Technique, Nature and Origin*.p 58). However, these blocks were not shaped following any geometric design process. In contrast, the typical Navy Board models of the 18th century –which are just miniature ships– were designed with the same design methods of their full-sized counterparts.

569 Sutherland. *Action and Reaction equal in a Fluid*. f. 7.

570 For early 19th century commentators, it was better to copy an existing bad design than to try to innovate without the use of mathematical knowledge. For example:

> '[...] I must observe, that there is less danger to be apprehended from copying even a defective [ship design], than from making a new projection, which may please the eye, without accurately ascertaining what effect the alteration may produce.' (Stirling, C. 1825. *Letters on Professional Topics. London*, J. and W. T. Clarke, p. 29).

described in those treatises and expressed on the design-recipes is based on an innate or natural way of visualising three-dimensional shape. However, if that were the case, could this innate way of visualising three-dimensional shape be identified in other shipbuilding traditions which are said to have a radically different approach? The following paragraphs will argue in favour of this.

Fred Attneave, who studied visual perception, wrote, 'information [about the shape of an object] is concentrated along contours.'[571] The edges of an object, or its contours, would play a fundamental role in the human ability to recognise its three-dimensional shape.[572] This is fully exploited in numerous publications which provide visual information helpful to identify three-dimensional objects, such as aeroplanes and boats (figure 93), or on some cartographic styles (figure 94). Therefore, if humans in general tend to recognise the shape of three-dimensional objects by paying special attention to their contours, it is safe to assume that shipwrights and ship users are no different.

Given the importance of the contours in the recognition of three-dimensional shape, it is plausible that, for practical shipwrights, the two most visible contours of the hull –the profile (backbone) and the cross-sectional shape of the widest part of the hull (master section)– would become the most prominent elements which define its three-dimensional shape (figures 95 and 96). Hence, these shapes would become the point of focus when linking basic performance characteristics and hull shape –albeit in a qualitative manner. For example, it requires no effort to imagine a shipwright or ship-user approaching a boat (figures 95 and 96) pondering if it would be safe to use at sea. One can imagine them observing the boat at a distance, from an angle close to the one shown in the photographs. If the shipwright or user were familiarised with similar boats, these two views would allow them to estimate its behaviour in the water –its performance–, and decide to embark on it or not, for example. Those shapes would be '*self-apparent'* to shipwrights and experienced ship users.

For this author, it can be safely assumed that anyone who has had any experience with boats and ships, and seen them out of the water, would find it natural to 'look' at the boat from these two angles. Consequently, in the paradigm that defines the 'problem' of what a boat or ship is –or as Rieth calls it their way of 'thinking' about the ship–[573] these two contours would be recognised at the core of the paradigm.

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[571] Attneave, F. 1954. Some informational aspects of visual perception. *Psychological review*, 61(3), p. 184.

[572] Knill, D.C., 1992. Perception of surface contours and surface shape: from computation to psychophysics. *JOSA A*, 9(9), pp. 1449–1464 (p. 1449).

[573] Rieth. L' architecture navale médievale en Méditerraneé, p. 42.

7.1.4 The conception of hull shape in the different shipbuilding traditions. A shared paradigm

Following on the previous ideas, this section will argue for the existence of a common design paradigm built up around the innate manner in which humans interpret three-dimensional shapes based on their contours. In the case of ships, its profile and main transversal section. It will be shown that the different traditions – regardless of their assembly sequence (chapter 2) – created methods to store information about these two contours, without favouring one above the other. Thus, suggesting a common paradigm of understanding hull shape.

As stated in Chapter 2, Hocker defined the theoretical framework which allows scholars to study the paradigms of the different shipbuilding traditions by breaking down the process of building a ship into three distinct phases which he called: *conception*, *assembly* and *structural philosophy. Conception* would represent the mental process by which the shape of the ship is imagined in the mind of the shipwright.[574] In order to improve on the current understanding of shipbuilding traditions allowed by Hocker's theoretical framework, this author proposes to subdivide the phase of *conception* into three additional aspects. This subdivision would only be a means of analysing further the paradigm of hull conception in a theoretical manner, without suggesting that the shipwright would ever consider such artificial divisions. The first aspect in which *conception* could be subdivided would be the *core information* required to define the shape of the hull. The second aspect would be the actual mechanism –physical, cognitive, etc.– used to *store the core information* defined in the first step. Finally, the third aspect in which *conception* could be subdivided would be the strategy followed to *develop the three-dimensional surface* of the hull from the core information stored in step two.

The following sections will analyse the three separate aspect in which the *conception* phase can be subdivided in the shell-first and frame-first traditions of Europe. It will be done by first looking for the *core information* of the design paradigms for each tradition. That is, what parts of the ship are defined in the design paradigm? Is the whole surface designed? The two contours? One contour only and the rest of the shape defined by eye? Is there no design method and is the ship's surface developed fully by eye? Then, having established which areas of the hull are defined following some design strategy, the actual *mechanism* used to *store the core information* will be described. And finally the *strategy* that might be used to *develop the three-dimensional surface* of the hull from the core information will be described.

[574] Hocker. Shipbuilding: philosophy, practice, and research, p. 6.

The analysis in the following sections will focus on the design paradigm in place in the four traditions which cover the principal shipbuilding traditions in Europe since antiquity to the modern period. They are: (1) the early-modern frame-first paradigm reflected in chapters 4-5; (2) the early-modern Dutch bottom-based ship building tradition (chapters 3-4); (3) the shell-first clinker-building traditions in Northern Europe;[575] (4) the shell-first building traditions of the ancient Mediterranean.[576] The subdivision of *conception* in these three aspects should help redefine their design paradigms (see table 5 for a tabular representation of the following sections) and will help locate the ship-design knowledge of early-modern shipwrights within a more nuanced theoretical framework (chapter 8).

7.1.4.1 Early modern frame-first (chapters 4-5)

The core information: the contours:

The analysis on chapters 4-5 shows that early modern frame-first builders built up their design paradigm around the two contours of the ship, its backbone and its master section through the widest part of the hull (table 5).

The 'mechanism' used to store the contours:

Having chosen those two elements, shipwrights developed a means of storing their shape in a code (chapters 4-5). In theory any shape defined in a free manner could be used to define these two shapes. However, trying to store them for future reference would require the ability to record those shapes in graphical or numerical methods which at the time had not been developed fully yet.[577] A full-sized template would also work, but only for smaller boats, as their size in larger ships would render them difficult to store and transport outside of the shipyard, hence, defeating the idea of storing and transferring the knowledge.[578] Therefore, lacking this ability to store free

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[575] Hasslöf's studies on the Nordic clinker traditions established the groundwork for the current understanding of the design paradigms of the shell-first and frame-first traditions (e.g. Hasslöf. Main Principles in the Technology of Ship-Building).

[576] In the current understanding of shipbuilding in the ancient Mediterranean ideas about the conceptual approach followed to develop the three-dimensional shape of ships play a crucial role (e.g. Pomey *et al*. Transition from Shell to Skeleton in Ancient Mediterranean).

[577] The exception would be Venetian shipwrights building standard designs in formally organised ship construction programs. Building repeated designs within well-established shipyards allowed them to store the shape of the stems and master sections of the hulls as a series of offsets, and most probably in full sized templates (chapter 4).

[578] Templates are commonly used to store and transmit the shape of boats in traditional boatyards. For example see: Castro and Gomes-Dias. Moulds, Graminhos and Ribbands, p. 3; McGrail. Portuguese-derived ship design methods in southern India? p. 123; Rieth. *Le Maître-Gabarit la Tablette et le*

shapes effectively, and bearing in mind that the objective was to create a shape that could be remembered and modified in a controlled manner, early modern shipwrights relied on constructive geometry as a means of creating shapes. Thus, the recipe played the dual role of creating and storing information (table 5).

At first sight, the use of seemingly complex geometric methods would seem to be suggest, as often stated in the literature, that highly skilled and sophisticated minds were responsible for the invention of these methods. However, in the technological and cultural landscape of the period, constructive geometry was used by other craftsmen in the same manner as the one suggested above. For example, in architecture –both for high status buildings[579] and vernacular architecture[580] – the construction of musical instruments[581], furniture[582], to name a few. In those cases, geometry is not seen as a response to the world view of learned individuals who developed complex design approaches which were then imposed onto the more humble craftsman. On the contrary, the use of geometry is seen as a tool developed by the common practitioner as a means of guaranteeing the storage and transmission of shape and, hence, shape-related performance characteristics and also to allow repeatability and controlled variation of designs. The type of geometry used in these crafts did not require complex knowledge, nor sophisticated tools. All that was required was a simple set of instruments which were, at the same time, construction aids, storage devices for design information, and transmission devices which allowed the movement of ideas and information.[583] The actual tools –square, straight edge and compass– were accessible to

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Trébuchet, p. 191; Rieth. *Navires et Construction Navale au Moyen Age*, pp. 256-261; Taylor. *Boat Building in Winterton*, p. 5.

[579] Ottenheym, K. 2011. 'Architecture according to proportions and rules of the Antique.' Architectural design systems in Dutch seventeenth-century classicism. In Jean-Philippe Garric, Frédérique Lemerle et Yves Pauwels (dir.), *Architecture et théorie. L'héritage de la Renaissance. Collections électroniques de l'INHA. Actes de colloques et livres en ligne de l'Institut national d'histoire de l'art*.

[580] Hubka, T. 1979. Just folks designing: Vernacular designers and the generation of form. *Journal of architectural education*, 32(3), p. 28.

[581] Birkett and Jurgenson. Why Didn't Historical Makers Need Drawings? Part I; Birkett and Jurgenson, W. Why Didn't Historical Makers Need Drawings? Part II; Birkett, S., and Jurgenson, W. 2000. Geometrical Methods in Stringed Keyboard Instrument Design and Construction. *Matière et musique: the Cluny encounter: proceedings of the European encounter on instrument making and restoration, 1,* p. 283.

[582] Walker and Tolpin. *By Hand and Eye.*

[583] For example, in the context of stonemasonry, the role of tools (square, straightedge and compass) as a means of storage and transmission of information has been studied: Sené, A. 1970. Un instrument de précision au service des artistes du moyen âge: l'équerre. *Cahiers de civilisation médiévale*, 13(52), p. 349–358; Sené, A. 1972. Quelques instruments des architectes et des tailleurs de pierre au Moyen Âge: hypothèses sur leur utilisation. *Actes des congrès de la Société des historiens médiévistes de l'enseignement supérieur public*, 3(1), pp. 39–52; Shelby, L.R. 1961. Medieval Masons' Tools: The Level

all. However, the geometrical knowledge which could be used to design buildings, instruments and other constructions would require more specialised knowledge, shared only by a few, but always based on the same simple tool-set.[584]

How to develop the three-dimensional surface:

In the case of early modern frame-first builders designing ships following the methods analysed in chapters 4-5, it has been shown that the method to develop the three-dimensional surface of the hull was determined by the main contours of the ship. The shapes of the transversal sections of the hull were obtained from a controlled transformation of the shape of the master frame (table 5) (chapter 5).

In order to transform the master section, designers relied on a variety of methods, which in effect used long gentle curves to control the gradual change in shape of the master section into the other sections of the hull (chapters 4-5). Those control curves were obtained by geometric or numerical methods. The adoption of geometric constructions for the longitudinal fairing of curves would fit well within the technological-landscape of the period, as similar strategies are known to have been used for the creation of gentle curves in architecture. For example, for the shaping of long curved elements, such as the *stylobate* or curved floors of public spaces.[585]

7.1.4.2 Early-modern Dutch bottom-based tradition

The particularities of Dutch ship design methods have been discussed in chapters 2 and 4. The Dutch of this period started the construction process by erecting large parts of the bottom of the hull before any internal structural members were inserted. As such they would belong to the shell-first tradition, although, taking into account that only the bottom is erected shell-first it is often known as bottom-based construction.[586] As already stated in previous chapters, the process of design in Dutch construction is often associated with a building process where the shipwright

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and the Plumb Rule. *Technology and Culture*, 2(2), pp. 127–130; Shelby, L.R. 1965. Medieval Masons' Tools II. Compass and Square. *Technology and Culture*, 6(2), pp. 236–248; Wu, N. 2000. Hugues Libergier and his Instruments. *Nexus Network Journal*, 2(1-2), pp. 93–102.

[584] Abbate, F. 2006. The Planning and Building Instruments of Architects in the Late Middle Ages. In M. Dunkeld, J.W.P. Campbell, H.Louw, M. Tutton, B. Addis and R. Thorne (eds) *Proceedings of the Second International Congress on Construction History [Volume 1]*. Queens' College, Cambridge University, pp. 111-125; Shelby, L.R. 1972. The geometrical knowledge of mediaeval master masons. *Speculum*, 47(03), pp. 395–421.

[585] Heyman, J. 2009. The curvature of the stylobate. In F. J. Girón Sierra and S. Huerta Fernández (eds), *Auguste Choisy (1841-1909): L'architecture et l'art de bâtir : Actas del Simposio Internacional celebrado en Madrid,19-20 de noviembre de 2009*, pp. 277-288.

[586] Hocker. Bottom-based Shipbuilding in North Western Europe.

builds and designs simultaneously. However, chapters 2 and 4 have shown that methods of predesign and geometric control had been suggested in the literature and can be identified in the few available contemporary written documents (chapter 4). This section will suggest that the design paradigm of the early modern Dutch shipwright building on the bottom-based tradition included a precise understanding of both contours of the ship before construction commenced.

The core information: the contours:

In Dutch bottom-based construction the contours of the ship also played a central role in the manner in which shape was perceived. The idea that Dutch shipwrights of this period pre-determined the shape of the backbone of the hull is not disputed. The problem arises when the idea of predetermination of the main section of the hull is suggested.

Figure 47 shows, in graphical form, the data included in a written specification for a yacht described by Witsen in his treatise (chapter 4). The reference points for which Witsen gives their position are shown in red and can be used by the shipwright to define the shape of the two contours of the ship: the backbone and transversal master section. The tools described in the following section will show the process.

The 'mechanism' used to store the contours:

In Witsen's specification for a yacht, shown in figure 47, the longitudinal profile of the hull is defined by the four points marked in red supplemented by the geometric definition of the stem. This would usually be made up of an arc of a circle or would be defined as an offset from a straight line thus, if this was known, the shape of the backbone could be pre-determined and made before the construction process began. The shape of the other self-evident shape, the contour of the master section, is defined in this case by three points. One of the points marks the deadrise angle and half-breath of the bottom which has been described as one of the key elements in Dutch design procedures (chapter 4). This may appear to be insufficient as, obviously, the master frame would have a curved shape. However, there are evidences which suggest that additional methods to determine the shape of the master section were used in the Dutch bottom-based tradition. Thus, the geometric design-method of the master frame shown by Witsen (figure 54), the pre-erected frames described by Van Holk[587], the control frames suggested by Batcharov for the hull of the Vasa,[588] and the pre-erected frames shown by contemporary author Rålamb (figure 56) suggest that transversal master frames were commonly erected during construction.

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[587] Van Holk. Maritime archaeology, mind-set and money, p. 46.

[588] See chapter 2.2.3.

Consequently, the few points shown in Witsens specification might have been sufficient for a simple written specification –which would set certain key points of the hull shape–, leaving the actual design of the master section to the shipwright. Whether this method followed a geometric approach as described by Witsen, or was based on templates, or even on controlled variation of bevel angles between planks as suggested by Lemée[589] does not negate the fact that a direct manner of controlling transversal shapes was part of the repertoire of design-tools available to the 17th-century Dutch shipwright of the bottom-based tradition. And, indeed, Rose suggested that certain areas of the hull of the 17th-century Vasa might have been designed using simple geometrical forms.[590]

The painting *The Shipbuilder and his Wife,* painted by Rembrandt in 1633 provides further evidence to suggest that Dutch shipwrights of the period designed the two contours of a hull before construction started. It shows, Jan Rijcksen (1560/2-1637), master shipbuilder of the Dutch East India Company at his desk (figure 97).[591] He is shown working in a document which contains information about the profile of the ship, its master section and the shape of the transom. This is the graphical equivalent of the information contained in the specification by Witsen discussed above (figure 98). From the painting it is not possible to establish how those shapes were obtained. But, it could be suggested that, in common with the strategies shown in Witsen's treatise (figure 56) geometry might have played a role in defining those shapes.

Rembrandt depicted the shipbuilder in a manner that would be fully recognisable to the public. As such, he is shown with a shipwright's plan, the inclusion of which, indicates that the viewing audience would have been familiar with the concept of shipwrights using plans where, at least, the main contours of the hull were specified. It is interesting to note the similarities between the plan that Jan Rijcksen is holding (figure 98) and figures 18 and 78 which represent the information required to shape a Venetian hull of the 15th century (figure 18) and an English design of the second half of the 18th century (figure 78). In all cases identical information shown, albeit with extra lines in figure 78.

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[589] Lemée. *The Renaissance Shipwrecks from Christianshavn*, p. 139.

[590] Rose, K. 2014. *The Naval Architecture of Vasa. A 17th-century Swedish Warship*. Phd Dissertation. Texas A and M University, p. 292.

[591] "The Shipbuilder and his Wife": Jan Rijcksen (1560/2-1637) and his Wife, Griet Jans 1633. *RCIN 405533*. Picture Gallery, Buckingham Palace. https://www.royalcollection.org.uk/

<u>*How to develop the three-dimensional surface:*</u>

A means of developing the shape of the hull from its main contour amidships towards the ship's ends would still be required. However, in the case of Dutch bottom-based construction, the shape of the bottom, and especially how it narrows and rises towards the ends of the hull plays a central role (see chapter 4, figure 50). Information about this rising and narrowing of the ends of the bottom are included in specifications and were described by Arnoul and Witsen (chapter 4). This, and the use of templates for the topsides, or some pre-erected frames would allow shipwrights the means to develop the shape of the hull from a reduced number of parameters (figure 47). However, instead of using mathematically or geometrically derived longitudinally fairing lines, the Dutch used the 'rising' and 'narrowing' of the bottom and physical ribbands for the topsides for this purpose (figure 52) (table 5).

7.1.4.3 Northern European shell-first builders

<u>*The core information (the contours) and how the shape of the contours is stored.*</u>

Based on the analysis of ethnographic and archaeological evidence in which the current narrative describing the design strategies of Northern European shell-first builders is sustained, Thomas Dhoop and the present author proposed that in the design process followed by shell-builders mental templates of the transversal shape of the hull play a fundamental role that has not been fully recognised in current scholarship. Based on the particularities of the building process of northern European shell first builders, such templates need not take a physical form and are transformed into simple rules-of-thumb or small tools and control devices.[592] These could have been the cognitive devices developed by Northern European shell builders in order to be used for the design of hulls, and play a crucial role in the storage and transmission of their traditional ship design knowledge (table 5).[593]

Just as in the case of shipwrights of other traditions described above, who would have organised their strategy to store hull shape around the natural role of the contours of an object in the process of identifying its three-dimensional shape, the cognitive tools derived by northern European shell-first builders point in the same direction. These tools are shown in figures 99 and 100 which show two of the most relevant information storing devices that have been described in Northern shell-first building. With both devices the basic shape of a ship can be defined, and it will

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[592] Dhoop and Olaberria. Practical Knowledge in the Viking Age, p. 3.

[593] Dhoop and Olaberria. Practical Knowledge in the Viking Age, p. 13.

be shown that they facilitate the storage of the two 'self-apparent' shapes defined above: the backbone of the ship and its maximum transversal contour, or master section.

The first such element is a simple geometric design method followed to define the shape of the profile of the hull (figure 99). More precisely, it is the geometric method that was identified in the stem of the Skuldelev3 ship, built *c.*AD 1030–1050 with wood that was felled in western Denmark.[594] Most likely, such a geometric construction would have been contained in a rule-of-thumb which could be remembered. The second, and crucial, element is shown in figure 100. It is a boat bevel-board used by clinker builders to control the angles of the planks of a boat during construction. This and similar tools are often described as aids for the construction of symmetrical ships.[595] Also their role as storage of information of plank bevels is sometimes suggested.[596] But, on those occasions the full significance of this is not acknowledged.[597]

When figure 101 is observed, the full significance of the tool becomes apparent. The information contained on one of the faces of the tool (figure 100-left) describes the bevel angle of each of the 12 planks of the hull with respect to a plumb line at one specific location along the ship's length: the point of maximum breadth or master section. It should be noted that this face of the tool does not include any extra information about other sections of the hull, nor about any other position along the ship. Therefore, it should be understood as a physical record of the master section of the hull which is shown in figure 101. It is a simple and very effective method of storing the transversal shape of the hull, which is not visually apparent. It might not be a drafted plan, or a full-size template or a recipe to create a shape, however, it is a detailed record of a master section, thus, a sign that for the makers of this tool, the shape of the master section was significant and, most crucially, that it formed one of the core elements of the design paradigm (table 5).

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594 Crumlin-Pedersen. and Olsen. T*he Skuldelev Ships I*, pp. 240–1.

595 Christensen, A.E. 1972. Boatbuilding Tools and the Process of Learning. In O. Hasslöf, H. Henningsen and A. E. Christensen (eds) *Ships and Shipyards – Sailors and Fishermen*, 27-59. Copenhagen, p. 242; Hasslöf. *Carvel Construction Technique, Nature and Origin*, p. 50; Westerdahl, C. 2008. Boats Apart. Building and Equipping an Iron-Age and Early-Medieval Ship in Northern Europe. *International Journal of Nautical Archaeology*, 37(1), p. 18.

596 Christensen, A.E. 1972. Boatbuilding Tools and the Process of Learning, p. 241.

597 Westerdah wrote that '[building] according to the 'shell-first' principle [n]othing could be committed to paper or to any other type of record to be consulted along the way' (Westerdah. Boats Apart, p. 18). Figures 100, 101 shows that there were indeed recording methods in use.

When this tool and the information it contains is combined with the knowledge of the geometric method followed to derive the shape of the stems, hence the backbone, two of the main parameters which help humans recognise, and remember, three-dimensional shape –the contours– become available to the shipwright. Thus, showing again that in this tradition, the shipwright had means of storing longitudinal and transversal information (table 5).

How to develop the three-dimensional surface:

Although, the bevel-board described above is an effective way of storing transversal cross-sections, there are no indications of how this shape was conceived initially. Similarly, the manner in which the shape of the hull is formed towards the ends, does not seem to follow a regulated procedure, perhaps relying on the fairing properties of the planking to control the gradual thinning of the hull towards the ends. However, means of recording the widths of the hull at intermediate positions from amidships to the ship's ends have been recorded on historic documents and ethnographic examples, thus suggesting some intermediate controls (table 5).[598]

7.1.4.4 Shell-first builders of the ancient Mediterranean

The core information: the contours:

In the current scholarship that describes ancient Mediterranean shell-first design and construction, methods of pre-design for the backbone had been identified in the literature and had become accepted (figure 102). However, it is generally considered that, following the definition of shell-first construction, shipwrights of this tradition did not use any direct means of controlling the transversal shapes of the hull. Interestingly, during the 1st millennium, a transition took place within the Mediterranean from shell-first to frame-first construction. This process raises the interest of scholars who try to understand this transition. However, as the current scholarship assumes, in general, that both traditions visualised the ship as two opposing paradigms, the study of the process of transition is made complex and is obscured by such an oversimplified definition of the design paradigms.[599]

Authors like Bonino, Bellabarba, and the present author, however, suggested that design procedures which defined the transversal shapes of the hulls could be identified in the archaeological record on ships built prior to the transition from shell-building to frame-first

[598] Christensen, A.E. 1972. Boatbuilding Tools and the Process of Learning, p. 241; Manwaring, G.E. 1922. A ship of 1419. *The Mariner's Mirror*, Vol 8, p. 376.

[599] Hocker. Shipbuilding: philosophy, practice, and research, p. 6.

building (e.g figure 103). [600] The analysis of archaeological material and previously published work identified possible signs of pre-design of the master frames and transversal section in a number of well-preserved ship remains such as the Kyrenia (4BC), Marsala, (3BC), Laurons-2 (2-3AD), of Hellenistic, Punic and Roman origin respectively.

Therefore, modes of predesign for both contours were identified, without favouring transversal or longitudinal aspects of hull shape (table 5).

The 'mechanism' used to store the contours:

In the cases of the Kyrenia, Laurons 2 ship (figure 103) –where the ship remains allowed for an analysis of their shape–, it was suggested that the contours described above were derived following geometric design methods (table 5). The geometrical constructions were simple, based on arcs of a circle and simple ratios.[601] The use of constructive geometry to define the shape of some of the key curves on a ship, its main contours, would appear to be a natural choice in a technological-landscape where using geometry to define the shapes of curved objects was common among craftsmen, such as stone masons and engineers. [602]

How to develop the three-dimensional surface:

One of the most interesting aspects of ancient Mediterranean shell-first hull design is the manner in which the three-dimensional shape of the hull's surface is obtained. According to the currently prevalent narrative, the transversal shapes of the hull were not predesigned. However, authors like Bonino, Bellabarba, and the present author suggested that, in addition to the master sections of the hulls being predesigned, the analysis of the evidence suggested that the transversal shapes of the Kyrenia, Marsala, Laurons-2, Nemi boats had been obtained by a process conceptually identical to processes described in chapters 4-5.[603] According to this, a template made with the shape of the master section would have been used to define the transversal shapes of the hull by risings and narrowings (table 5). This method is conceptually identical to the process called whole

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[600] Bellabarba. The Origins of the Ancient Methods of Designing Hulls: a hypothesis; Bonino, M. 2012, Evidence of Geometric Operators used to Shape Ancient Hulls; Olaberria. The Conception of Hull Shape by Shell-builders in the Ancient Mediterranean.

[601] Olaberria. The Conception of Hull Shape by Shell-builders in the Ancient Mediterranean.

[602] For example: Wilson Jones, M.A. 2009. Ancient Greek and Roman Architects' Approach to Curvature-The Corinthian Capital, Entasis and Amphitheaters. In H Nowacki and W Lefèvre (eds), *Creating Shapes in Civil and Naval Architecture: A Cross-Disciplinary Comparison*. Leiden: Brill, p. 100.

[603] Bellabarba. The Origins of the Ancient Methods of Designing Hulls: a hypothesis; Bonino, M. 2012, Evidence of Geometric Operators used to Shape Ancient Hulls; Olaberria. The Conception of Hull Shape by Shell-builders in the Ancient Mediterranean.

moulding described in chapter 5. This will be used in section 7.2 to suggest a possible link between the design approach in the ancient Mediterranean and the post-medieval methods which eventually reached the early modern period (chapter 2, 4 and 5).

7.1.4.5 The conception of hull shape in the different shipbuilding traditions. A common approach based on the contours of the hull.

The previous sections have analysed the paradigm used by different shipbuilding traditions to *conceive* the shape of their hulls. These four traditions are: (1) the early-modern frame-first tradition reflected in the treatises analysed in chapters 4-5; (2) the early-modern Dutch ship builders building in the bottom-based tradition; (3) the shell-first clinker-building traditions in Northern Europe; and (4) the shell-first building tradition of the ancient Mediterranean. The goal of the analysis has been to establish if the four traditions had different design paradigms as it is accepted in the academic literature or if, on the contrary, they shared a common paradigm with respect to the manner in which hull-shape was visualised, defined and stored. To do so, Dosi's definition of paradigm has guided this analysis. Thus, this analysis has looked at the paradigm of hull conception by trying to answer the following question: when shipwrights were confronted with the *'problem'* of building a new hull, what *'solution'* did they find in order to solve the *'problem'* of developing the three-dimensional shape of its hull?

The *'solutions'* found to the *'problem'* of creating/storing three-dimensional hull-shape have provided the clues which can be used to analyse the paradigm of hull *conception* for each of the four traditions. In order to analyse the paradigm used by each tradition, the idea of *hull conception*, as defined by Hocker (chapter 2), has been divided in three additional aspects which are: (1) the *core information* required to define the shape of the hull; (2) the actual *mechanism* – physical, cognitive, etc.– used to *store the core information*; (3) the strategy followed to *develop the three-dimensional surface* of the hull.

By comparing the *core information* around which the design paradigm of the four traditions is formed, it becomes apparent that, when shipwrights of each tradition were confronted with the *'problem'* of creating/storing three-dimensional shape, they found that the *'solution'* rested in creating/storing information about, at least, the two contours of the hull – master section and backbone (table 5) (e.g. figures 95-96). The innate manner in which humans perceive three-dimensional shape by focusing on the contours of an object would be relevant in this respect. The *'outlook'*, or paradigm, of the shipwrights in all four traditions considered the two main contours of the hull simultaneously and with equally sophisticated cognitive mechanisms. All four traditions would share the same abstract approach to 'understanding' hull shape –the same paradigm–

which, contrary to the currently widely accepted ideas, would be neither longitudinal nor transversal.

The main differences between the four shipbuilding traditions would lie in the actual techno-practical approach followed in order to, firstly, create the 'tool' which would allow shipwrights the means to create and store the two contours of the hull and, secondly, in the manner in which the three-dimensional shape of the hull's surface would be created from those two contours (table 5). In all four cases, geometrical methods used to conceive the shape of the backbone had already been accepted in the current scholarship. However, while it is fully accepted that early modern frame-first builders had geometric methods which they could use to define the shape of the transversal contour of the hull –the master frame–, this is not normally the case for shell built hulls (chapter 2). Despite this, the discussion has highlighted that there have been authors who after analysing archaeological and historic material, arrived at the conclusion that, indeed, in two of the shell first traditions – early-modern Dutch bottom-based and ancient Mediterranean shell-first–, shipwrights had developed 'tools' to define the shape of their master-sections based on simple geometry. Thus, in those two traditions, shipwrights would have used simple rules-of-thumb and simple geometric-recipes to store information regarding the main transversal-section of the hull. In northern European shell-first construction, physical tools to record the shape of the master-section of the hull have been recorded, although, the manner in which those shapes were derived in the first place cannot be ascertained (for example: figures 100-left, 101). This common manner of reducing three-dimensional hull shape to that of its two main contours could help understand the transmission of knowledge between shipwrights of different traditions. Thus, shipwrights willing to learn the methods of another tradition would not be required to change the manner in which they visualised hull shape. All that would be required would be to learn to use the 'tools' necessary to conceive and store the two main contours of a hull. In some cases those tools would be cognitive devices (geometric recipes) and in other cases physical tools (bevel-board, templates etc.). This of course would not be a simple task.

Finally, the manner in which shipwrights use these contours to determine, or control, the shape of the rest of the hull shows two distinct approaches. These, again, can be understood as 'tools' the use of which can be learned without it requiring a change in the paradigm which defines how hull shape is understood (table 5). In the case of early modern Dutch bottom-based construction and the northern European shell-first tradition, builders do not seem to have a regulated method of controlling the manner in which the shape of the hull surface is transformed from its widest section in the master-section towards the ends of the ship where, obviously, it becomes narrower. In both cases the fairing properties of either ribbands –for the Dutch case– or the planking itself may play an important role. Although, in the Dutch case the narrowing and rising of the bottom would also play a fundamental role (chapter 4). Mediterranean shell-first builders and early modern frame-first builders, on the other hand, show an identical approach to the problem of controlling the manner in which the shape of the surface of the hull is obtained as it changes from the widest section towards the ends. Remarkably, in both cases the strategy adopted by shipwrights would be based on the same principles.

7.2 Same ship design strategy from antiquity to the (19th century) modern period

The discussion in the previous section will be used to return to the particular case of early modern shipwrights and ship-designers in order to explore the origins of their ship-design knowledge. It will be proposed that a direct link can be suggested between the design-knowledge of the ancient Mediterranean and the post-medieval period. This would suggest that since antiquity to the early 19th century there was no real alteration in ship-design knowledge and that the design paradigm remained constant.

In 1988 Richard Barker suggested that the post-medieval tradition of building ships after a process of design based on the conceptual approach described in the treatises in chapters 4 and 5 could have originated in the ancient Mediterranean. He wrote:

> In view of the extensive use of Greek geometry by treatises and shipwrights alike; of the preliminary reconstructed lines of the 7th century pre-skeleton Yassi Ada wreck; and of records such as the mass production of classical galleys in time of war, **we may even wonder whether the basic design technique for forming [frame-first] hull shapes derive directly from the classical world**. (Highlights JPO)[604]

Such a link is not disputed in other fields of study such as, for example, architecture or water technologies. However, in the case of historical ship studies, the current scholarship poses some challenges when such a link is proposed between the design methods of the ancient Mediterranean and the post medieval period.[605] In this section the focus of interest lies in trying to find a link between the ancient Mediterranean shell-first tradition and the early modern frame-first tradition. After all, the methods described in chapters 4 and 5 have been described as having

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[604] Barker. Many May Peruse Us, p. 559.

[605] For example, the attempt to clarify this transition within the current framework of the two opposing paradigms leads, in the opinion of this author, to unsatisfactory solutions. See: Pomey et al. Transition from Shell to Skeleton.

Venetian origins from where they spread to the rest of Europe via alternative routes. Thus, a link between the ancient Mediterranean shell-first construction and early modern frame-first construction would seem a plausible proposition, were it not for the alleged opposing paradigms which these two traditions are said to represent (chapter 2).

Section 7.1.4 has looked into the design paradigm of different traditions –by subdividing the idea of *conception* described by Hocker in three different aspects which are shown in table 5– and concludes that there are no such paradigmatic differences between the manner in which three-dimensional hull shape is conceived in the four shipbuilding traditions described. Looking for similarities in the manner in which both traditions –ancient Mediterranean and early modern– understood the problem of conception of hull shape, from table 5 and section 7.1.4.5, it is apparent that in both traditions the design paradigm of the shipwright was centred around the two contours of the hull: a longitudinal section defined by a transversal section at its point of maximum breadth (e.g. figure 95) and its backbone (e.g. figure 96). However, this is not sufficient to suggest a link as it has been argued that visualising three-dimensional hull-shape around its two main contours responds to an innate characteristic of human perception. In fact, the other two traditions analysed (Dutch bottom-based, and northern European shell-first) –for which no link is suggested with ancient Mediterranean shipbuilding practices– would also share this approach when developing hull shape (table 5 and section 7.1.4).

Looking for similarities between the mechanisms used to define and store the shapes of the two contours in the ancient Mediterranean shell-first tradition and the early modern frame-first tradition, table 5 and section 7.1.4 show that, in both cases, shipwrights used geometry to define and store those shapes. Although this could be pointing towards a shared approach, thus a link, one has to realise that the geometry used was simple. It required basic tools; just a compass and straightedge which, in practice, is nothing more than a piece of string. Moreover, the use of geometry –used as a design and storage tool– would be common among craftsmen in those periods.[606] Thus, the use of geometry by shipwrights of both tradition–ancient Mediterranean and early modern shipwrights– would not necessarily suggest a link. On the other hand, it does not rule out a link either.

The final similarity, and the one which suggest a link between the ancient Mediterranean shell-first tradition and the early modern frame-first tradition, is found on the identical manner in

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[606] Ottenheym. 'Architecture according to proportions and rules of the Antique'; Birkett and Jurgenson. Why Didn't Historical Makers Need Drawings? Part I; Birkett and Jurgenson, W. Why Didn't Historical Makers Need Drawings? Part II; Birkett, S., and Jurgenson, W. 2000. Geometrical Methods in Stringed Keyboard Instrument Design and Construction, p. 283.

which the shape of the transversal sections of the hull were obtained in those two traditions. It has been noted in 7.1.4 that several authors had concluded that the analysis of archaeological remains of ancient Mediterranean wrecks showed that the shape of the transversal sections of the hulls could have been obtained by a transformation of a master-frame template by rising and narrowing (e.g. figure 103). This manner of obtaining the shape of a hull would be identical, conceptually, to what became known as whole-moulding in the early modern period (chapter 5). Bellabarba and Bonino noted these conceptual similarities but concluded that, although probable, a direct link could not be proven.[607] However, this author published elsewhere that there were arguments to suggest such a link. [608] In both cases, the idea of modelling the three-dimensional shape of the hull based on a controlled transformation of a master template, by risings and narrowings, could be understood as inventions based on arbitrary rules, chosen only for convenience. There is nothing natural or innate in that. It is a cultural choice of the shipwrights. Thus, the likelihood that ancient shipwrights and medieval shipwrights—acting independently, within their own technological-landscapes—would produce two separate acts of invention, resulting in the same arbitrary principles, would seem unlikely.[609] A more likely conclusion would be that, in common with other technological trajectories from the ancient Mediterranean to post-Medieval Europe (e.g. architecture) ship design-technology was transmitted over this period in an environment where knowledge was passed on orally, thus left no written records until the earliest written treatises wrote down this knowledge.[610]

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[607] Bellabarba. The Origins of the Ancient Methods of Designing Hulls: a hypothesis, p. 267; Bonino, M. 2012, Evidence of Geometric Operators used to Shape Ancient Hulls, p. 132.

[608] Olaberria, J.-P. 2014. The Conception of Hull Shape by Shell-builders in the Ancient Mediterranean, p. 362.

[609] Olaberria, J.-P. 2014. The Conception of Hull Shape by Shell-builders in the Ancient Mediterranean, p. 362.

However, there is a curious example of a patent application filed in 2002 which describes a new method of designing yachts based on the transformation of the shape of the master section along a longitudinal line. It could be said that the method described in the patent is similar to the processes described in chapters 4 and 5. However, the inventor of the method does not use geometry or any mathematical means to derive the shape of the master section or the single control line. He cannot justify the choice of lines as they are done by eye. In contrast with the methods described in chapters 4 and 5, the method cannot provide any means of storing design information unless the curves are committed to plans. See: Skira, D. 2003. Single-frame-curve method of designing and constructing hulls. United States patent application US 2002/0189518 A1, Decembere 19, 2002.

[610] Olaberria, J.-P. 2014. The Conception of Hull Shape by Shell-builders in the Ancient Mediterranean, p. 362.

A further evidence which allows to suggest a seamless connection between the ancient Mediterranean shell-first shipbuilding tradition and the frame-first tradition which substituted it during the first millennium can be found on the 4 AD Yassiada wreck which was analysed by Van Doorninck. The analysis provided convincing evidence which suggested that this ship featured a midship frame which would have helped the shipwright determine the transversal shape of the hull, despite being a ship with a largely shell-based structure.[611] Thus, providing some archaeological evidence in support of the idea that shell-based builders would also find it desirable to define the shape of the transversal sections of the hull –its main contour at least– prior to the construction of the hull.

The possible trajectory, of ship-design knowledge, from the ancient Mediterranean to the early modern period is shown in a visual manner in figure 104. It shows a timeline from 4BC to 20AD where some shipwrecks of different periods, which have been identified as being designed by a controlled transformation of the master section by risings and narrowings are indicated. [612]

The figure illustrates the long period of time in which these practices were followed and help situate the ship-design treatises analysed in chapters 4 and 5 within this timeline. Written treatises have been linked to these design methods and have helped support a narrative which indicates that these methods were the creation of highly sophisticated individuals; that the methods contained on them were beyond the capabilities of the common shipwright (chapter 2). However, the figure shows that written treatises represent a brief period in the long history of these design procedures. Moreover, as the timeline shows, these methods pre-dated the earliest known written records by centuries, thus showing that although some of the writers of the

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[611] Van Doorninck, F. H. 1976. The 4th century wreck at Yassi Ada. An interim report on the hull. *International Journal of Nautical Archaeology*, 5.2, pp. 115–131 (p. 127).

[612] These are:

The Cala Culip 13-14 century ship (Rieth, E. 2003. First Archaeological Evidence of the Mediterranean Moulding Ship Design Method, The Example of the Culip VI Wreck. Spain, XIIth-XIVth C. In H. Nowacki and M. Valleriani (eds) *Shipbuilding Practice and Ship Design Methods from the Renaissance to the 18th Century. Max Planck Institute for the History of Science. Preprint 245*, pp. 9-16).

The Serçe Limani vessel sank about 1025 AD (Steffy, R. 1991. The Mediterranean Shell to Skeleton Transition; A Northwest European parallel? In R. Reindeers and K. Paul (eds), *Carvel Construction Technique. Skeleton-first Shell-first. Fifth International Symposium on Boat and Ship Archaeology, Amsterdam 1988*, p. 1-9. Oxbow Monograph 12, Oxford, pp. 6-7)

The design method based on rising s and narrowings identified by Harpster for the 9th-Century-AD Vessel from Bozburun (Harpster. Designing the 9th-Century-AD Vessel from Bozburun, Turkey).

earliest treatises were, indeed, learned individuals, they cannot be linked with the origin of these methods.

For this author it can be suggested, that for two millennia, from the ancient Mediterranean until the adoption of engineering methods in the mid-19th century, ships would have been built following the same design-strategy. It would be based on storing the information of past ship shapes by reducing them to their self-apparent shapes, that is, their main contours. In the technological-landscape of the period, such shapes would be defined, hence stored, as a series of simple rules-of-thumb based on geometry and proportion. Obviously recipes would change with time, or from place to place, or indeed, according to the type of vessel being built. However their underlying principle remained the same:

a) In order to shape a hull the builder first chose, from tradition, the main proportions of the hull (length, beam, depth);

b) having decided those, the shipwright defined the shape of the profile of the ship and the master section using design recipes or rules-of-thumb;

c) the builder could obtain the shape of the rest of the hull, normally by basing them on the shape of the master section. This could be done by using a series of methods of longitudinal transformation.

Such a simple conceptual approach to defining the shape of a hull would have facilitated the storage and transmission of knowledge. An inquisitive shipwright wanting to know the design method of another builder, or an apprentice learning the trade, only needed answers to the following questions: how do you shape your profile and master-section? And, how do you control its transformation? The answers to these question would be sufficient to obtain the abstract approach to design. For example, the answer could be: 'I use a two-arc master section transformed by narrowing only'. Or, the answer could be 'I use a master section made up of multiple arcs transformed by narrowing and rising lines in the bottom, and maximum breadth line for the topsides'. A hypothetical conversation of this type could very well happen between a shipwright of the ancient Mediterranean and one of the early 19th century or, indeed, with one of the practitioners of the surviving traditional techniques described in Chapter 8.1.2. In fact, the treatises analysed in chapters 4 and 5, are written in such a manner that their contents seem to respond to this question only.

For the followers of the design methods described in this research, it would be easy to state the conceptual knowledge. However, trying to define it in detail, with precision, would not be so simple as it would require the transmission of precise parameters, ratios and tricks of the trade. Until the adoption of the written treatise as the medium for storing and transmitting this information, it had to be learned through apprenticeships in a mostly oral tradition. The ethnographic examples described in Chapter 8 will show that such a simple mode of transmission (oral) is not a practical impediment for the transmission of such, seemingly, complex knowledge.[613]

During the 19th century new methods of analysis and estimation of performance on paper, before the ship was even built, were developed. This freed the naval architect from the design methods described in this research. However, the idea of successfully building up on past knowledge has remained in practice one of the pillars in which successful engineering is still based.[614]

7.3 Conclusion chapter 7

Following on the criticism to the current scholarship in chapter 6 this chapter has built upon previous theoretical approaches which tried to understand the complex problem of building a ship on different shipbuilding traditions, most notably, the manner in which hull shape was conceived. By dividing the idea of *conception* in three separate aspects, it has been possible to analyse the paradigm of hull shape design for the four main shipbuilding traditions contemplated by the current scholarship in Europe. The manner in which, all four traditions visualise hull form, would be based on an innate manner in which humans ‘visualise’ three-dimensional shape: by focusing on its contours. In each tradition, this common manner of visualising hull shape would be put into practice through different techno-practical devices whose end goal would be the definition and storage of the shape of the contours. By highlighting the remarkable similarities between the techno-practical devices used in the ancient Mediterranean and in the post-medieval frame-first tradition it has been possible to suggest a direct link within a common technological trajectory. This, which according to the current narrative would require a change of paradigm, becomes a more fluid trajectory, based on the idea of a common paradigm discussed previously.

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613 One consequence of writing down the recipes is that they could be made more complex and geometrically elaborate as the user would not be required to commit all parameters to memory. Thus, a larger number of parameters could be introduced to control the shape of the different curves which, ultimately, determined the shape of the hull.

614 Astrup, O.C., Tangen, K. and Aae, O. 2012. A Rule-Based Approach to Capture Engineering Knowledge in Ship Design. In V. Bertram (ed) *11th International Conference on Computer and IT Applications in the Maritime Industries, COMPIT’12. Liege 2012*, pp.227-240

Chapter 8: Early modern ship-design knowledge

This thesis started by introducing Charles II's yachts. They provided the pretext to look into the ship-design knowledge in early-modern England and the Dutch Republic and the manner in which such knowledge is described in the main literature (chapter 2). Our present understanding of the design knowledge of the early modern period is based on the interpretation of written manuscripts and printed treatises. Therefore, chapters 4 and 5 have analysed treatises published in the period spanning from the 15th to the 18th centuries. Based on this analysis, in chapter 6, some of the shortcomings of the current narrative have been criticised. Following this, chapter 7 has approached the theoretical framework that describes the ship design paradigm of the different shipbuilding traditions which are used to study shipbuilding practices in the past. It has been possible to provide a more nuanced view of the manner in which design paradigms are defined and understood. This has led to the conclusion that all shipbuilding traditions described shared the same conceptual understanding of hull shape (chapter 7).

This chapter brings the focus back to the early-modern shipwright, contemporary of the written treatises and responsible for the design and construction of the yachts described in chapter 2. This chapter will produce a picture of the early-modern shipwright's design paradigm, somewhat distanced from the current image which points towards sophisticated, mathematically minded, learned practitioners. In this chapter, a simple test is performed that explains the manner in which these apparently complex design methods could be modified intuitively, thus, allowing traditional shipwrights and ship-designers to experiment with shapes whilst keeping a certain control over the performance of the ship. The chapter will finish by looking at the treatises themselves to suggest that the ever increasing complexity of the design treatises of the early modern period does not reflect an evolution of the knowledge contained in them. Instead, such apparent evolution would be a reflection of the increasing improvement in the quality and sophistication of drafted plans and, especially, of the how-to manual as a genre for the storage and transmission of existing knowledge.

8.1 The early modern ship-designer: a shipwright with specialised knowledge

Chapter 7 has argued that the ship design paradigm remained grounded on the same principles since antiquity to the early 19th century. Thus, throughout this period the paradigm followed by shipwrights to 'think' about the ship, their 'outlook', remained unaltered. The relative relevance of written treatises as a means of storing and transmitting knowledge within this long technological trajectory is shown in figure 104. It is visually apparent that, for at least 24 centuries (4BC to 20 AD), a common design paradigm existed (chapter 7.2) and only for a period of four centuries (15AD to 19AD) did these design approaches, this 'outlook', get converted into written information. However, although this knowledge was first converted into written and graphical form in the 15th century, it survived in use, within a culture of craftsmanship –where the knowledge was transmitted mostly orally–, until the early years of the 19th century in Europe and until the 20th century in other areas of the world (below). This provides an opportunity to observe this knowledge and to characterise its users.

Chapter 6 has argued, based on the interpretation in chapters 4-5, that the contents of the treatises represent a type of knowledge that could be used by common shipwrights. Following sections will provide further evidence which will help justify this interpretation.

8.1.1 Near contemporary interpretation (19th C.): A variety of practical methods with a common base.

One body of evidence, which provides first-hand opinions about the design methods described in the treatises analysed in chapters 4-5, is available in discussions which were published during the early 19th century when naval architects were trying to break away from these design approaches. During this period design methods based on analytical tools and 'scientific' knowledge can be increasingly recognised. It became apparent for some that the old practices had to be abandoned in favour of the new methods based on the newly developed analytical tools. These 'authors' were not criticising practices from the past. They were direct witnesses of these design practices still being used to design ships. Their criticisms are invaluable because they highlight the shortcomings and, also, the advantages that such methods had. Moreover, as these authors had a vested interest in abandoning such practices, any positive comment that they may have for the use of such methods must be taken as a true recognition of their merits.

The following quotation by W. Morgan and A. Creuze, editors of *Papers on Naval Architecture*, may suffice to illustrate a first-hand opinion of a contemporary qualified observer:

> Many of these mechanical systems [of ship design] [615] are **of such easy application**, that the form of a ship may be determined on the **mould loft floor, even without [previous] drawings, in a few hours**; and many of them are so simple, that **persons possessing**

[615] Mechanical systems of ship design: by this term they refer to methods based on design-recipes as the ones described in chapters 4 and 5.

> **little or indeed no knowledge of naval architecture, may be taught them in a short time**.[616] (Highlights JPO.)

Thus, for naval architects[617] (in the present-day sense of the word) who witnessed these methods in use, these mechanical methods or design-recipes were easy to apply. They were so simple, in fact, that they could be learnt by anyone in a few hours. This would obviously make them very desirable for shipwrights. The original paragraph continues with more first-hand comments that point at the possible origins of these design methods:

> The invention of such systems is so easy, that, were it considered desirable to increase their number, **persons with very little mechanical knowledge might invent almost any number of them**.[618] (Highlights JPO.)

From these contemporary accounts of well-informed observers, it would be possible to conclude that these methods were not necessarily the creation of gifted individuals, nor were they above the comprehension capabilities of the common shipwright. Any practical craftsman could easily learn them and invent their own version. This, however, did not make them necessarily inferior. On the contrary, they were a practical way of designing and building a ship based only on past experience and no mathematical analysis. They were useful in a context where a large part of the industry was still unlearned in technical matters and many even opposed abandoning the old methods of design and construction.[619]

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616 Morgan and Creuze. *On Mechanical Methods of designing Ships' Bodies*, p. 5.

617 Morgan and Creuze were two naval architects who had been trained in the School of Naval Architecture in Portsmouth (UK). They were the directors of *Papers on Naval Architecture and Other Subjects Connected with Naval Science*.

618 Morgan and Creuze. *On Mechanical Methods of designing Ships' Bodies*, p. 5.

619 For example, read the debate that followed the appointment of a captain for the post of Surveyor of the Navy instead of a naval architect. It shows the inertia of the establishment which struggled to accept qualified naval architects at posts of responsibility in ship-design and policy making. See *Apology for English Ship-Builders*, written in 1833 –which defends the need to incorporate naval architects– and the critical response to it called *School of Naval Architecture*.

In *School of Naval Architecture*, graduates from the School of Naval Architecture are described as:

> ... [being] of little or no use, too much puffed up with their own consequence, and too much above their business, sauntering about the yards, and picking their teeth with chips ; and further, that if the major part of them were dismissed, the work of the dock-yards would go on much better than it does at this present moment. The founding of the school was ill-advised, and we trust that no more students will be admitted, [...]. (p. 232)

Thus, it shows that even in the 1830-s there was still a strong opposition to design methods based on engineering approaches.

Eventually, engineering based methods replaced traditional methods of design. There is, however, evidence which shows that during the 19th and 20th centuries traditional ship design-methods based on a template of the master-section and risings and narrowings were still being used in shipyards of Europe for the drafting of lines plans to scale prior to the construction of the vessel.[620] This provided a combination of methods that made use of the advantages of the two different design approaches. By using a mechanical method of design, the shape of the hull could be obtained in a near automatic manner, and a fair lines-plan produced, in just a matter of hours (figure 105).[621] This was appropriate for the design of simple utilitarian boats of well-proven typologies and performance and no real need for innovation, such as fishing and cargo boats (figure 106). In those cases, calculations and experimentation with novel shapes would not have been required. In parallel, those same yards and designers, can be seen to adopt modern engineering based 'scientific' design methods for large commercial ships (figure 107). In this case, economic pressures might encourage designers to experiment in non-traditional shapes and designs and, most crucially, in using more sophisticated design methods which do not create hull shapes based on design-recipes.

8.1.2 Ethnographic material

Design methods which are conceptually similar to the ones analysed in chapters 4-5 have survived in use in boatyards around the world until very recent times. Some are still practiced today.[622] For example, in the Mediterranean basin, methods based on the transformation of a mould made in several parts by a process of rising and narrowing derived by simple geometric constructions have been recorded in Greece and in Tunisia during the 20th century (figures 108-109).[623] Similar methods have also been identified outside Europe in boatbuilding communities where the

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620 Olaberria and Olaizola. A Basque Shipyard Design Method of the Late 19th and Early 20th Centuries, pp. 358–364.

621 The plan shown in figure 105 was drawn in under 1 hour, using a cardboard template shaped as the master frame. The transversal sections were obtained by modifying the cardboard template following a process of rising and narrowing. The result is a fully faired hull, drawn automatically.

622 All the examples which have been studied are in countries which were colonised by Europeans, thus, their shipbuilding techniques were of European origin: Castro and Gomes-Dias. Moulds, Graminhos and Ribbands; Blue, L., Kentley, E. and McGrail, S. 1998. The vattai fishing boat and related frame-first vessels of Tamil Nadu. *South Asian Studies*, 14(1), pp. 41–74; McGrail, S. 1998. Portuguese-derived ship design methods in southern India? pp. 19–23; Carrell, T.L. and Keith, D.H. 1992. Replicating a ship of discovery: Santa Clara, a 16th-century Iberian carave l. *International Journal of Nautical Archaeology*, 21(4), pp. 281–294; Taylor. *Boat Building in Winterton.*

623 Damianidis, K. 1991. Vernacular boats and boatbuilding in Greece. University of Saint Andrews (PhD Thesis); Rieth. *Le Maître-Gabarit la Tablette et le Trébuchet.*

shipbuilding practices carried by their European colonisers are still used. For example, in Brazil and Newfoundland, where a three-part mould –like the ones shown by Sunderland and Mungo Murray in the 18th century (chapter 5)– is used to design utilitarian boats (figures 110-111(b)).[624] Similarly, design methods with a possible Portuguese origin based on a single mould have been identified in India (figure 111(a)).[625] Other 19th century examples like the design procedure identified in the French Mediterranean coast (figure 112) complete the picture.[626] These methods share the same hull design approach with the treatises analysed in chapters 4-5, with the exception of the Dutch bottom-based treatises. Thus, by studying their use they help understand past societies who used similar methods.

These surviving methods of design have one thing in common with many of the methods described in chapters 4-5. They do not require that the craftsman draws the shape of the hull before construction. The boat builder makes a template of the master frame, normally in several parts. Then, the boat builder draws rising and narrowing curves, or similar geometric constructions based on similar principles as the ones described in the treatises (e.g. figure 111(b)). With these, the boat builder obtains a series of marks, regulated in incremental spacings which are transferred to the templates. By adjusting the different parts of the template according to the marks, the shape of the frames is obtained. These methods are, in principle and in detail, identical to some of the methods described in the treatises. If they seem more simple is because they are not represented on paper and thus do not produce those complex drawings that seem elaborate and highly sophisticated.

The process of whole moulding as described by Mungo Murray and Sutherland is shown in figures 110(a) and (c). The drawings look technically advanced. They give the impression of a highly sophisticated design procedure. However, the reality of the process, and its simplicity, becomes apparent when boat builders are observed using this design method. The boat builders in the photograph (figure 110(d)) are demonstrating the manner in which the three-part mould is used. The process does not require any previously drafted plan. It is very simple to execute by adjusting the different parts of the template, but visually very complex if it is drawn on paper. The same procedure is shown again, in figure 110(b), shown in perspective. Once again, the observer may conclude that the process is complex and elaborate, however, it is nothing more that the representation on paper of the practical process being shown by the boat builders in the

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[624] Castro and Gomes-Dias. Moulds, Graminhos and Ribbands.

[625] McGrail. Portuguese-derived ship design methods in southern India?

[626] Rieth. *Le Maître-Gabarit la Tablette et le Trébuchet*, pp. 166-176.

photograph. Similar cases can be seen in figures 111. These methods are simpler to apply in practice than their graphical representation would suggest, therefore, making them suitable to be transmitted orally. Similarly their simplicity makes them suitable to be stored by recording the information on simple tools or even by committing it to memory.

Probably, it would not be correct to define all current practitioners of these methods as illiterate or unlearned. However, with respect to their boat building/designing knowledge, they all learned their craft from their elders in an oral tradition and not after a period of formal schooling. Irrespective of the ability to read or write, their knowledge is stored in their memory or on the actual tools used for their work. And, if some information is committed to writing, it is in the form of simple notes or markings on suitable surfaces (not always on paper), normally noted down for personal use.[627]

Interestingly, when modern scholars analyse these methods and the technological-landscape that supports these surviving techniques they are interpreted differently from the manner in which the treatises and their technological-landscape are interpreted. Thus, for obvious reasons, the design methods used by current traditional builders are not interpreted as scientific. A superficial glance at the organisation of the yards, the type of ships/boats built, the craftsmen themselves, and the social landscape in which these practices take place, make it very clear to the current observer that higher learning, science, mathematical knowledge, literacy, and so on, play no role in these practices. In common with other crafts, these techniques have survived because they provide a reliable production method that functions in a satisfactory manner, suitable for the technological-landscape of the practitioners.[628] Without the need for higher learning, nor sophisticated tooling, these procedures guarantee the repeatability of past experiences and experiments, making knowledge generalized, replicable, and transmissible.[629]

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[627] Taylor. *Boat Building in Winterton*, p. 51.

For a discussion on a similar idea in the context of shell-building see: Dhoop and Olaberria. Practical Knowledge in the Viking Age.

[628] Smith, P.H. 2014. Making and Knowing: Craft as Natural Philosophy. In P.H. Smith, A.R.W. Meyers and H.J. Cook (eds) *Ways of Making and Knowing: The Material Culture of Empirical Knowledge*, p. 19.

[629] Smith. Making and Knowing: Craft as Natural Philosophy, p. 40.

8.1.3 Conclusion: The early modern ship-designer. A shipwright with specialised knowledge

Previous sections have argued that during the early modern period there were no substantial changes to the knowledge that was developed and used to design the shapes of ships' hulls. Consequently, sophisticated ship-designers and shipwrights would share the same knowledge. Thus, it is possible to imagine a hypothetical conversation between any of the traditional boat-builders shown above building boats in Newfoundland and Brazil with shipwrights accustomed to designing the shape of ships' hulls using the methods shown in the treatises –from the relatively simple methods of Bushnell or Hardingham, to the more visually sophisticated methods like, for example, Deane's. In this hypothetical conversation, the participants may belong to different social hierarchical levels. The ships they designed and built might be perceived to be at different levels of technological sophistication and status. But, when it came to their knowledge, there would be no appreciable differences. All used the same type of design recipe. They shared the same design paradigm. Consequently, they would have been able to converse in equal terms. Each, would be familiar with certain ship types for which they would know the acceptable range of values for the design parameters. It is such parameters which would be their secret knowledge and not the conceptual approach to hull-design which would be shared by all.

However, although they shared the same design paradigm, it is possible to appreciate differences in the manner in which design-knowledge was acquired throughout this period.

Figure 113 tries to illustrate the manner in which design-knowledge was acquired and applied by *(a)* shipwrights in a traditional pre-literate (pre-treatises) group, *(b)* by shipwrights and ship-designers in the early modern period when treatises and traditional methods coexisted and, finally, *(c)* by ship-designers in the post-19th century industrial setting which, as it has been argued, abandoned these design-methods based on recipes.

The figures show a social group building ships after a series of actions which are represented by the arrow linking the society to the ship. In all cases, the ship is made by shipwrights and a certain design-knowledge is applied in order to influence the outcome of the production process. In the case of pre-literate shipwrights, the design knowledge that is necessary is obtained through a hands on approach –through an apprenticeship– while being engaged in the construction of ships (figure 113(a)). Not all shipwrights would learn to design ships. Just as today in traditional set ups, it would be a specialised job.[630] However, all shipwrights who learnt how to design a hull would have done it through a process of apprenticeship, in common with other crafts of the period.[631]

In the case of the early-modern society, it must be remembered that the first school of Naval Architecture did not open in England until 1810[632] and in France only a few decades earlier, in 1752.[633] Therefore, the route to acquiring design-knowledge through a hands-on apprenticeship would still be common, especially in the case of commercial yards. However, treatises begin to show changes in the manner in which this knowledge could be transmitted. Thus, figure 113(b) shows shipwrights acquiring the necessary design knowledge through a process of apprenticeship. However, a parallel route became available which allowed a different group of people (the designers) to acquire this knowledge. Treatises, especially the latest ones, would allow them to gain design knowledge more effectively than a hands-on apprenticeship would. The design paradigm was common, thus, communication between shipwrights engaged in design and ship-designers would still be possible. It could be suggested that treatises like Bushnell's, Hardingham's and Sutherland's could have been used to 'improve' the knowledge of shipwrights engaged in the design of ships which they would have acquired, previously, through a process of apprenticeship.

Finally, figure 113*(c)* is shown to illustrate, by contrast, the break up with the old methods. It describes a post-19th century setting where ships are designed, 'scientifically' by naval architects. In common with the previous cases the ship is still built by shipwrights. In contrast, shipwrights cannot acquire design knowledge through apprenticeship. Designers (naval architects) must acquire theoretical knowledge and a series of skills like mathematical analysis to which shipwrights are not exposed in their work. Thus, design knowledge must be acquired as an independent pursuit to that of building ships. Both social groups become independent and only the designers are able to make design decisions. Shipwrights are hierarchically below the designers. Some authors interpret that this last case best reflects the realities of ship design and the social arrangements in shipyards of the early-modern period (chapter 2.2.3). However, the case illustrated by figure 113*(b)* would represent the social organisation of the workforce and the knowledge in the early-modern shipyard in a more realistic manner. Shipwrights could still obtain

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630 Taylor. *Boat Building in Winterton*, p. 50.

631 Westerdahl, C. 1994. Maritime cultures and ship types: brief comments on the significance of maritime archaeology. *International Journal of Nautical Archaeology*, 23(4), p. 267.

632 Morgan, W. 1827. Introductory Remarks on the State of Naval Architecture. In W. Morgan and A. Creuze (eds) *Papers on Naval Architecture and other Subjects Connected with Naval Science. Vol I*. London, p. 8.

633 Duhamel du Monceau. *Élémens de l'Arrchitecture Navale ou Traité Pratique de la Construction des Vaisseaux*. Title pages.

their design-knowledge through a hands-on exposure during a process of apprenticeship. However, just as not every mason becomes a master-mason, or master-craftsman at any other craft, not all shipwrights would be responsible for the design of ships. It would be a specialised job; probably it always was through history. The design-knowledge of master-shipwrights would not differ conceptually with the knowledge used by ship designers who would have acquired it after a process of formal instruction in which treatises played an increasingly important role.

8.2 The design method based on the transformation of a master curve: an intuitive tool, adequate for the common shipwright

It has been argued that ship design requires a harmonious balance between the physical fabric of the ship which has a direct effect on its weight and centre of gravity, on the one hand, and of the three-dimensional shape of the hull which determines its hydrostatics, on the other. Pre-mid-19th century shipwrights did not have the analytical means which would allow them to test on paper the basic performance of different design-configurations prior to the construction process –as a modern naval architect does. In such a scenario, it becomes clear that a route towards a certain measure of success would be to base design decisions on past successful ship designs. By repeating past shapes –which are known to have worked– the knowledge obtained from past experiences could be re-used as a means of avoiding failure. Accordingly, the ultimate goal of the shipwright would be to have the ability to repeat successful hull shapes which could be modified in a controlled manner. These requirements would seem to suggest that the design methods used by shipwrights of the period would limit the variability of possible shapes which could be produced. Or at least, they would tend to limit the number of design parameters which the shipwright could change in order to produce a new design. However, the reality of the design-methods described in chapters 4 and 5 would appear to suggest the opposite.

Chapters 4 and 5 have shown that within each of the methods described by individual authors the changes to the parameters which ultimately determined the three-dimensional shape of the hull were left to the judgement of each particular shipwright. Moreover, shipwrights had no way of estimating –from theoretical knowledge– the consequences of the changes before the hull was built and put into the water. Consequently, this author faced certain doubts about the manner in which these design methods should be understood, especially, when describing their use in an oral environment, by illiterate shipwrights.[634]

[634] These could be illiterate in the strict sense. Alternatively, they could be shipwrights who might know how to read and write but practice their craft in an environment where notes are rarely written down.

Although the number of parameters is relatively small, as the following list shows, it still is sufficiently large to suggest that certain level of organisation would be needed in order to record the data efficiently. In general, a shipwright following the methods described in chapters 4 and 5 would require to record the following parameters:

1. Principal dimensions of the ship, normally related proportionally to each other:
    a. Length of the hull
    b. Beam of the hull
    c. Depth of the hull
2. The design parameters of the master section, normally related proportionally to each other:
    a. Length and rise of the straight floor
    b. Radius and position of centre of bilge arc
    c. Radius and position of centre of breadth arc
    d. Radii of additional arcs (when present) or measurements of straight elements of the master section
3. Profile shape of the stem and sternpost
    a. Geometric shape of the stem
    b. Height and rake of the sternpost (in the case of a straight sternpost); geometry and shape of the sternpost (in the case of a curved sternpost)
4. The design parameters of the longitudinal shape-control curves
    a. Rising of the floor line
    b. The geometric construction used to derive the rising of the floor for each intermediate frame.
    c. Narrowing of the floor line
    d. The geometric construction used to derive the narrowing of the floor for each intermediate frame.
    e. Rising of breadth line

f. The geometric construction used to derive the rising of the breadth line for each intermediate frame.

g. Narrowing of the breadth line

h. The geometric construction used to derive the narrowing of the breadth line for each intermediate frame.

5. Also important is the geometric construction or method used to fair the floor area in intermediate frames. This subject is rarely discussed in detail in the treatises

6. Although not strictly related to shape, the scantlings of the different structural and rigging elements of the hull would also be related by proportion to the ship's dimensions, normally length.

The list is long but, bearing in mind that many of these parameters were proportionally related to each other, even shipwrights with low levels of literacy could devise a method to store this information either in writing, in physical tools, or even in a rule-of-thumb (e.g. 8.1.2). However, shipwrights were free to change the parameters to suit their needs and expectations. Therefore, several questions come to mind. How could shipwrights manage to keep record of the variables and their effect in the performance of the ship? How would all this data be organised and recorded, especially in non-literate groups? Also, if a shipwright based a new design on a past ship of known parameters and performance characteristics, how could they change individual design-parameters and still maintain other desirable characteristics of the ship used as an example?

Numerous other questions could be raised about these methods which, on the one hand, have been described as records of past practice, thus, a guarantee of a continuum in the design-knowledge while, on the other hand, they have been shown to be highly variable, with no possible way of linking changes of design-parameters with performance. Therefore, it was felt necessary to focus on the design methods themselves. There was, perhaps, something in these design methods which allowed shipwrights to vary hull-shapes whilst providing an intuitive manner of maintaining performance. If the methods could be controlled intuitively it would explain why they were a suitable means of storing information which at the same time could be changed at will. In order to evaluate this the following test was conducted.

8.2.1 The test

A simple test was conducted to develop a 'feel' for the controllability of the design methods described in chapters 4-5. A simple scenario was assumed in which a shipwright would already have built a ship which satisfied two basic conditions. Firstly, that the ship floated at the correct waterline, thus with a correct draught and sufficient freeboard to be useable during its expected operational life (figure 114). This draught would, obviously, result from a match between the weight of the ship and the volume of its underwater portion of the hull. A second condition which would have produced a satisfactory ship would be that the ship remained upright during normal operation. This ideal ship will be known in this test as the *base model* or *base ship*.

For the purposes of the test it was assumed that the shipwright built the hull on a master section of known shape and that the ends had been obtained by a process of rising and narrowing, conceptually in tune with the methods described in chapters 4-5. Next, it was assumed that the shipwright would like to produce two different designs by modifying the original base ship. Both new ships would have the same exterior dimensions as the base ship. However, it was decided that the shipwright wished to produce two alternative designs with increasingly finer ends. The end goal of the test would be to ascertain if it is possible to modify the *base ship's* rising and narrowing lines in an intuitive manner in order to produce ships with different ends whilst guaranteeing that their displacement and draught, remain unaltered. As it turned out, this proved to be very simple to achieve.

8.2.2 The model and its variants

The base model (Model A):

To simplify the test, a hull with a rectangular master section was chosen for the *base ship* (figure 115 table 6). The rest of the transversal sections of the hull were obtained graphically in AutoCAD[635] following a process of rising and narrowing similar to those described in chapters 4-5. The rising and narrowing curves were both based on a quadrant.[636] The dimensions of the model and the maximum values of rising and narrowing are arbitrary. They were chosen to produce a ship-like shape of reasonable proportions. In the case of the base model (A) the value for the maximum rising and narrowing were chosen to be equal. For simplicity, the hull was made symmetrical: the bow and stern ends have the same shape. In common with some of the methods described in chapters 4-5 the master section has been repeated, in effect increasing the volume of the central part of the hull. The last section obtained by rising and narrowing of the master

[635] AutoCAD is a commercial computer-aided-design (CAD) and drafting software application.

[636] Any other fair curve would have led to the same result.

section was section 4. The ends of the hull (sections 5 and 6) were faired graphically (figure 116(A)).

The modified models (Models B and C):

The *base ship* was modified into two other shapes shown in (figures 116(B, C)) table 6. The three models share the same rectangular master section. However, in models B and C, the maximum values of rising and narrowing were altered in order to give hull-shapes of different three-dimensional shape. Section 8.2.3 below explains the rationale behind the new shapes. In order to calculate the hydrostatic characteristics of each hull, three-dimensional models were created in DelftShip from the shapes of the frames defined in AutoCAD. The results of the calculations performed in the test are used for comparison purposes only (table 6).

8.2.3 The results

Keeping constant displacement and draught:

It soon became apparent that changing the rising and narrowing independently by-eye, without a method, whilst trying to keep the draught and the underwater volume of the hull constant proved not to be an intuitive process. In all cases tried, the volume of the hull below the theoretical waterline proved to be different to that of the *base ship*. Consequently, if the new ship were to be built with the same weight as the base hull, it would float at a different draught from that of the base ship.

As an alternative test, a controlled variation of these rising and narrowing values was tried following a simple rationale: the maximum values of rising and narrowing were altered simultaneously and inversely. In other words, if the maximum rising was increased in any given proportion, the maximum narrowing was decreased in the same proportion.[637] As a result, two hull shapes were produced with markedly different three-dimensional shapes (figures 116(A, B, C)). However, by following this rationale, their draught and their volume below the waterline remained constant as shown by the hydrostatics calculated in in DelftShip, (table 6).

This test helps explain how shipwrights could change the three-dimensional shape of the hull without altering its draught and displacement which are two main characteristics of a ship stated in the numerous treatises analysed in chapters 4-5. All that was required was to alter the known values of rising and narrowing simultaneously, in the same proportion, but inversely. Thus, any

[637] The proportions used are irrelevant. They were used for comparison purposes only.

increase in one of the values should be matched by a reduction of the other. This intuitive understanding could be exploited when trying alternative values for the main control curves, as shown.

Keeping weight constant:

The manner in which a shipwright could guarantee that the draught of a ship and its displacement remained constant by following the rationale explained above remains correct, only, if the weight of the modified hulls also remained constant. Therefore it was necessary to estimate if there are any significant differences in weight between the new hull shapes and the *base ship*.

The analysis in DelftShip showed that despite significant changes to the three-dimensional shapes of the three hulls, their surface areas experienced minimal changes (table 6). Consequently, if the three ships were to be made of materials of identical scantlings, their change in weight would be small enough to consider it negligible within the levels of uncertainty acceptable for ship designers of the period. Therefore, the method of changing the three-dimensional shapes of the hulls whilst keeping draught and displacement constant would have been a practical undertaking.

Ship stability:

In contrast to the design aspects described above, ship stability poses a challenge which could not be controlled in such an intuitive manner. The test in DelftShip showed that, as expected, the hulls with the finer ends would be significantly less stable than the *base ship* which showed fuller ends. This is shown in table 6 where the metacentric height (GM)[638] of the three hulls is shown.[639] It is noticeable that the GM is greatly reduced in the two narrower hulls (table 6). The significance of this is highlighted by the following example which refers to the three ships shown in table 6. Let it be assumed that ship *(a)* is sailing under a given sail area and wind strength which results in an angle of heel of, say, 10º. Let it be assumed, now, that the captains of sips *(b)* and *(c)* would also be sailing at the same 10º of heel. Under the same wind conditions as ship *(a)*, ship *(b)* would only be capable of carrying 83% of the sail area until it reached a heel angle of 10º. In the case of ship *(c)*, it would heel to the same 10º with only 68% of the sail area displayed by ship *(a)*. Thus, the reduction on ship stability has a noticeable effect on the amount of sail that each of the ships can

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[638] The metacentric height, GM, is a parameter which is used by naval architects to determine –and compare– the stability characteristics of a floating body. For a full technical discussion see: Tupper, E.C. 2004. *Introduction to Naval Architecture* (4th edition).

[639] The position of the centre of gravity has been assumed to be at the waterline as suggested by Hubregtse in the performance tests of the replica of the V.O.C. ship *The Amsterdam* (Hubregtse. The V.O.C. ship Amsterdam, p. 161).

set. This reduction of sail area would have a direct effect on the available propulsive force generated by the sails which would be reduced in the same proportion as the sail area. Therefore, the potential speed of ship *(c)* would be much lower than that of ship *(a)*. On the other hand, if both ships *(b)* and *(c)* sailed with the same sail area as ship *(a)* their inherently lower stability would make them heel beyond the originally assumed 10^{0} heel angle with unpredictable results.

8.2.4 Conclusion: The design method based on the transformation of a master-curve: an intuitive tool

The simple test has shown that it is relatively straightforward to develop a feel for the manner in which a shipwright could alter the three-dimensional shape of the hull whilst guaranteeing that the draught, the displacement (volume) and the weight of the hull remained constant or with small enough changes to be considered negligible. Shipwrights could inherit the design of a ship in the form of a design-recipe and a series of parameters which allowed them to define the shape of the master-section and the different narrowing and rising lines. The shipwright would know that by adjusting the rising and narrowing lines together, in the manner described above, it would be relatively simple to maintain the displacement (volume) and the draught of the ship constant.

If the shipwright started from a previous example, the road to success may not be guaranteed, but at least it would be clear of imminent dangers. With this in mind, in many of the treatises analysed the writer gives the main parameters of the design, which are: the principal dimensions, the values of rising and narrowing and the shape of the master frame. Thus, the details required to produce the three-dimensional shape of a generic base ship are given. The values of the parameters given in the treatises are not prescriptive. On the contrary, the reader is encouraged to change them at will. Sometimes a range of maximum and minimum values are given as guidance but the reader can accept the figures given or change them at will. As shown above, by altering each of the parameters in proportion to its matching value (e.g. rising and narrowing) the shipwright would know, for example, that the finished ship would weigh the same as the ship as defined by the recipe and that it would float at the same waterline. Thus, two very important characteristics that determine the usefulness of a design can be guaranteed whilst allowing for experimentation of alternative shapes. What appears to be a complex design method, highly variable, thus requiring to record numerous parameters or else the shipwright could lose track of the changes, becomes a more simple process for which the shipwright could develop an intuitive feel. Needless to say this would make these methods suitable for the technological-landscape of the period. Especially if this is understood as the landscape in which common shipwrights, with no means to record three-dimensional shape, had to build ships, create knowledge and transmit it to the next generations or to other shipwrights.

With respect to the problem of ship stability, on the other hand, the results of the test show that the control of the stability characteristics of the hull, by altering risings and narrowings, is not intuitive. This is supported by the analysis in chapters 4 and 5 which have shown that shipwrights of the period never developed a method by which they could control the stability characteristics of a ship other than by keeping hull shape within known parameters and the scantlings of structures and rigging according to customary practice.

8.3 Early modern ship design treatises: a development of the How-to manual

The previous sections have described the early modern ship-designer and shipwright, followed by a look into the design-knowledge itself as a means of reducing some of the uncertainties of the process of building a hull in a period when analytical methods had not been developed yet. This section will describe the treatises by placing them within the numerous how-to manuals and written reference books which were published during the early modern period.

8.3.1 The ship design treatise. A How-to manual

The oldest treatises that exist appear to be builder's notebooks or based on them, for which similar examples exist in other branches of technology.[640] These early note books were not thought for publication and, hence, do not provide a coherent account of the practices being described. Most importantly, they contain many lacunae in the knowledge described. Within the period the transmission of technical knowledge relied heavily on oral transmission, in a manner that some modern scholars have defined as a 'stubborn reliance on oral tradition'.[641] However, this characterisation of the manner in which knowledge was passed on, preferably orally, would suggest that shipwrights had a choice. In reality they did not have a choice. The reliance on oral transmission and the poor descriptions that can be found in the earliest examples of written treatises, are a direct consequence of the difficulties of writing a technical treatises without other examples at hand. This was clearly expressed by García de Palacio in 1587 when he tried to offer an explanation for the many lacunae that he recognised in the contents of his treatise. In his words, the difficulty of writing a treatise that describes ship design with sufficient detail was due to the fact that there were:

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[640] Wolfe, M., 2009. Urban Design Traditions and Innovations in France, 1200-1600. *Histoire & Mesure* 24(1), pp.109–156 (p. 113).

[641] Tebeaux. Technical writing in English Renaissance shipwrightery. p 10.

> ... many things which, for their complexity, cannot be said in [text and drawings] and which are common to the practitioners of this art.[642]

As the analysis has shown, and logic mandates, García de Palacio was wrong – and probably was fully aware of it. The problem of creating a written account of a complex technological matter does not really lie in the fact that due to their complexity they cannot be explained in written or graphical form. A better portrayal of García de Palacio's difficulties, in common with other early-modern authors, would be that due to their complexity, and in view of the lack of experience in conveying this information in writing, early authors of these treatises did not know how to describe in words the complex processes that they were trying to explain. In addition, they did not have the means to represent these processes in the form of drawings as they had not been invented yet. Thus, in order to put such knowledge on paper, the writers of early technical treatises, first had to invent a way of transforming the knowledge which previously had transmitted orally, through aide memoirs, rules-of-thumb, and practical engagement into a form capable of being put to paper. By the 16th century illustrations were used to convey more information by the combination of words and graphical representation.[643]

Conveying complex three-dimensional shape onto a graphical form suitable to be reproduced on flat paper, or translating an abstract process into graphical expression, is not a straight-forward process. It requires a graphical language and tools that must be developed first. For that reason, inventing methods to represent ideas and procedures graphically was more important to Renaissance engineers than creating theoretical knowledge, as images provided a system which allowed them to communicate 'materials of non-verbal thought' in a manner that written text could not convey.[644] These shortcomings, as well as the realisation that much of the knowledge was already known by the practitioners, made writing these early treatises difficult. With time, the quality of the contents of the treatises improved, as the analysis in chapters 4-5 has shown. The readers of these early treatises, and similar treatises of the period, were more interested in direct instructions than on unnecessary theoretical details.[645] One of the effects of writing the

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[642] García de Palacio. *Instrucción Nautica* , p. 95-v (Translation from the original JPO).

[643] Ferguson, E.S. 1977. The mind's eye: Nonverbal thought in technology. *Science*, 197(4306). pp. 827–836 (pp. 828-829).

[644] Ferguson. The mind's eye: Nonverbal thought in technology, p. 830.

[645] Tebeaux, E. 2010. English agriculture and estate management instructions, 1200-1700. From orality to textuality to modern instructions. *Technical Communication Quarterly,* 19(4), pp. 352–378 (p. 367).

design procedures down would be to serve as a means of consolidating the existing cultural tradition.[646]

During the 17th century and early 18th century a great number of publications were produced which describe a wealth of knowledge aimed at a very diverse readership. Among those, how-to manuals provide an insight into the manner in which practical knowledge was recorded and the twofold effect that recording this knowledge had. The first effect that can be highlighted is that once practical knowledge was recorded into how-to manuals, it became durable. The second effect is that, by being recorded into a how-to manual, the knowledge could reach a wider audience. The shape that these publications took varied from well-structured treatises aimed at learned sectors of society (figure 117), to collections of heterogeneous practical knowledge aimed at craftsmen with a certain level of schooling (figure 118), to more humble small reference books and manuals were information was conveyed rather superficially (figure 119). Other alternative media such as posters, or even playing cards, were also used to store and transmit technical information as a means to complement the text (figure 120). As a result, the knowledge reached different segments of society and became consolidated. Interestingly, often the title page specifies that the knowledge contained in the treatise came from practice and not from reading other books (figure 121). For some authors the knowledge of the practical man is superior to the theoretical knowledge of allegedly learned scholars. For example, in *The Idiot*, which was written as a conversation between two learned men and a common man called the 'idiot', it is the learned men who ask the questions which are answered by the so called 'idiot'. Although the common man is identified by the term 'idiot' he is the personification of common sense and practical knowledge (figure 122). Thus, it can be seen that during this period there were a variety of manuals written for the instruction of the public which varied greatly in style, contents and length, depending on the readership for which the manual was intended.[647]

Going back to shipbuilding treatises, the differences between the quality and length of the contents of the treatises analysed in chapters 4-5 is noteworthy. Thus, for example, the procedure

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[646] Goody, J. and Watt, I. 1963. The consequences of literacy. *Comparative Studies in Society and History,* 5(03), pp. 304–345 (p. 317).

[647] A good example of the manner in which the author of a how-to manual modulates the language and theoretical explanations to suit the assumed knowledge of the reader is found on: King, D. 1659. *Mr. De Sargues Universal Way of Dyaling.* London. This How-to manual was written for three separate readerships which the author identified as 'all sorts of people', 'the workmen of many of the arts' and 'theoriciens and those skilled in geometry'. The process of making a sundial is explained three times, using different language and explanations, suited to each of those three groups of readers.

to shape a hull in Bushnell's mid-17th-century treatise occupied 9 pages of a small sized book.[648] In contrast, by the mid-18th century the number of pages required by Duhamel du Monceau to describe the method of drafting the plan of a 70-gun ship grew to 108 pages of a medium-sized book.[649] The difference in length between the explanations in both treatises should not be seen as an indication of the evolution in ship design knowledge during the 17th and early 18th century which remained, in concept at least, unaltered (chapters 4 to 6). Instead, the differences in the extension of both treatises reflects the development in complexity of technical language and the technical manual as a literary genre. In Duhamel du Monceau's treatise the written explanations are better ordered, they are more methodical and include deeper discussions about the reasons behind certain aspects of the design process. Similarly, the quality and quantity of illustrations and the information included in them can be seen to improve (compare figures 34-38 with 70, 72). This was not limited to ship building treatises, and most forms of written treatise saw a rapid transformation in their contents, arrangements and the quality of the visual representations contained in them, as printing techniques evolved.[650] However, the main transformation from earlier builders' notebooks to informative How-to manuals came from the adoption of a coherent descriptive style in which the contents are described in an orderly manner which the reader can follow in a step-by-step fashion assisted by more sophisticated language, adapted to the abilities of the reader, and improved techniques of graphical representation.[651]

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[648] Bushnell. T*he Compleat Ship-Wright*.

[649] Duhamel du Monceau. 1758. *Élémens de l'Arrchitecture Navale ou Traité Pratique de la Construction des Vaisseaux*.

[650] For a very comprehensive discussion on the use of images as a means of transmitting information and, most importantly, as a means of understanding the role that images played in the shaping of the thought processes of early-modern scientists and technologists see: Lefèvre *et al.* (eds) 2003. *The Power of Images in Early Modern Science.* The chapter on the value of drawings as a means of creating a virtual reality where technologists can test and experiment is of especial interest: Art and Artifice in the Depiction of Renaissance Machines by P. Galluzzi.

[651] It is noteworthy that all treatises published after 'Salisbury, W. and Anderson, R.C. (eds), 1958. A Treatise on Shipbuilding and A Treatise on Rigging, Written About 1620-1625' describe their contents in a very similar order. This makes it possible to follow the contents easily and efficiently.

The search for order and coherence became a common pursuit for editors and publishers as soon as oral traditions and manuscript notes were transformed into printed works (Eisenstein, E.L. 1993. *The Printing Revolution in Early Modern Europe*. Cambridge University Press, p. 70).

8.3.2 The development in the graphical representation of ships in early modern treatises and a comparison with modern-day lines plans

At present times, plans and written specifications are the most usual method of transmitting information about the shape and physical configuration of ships. However, for centuries, traditional shipwrights and ship designers could not represent three-dimensional shape in abstract terms on paper, hence, they had to devise alternative methods of definition of hull shape. Templates, recipes and, finally, a mix of both in the form of drafted plans with instructions and specified properties are the methods devised by shipwrights to store information regarding hull-shape.[652] In the period under consideration an interesting transition took place in the method used by shipwrights to store and transmit information about hull-shape. Templates and design-recipes gave way to graphical representations. Likewise, the drawings shown in the treatises evolved from early descriptive drawings which contain information about the main parameters and control lines used to define the shape of the hull, to drawings which describe the actual three-dimensional shape of the surface of the hull.

As seen in the analysis in chapters 4-5, the design methods of the early modern period required that the shipwrights knew a recipe which would allowed them to shape a hull. When the shipwright decided on the few parameters needed by the recipe, a fair hull could be obtained by an automatic process. Initially this approach would be followed without any drawings. One obvious drawback of this method is that the shipwright had no means of checking that the shape produced was satisfactory, hence, the recipe was reserved for the central part of the hull only and other empirical methods were reserved for the ends. In this manner the possibilities of producing ships with unsuitable shapes were reduced.

As soon as graphical representations, to scale, became common shipwrights started to use them. However these early drawings cannot be compared to modern-day lines-plans. They do not transmit any relevant information about the shape of the surface of the hull in the sense that a modern lines plan does. These plans are a graphical representation of the parametric method – recipe– followed to define the shape of the hull. They show, in graphical form, the shape of the master-section and the control curves used to control its transformation into the other sections. However, in most cases these plans do not show the surface of the hull. For example, figures 23, 35-36, 61-62 and 67, show the drawings included in Mathew Baker's *Fragments of Ancient English Shipwrightry*, Bushnell's *The Compleat Ship-Wright*, Hardingham's *The Accomplish'd Ship-Wright*

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[652] Sabin, M. 2013. Talking about Shapes. *Mathematics Today*. August 2013, pp. 170-173 (p. 170).

and Sutherland's *Britain's Glory: or Ship-Building Unvail'd*. By observing the lines shown in them it becomes apparent that there is very little information about the real shape of the surface of the hull. The lines showing the shape of the backbone, the master section and in figures 23 and 67 two additional frames do lie on the surface of the hull, thus, convey their true shape. However, the rising and narrowing curves do not lie within the surface of the hull, therefore, cannot inform of its real shape. It becomes apparent, then, that the writers of these treatises were not interested in conveying the real shape of the three-dimensional surface of the ship. Their main concern, instead, was to convey in graphical form the shape of the lines used to generate the three-dimensional shape of the hull. Very fittingly, Sutherland called them 'the Lines that shape the Body [of the ship]'.[653]

Post mid-18th century treatises, on the other hand, show graphical representations which are in the strict sense equivalent to a modern lines plan. Thus, these plans represent the three-dimensional shape of the hull's surface. These plans are made up of numerous lines which lie on the actual surface of the hull ('frames', waterlines, buttocks and diagonals). They convey hull-shape in a visual form in a manner which is fully equivalent to a modern day lines plan (figures 68((a) and (b)), 72, 74, 83). Interestingly, Sutherland's treatises, which were published before and after this gradual change took place, show both types of drawing, each used at their best advantage. The parametric plan which shows the graphical representation of the recipe is used as a means of describing the design method in its abstract form (figure 68(*a* and *b*)). Additionally, a conventional lines plan showing plane sections through the surface of the hull is shown as a means of conveying its actual three-dimensional shape (figure 68(*c*)). Each type of plan serves a different purpose and, as such, should not be confused. Only the latter one is equivalent to a modern lines plan. However, there is still a substantial difference with a modern post-mid-19th-century lines plan. In a modern lines plan designers are free to create any shape they like. In contrast, in all the treatises analysed, regardless of the type of graphical representation shown in the plans, the shape of the hull was obtained following a design-recipe which, in effect, constrained the possible outcome of the design process to a hull-shape which the design recipe could produce.

8.4 Conclusion to chapter 8

Chapter 7 has argued that there is a common approach to the manner in which, traditional shipwrights visualise hull form which was put into practice through different techno-practical

[653] Sutherland. *Britain's Glory: or Ship-Building Unvail'd*, p. 25.

devices. In this chapter, the knowledge used by early modern shipwrights to shape their hulls has been put into perspective by showing that it was used and is still used by common shipwrights, far removed from ideas of academic sophistication which are still prevalent in the academic literature. A simple test has shown the manner in which a shipwright could use these methods to design ships with variable dimensions whilst keeping basic hydrostatic characteristics under control in an intuitive manner. To finalise the chapter, the treatises themselves have been put into perspective, suggesting that the ever increasing complexity of the materials in the texts do not respond to an improvement of the knowledge itself. Instead, it would suggest an improvement of the ability to transmit technical knowledge in writing and in pictorial form. This, trajectory can be witnessed in How-to manual published during the early modern period on other subjects.

Chapter 9: Conclusions

This research started with a specific goal. By using modern engineering tools used in naval architecture it would try to compare the performance characteristics of the yachts belonging to King Charles II of England during the latter years of the 17th century. More precisely, the initial goal called for a comparison of the performance of two of Charles II's yachts, both called the *Mary*. The first was of Dutch construction while its replacement was designed and built in England. By comparing their performance, it was expected that this research might be able to relate hull-design and performance characteristics with specific environmental conditions and service requirements of Dutch and English ships.

The design choices leading to the construction of the yachts would not have been made in a vacuum of individual ship-designers or shipwrights each with their own set of beliefs and technological knowledge. On the contrary, these choices would have been taken within a shared knowledge-space and technological-landscape. Consequently, early on this research, it became necessary to understand the technological-landscape and knowledge-space in which design-decisions were taken. This proved to be an interesting avenue of research. Therefore, it was soon decided that, instead of focusing on the performance of each ship or, more precisely, on their theoretical –therefore questionable– reconstruction, this research would focus on the design-knowledge used to design the different yachts. This was necessary, firstly, as a means of helping with the theoretical reconstruction which was one of the initial aims of the research. But, most importantly, it became necessary with the objective of producing a picture of the knowledge-space in which ships of this period were designed and built which could complement the current understanding of such knowledge in the academic literature.

With this outlook in mind, this research followed two parallel lines of enquiry around two main ideas. The first focus of interest would be the design knowledge of early modern shipwrights. The second, would be the manner in which such knowledge is portrayed in the current academic literature. Thus, this research has tried to answer the following questions:

- With respect to the knowledge of early modern ship-designers and shipwrights:
    - What is the design-paradigm of early modern ship designers and shipwrights?
    - Do they share a common design-knowledge or, on the contrary, do they have different design-paradigms?

  - What is the real purpose of the seemingly different design-strategies? Are they means of obtaining new shapes, or on the contrary are they just strategies for the storage and transfer of knowledge?

- With respect to the manner in which the knowledge of early modern ship designers and shipwrights is portrayed in the current academic literature.

  - Is the knowledge of early modern ship-designers and shipwrights characterised correctly?

  - Can the current narrative be reviewed to offer a modified account that helps characterise the knowledge of early modern ship designers and shipwrights?

In the current scholarship that studies the shipbuilding technology of the early modern period, 17th-century English and Dutch shipbuilding traditions are considered to be exemplars of two opposite ways of approaching the conception and construction of ships (chapter 2). The English would follow a *frame-first* approach, while the Dutch would follow a partially *shell-first* approach. These are not mere considerations about building sequence. Both approaches are considered to represent different approaches to the idea of conceiving and building the hull. Moreover, these two approaches to assembling a hull have been used to conclude that the societies who used the different approaches would have different social arrangements with respect to the manner in which ship-design knowledge was created and shared around the community of shipwrights (chapter 2).

The theoretical framework that divides shipbuilding traditions in two opposite paradigms, *shell-first* and *frame-first*, constitutes on of the pillars that sustains current scholarship on shipbuilding traditions, not exclusively of the early modern period. Most crucially, it is the basis of the current scholarship that describe social changes and technological transitions which were witnessed in at least two major transition processes in Europe: the *shell-first* to *frame-first* transition during the first millennium in the Mediterranean and the post-medieval transition in northern Europe, where *shell-first* processes were abandoned in favour of a *frame-first* approach. Therefore, a correct definition of the design paradigms of bottom-based Dutch shell-first tradition and the frame-first English traditions, in which two of Charles II's yachts were built, becomes of interest. This would make it possible to characterise correctly the design paradigm and design knowledge of early modern shipwrights which, currently, is heavily influenced by the definition of shell-first and frame-first building as constituting opposite paradigms, hence different world views.

Consequently, Charles II's yachts, built under seemingly opposite design paradigms provided a good opportunity to explore the knowledge-space of ship-designers and shipwrights of 17th-century English frame-first and Dutch shell-first (bottom-based) traditions. However, such a particular focus, proved again unsatisfactory, and the research opened its scope to analyse all design treatises possible –from the earliest Venetian manuscripts (15AD) to the early 19th century papers on ship-design– where conceptually similar approaches used to obtain hull shape were described (chapters 4 and 5).

One of the objectives of this thesis became to establish the nature of the knowledge contained in the different early modern shipbuilding treatises and to establish whether the variety of methods of creating a hull shape described in the different treatises represent differences in knowledge. In order to do so, chapter 3 established the outlook of this research with respect to what features of the design methods would be considered relevant and which would be considered irrelevant details. This, obviously responds to a choice of the present author. However, it was argued that in order to research the design paradigm of each treatise, the researcher should focus on the general concept only, disregarding details that may distract from the abstract knowledge (chapter 3).

A series of design treatises from the 15th to the late 18th century were analysed (chapters 4 and 5) in order to respond to the first group of research questions which were centred around the knowledge of early modern ship-designers and shipwrights: (a) trying to identify the design-paradigm, (b) to see if it was shared or different amongst different groups of shipwrights, (c) and to understand the real purpose of the seemingly different design-strategies shown in the treatises. A number of these treatises are currently identified in the academic literature, however, in chapter 6 it has been noted that most have played no role in the process of shaping current thoughts about the design-knowledge of early modern ship-designers and shipwrights. Therefore, a database of the treatises available in PDF format used in this research is provided with this thesis in an accompanying DVD with a double goal. Firstly, this database should allow the reader to have easy access to original treatises. Secondly, this should allow the reader to contrast the original material with the manner in which it is currently interpreted in the accepted scholarship and, indeed, to contrast it with the manner in which they have been interpreted in this research. In addition to this database of design treatises, this research brings Arrospide's posters to the attention of scholars for the first time (Chapter 5 and included in the DVD). The manuscript posters are transcribed for the first time into its original language, Spanish, correcting grammar and obscure syntax which reduced its comprehension (appendix B). Moreover, in order to increase their value for researchers who may not be familiar with the Spanish language, they have been translated it into English (appendix B). These documents help form a richer depiction of late 18th-century Spanish shipbuilding practices and, crucially, its practitioners (appendix B). However, most crucially, these posters highlight that besides written treatises, there is possibly a set of sources of information in the form of notes and plans, unexplored yet, which should help produce a richer depiction of the design-knowledge of the period. Figures 123-124 show another example of this type of document, in this case of Danish origin.[654]

In order to extract the knowledge from each of the treatises analysed in chapters 4 and 5, current ideas that link assembly sequence with the manner in which the shipwright 'thought' about the ship have been abandoned. Consequently, this researcher approached the contents of the treatises without a pre-conceived notion of their contents and about the design paradigm of their writers. Instead, the treatises have been approached from a practical point of view focusing on the ideas that the reader can obtain from them. These in turn have been used to interpret the ship design paradigm of each of the treatises. Of the many possible definitions of a technological paradigm, Dosi's definition of paradigm guided this research.

Dosi, defined a technological paradigm 'as an "outlook", a set of procedures, a definition of the "relevant" problems and of the specific knowledge related to their solution'.[655] Therefore, this research focused on the technological paradigm of early modern shipwrights responsible for writing and using the treatises by reading the treatises with the following question in mind: When an early modern shipwright was confronted with the *'problem'* of building a new ship, what *'solution'* did they find to solve the problem of developing its three dimensional hull? The answer to this question should help characterise the 'solution' found by the shipwright, hence, the knowledge contained in the treatise.

The main dataset used in this research is analysed in chapter 4 and 5. These are the design-treatises from the earliest 15th-century Venetian manuscripts to the late 18th- and early 19th-century printed sources. The treatises are analysed in chronological order, without consideration for national boundaries, with the exception of the three documents used to describe Dutch design practices of the period. These are discussed as a separate unit at the end of chapter 4. The analysis has shown (chapter 4, 5, and summary in 6) that during this period the design paradigm used by shipwrights to solve the problem of designing a new ship, remained constant. In all cases, a design-recipe based on geometry and the control of hull shape by a transformation of a master section remains at the core of the design paradigm, which can be summarised as follows:

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[654] I must thank Rolf Warming for his help in translating the general idea contained in the text that accompanies the plans.

[655] Dosi. Technological paradigms and technological trajectories, p. 148.

a) The shipwright knew from tradition, the main proportions between length, beam, and depth of the ship.

b) The shape of the hull was defined by a series of lines which were used to generate its three-dimensional shape based on a few control parameters. The shape of these lines was obtained by a series of graphical, geometric or mathematical procedures.

f) The lines used to generate the three-dimensional shape of the hull were:

- The ship's profile shape: made up of the keel, sternpost and stem.
- The master frame which influenced the transversal shapes of the frames of the hull.[656]
- Several lines of longitudinal control which determined how the shape of the frames changed as they neared the ends and 'moved' further away from amidships.

g) The shape of the transversal frames of the hull were obtained by a transformation of the master section, controlled by the lines of longitudinal control defined in (c).

h) The method could be used directly on a full size loft floor, or by drafting a simple plan previously where the lines mentioned in point *(c)* were drawn.

Therefore this research shows that when the treatises are read with Dosi's definition of technological paradigm in mind, looking at their technological-paradigm (or 'outlook'), through observing the 'solutions' found by shipwrights for the specific 'problem' of creating a ship's hull, it becomes clear that all treatises view the 'problem' of shaping a hull through identical 'solutions'. The authors of all the treatises analysed could have described that their design method followed the steps (a) to (h) shown above. They would share a common knowledge-space and ship design paradigm which would have shown no appreciable difference from the earliest written manuscript to the latest printed treatise. In this respect, Dutch shipwrights would describe a different set of parameters, but always with a conceptually similar core. In their case, the role of the rising and narrowing line was taken by the definition of a series of breads and deadrise angles before construction. Thus, this control of the shape of the bottom led the way to the rest of the design, which would also be influenced by the previous knowledge of transversal shapes as shown in chapter 5.

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[656] This is for a double ended ship. If it had a transom, its shape would also be defined in the recipe.

The analysis of early modern treatises in chapters 4 and 5, has been used in chapter 6 to reflect on one of the research questions which focused on the knowledge contained in the treatises and the manner in which it is portrayed in the current literature. Chapter 6 criticises several key aspects of the current narrative that explains the technological-landscape of the early modern shipwright. These criticisms highlight some of the shortcomings which in view of this researcher distort the manner in which the current scholarship describes the knowledge-space of early modern shipwrights. Mainly, that the evidence –the treatises– have generally been approached with an over-particularistic outlook leading to distorted description of the ship-design knowledge of the early modern period.

Thus, it has been highlighted that the current narrative is based on few treatises, mainly manuscripts, which has led to ideas of sophistication and mathematical knowledge which is not necessarily present in the variety of treatises analysed in chapters 4 and 5. Similarly, an over-particularistic focus on certain features of the design methods have created an idea of the relevance of the master section over other longitudinal lines which have been shown to be just as important in the process of creating a three-dimensional hull shape. Also, ideas of geographic boundaries, which limit the scope of modern researches have been criticised. Instead, it has been highlighted that treatises clearly state that there existed other design methods that were known by their authors, who chose not to write them down. Thus, realising that within the same design paradigm, there are still many methods, recipes and tricks of the trade, which could have been used to produce hull shapes, which are unknown to the modern researcher. The criticism also highlighted the manner in which sometimes the evidence was made to fit within the currently accepted narrative, not always easily, instead of shaping the narrative according to the available evidence. This has been highlighted with two examples. Lavery's interpretation of Bushnell's treatise (chapter 6), and Hoving's interpretation of Witsen's design method (chapter 4). However, the most notable case, taking into consideration its repercussion in the current scholarship, would be Hasslöf's interpretation of Arnaul's account of Dutch methods of shaping the bottom of the hull with significant variation in the translations used by Hasslöf over the years. This has been described in chapter 4 and, bearing in mind its repercussion in the creation of current scholarship, in a separate appendix A. The analysis on appendix A should help cast a light on the manner in which historical studies of ship-design technology have built up on evidence that should be reconsidered.

Chapter 7 built on the ideas discussed in the previous chapters in order to propose a description of the ship-design knowledge used by shipwrights building ships before the introduction of analytical tools based on engineering knowledge during the 19th century. Therefore, chapter 7 introduces a series of thoughts which build upon the theoretical framework which is currently used to understand and classify the apparently opposing paradigms which different shipbuilding *shell-firs*t and *frame-first* traditions had for visualising and building their ships. Currently, Hocker's theoretical framework is used to analyse shipbuilding paradigms from a theoretical standpoint (chapter 2). Hocker broke down the process of creating a ship in three distinct phases which he called: *conception*, *assembly* and *structural philosophy.* The ideas proposed in chapter 7, that conception should be divided in three additional aspects, would help improve the present understanding of the manner in which the different ship-building traditions conceived hull shape. The analysis in chapters 4 and 5 and theoretical reasoning have allowed this researcher to build on the idea of *conception* as defined in Hocker's framework.

By dividing the idea of *conception* in three separate aspects, it has been possible to analyse the paradigm of hull shape design for the four main shipbuilding traditions contemplated by the current scholarship in Europe. They are, the ancient Mediterranean tradition, the northern European clinker tradition, the early modern Dutch bottom-based tradition, and the post medieval frame-first tradition which led to the early modern methods analysed in chapters 4 and 5. Of these, the first three are shell-first, or partially shell-first traditions. The latter is a frame-first tradition. It has been suggested in chapter 7 that, contrary to the currently accepted scholarship which considers that shell-first and frame-first builders had opposing paradigms with respect to the manner in which hull shape was visualised, there is a common design paradigm which is shared by shipwrights of the different shipbuilding traditions.

The manner in which all four traditions visualised hull form would be based on the innate manner in which humans 'visualise' three-dimensional shape: by focusing on its contours. Therefore, it has have been proposed that, when the need to build a new ship arose, in order to be able to re-use information gained from past experiences effectively, shipwrights of the four traditions found the need to define the shape of both contours (chapter 7). However, in contrast to the common, innate, paradigm which considered both contours as their core information regarding hull-shape, each tradition created a series of different techno-practical devices for the actual definition and storage of the shape of the contours. In all cases, the methods to store the shape of the longitudinal or transversal contour are similarly sophisticated. This lead to the otherwise logical conclusion that shipwrights of either tradition did not have a transversal or longitudinal understanding of the hull. They would all share a similar paradigm to visualising hull shape. Thus, it is hoped that the proposal made here of breaking up the conception of hull -shape in three parts, should help improve the current understanding of the different transitions that took place in Europe, from shell-first to frame-first traditions. At the moment their understanding is very much distorted by the alleged paradigmatic differences between the manner in which these two approaches to shipbuilding visualised and understood hull-shape.

By highlighting the remarkable similarities between the techno-practical devices used in the ancient Mediterranean and the post medieval frame-first tradition it has been possible to suggest a direct link within a common technological trajectory. This, which according to the current narrative would require a change of paradigm, becomes a more fluid trajectory, based on the idea of a common paradigm discussed previously.

This thesis ends by moving away from general discussions about shipbuilding/design paradigms (in chapter 7), to return in chapter 8 to the case of early modern shipwrights and their ship-design knowledge. Chapter 8 brings to focus the ideas that have been discussed in this thesis by returning to the case of the early modern shipwright, contemporary of the written treatises and responsible for the design and construction of the yachts described in chapter 2 and other contemporary ship types. A picture of the early modern shipwright's design paradigm, distanced from the current image which points towards sophisticated, mathematically minded, learned practitioners is proposed. Based on the analysis of the treatises in chapters 4 and 5 and additional evidences in the form of near-contemporary informed opinions (19th-century) and 20th-century ethnographic material, it is possible to suggest that the knowledge contained in the treatises does not differ from the knowledge used by less sophisticated shipwrights using the same methods of hull design. Thus, ideas of mathematical sophistication, social hierarchy, scientific approaches, should not be identified with the design methods of the early modern shipwright. Undoubtedly, some details shown in the treatises may deserve to be described with these adjectives. Some of the practitioners may have had a mathematical, or scientific interest. However, the knowledge itself was practical and easy to use. All that it required would be to know a simple design-recipe, and the use of some simple tools which in most cases could be reduced to a compass and a straightedge. In the case of a ship designed full-size on the loft floor, a piece of string which could be used both as a chalk-line (straightedge) and a compass would suffice.

Chapter 8 has also looked into the actual design methods themselves to establish the manner in which shipwrights could develop an intuitive feel for these design methods. With this in mind, a simple test was performed. A basic hull-shape was proposed to establish the manner in which these apparently complex design methods could be modified intuitively thus allowing shipwrights to experiment with shapes, whilst keeping control over certain performance characteristics of the ship. It was shown that such intuitive control was possible and relatively simple to implement. This again would point towards design methods for which sophistication would not be required. The chapter finishes by looking at the treatises themselves, to suggest that the ever increasing complexity of the design treatises of the early modern period do not reflect an evolution of the knowledge contained in them, from simple to complex. Instead such apparent evolution would be a reflection of the increasing improvement in the quality and sophistication of the How-to manual as a genre of storing and transmitting existing knowledge.

It is hoped that by bringing these ideas together, this thesis will have helped improve our current understanding of traditional (pre-engineering) shipwrights, and more specifically early modern shipwrights.

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UNIVERSITY OF SOUTHAMPTON

FACULTY OF HUMANITIES

History

Volume 2 of 2

Ship design-knowledge in early modern Europe:

Royal yachts and the shared knowledge of ship-designers and common shipwrights.

by

Juan-Pablo Olaberria

Thesis for the degree of Doctor of Philosophy

February 2018

UNIVERSITY OF SOUTHAMPTON

ABSTRACT

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SHIP DESIGN-KNOWLEDGE IN EARLY MODERN EUROPE:

ROYAL YACHTS AND THE SHARED KNOWLEDGE OF SHIP-DESIGNERS AND COMMON SHIPWRIGHTS

Juan-Pablo Olaberria

The initial objective of this thesis aimed at comparing the performance characteristics of two yachts belonging to King Charles II of England during the latter years of the 17th century. This goal, which called for accurate modelling of the shape of each yacht, was extended to investigate the design processes used by Dutch and English shipwrights of the period. It was soon decided that, instead of focusing on the performance of each ship or, more precisely, of their theoretical – therefore questionable– reconstruction, this research would focus on the design knowledge of the early modern period used to design the different yachts and contemporary ships. This was necessary, firstly, as a means of helping with the theoretical reconstruction which was one of the initial aims of the research. But, most importantly, it was necessary to produce a picture of the knowledge-space in which ships of this period were designed and built. Consequently, this research offers an overview of the current narrative that describes ship design knowledge of the early modern period and criticises some aspects of it. Moreover, as the current understanding of such knowledge is included within a longer narrative that describes ship design knowledge of shipwrights from the earliest known examples of ships to the present, this research also looks into the manner in which ship design knowledge is understood within such a long narrative. This research provides arguments to show that ship design knowledge could be re-defined. It provides a more nuanced description of the design knowledge of traditional shipwrights and includes the knowledge of early modern shipwrights within this re-modelled narrative.

Table of Contents

List of Tables

List of Figures

List of Accompanying Materials

- Attached to Volume 1 of this thesis, the reader will find a DVD containing ship design treatises of the 17th and 18th century which have been used in this research. It should allow the reader to contrast the contents of the treatises with their interpretation in this thesis.

DECLARATION OF AUTHORSHIP

I, Juan-Pablo Olaberria declare that this thesis and the work presented in it are my own and has been generated by me as the result of my own original research.

Ship design-knowledge in early modern Europe: Royal yachts and the shared knowledge of ship-designers and common shipwrights.

I confirm that:

1. This work was done wholly or mainly while in candidature for a research degree at this University;
2. Where any part of this thesis has previously been submitted for a degree or any other qualification at this University or any other institution, this has been clearly stated;
3. Where I have consulted the published work of others, this is always clearly attributed;
4. Where I have quoted from the work of others, the source is always given. With the exception of such quotations, this thesis is entirely my own work;
5. I have acknowledged all main sources of help;
6. Where the thesis is based on work done by myself jointly with others, I have made clear exactly what was done by others and what I have contributed myself;
7. None of this work has been published before submission:

Signed: ....

Date: ....

Acknowledgements

There are numerous people who must be thanked for their help in making this thesis possible. First of all, I would like to start by expressing my gratitude to my three supervisors who have supported me throughout this research: Maria Hayworth, Dominic Hudson and Julian Whitewright. Their support and encouragement have made this sometimes long and arduous process possible. Also, I would like to thank Lucy Blue of the University of Southampton who first told me of the possibility of doing this research. Without her suggestion I would not have started this process.

Next I must express my gratitude to my colleague Thomas Dhoop for his always constructive input and enlightening discussions during the five years that we have shared our common interest in ships. His comments and suggestions to an earlier draft of this thesis have also been very helpful. Other colleagues at the university deserve to be thanked as well. Rodigo Ortiz for his help in obtaining documents from the Naval Museum in Madrid, Spain. Felix Pedrotti for his translation of several sections of Furttenbach's treatise from the original German. I should also thank Jaap Luiting for translating a whole chapter of Van Yk's treatise from the original Dutch and for the productive exchange of ideas that followed our first communication by email. Also, Rolf Warming helped by providing a quick translation of 18th century Danish documents used in this research. Also, I must thank Pat Tanner. It is during the week long meeting of maritime archaeologists organised by Pat in Baltimore, Ireland, that some of the ideas that have seen the light in these thesis took shape.

I would also like to express my gratitude to Iñaki Olaizola who has inspired me and encouraged me to pursue this research.

Finally, I should dedicate this work to my wife, Ana, and our children, Amaia, Mikel and Helene. I must thank them for their support and patience, and for allowing me to spend endless hours at my desk when my attention should have been directed to them.

Chapter 1: Figures

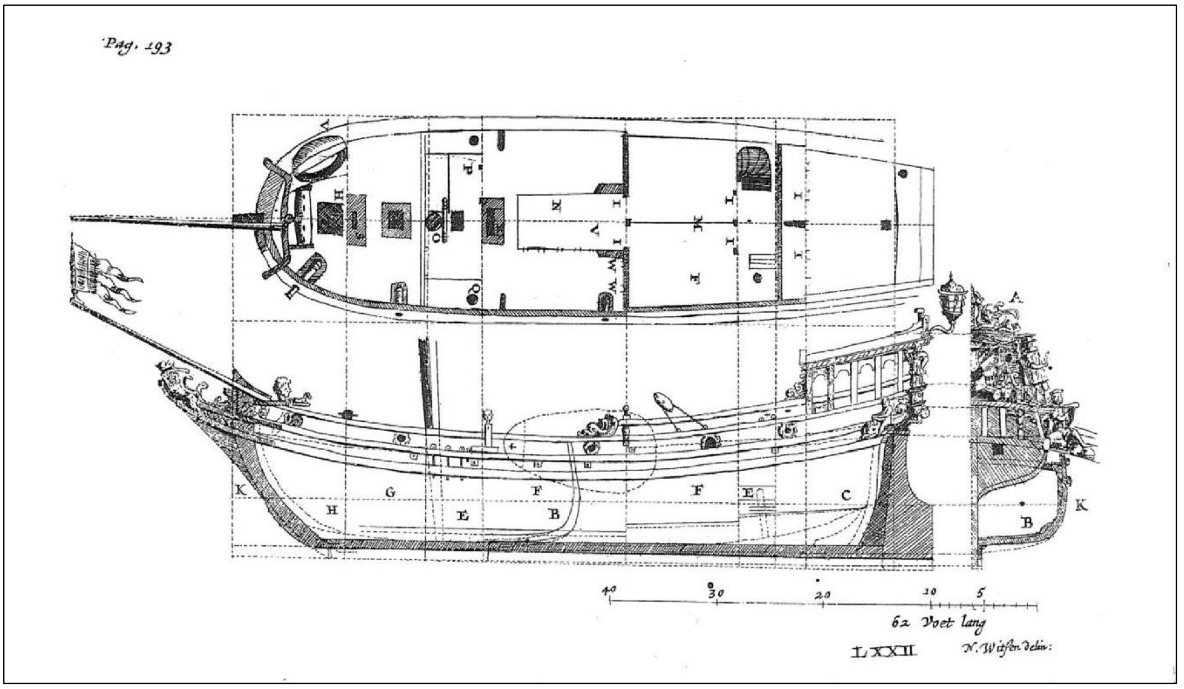


Figure 1: Dutch yacht depicted in Witsen, *Aeloude en hedendaegsche scheepsbouw en bestier* (1671), plate LXXII. It shows a yacht built by Jan Ysbrantsz Hoogzaat of Amsterdam for the King of Sweden.
Although the plan does not describe the three-dimensional shape of the hull in detail, it provides sufficient information to be able to develop a general idea of the shape of the hull. With the master section, the transom and the stem in profile, there is probably sufficient information to build a hull of conventional shape. Observe how the master section is shown both in the transversal section, and also in the profile view, where its shape and longitudinal position is established. (Image from Witsen, N. 1671. *Aeloude en Hedendaegse Scheeps-bouw en Bestier*. Plate LXXII)

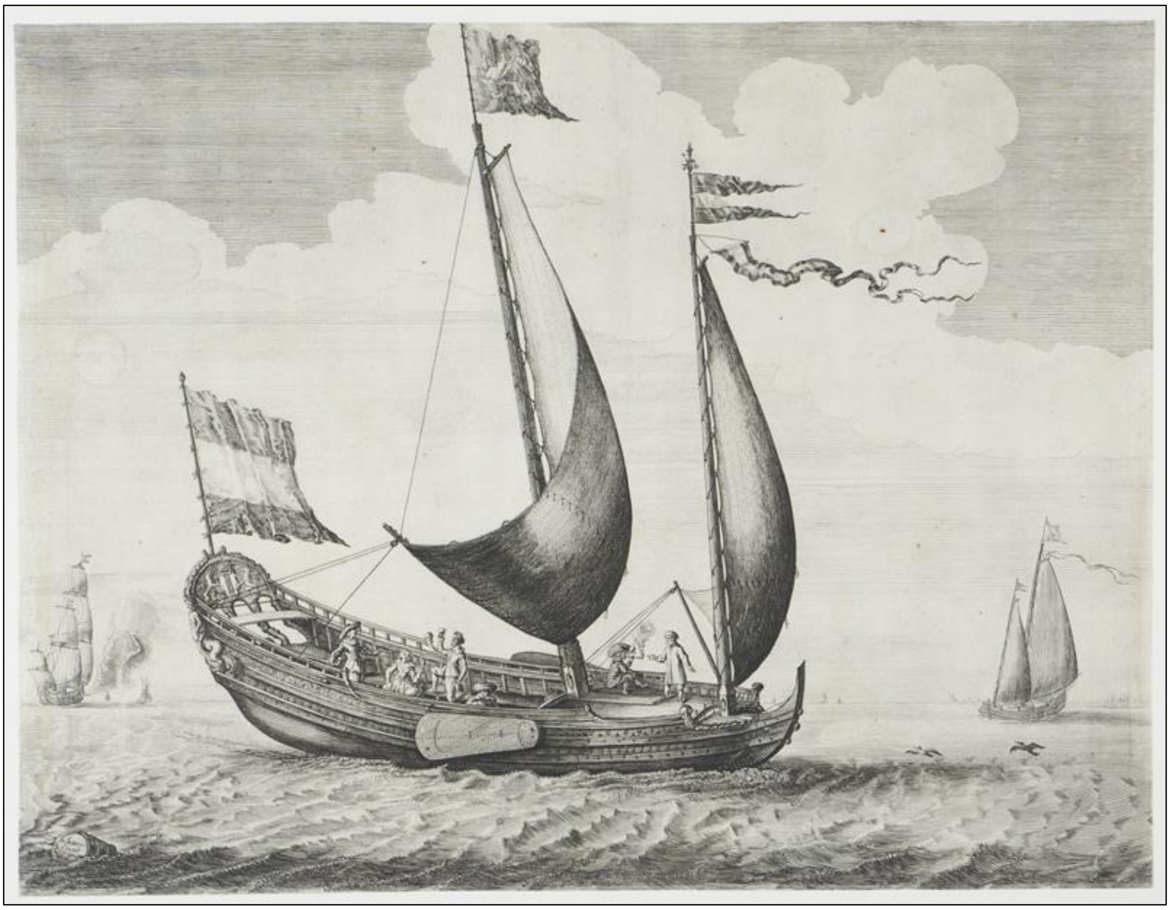
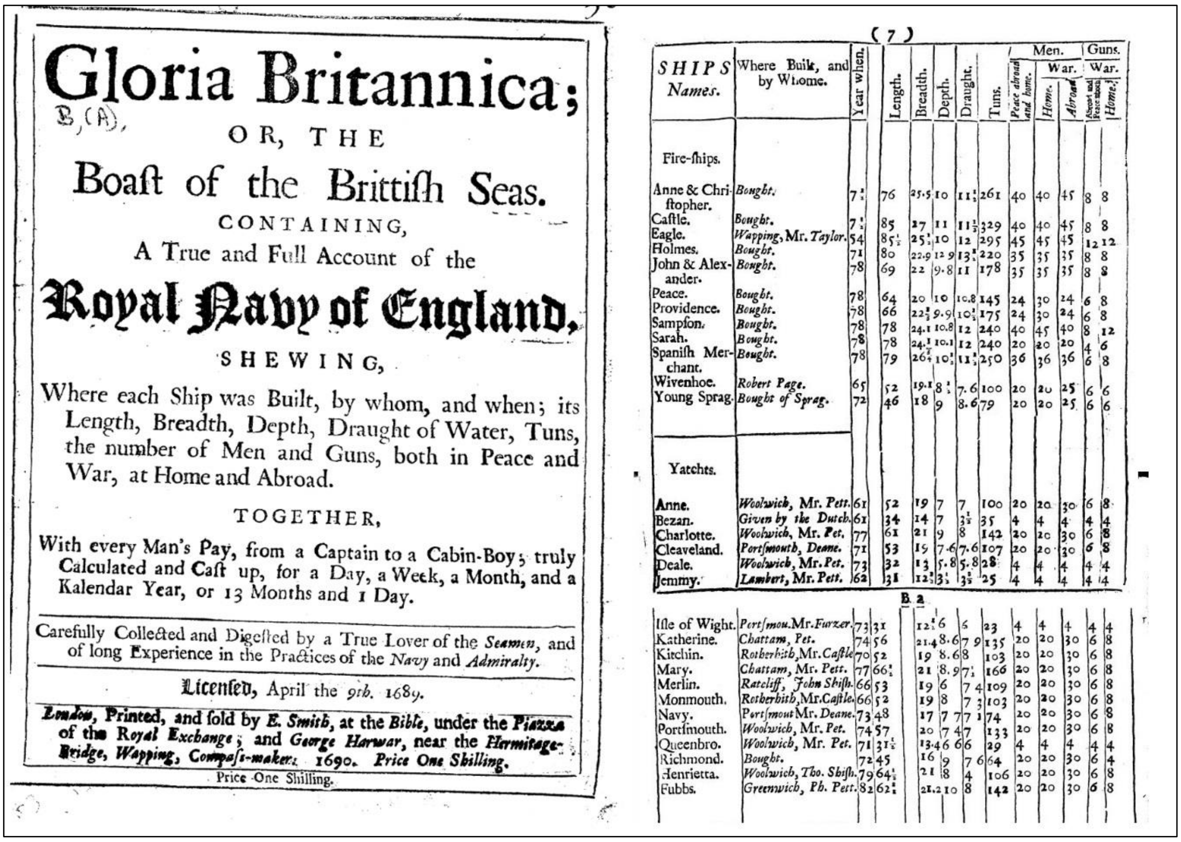


Figure 2 Image of a *speeljaght* from 1640 showing a group of people sailing in a yacht. The group is made up of six members of which one is female and one seems to be a boy looking over the rail into the water. They are shown in a relaxed attitude which conveys the idea of a pleasurable outing. (Image from Het Scheepvaartmuseum, the Netherelands: A.0145(121)7)



Gloria Britannica;

OR, THE

Boast of the Brittish Seas.

CONTAINING,

A True and Full Account of the

Royal Navy of England,

SHEWING,

Where each Ship was Built, by whom, and when; its Length, Breadth, Depth, Draught of Water, Tuns, the number of Men and Guns, both in Peace and War, at Home and Abroad.

TOGETHER,

With every Man's Pay, from a Captain to a Cabin-Boy; truly Calculated and Cast up, for a Day, a Week, a Month, and a Kalendar Year, or 13 Months and 1 Day.

Carefully Collected and Digested by a True Lover of the *Seamen*, and of long Experience in the Practices of the *Navy* and *Admiralty*.

Licensed, April the *9th.* 1689.

London, Printed, and sold by *E. Smith*, at the *Bible*, under the *Piazza* of the *Royal Exchange*; and *George Harwar*, near the *Hermitage-Bridge*, *Wapping*, *Compass-maker*. 1690. *Price One Shilling.*

Price One Shilling.

(7)

SHIPS Names.	Where Built, and by Whome.	Year when.	Length.	Breadth.	Depth.	Draught.	Tuns.	Men: Peace abroad and home.	Men: War. Home.	Men: War. Abroad.	Guns: War. Abroad and Peace abroad	Guns: War. Home.
Fire-ships.												
Anne & Christopher.	*Bought.*	7½	76	25.5	10	11½	261	40	40	45	8	8
Castle.	*Bought.*	7½	85	27	11	11⅓	329	40	40	45	8	8
Eagle.	*Wapping*, Mr. *Taylor.*	54	85½	25½	10	12	295	45	45	45	12	12
Holmes.	*Bought.*	71	80	22.9	12 9	13½	220	35	35	35	8	8
John & Alexander.	*Bought.*	78	69	22	9.8	11	178	35	35	35	8	8
Peace.	*Bought.*	78	64	20	10	10.8	145	24	30	24	6	8
Providence.	*Bought.*	78	66	22⅔	9.9	10½	175	24	30	24	6	8
Sampson.	*Bought.*	78	78	24.1	10.8	12	240	40	45	40	8	12
Sarah.	*Bought.*	78	78	24.⅓	10.1	12	240	20	20	20	4	6
Spanish Merchant.	*Bought.*	78	79	26¼	10½	11½	250	36	36	36	6	8
Wivenhoe.	*Robert Page.*	65	52	19.1	8½	7.6	100	20	20	25	6	6
Young Sprag.	*Bought of Sprag.*	72	46	18	9	8.6	79	20	20	25	6	6
Yatchts.												
Anne.	*Woolwich*, Mr. *Pett.*	61	52	19	7	7	100	20	20	30	6	8
Bezan.	*Given by the Dutch.*	61	34	14	7	3½	35	4	4	4	4	4
Charlotte.	*Woolwich*, Mr. *Pet.*	77	61	21	9	8	142	20	20	30	6	8
Cleaveland.	*Portsmouth*, *Deane.*	71	53	19	7.6	7.6	107	20	20	30	6	8
Deale.	*Woolwich*, Mr. *Pet.*	73	32	13	5.8	5.8	28	4	4	4	4	4
Jemmy.	*Lambert*, Mr. *Pett.*	62	31	12½	3½	3½	25	4	4	4	4	4

B 2

SHIPS Names.	Where Built, and by Whome.	Year when.	Length.	Breadth.	Depth.	Draught.	Tuns.	Men: Peace abroad and home.	Men: War. Home.	Men: War. Abroad.	Guns: War. Abroad and Peace abroad	Guns: War. Home.
Isle of Wight.	*Portsmou.* Mr. *Furzer.*	73	31	12½	6	6	23	4	4	4	4	4
Katherine.	*Chattam*, *Pet.*	74	56	21.4	8.6	7 9	135	20	20	30	6	8
Kitchin.	*Rotherhith*, Mr. *Castle*	70	52	19	8.6	8	103	20	20	30	6	8
Mary.	*Chattam*, Mr. *Pett.*	77	66½	21	8.9	7½	166	20	20	30	6	8
Merlin.	*Ratcliff*, *John Shish.*	66	53	19	6	7 4	109	20	20	30	6	8
Monmouth.	*Rotherhith*, Mr. *Castle.*	66	52	19	8	7 3	103	20	20	30	6	8
Navy.	*Portsmout* Mr. *Deane.*	73	48	17	7 7	7 1	74	20	20	30	6	8
Portsmouth.	*Woolwich*, Mr. *Pet.*	74	57	20	7 4	7	133	20	20	30	6	8
Queenbro.	*Woolwich*, Mr. *Pet.*	71	31½	13.4	6 6	6	29	4	4	4	4	4
Richmond.	*Bought.*	72	45	16	9	7 6	64	20	20	30	6	4
Henrietta.	*Woolwich*, *Tho. Shish.*	79	64½	21	8	4	106	20	20	30	6	8
Fubbs.	*Greenwich*, *Ph. Pett.*	82	62½	21.2	10	8	142	20	20	30	6	8

Figure 3 Cover and extract of pages 7 and 8 of *Gloria Britannica*. This account of the ships of the Royal navy includes a total of 18 yachts. It was printed in London in 1689. (JPO from the original. A. B. 1689. *Gloria Britannica, or the Boast of the British Sea,* p.7-8)

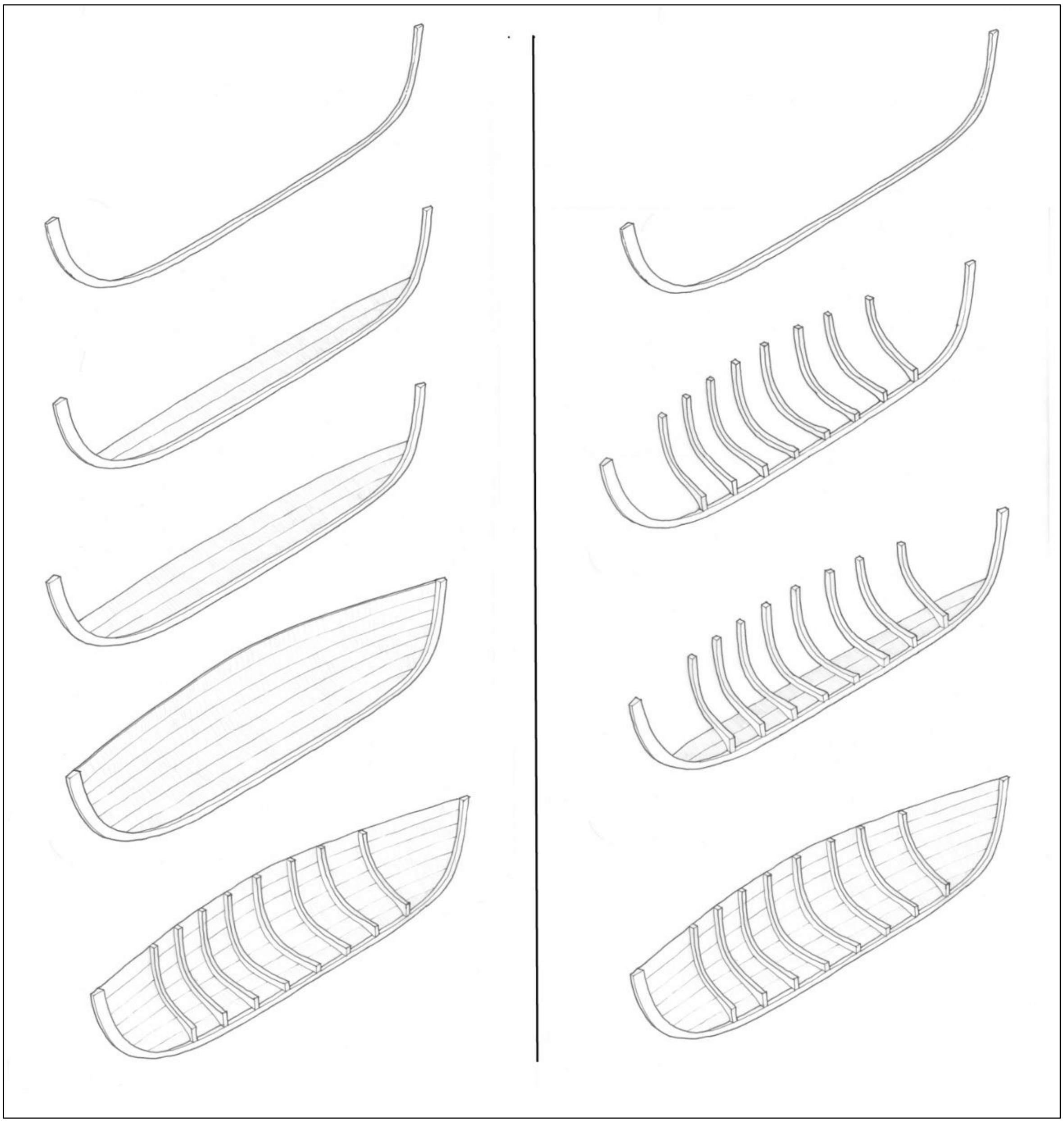


Figure 4 Two main wooden ship-building traditions: *shell-first* on the left and *frame-first* on the right. The illustrations show half of the ship. In both cases the construction process starts by erecting the backbone of the ship. Following this, the *shell-first* builders assemble the outside shell of the ship and the internal framing is inserted afterwards. Frame-first builders, on the other hand, erect the inner structure of the *ship first*. The outside planking is fixed to the frames in the next step. In both cases, once the hull is finished, it may not be possible to recognise the assembly sequence unless the material fabric is studied carefully to infer from work marks, fixings, etc. the order in which the different elements of the ship's structure were assembled. (Drawing JPO)

Figure 5 A traditional clinker boat under construction in a shell-first process. (www.oselvarverstaden.no)

Figure 6 Photograph of a frame-first boat under construction in a traditional yard in Egypt. The framework has been erected prior to the outside planking which will be fixed to it. (Photograph Julian Whitewright)

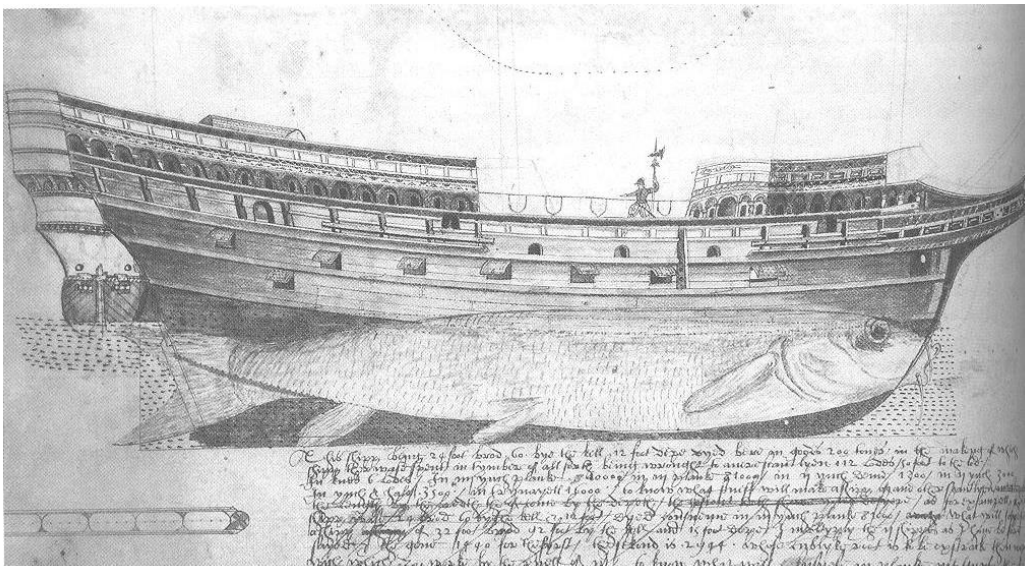


Figure 7 Illustration from Mathew Baker's *Fragments of Ancient English Shipwrightry*. (Adams, J. 2013. *A Maritime Archaeology of Ships*, p.116)

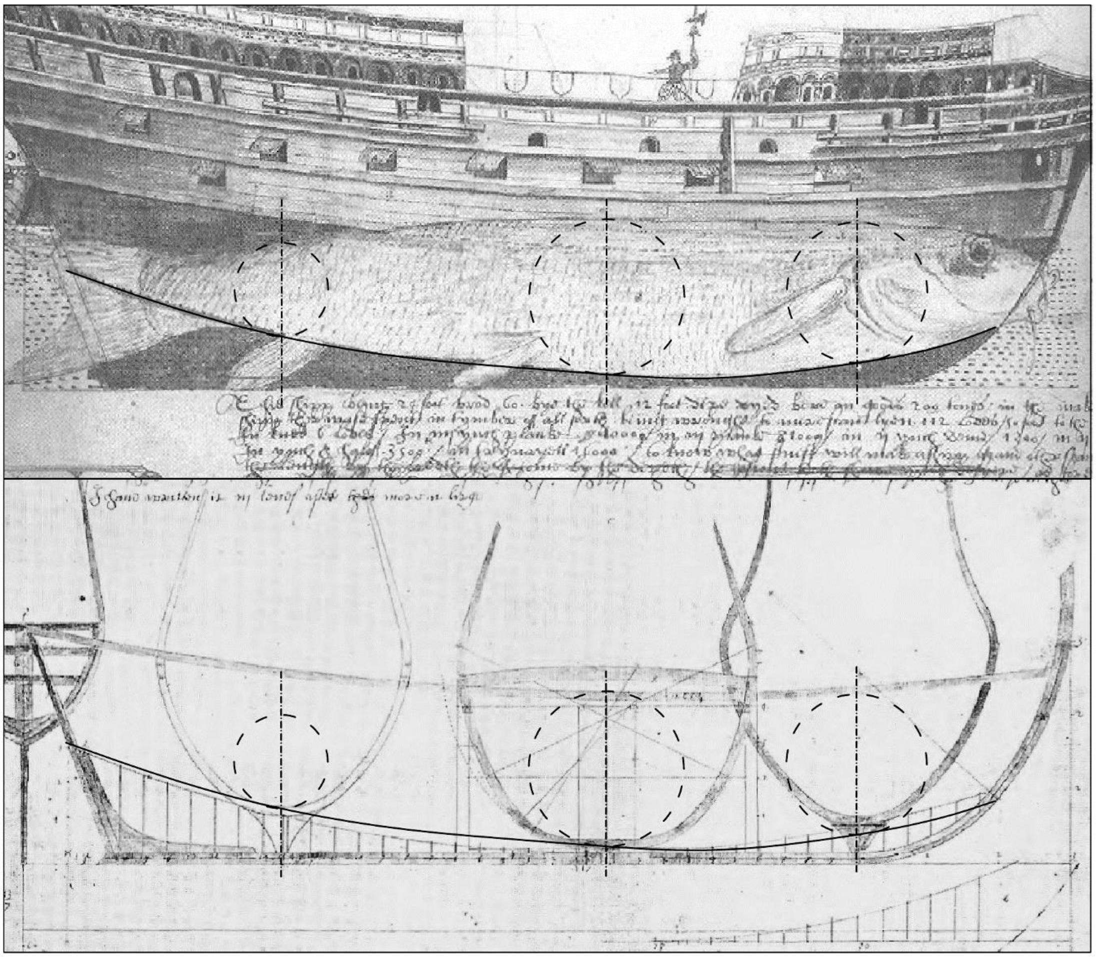


Figure 8 An alternative interpretation of the cod's head mackerel's tail expression?
In the top figure, the bottom perimeter of the fish has been traced over and three circles suggesting a simplified cross section of the fish are shown.
Below: these lines are superimposed on folio 19 of Mathew Baker's *Fragments of Ancient English Shipwrightry*.
It can be seen that the bottom line of the fish matches very closely the shape of the rising line. It can be noted as well that the simplified cross sections of the fish bear no relation with the shape of the cross-section of the hull as shown by the frames. Thus, while the fish does not describe the shape of the underwater volume of the hull correctly, it does match very accurately the shape of the rising line. (Lines drawn by JPO).

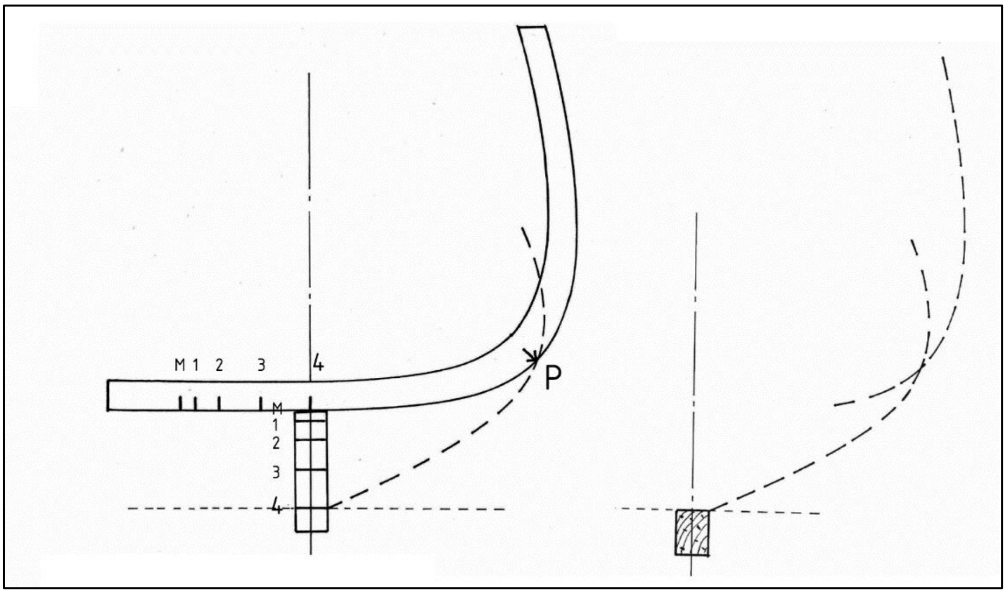


Figure 9 Design of a frame by rising and narrowing identified by this author in the 19th century Mutiozabal shipyard of Orio, Spain. All methods work on similar principles. The shipwright would have a template of a master frame where a series of marks that indicate by how much each frame should be narrowed according to its position would be inscribed. Similarly, an additional instrument, the rising staff, would be marked in order to inform the shipwright how much to raise the template.

Left: In this example the shipwright would be making frame number 4 by rising and narrowing to mark number 4. In this case, the method of 'filling up the gap between the keel and the template (shown as a dotted line in the left) is by rotating the template around point P. The end result is shown in the right. The distortion in the shape of the frame would have to be faired by the shipwright. (Drawing by JPO after Olaberria, J.P and Olaizola, I. 2012. Método de diseño en el astillero Mutiozabal de Orio. p.446)

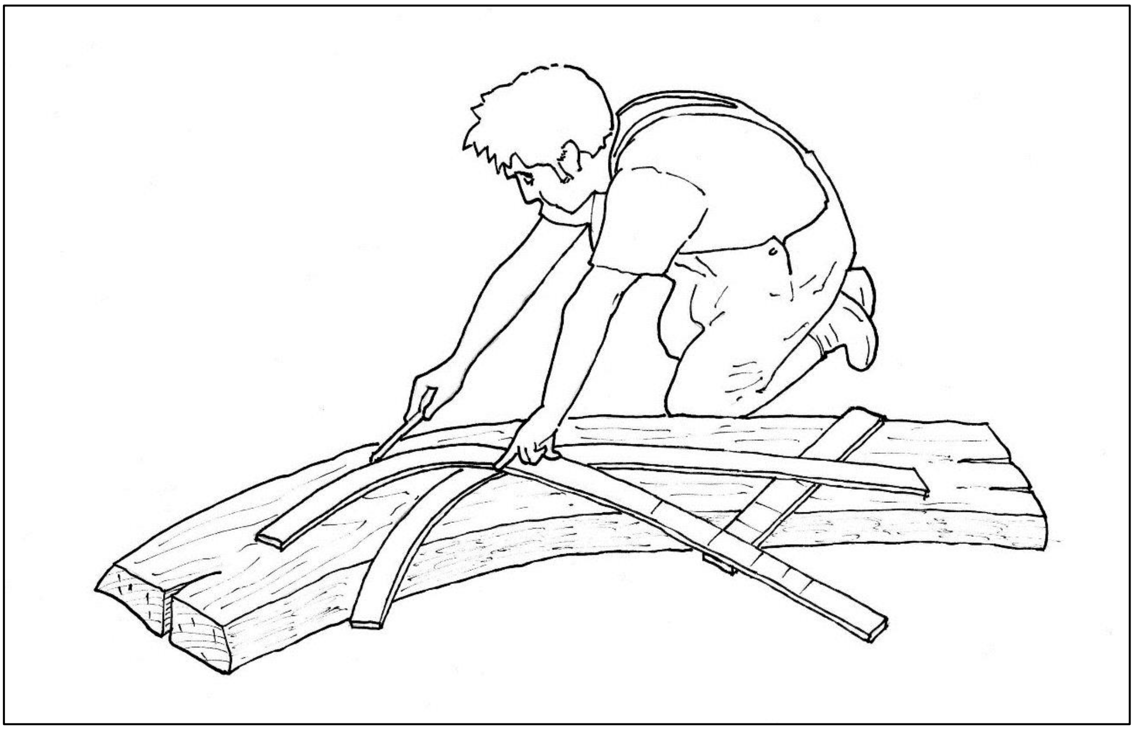


Figure 10 Practical use of a three part mould being used to make a frame following the method described in figure 9 above. (Drawing by JPO after Olaberria, J.P and Olaizola, I. 2012. Método de diseño en el astillero Mutiozabal de Orio. p.447)

Figure 11 Dutch ship being built in the bottom based tradition. Planks are being fixed to each other by small cleats. (Image from a series of 16 engravings by artist Willem Koning at the National Maritime Museum. http://212.219.145.45/collections/objects/111178.html)

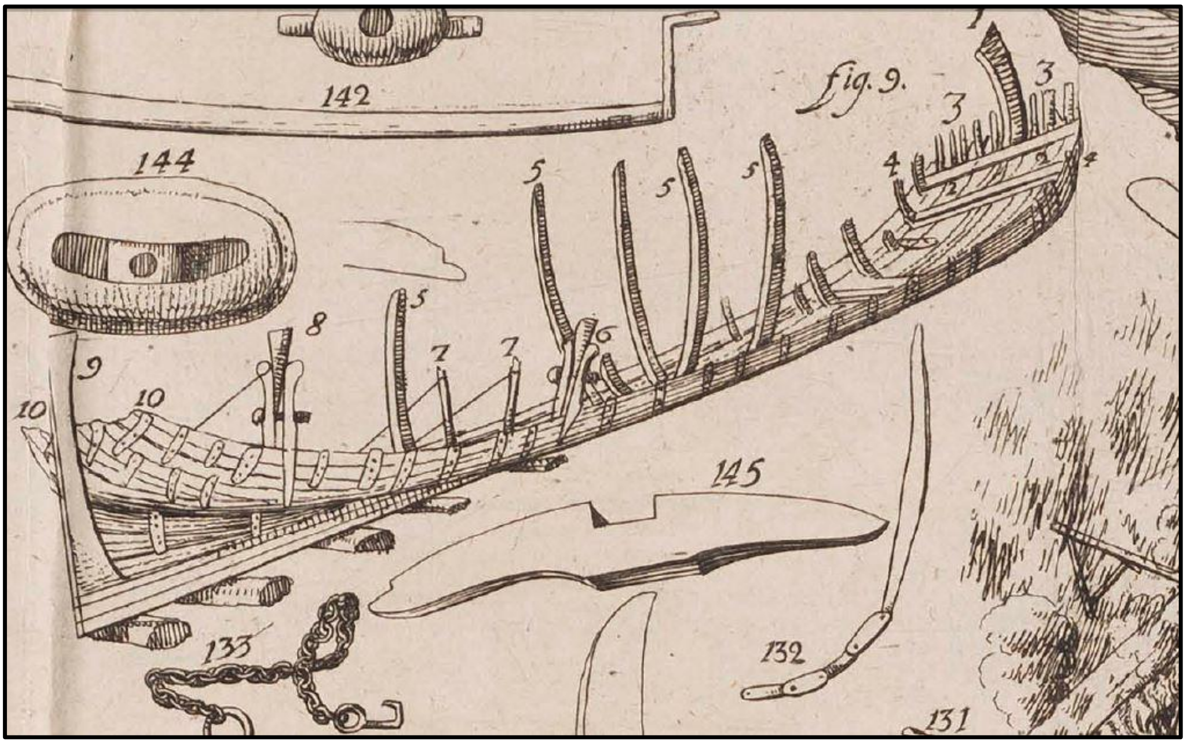


Figure 12 Detail of plate *I* from Rålamb, A. 1691. *Skeps Byggerij Eller Adelig Öfnings Tionde Tom.* It shows a ship being built in the Dutch manner. The cleats joining the planks to each other a clearly visible (10). The bottom has been planked partially, and some master frames (5) can be seen protruding. These will help shape the planking of the sides of the hull. (Edited by JPO from original)

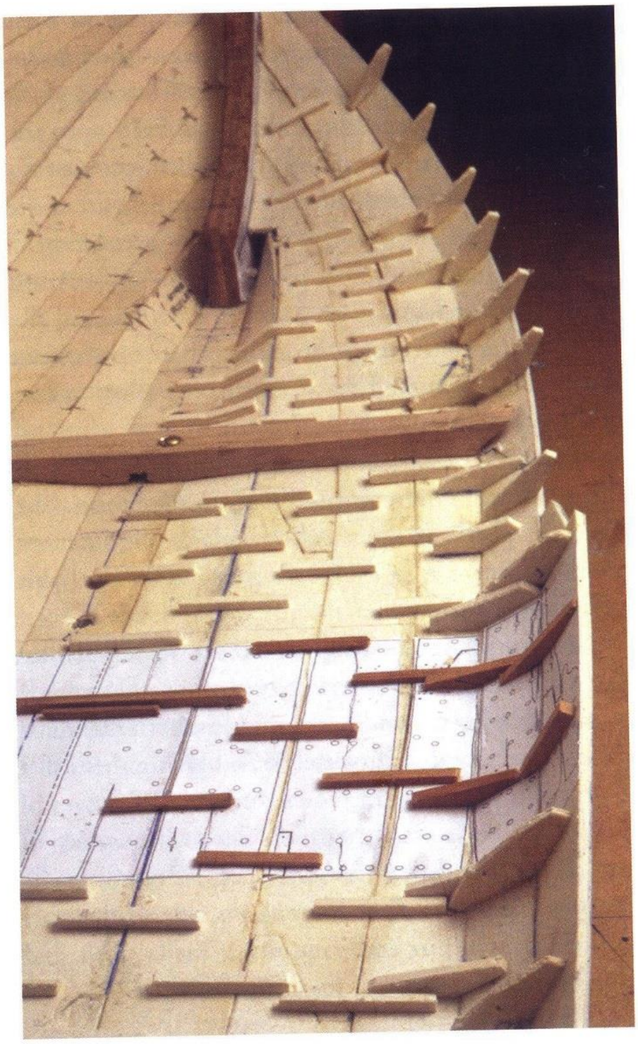
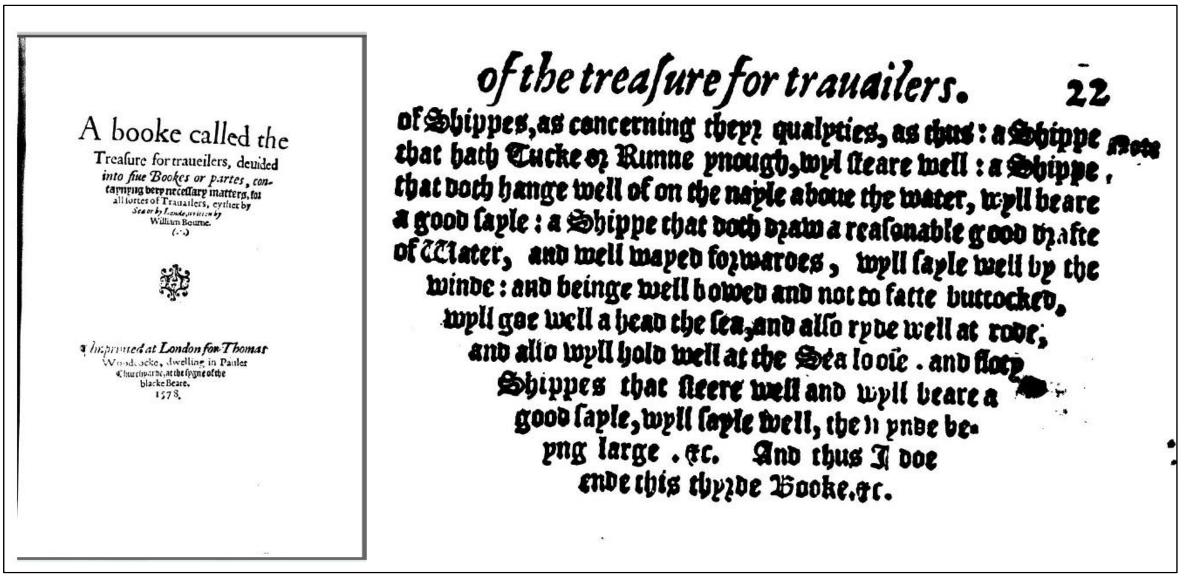


Figure 13 Angled cleats used to guide the shaping of the hull on a Dutch ship built in the bottom-based tradition according to Lemée. (Lemée, C.P.P., 2006. *The Renaissance Shipwrecks from Christianshavn.* p.132)



A booke called the Treasure for traueilers, deuided into fiue Bookes or partes, contaynyng verye necessary matters, for all sortes of Trauailers, eyther by Sea or by Lande, written by William Bourne.

Imprinted at London for Thomas Woodcocke, dwelling in Paules Churchyarde, at the signe of the blacke Beare. 1578.

of the treasure for trauailers. 22

of Shippes, as concerning theyr qualyties, as thus: a Shippe that hath Tucke or Rumne ynough, wyl steare well: a Shippe, that doth hange well of on the nayle aboue the water, wyll beare a good sayle: a Shippe that doth drawe a reasonable good drafte of Water, and well wayed forwardes, wyll sayle well by the winde: and beinge well bowed and not to fatte buttocked, wyll goe well a head the sea, and also ryde well at rode, and also wyll hold well at the Sea loofe. and flotye Shippes that steere well and wyll beare a good sayle, wyll sayle well, the winde beyng large. &c. And thus I doe ende this thyrde Booke, &c. Note

Figure 14 Image showing the cover of *A Booke Called the Treasure for Traveilers* and an extract of page 22, book 3, where the author details the characteristics of a good ship. (JPO from the original: Bourne, W. 1578. *A booke called the Treasure for traveilers.* p.22-book3)

4.3 Laminating a repair patch

The new skin must be laminated to approximately the same thickness to assure the strength and stiffness of the original skin. Multiple layers of lightweight cloth will develop the same or greater strength than a single layer of heavy cloth.

The patch can be laminated by either of two methods, depending on the size of the patch. For *large areas* it's easier to handle and lay up each piece of cloth one piece at a time. For *smaller areas* it may be more convenient to wet out and lay up all of the pieces together.

4.3.1 Large area patch

1. Cut an appropriate number of pieces of fiberglass fabric the same shape as the hole. The first piece should match the outside edge of the bevel, with subsequent pieces gradually getting smaller. The final layer should match the inside edge of the bevel at the hole. The combined thickness of the layers should be slightly thinner than the original panel to allow for shaping and fairing *(Figure 4-5)*.
2. Wet out and apply a layer of thickened epoxy to the beveled edge of the hole and to the backing piece to fill voids and provide good contact between the surface and the first layer of cloth. Thicken the mixture with 404 or 406 filler to the consistency of catsup and apply it with a disposable brush.
3. Lay the fabric in position on the repair area. Use a plastic spreader to smooth the cloth and remove trapped air.

4

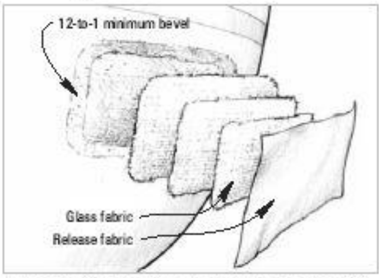


Figure 4-5 *Cut an appropriate number of pieces of fiberglass fabric. The first piece should match the outside edge of the bevel.*

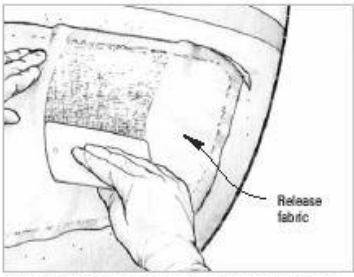


Figure 4-6 *Squeegee over the release fabric with firm pressure to remove excess epoxy and smooth the patch.*

Figure 15 Extract from a modern how-to manual. It gives a very clear idea of the combination of text and images in a modern manual. It is to be noted that the text is written in the imperative mood. This makes the text clearer to follow. However, few readers of the manual would interpret the imperative mood as an indication that this is the only way in which the instructions can be followed. (West System Epoxy. *2011. Fiberglass Boat Repair & Maintenance.* p. 26)

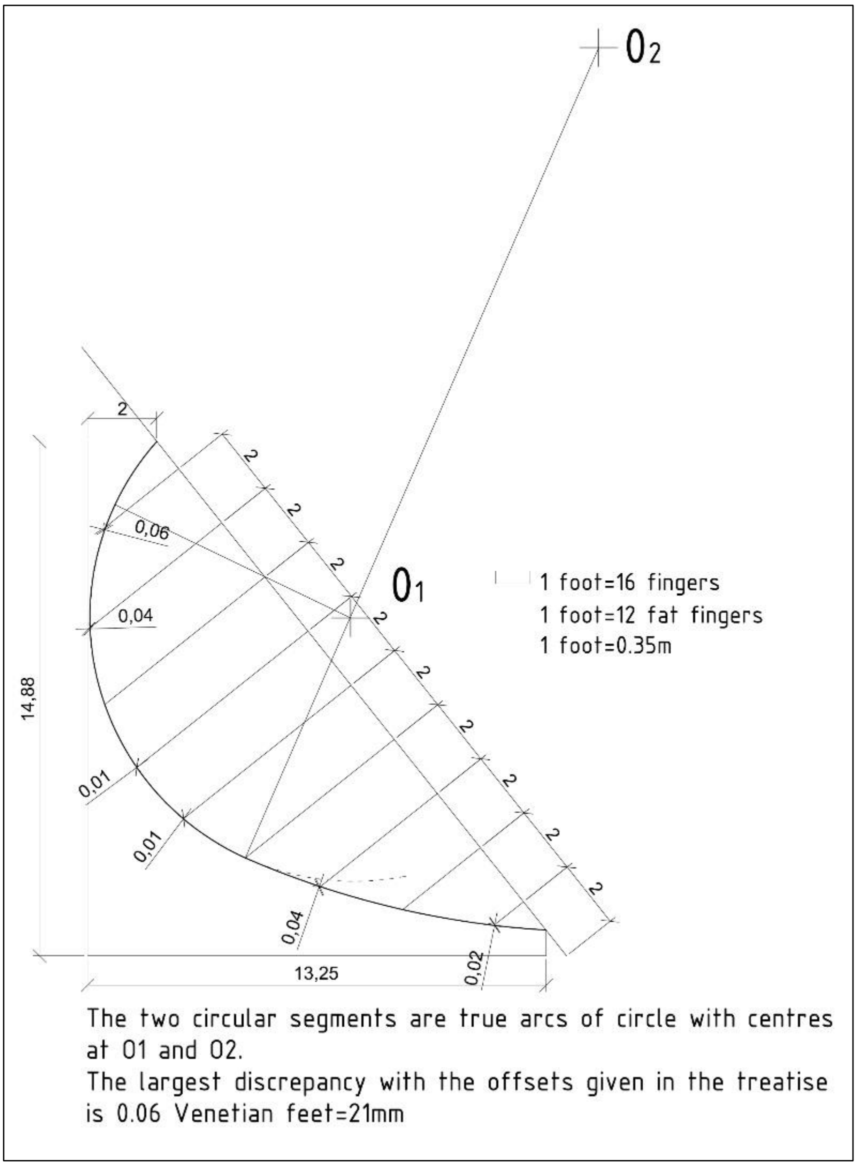


Figure 16 The sternpost of the Galley of Flanders drawn using the offsets given by Bondioli thorough which two arcs have been faired. The match is not perfect and several of the offsets do not coincide with the circular arcs. However, from the plot it can be suggested that this simple geometric construction could have been used to derive the shape of the sternpost. The errors between the offsets and the arcs of circle are indicated. The largest error is 0.06 Venetian feet or 21mm. Two of the offsets have an error of 0.04 Venetian feet or 14mm. One offsets has an error of 0.02 Venetian feet or 7mm and the rest show an error of 0.01 Venetian feet or 3.5mm with five of the points showing no error at all. (Drawn by J.P.O from dimensions given in: Bondioli, M. 2009. *Early Shipbuilding Records and the Book of Michael of Rhodes*. p. 24)

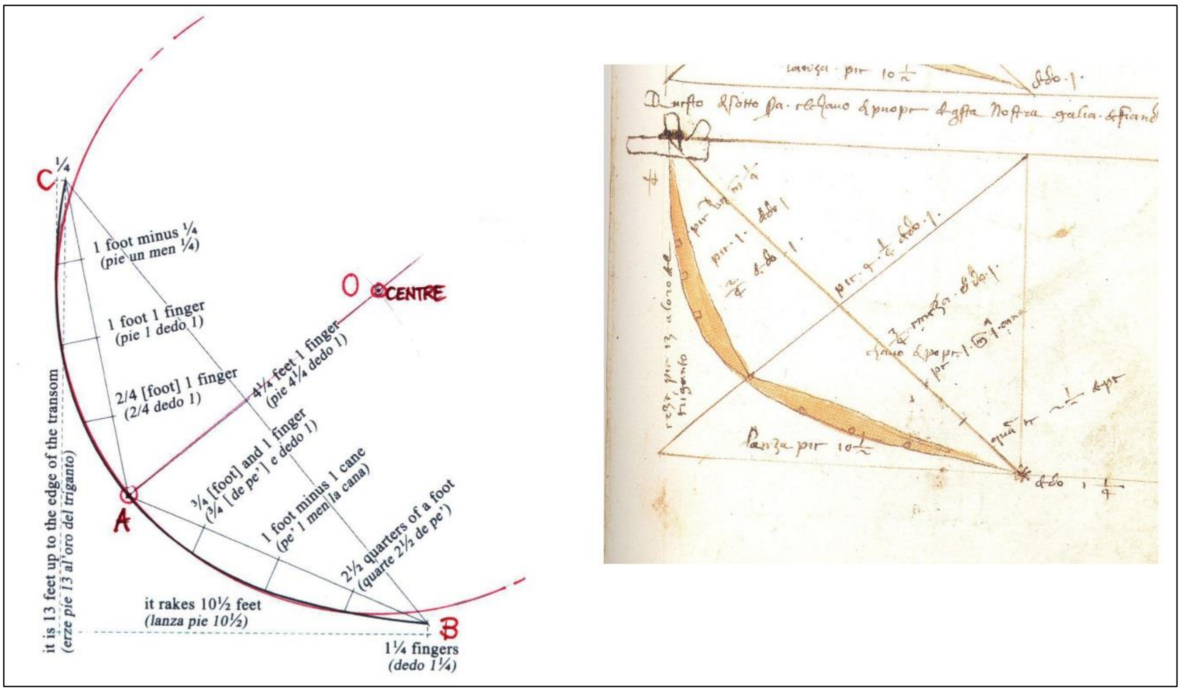


Figure 17 The figure on the right shows the representation of the sternpost in the original manuscript with dimensions specified as a series of offsets. The figure on the left shows a reproduction of the reconstruction of the sternpost by Bondioli following the offsets given in the original document. The red lines have been drawn by this author and show the good match between an arc of circle and the original shape as proposed by Bondiol. Moreover, the arc has a radius which corresponds to the geometrical construction of the offsets given in the original manuscript. Thus, distance AB and AC, given in the manuscript as four Venetian feet, are equal to the radius AO (found by trial and error). (JPO. after: Bondioli, M. 2009. *Early Shipbuilding Records and the Book of Michael of Rhodes*. p. 252)

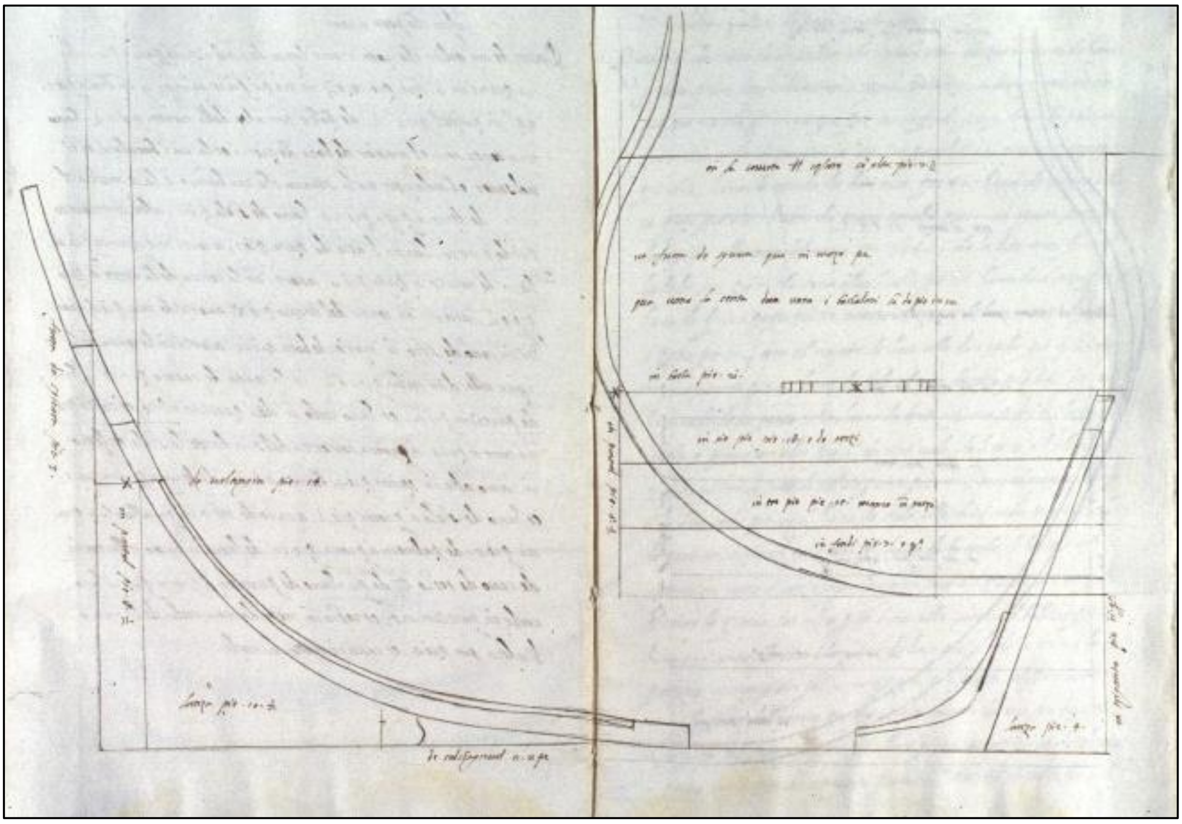


Figure 18 Page 24 from *Arte de Fer Vasselli* (c. 1590). It shows the information required to shape a hull. Each of the shaping elements is shown and explained in figure 19. (http://echo.mpiwg-berlin.mpg.de/ECHOdocuView?url=/permanent/shipbuilding/Conta_Arte-_01_1590-ca/index.meta&start=21&pn=24)

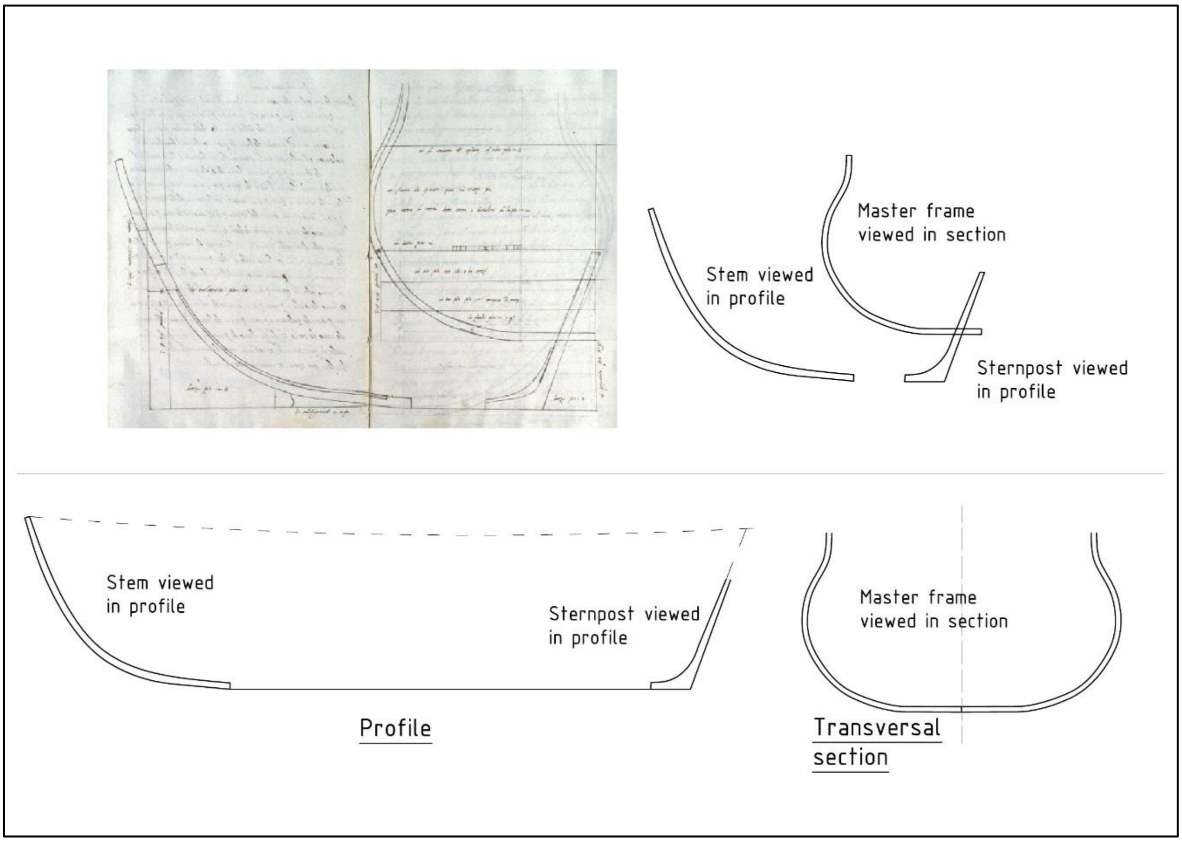
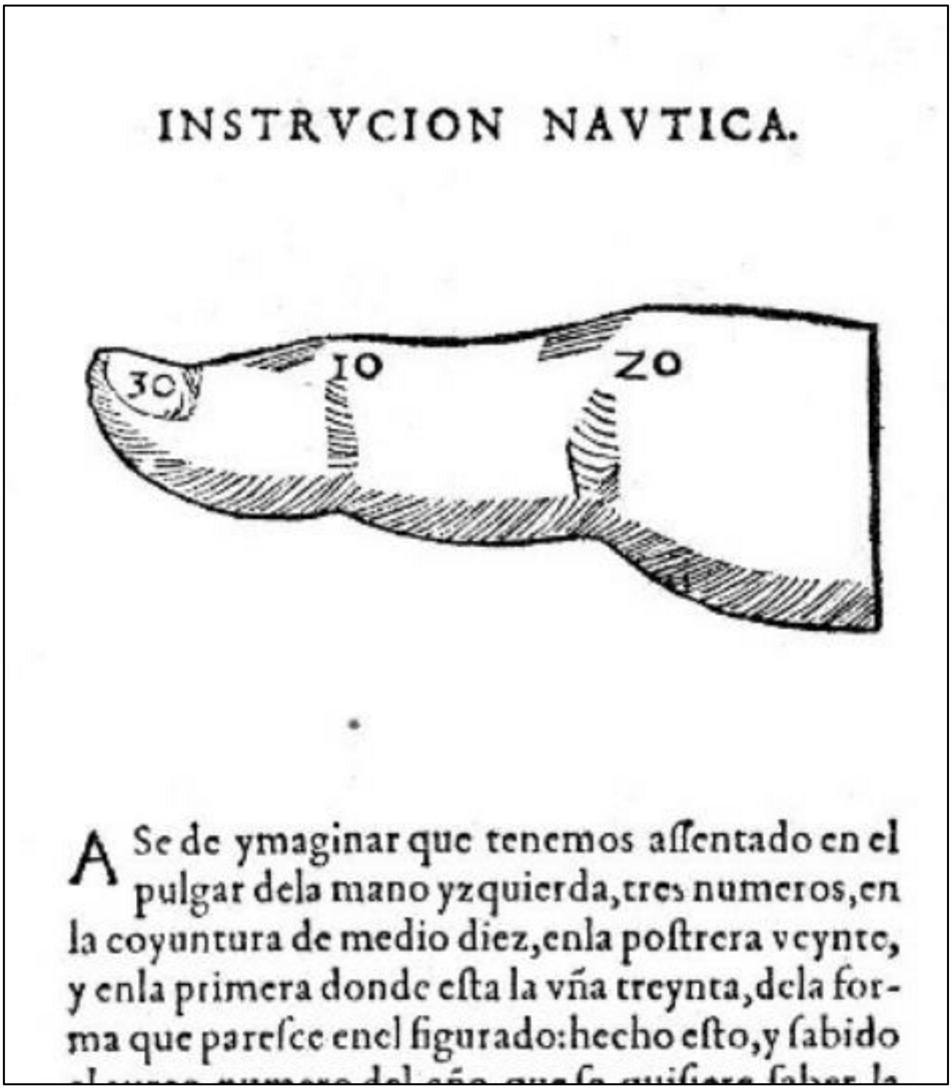


Figure 19 Top left: folio 24 of *Arte de Fer Vasselli.* Top right: same information redrawn and labelled. Bottom: a simple drawing of a hull shape drawn from the information given above. The shipwright would require to know the length of the keel and the height of the transom in order to complete the profile view of the hull.

This figure can be compared to the figure 98 which shows a detail of the drawing that Dutch shipbuilder, Jan Rijcksen, is holding. The similarities in the information contained in both documents is noteworthy. (Drawing by JPO after *Arte de Fer Vasselli*, Plate 24. http://echo.mpiwg-berlin.mpg.de/ECHOdocuView?url=/permanent/shipbuilding/Conta_Arte-_01_1590-ca/index.meta&start=21&pn=24)


INSTRVCION NAVTICA.

A Se de ymaginar que tenemos aſſentado en el pulgar dela mano yzquierda, tres numeros, en la coyuntura de medio diez, enla poſtrera veynte, y enla primera donde eſta la vña treynta, dela forma que pareſce enel figurado: hecho eſto, y ſabido

Figure 20 Detail of a figure which is used by García de Palacio to explain a method by which astronomical data could be calculated, easily, using the different joints in the fingers, without any mathematical means. (García de Palacio, D., 1587. *Instrucción Nautica* p.51v)

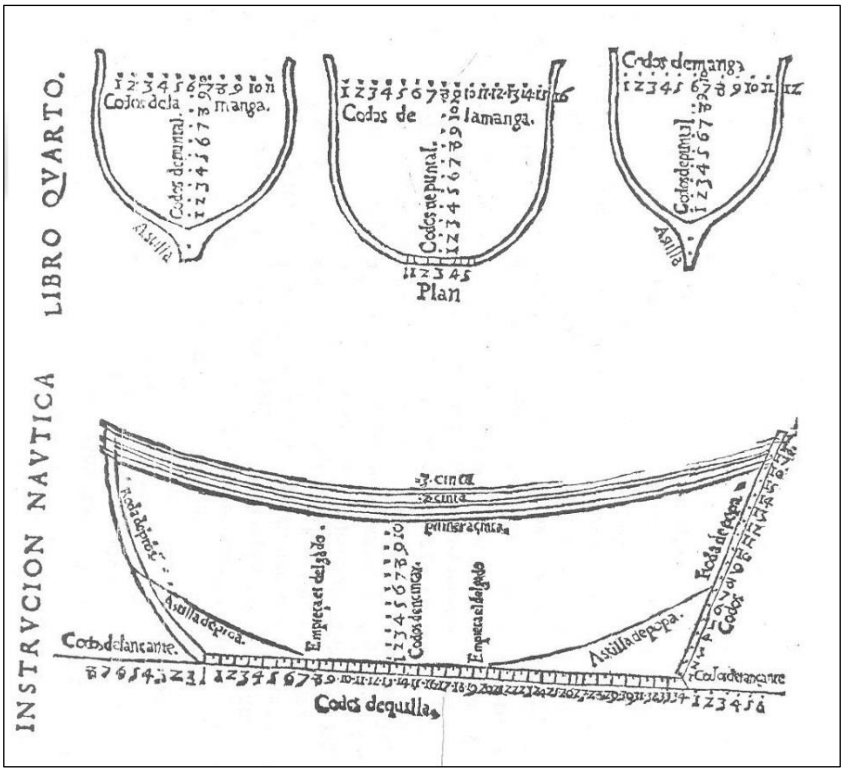


Figure 21 Combination of the illustrations shown in pages 93v, 94r of *Instrucción Nautica* . They show the profile of the ship with the rising lines clearly shown and labelled ('astilla'). The master section and the two tail-frames are also shown in schematic form. (JPO after García de Palacio, D., 1587. *Instrucción Nautica.* p.93v and 94r)

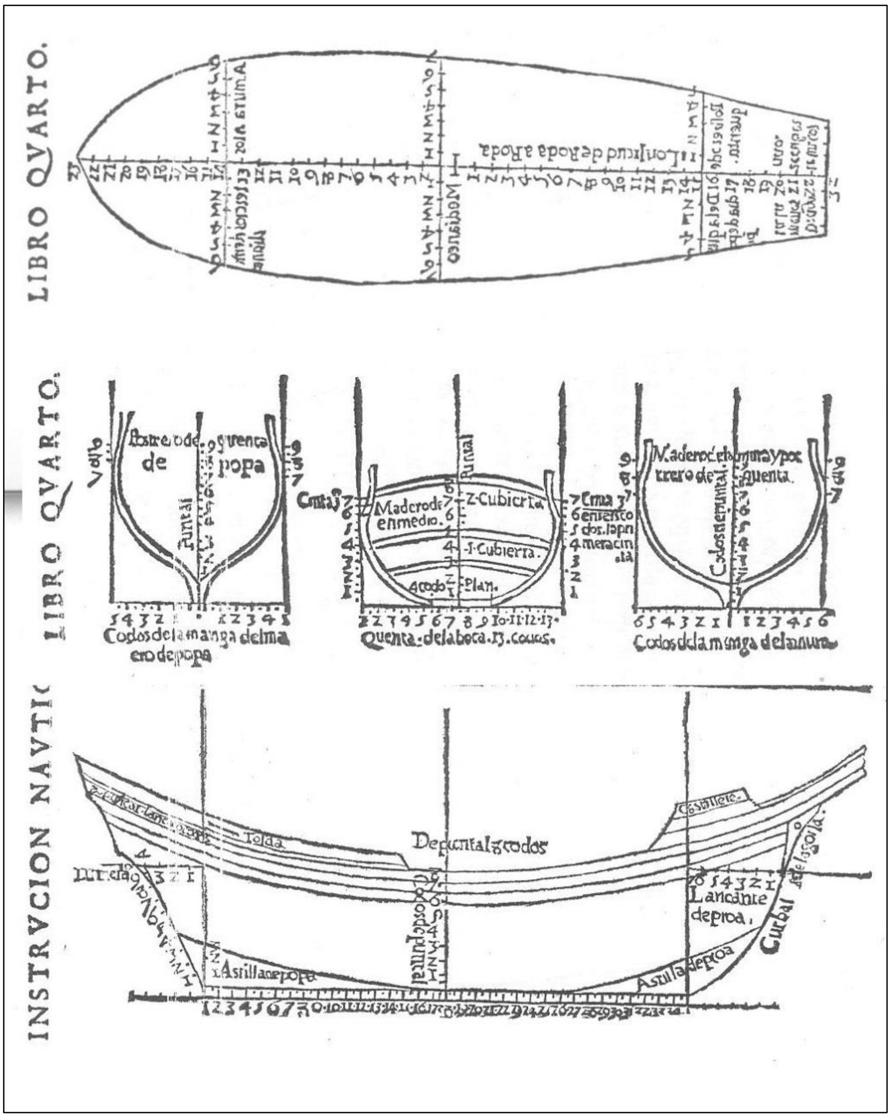


Figure 22 The figure shows a combination of the illustrations shown in pages 96r, 96v, 97r of García de Palacio. 1587. Again, similar information to the one shown in figure 21 is shown. However, it is given with more detail. (JPO after García de Palacio, D., 1587. I*nstrucción Nautica.* p. 96r, 96v, 97r)

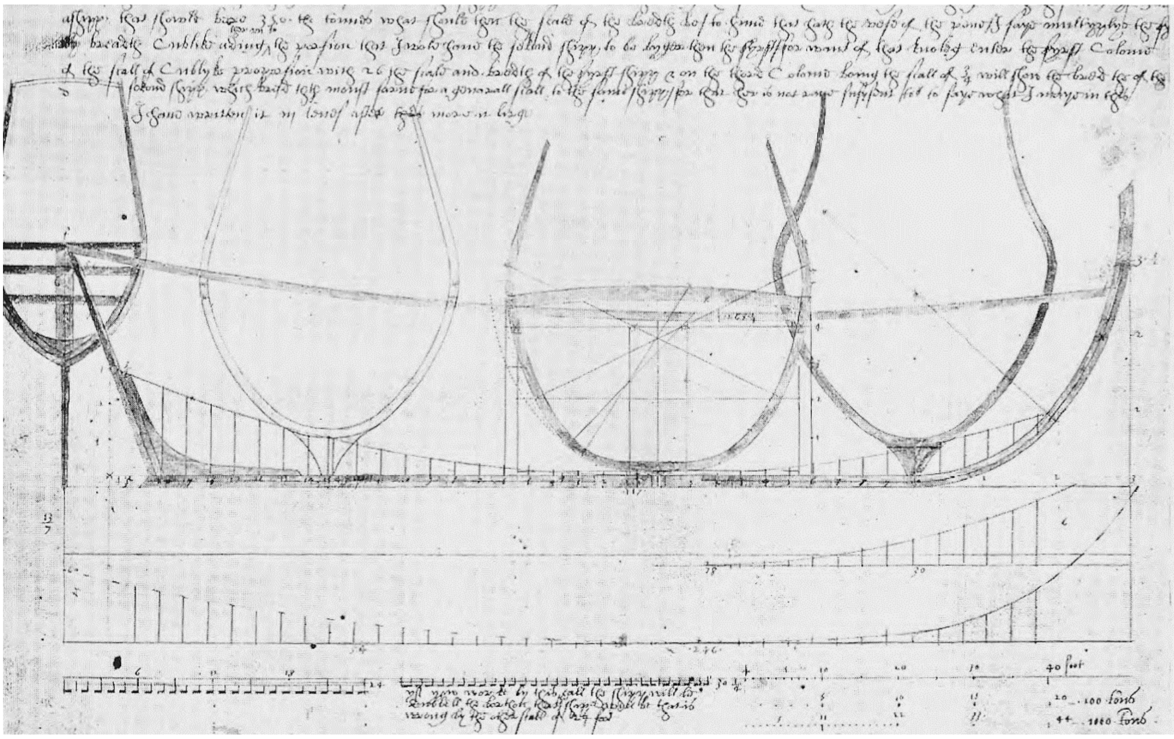


Figure 23 folio 19 of Mathew Baker's *Fragments of Ancient English Shipwrightry*. (Pepys Library, Cambridge)

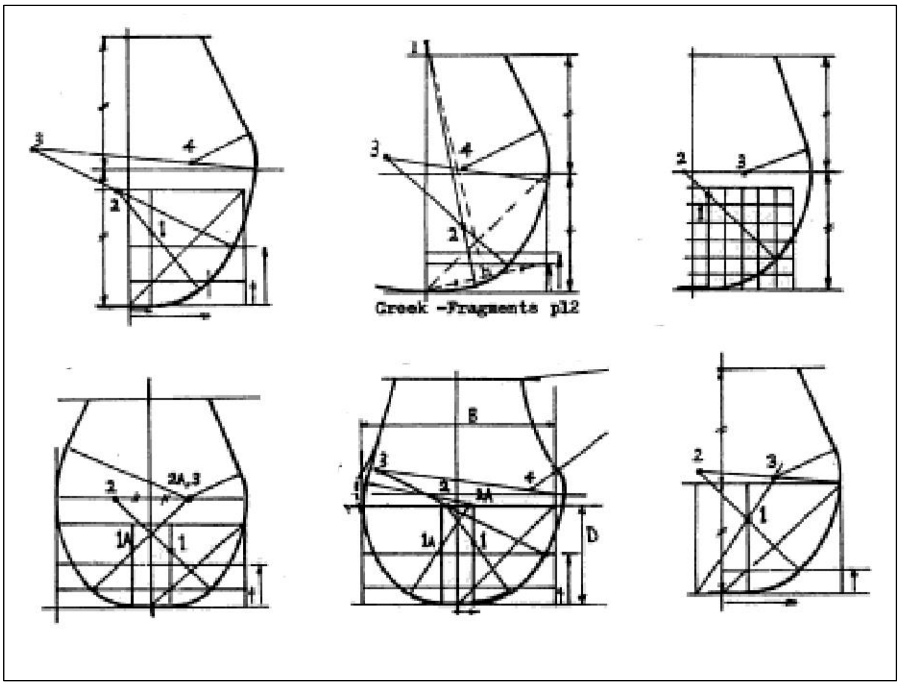


Figure 24 Some of the geometric design methods described by Mathew Baker. (Edited by JPO, after Barker, R., 1985. Fragments from the Pepysian Library p. 165)

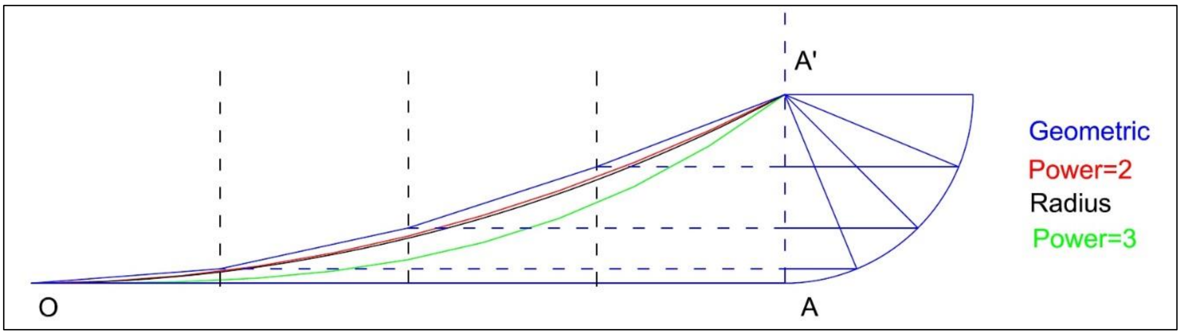


Figure 25 Different procedures described in A Treatise on Shipbuilding c.1620 to obtain the curvatures of rising and narrowing curves. A geometric quadrant has been included for comparison. (Drawing JPO)

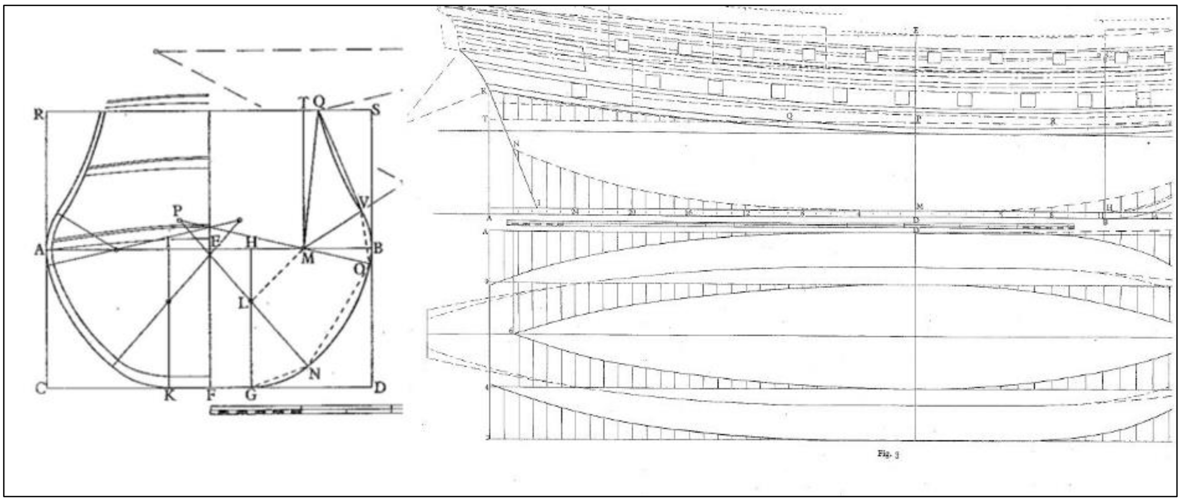


Figure 26 Combined image with the design procedure for the master curve and the rising and narrowing lines. (JPO after Salisbury, W. and Anderson, R.C., 1958. *A Treatise on Shipbuilding.* figure 1 and 3)

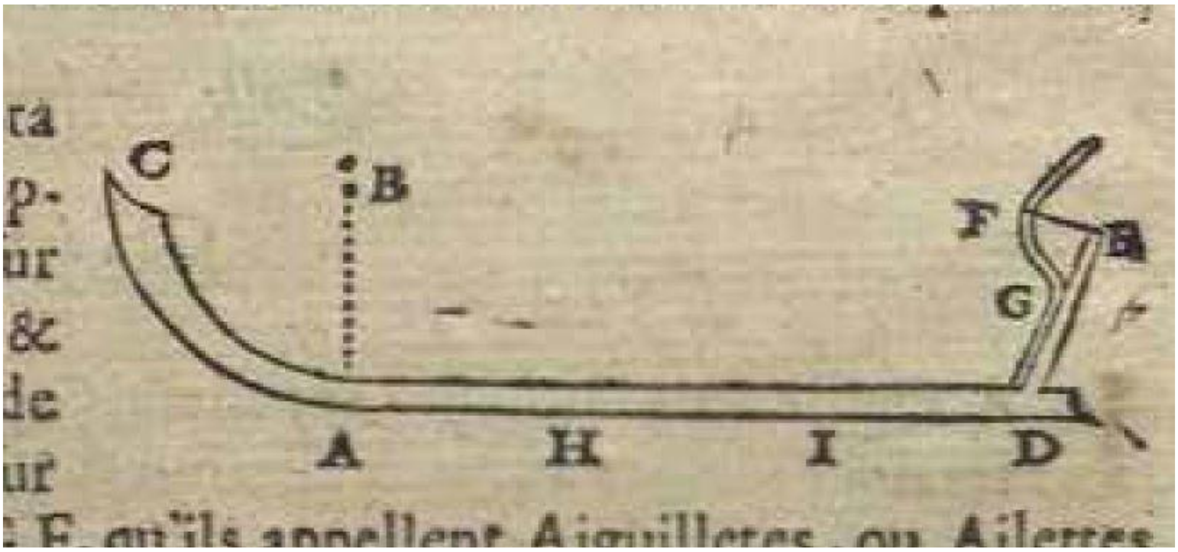


Figure 27 Detail of a small drawing that shows the backbone of a ship. (Fournier, G. 1643. *Hydrographie contenent la Theorie et la Practique de Toutes les Parties de la Navigation.* p. 18)

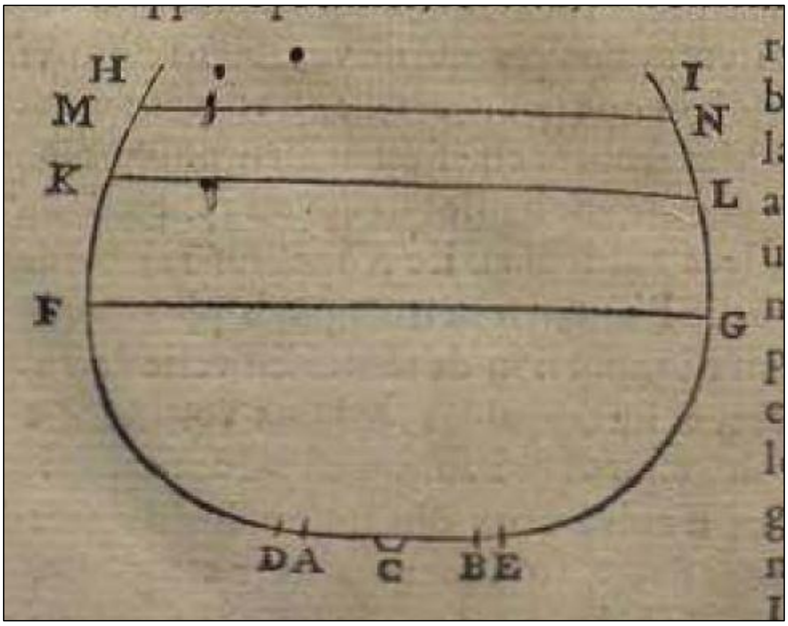


Figure 28 Ilustration showing a frame. (Fournier, G. 1643. *Hydrographie contenent la Theorie et la Practique de Toutes les Parties de la Navigation.* p. 19)

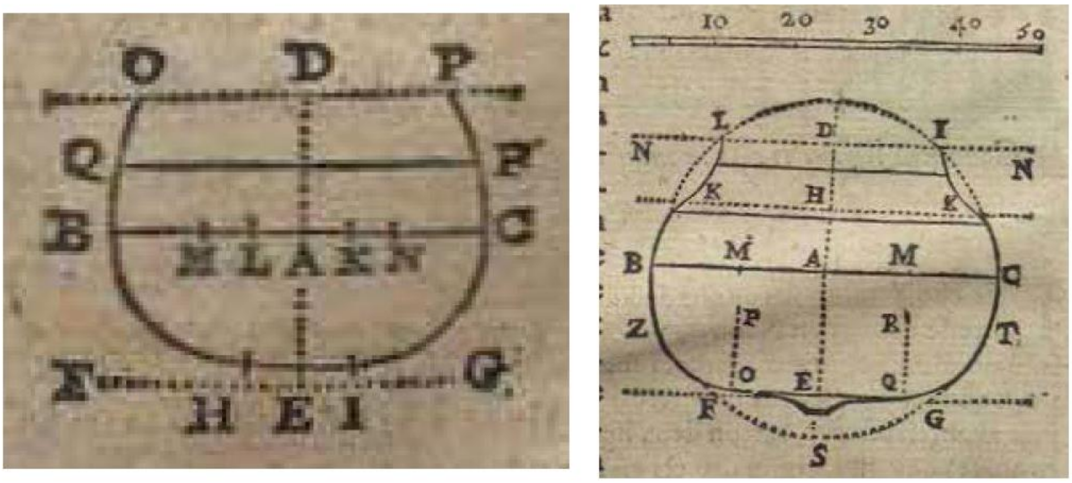


Figure 29 The two different frame styles according to Fournier. On the left is the frame which he called 'à l'ancienne'. On the right the type of frame that he called 'à la moderne' (Fournier, G. 1643. *Hydrographie contenent la Theorie et la Practique de Toutes les Parties de la Navigation.* p.23-24)

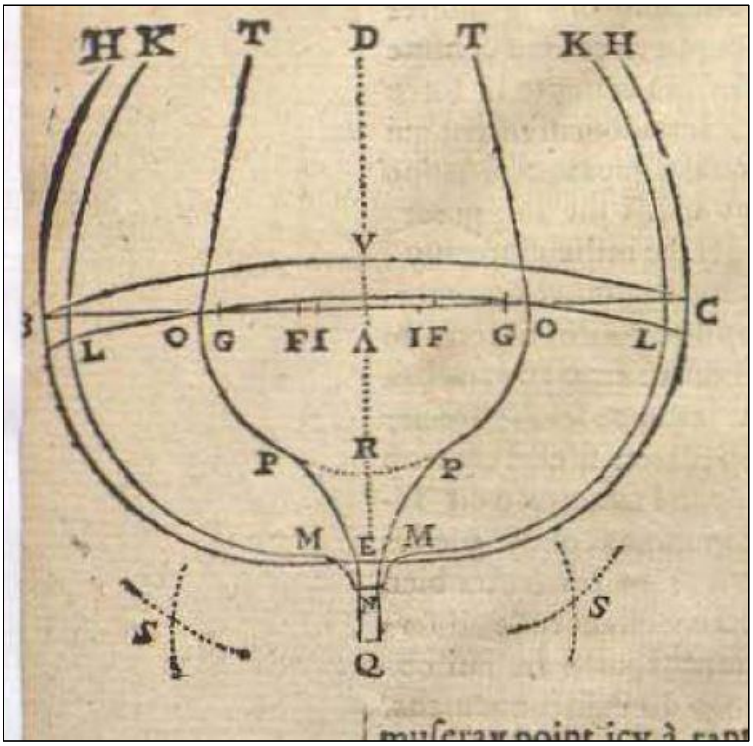


Figure 30 Figure that illustrates the process used to obtain a frame shape from the transformation of the master section. (Fournier, G. 1643. *Hydrographie contenent la Theorie et la Practique de Toutes les Parties de la Navigation.* p.26)

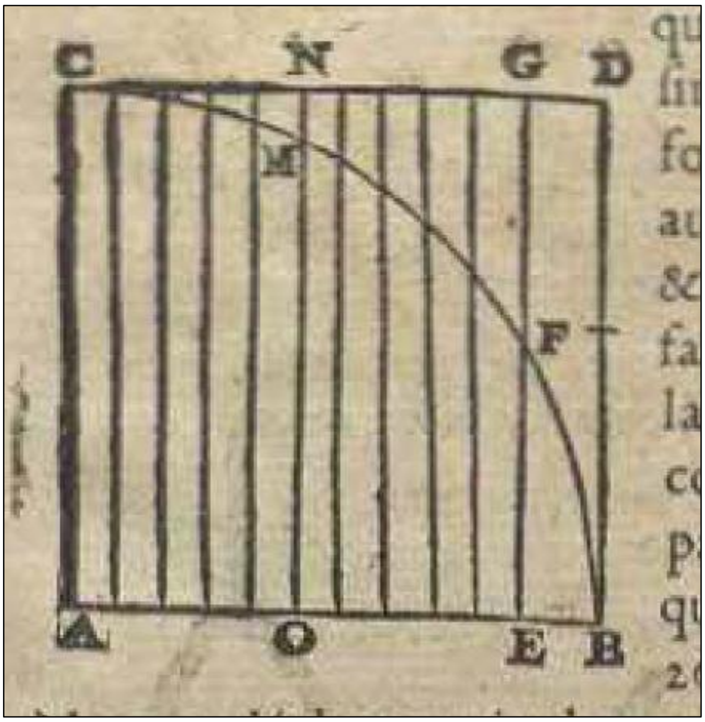


Figure 31 Quadrant used to obtain the values of narrowing and rising for the different frames. (Fournier, G. 1643. *Hydrographie contenent la Theorie et la Practique de Toutes les Parties de la Navigation.* p.25)

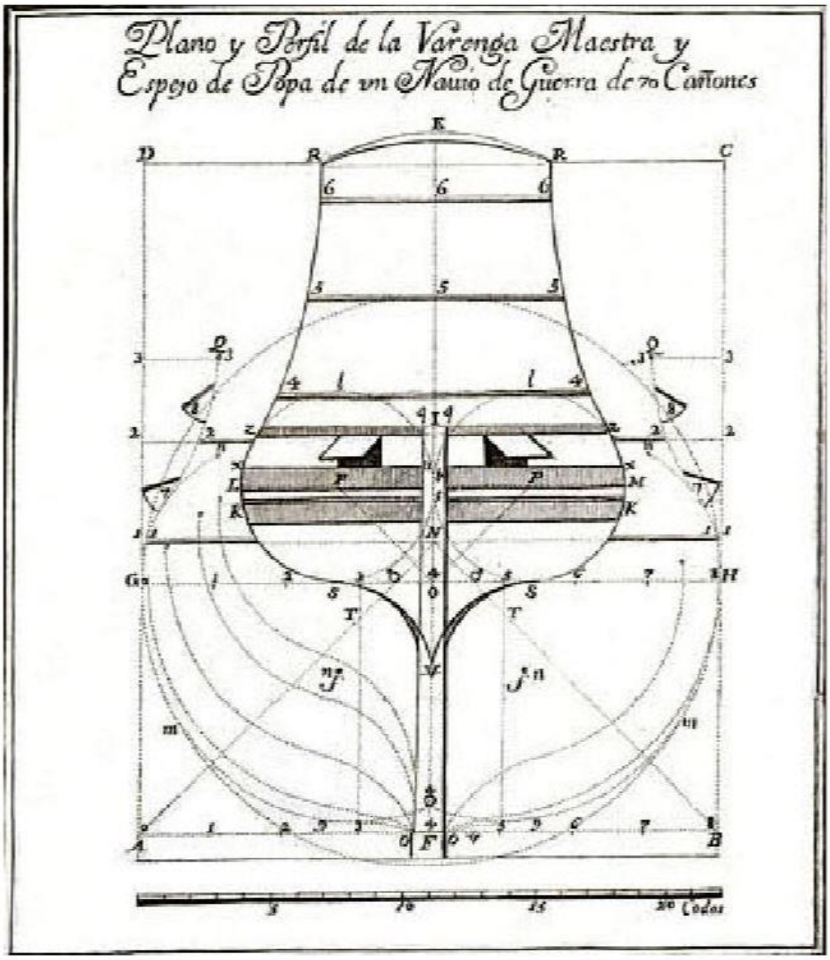
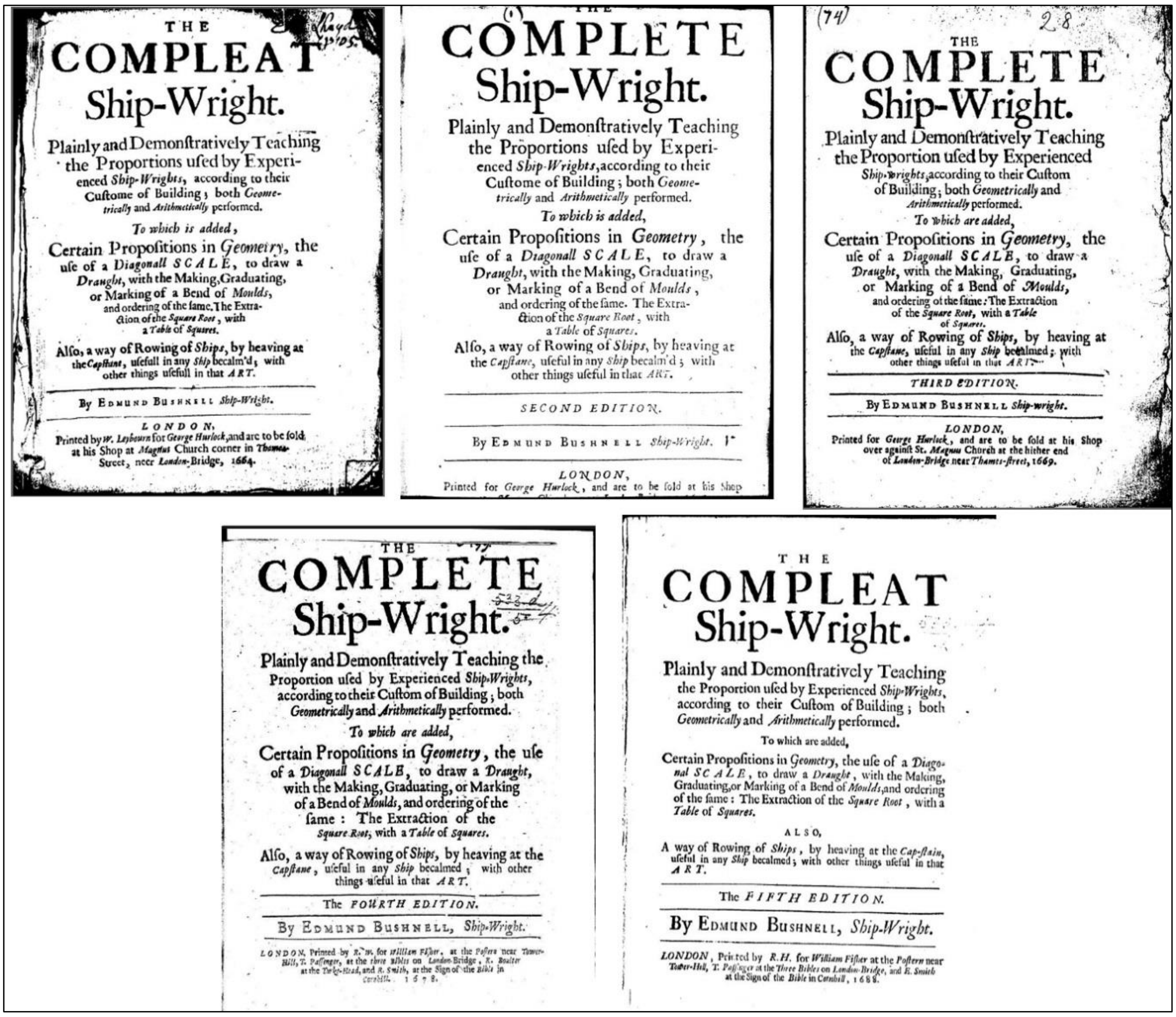


Figure 32 This figure drawn by Spanish ship designer Gaztañeta in the mid-18th century shows a master section defined by a single arc (Arenaza, H., 2014. La barra de Sanlúcar y el diseño del gálibo maestro en la obra de Antonio Gaztañeta. p.19)



THE
COMPLEAT
Ship-Wright.
Plainly and Demonstratively Teaching the Proportions used by Experienced Ship-Wrights, according to their Custome of Building; both Geometrically and Arithmetically performed.
To which is added,
Certain Propositions in Geometry, the use of a Diagonall SCALE, to draw a Draught, with the Making, Graduating, or Marking of a Bend of Moulds, and ordering of the same. The Extraction of the Square Root, with a Table of Squares.
Also, a way of Rowing of Ships, by heaving at the Capstane, usefull in any Ship becalm'd; with other things usefull in that ART.
By EDMUND BUSHNELL Ship-Wright.
LONDON,
Printed by W. Leybourn for George Hurlock, and are to be sold at his Shop at Magnus Church corner in Thames-Street, neer London-Bridge, 1664.

THE
COMPLETE
Ship-Wright.
Plainly and Demonstratively Teaching the Proportions used by Experienced Ship-Wrights, according to their Custome of Building; both Geometrically and Arithmetically performed.
To which is added,
Certain Propositions in Geometry, the use of a Diagonall SCALE, to draw a Draught, with the Making, Graduating, or Marking of a Bend of Moulds, and ordering of the same. The Extraction of the Square Root, with a Table of Squares.
Also, a way of Rowing of Ships, by heaving at the Capstane, useful in any Ship becalm'd; with other things useful in that ART.
SECOND EDITION.
By EDMUND BUSHNELL Ship-Wright.
LONDON,
Printed for George Hurlock, and are to be sold at his Shop

THE
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Ship-Wright.
Plainly and Demonstratively Teaching the Proportion used by Experienced Ship-wrights, according to their Custom of Building; both Geometrically and Arithmetically performed.
To which are added,
Certain Propositions in Geometry, the use of a Diagonall SCALE, to draw a Draught, with the Making, Graduating, or Marking of a Bend of Moulds, and ordering of the same: The Extraction of the Square Root, with a Table of Squares.
Also, a way of Rowing of Ships, by heaving at the Capstane, useful in any Ship becalmed; with other things useful in that ART.
THIRD EDITION.
By EDMUND BUSHNELL Ship-wright.
LONDON,
Printed for George Hurlock, and are to be sold at his Shop over against St. Magnus Church at the hither end of London-Bridge near Thames-street, 1669.

THE
COMPLETE
Ship-Wright.
Plainly and Demonstratively Teaching the Proportion used by Experienced Ship-Wrights, according to their Custom of Building; both Geometrically and Arithmetically performed.
To which are added,
Certain Propositions in Geometry, the use of a Diagonall SCALE, to draw a Draught, with the Making, Graduating, or Marking of a Bend of Moulds, and ordering of the same: The Extraction of the Square Root, with a Table of Squares.
Also, a way of Rowing of Ships, by heaving at the Capstane, useful in any Ship becalmed; with other things useful in that ART.
The FOURTH EDITION.
By EDMUND BUSHNELL, Ship-Wright.
LONDON, Printed by ... for William Fisher, at the Postern near Tower-Hill, T. Passenger, at the three Bibles on London-Bridge, R. Boulter at the Turks-Head, and R. Smith, at the Sign of the Bible in Cornhill. 1678.

THE
COMPLEAT
Ship-Wright.
Plainly and Demonstratively Teaching the Proportion used by Experienced Ship-Wrights, according to their Custom of Building; both Geometrically and Arithmetically performed.
To which are added,
Certain Propositions in Geometry, the use of a Diagonal SCALE, to draw a Draught, with the Making, Graduating, or Marking of a Bend of Moulds, and ordering of the same: The Extraction of the Square Root, with a Table of Squares.
ALSO,
A way of Rowing of Ships, by heaving at the Cap-stain, useful in any Ship becalmed; with other things useful in that ART.
The FIFTH EDITION.
By EDMUND BUSHNELL, Ship-Wright.
LONDON, Printed by R.H. for William Fisher at the Postern near Tower-Hill, T. Passenger at the Three Bibles on London-Bridge, and R. Smith at the Sign of the Bible in Cornhill, 1688.

Figure 33 The five different editions of the *Compleat Ship-Wright.* (Combined image by JPO)

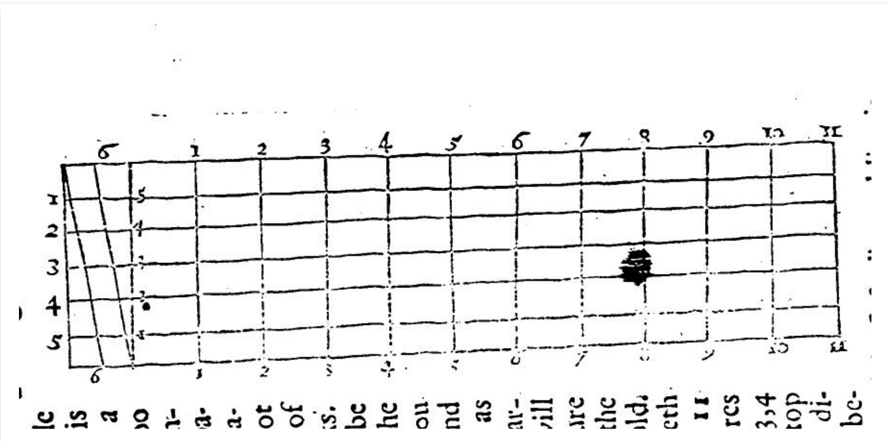


Figure 34 Graphic scale as described by Bushnell. (Bushnell, E. 1664. T*he Compleat Ship-Wright*. p.5)

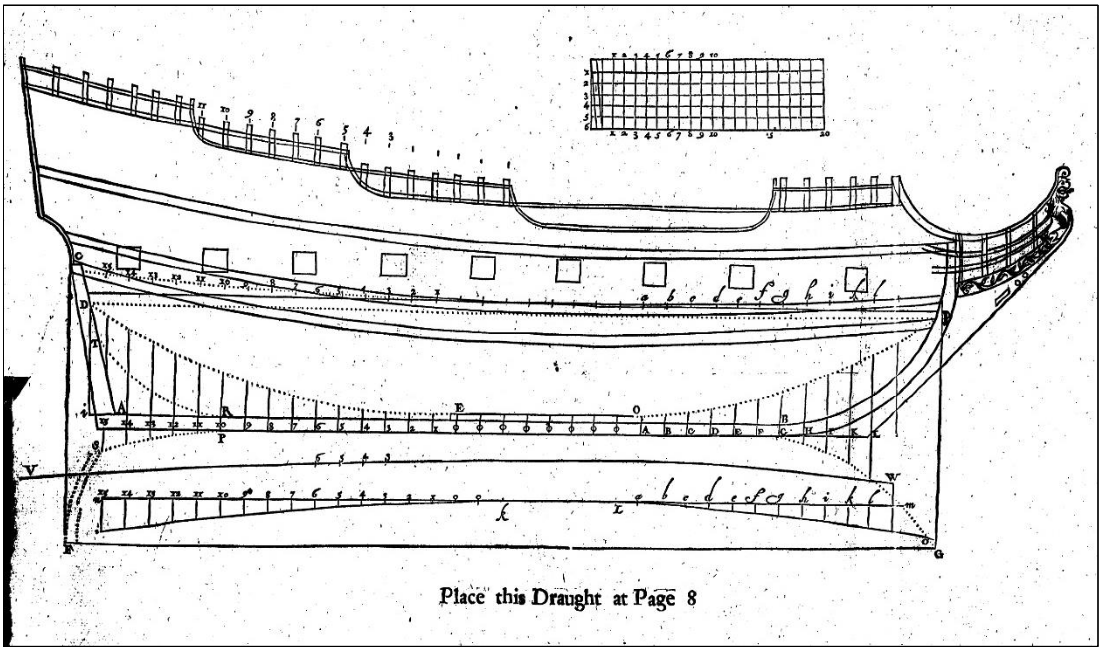


Figure 35 Profile view of the hull with the main element that control the shape of the hull drawn: the backbone and the rising and narrowing lines. (Bushnell, E. 1664. T*he Compleat Ship-Wright*. p.8)

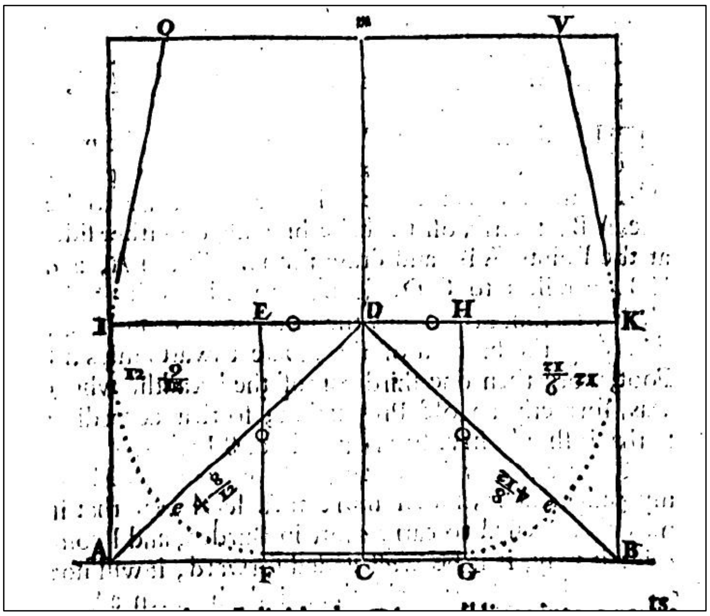


Figure 36 Geometric construction of the master frame defined by two arcs and two straight segments. (Bushnell, E. 1664. T*he Compleat Ship-Wright*. p.10)

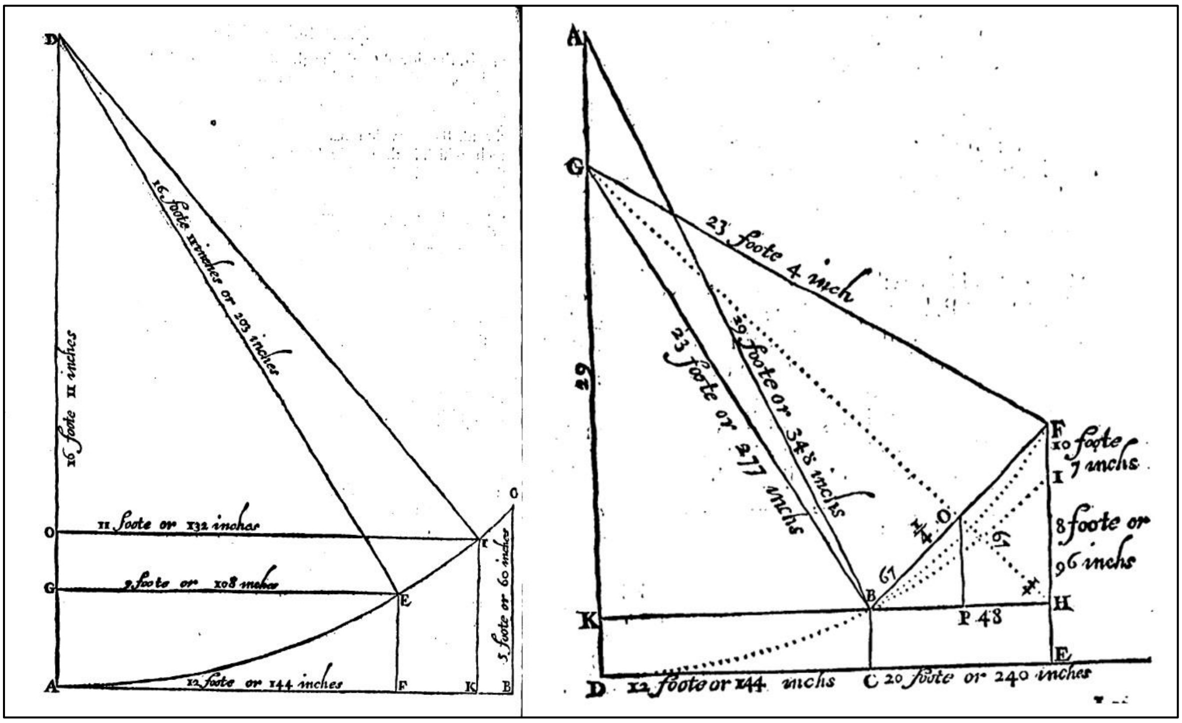


Figure 37 Bushnell's rising lines. **Left:** image used by Bushnell to help the reader understand the description of the process of obtaining the intermediate values for the rising using mathematical methods. **Right:** The figure on the right is used by Bushnell to describe the process of obtaining a curve with fuller ends using numerical means. (Combined figure by JPO after Bushnell, E. 1664. T*he Compleat Ship-Wright*. p.24, 55)

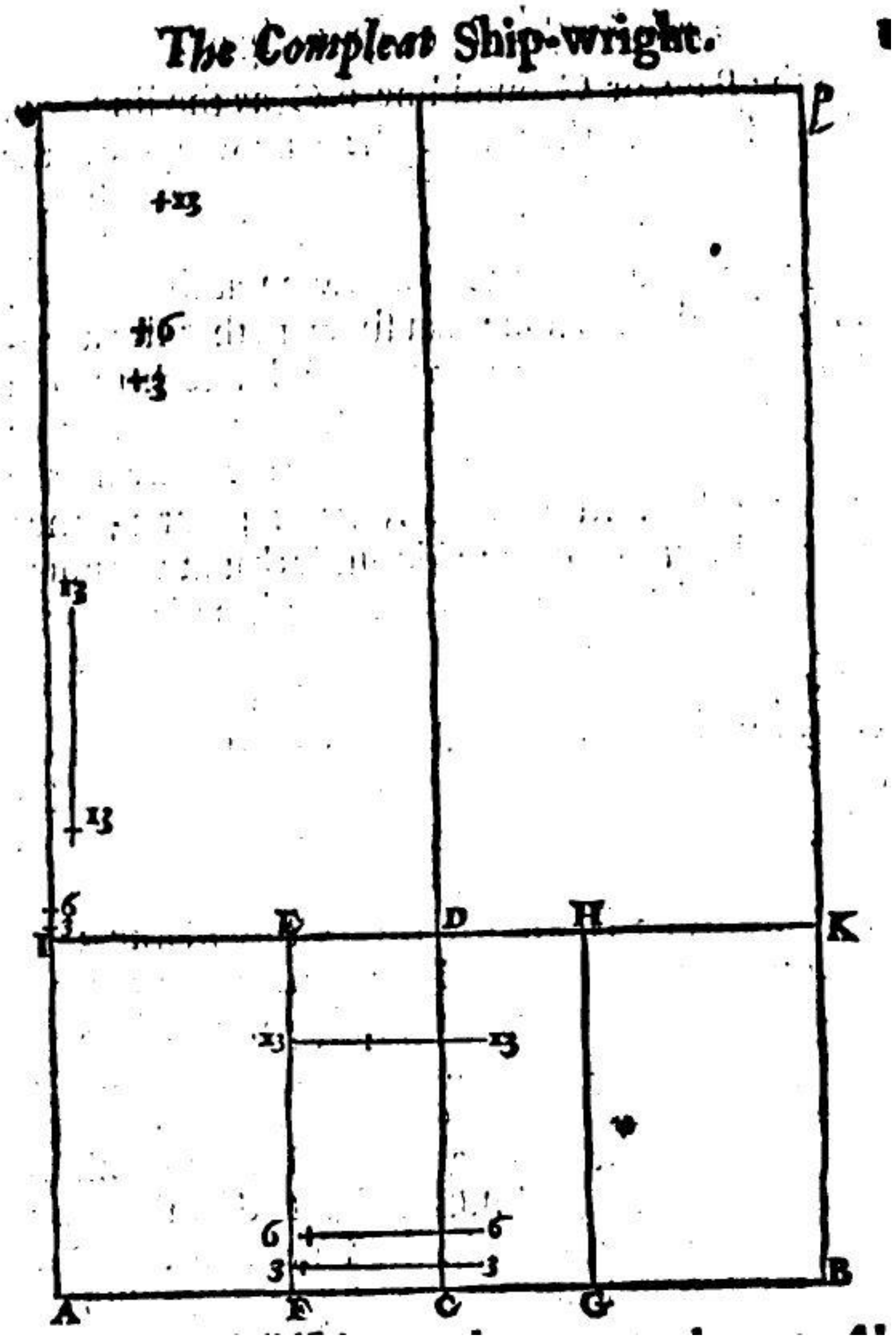


Figure 38 Grid used by Bushnell to describe the process of lofting the sections full size, based on the values of rising and narrowing and a mould made in three part with the shape of the master section. (Bushnell, E. 1664. T*he Compleat Ship-Wright*. p.17)

Page 1.

Inch	Feet Inches	Squares	Inch	Feet Inches	Squares	Inch	Feet Inches	Squares
1	1	1	41	3 5	1681	81	6 9	6561
2	2	4	42	3 6	1764	82	6 10	6724
3	3	9	43	3 7	1849	83	6 11	6889
4	4	16	44	3 8	1936	84	7 00	7056
5	5	25	45	3 9	2025	85	7 1	7225
6	6	36	46	3 10	2116	86	7 2	7396
7	7	49	47	3 11	2209	87	7 3	7569
8	8	64	48	4 00	2304	88	7 4	7744
9	9	81	49	4 1	2401	89	7 5	7921
10	10	100	50	4 2	2500	90	7 6	8100
11	11	121	51	4 3	2601	91	7 7	8281
12	1 00	144	52	4 4	2704	92	7 8	8464
13	1 1	169	53	4 5	2809	93	7 9	8649
14	1 2	196	54	4 6	2916	94	7 10	8836
15	1 3	225	55	4 7	3025	95	7 11	9025
				4 8	3136	96	8 0	9216

Figure 39 Extract of the table of squares and square roots. (Bushnell, E. 1664. T*he Compleat Ship-Wright*. p.43)

n^2 XIV. SQUARES. 37

n	0	1	2	3	4	5	6	7	8	9	d
6.0	36.00	36.12	36.24	36.36	36.48	36.60	36.72	36.84	36.97	37.09	12
6.1	37.21	37.33	37.45	37.58	37.70	37.82	37.95	38.07	38.19	38.32	12
6.2	38.44	38.56	38.69	38.81	38.94	39.06	39.19	39.31	39.44	39.56	13
6.3	39.69	39.82	39.94	40.07	40.20	40.32	40.45	40.58	40.70	40.83	13
6.4	40.96	41.09	41.22	41.34	41.47	41.60	41.73	41.86	41.99	42.12	13
6.5	42.25	42.38	42.51	42.64	42.77	42.90	43.03	43.16	43.30	43.43	13
6.6	43.56	43.69	43.82	43.96	44.09	44.22	44.36	44.49	44.62	44.76	13
6.7	44.89	45.02	45.16	45.29	45.43	45.56	45.70	45.83	45.97	46.10	14
6.8	46.24	46.38	46.51	46.65	46.79	46.92	47.06	47.20	47.33	47.47	14
6.9	47.61	47.75	47.89	48.02	48.16	48.30	48.44	48.58	48.72	48.86	14
7.0	49.00	49.14	49.28	49.42	49.56	49.70	49.84	49.98	50.13	50.27	14
7.1	50.41	50.55	50.69	50.84	50.98	51.12	51.27	51.41	51.55	51.70	14
7.2	51.84	51.98	52.13	52.27	52.42	52.56	52.71	52.85	53.00	53.14	15
7.3	53.29	53.44	53.58	53.73	53.88	54.02	54.17	54.32	54.46	54.61	15

Figure 40 Extract of a modern table of Squares. (MacFarlane, A. 1890. *Elementary Mathematical Tables*. Boston. p.37)

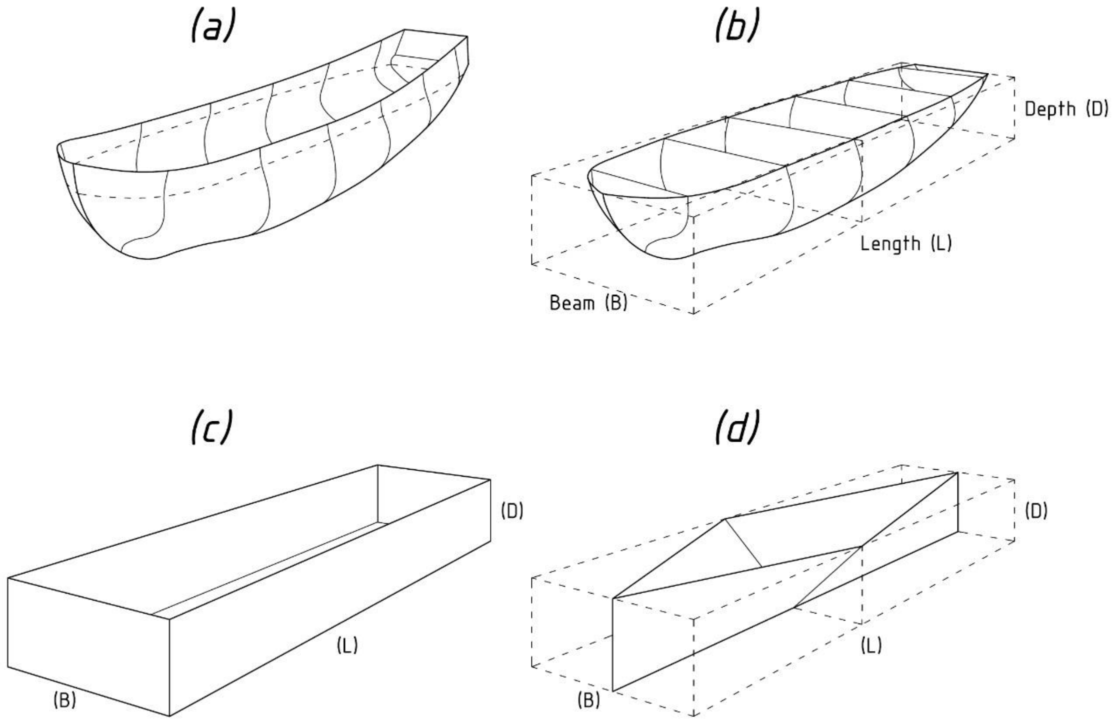


Figure 41 Concept of tonnage in the early modern period. The tonnage of a ship was calculated by multiplying its length, beam and depth (figure (b)) and the result of this multiplication was divided by a number which changed with time, etc. This gave an idea of the interior volume of the hull. However, it only worked if the ship was of 'conventional' shape. Ships with equal outside dimensions and different shapes would be considered to have the same tonnage. However, their internal capacities would clearly be different. For example, The three 'ships' shown in figures (a), (c) and (d) have the same outside dimensions, thus, they would have the same calculated tonnage. However, 'hull' (c) has four times the internal volume of 'hull' (d). (Drawings JPO).

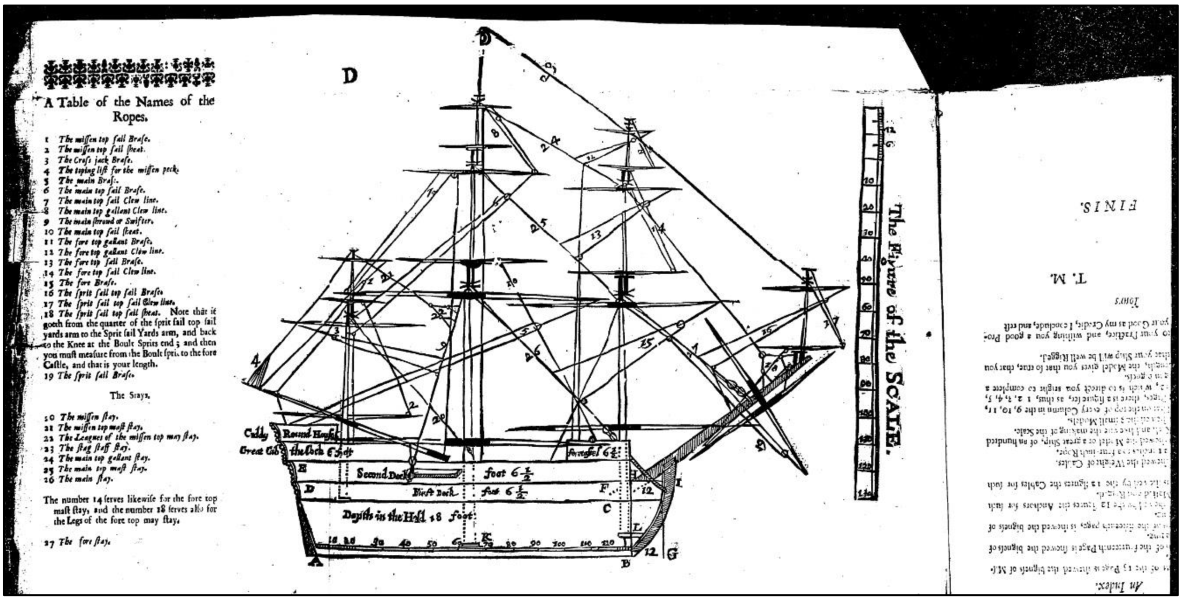


Figure 42 Drawing used by Miller to collect the information required to rig a ship. It should be noted that he is just interested in developing simple drawings as a means of storing information. Consequently, the ship is shown with straight decks and other simplified features. (Miller, T. 1676. *The Compleat Modellist.* Plate unumbered)

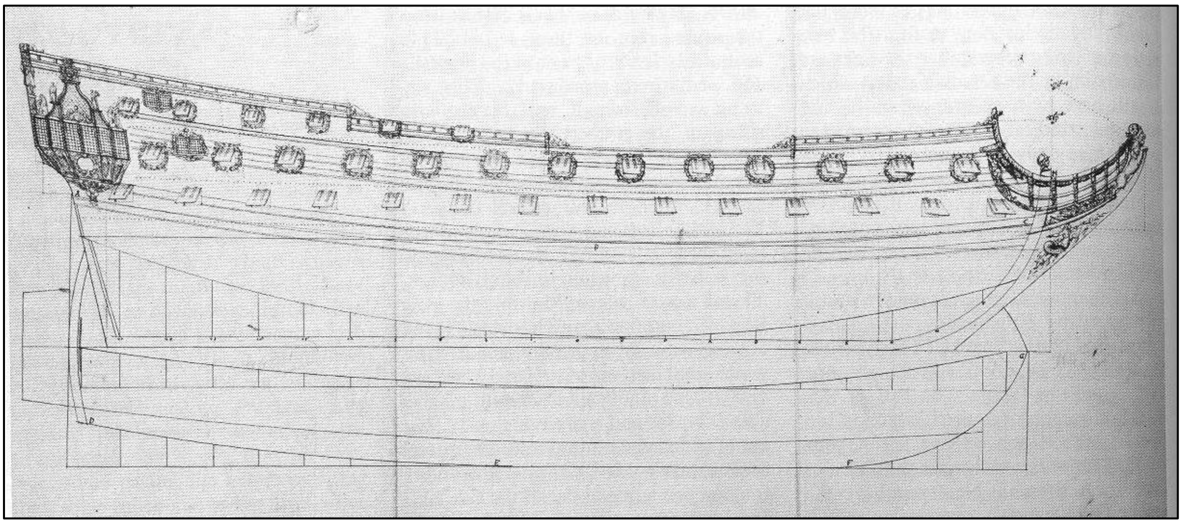


Figure 43 Plan from Deane's manuscript showing the profile and plan of the hull with the rising and narrowing lines. (Lavery, B. 1981. *Deane's Doctrine of Naval architecture, 1670*. p.70)

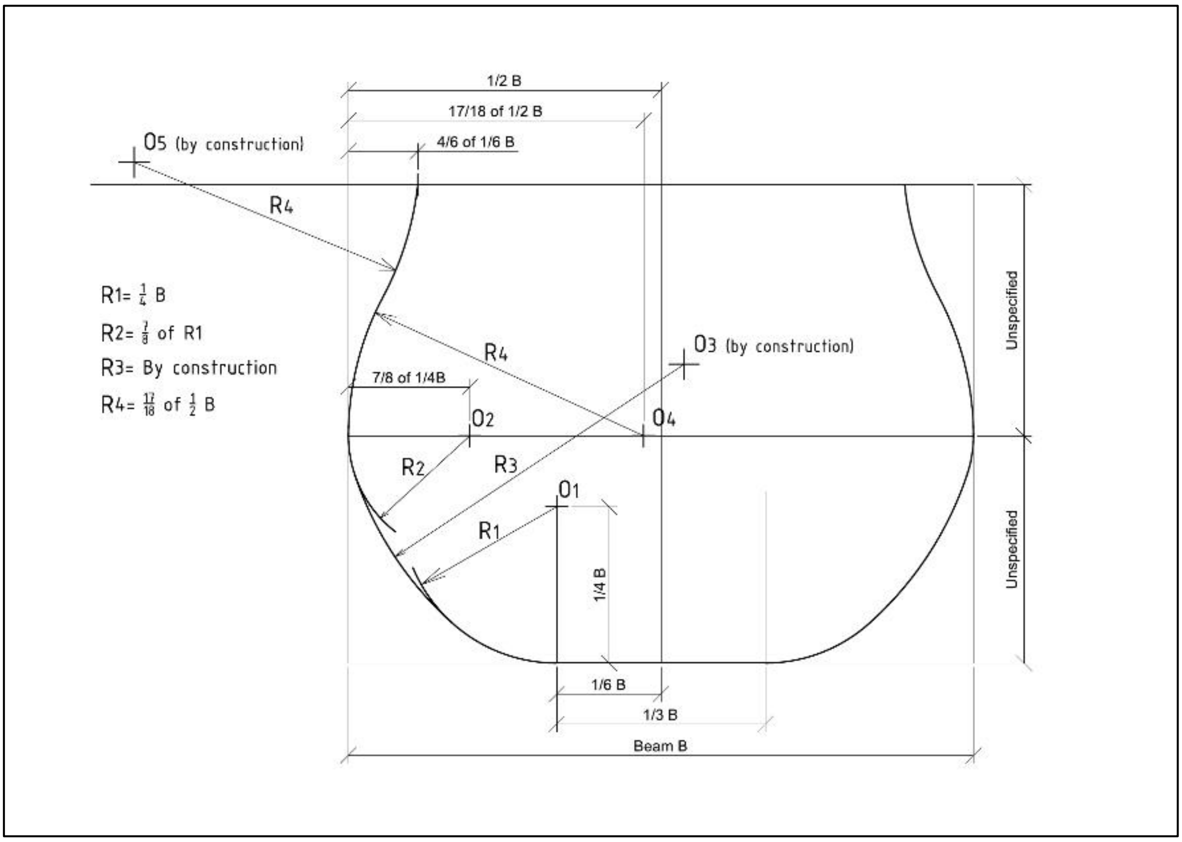


Figure 44 Master section as defined by Anthony Deane showing the proportional relation between the master section's beam (B) and the radii defining the section. The heights are not specified in the text. The centres are numbered in the order they must be drawn in. The values of the radii are specified. (Drawing by JPO after Lavery, B. 1981. *Deane's Doctrine of Naval architecture, 1670*. p.69-69)

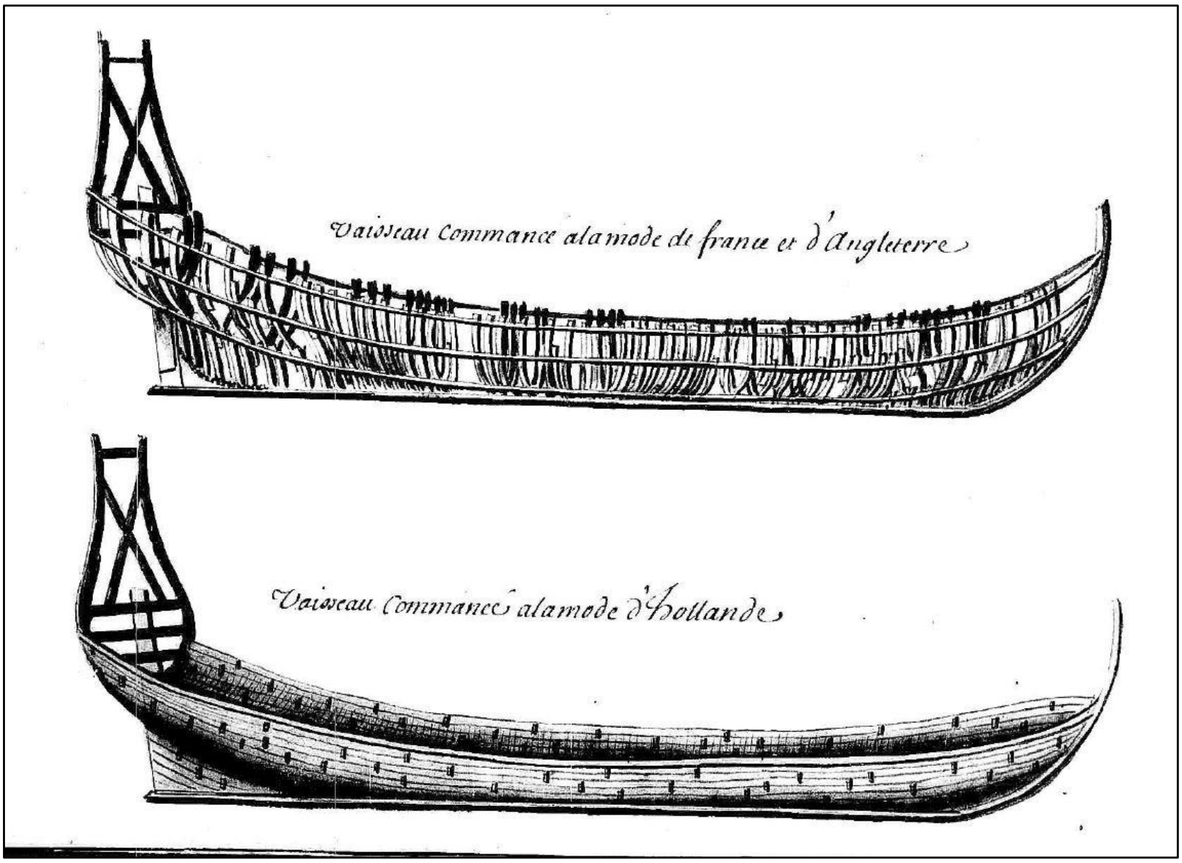


Figure 45 Figure from Arnoul's manuscript showing the two contrasting approaches to hull construction in England (top) and in the Netherlands (bottom). The English erected the framework before any planking was inserted. The Dutch are shown to build the bottoms of their hulls before the internal framework was erected. Observe the cleats fixing the planks to each other in the Dutch ship. (Arnoul. 1670. *Remarques Faites par le Sieur Arnoul sur la Marine d'Hollande et d'Anglaterre* p.10-11)

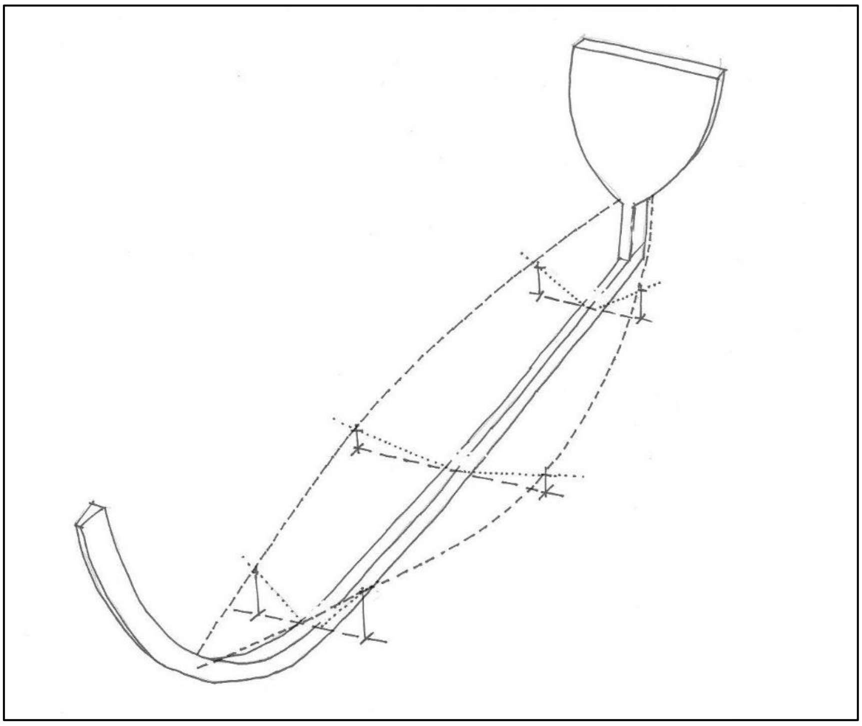


Figure 46 Schematic figure showing the three breadths that Dutch shipwrights used to define the shape of their bottoms. If these three dimensions are known, and the deadrise angle at these position is also known, the shape of the bottom of the hull is largely defined. (Drawing JPO)

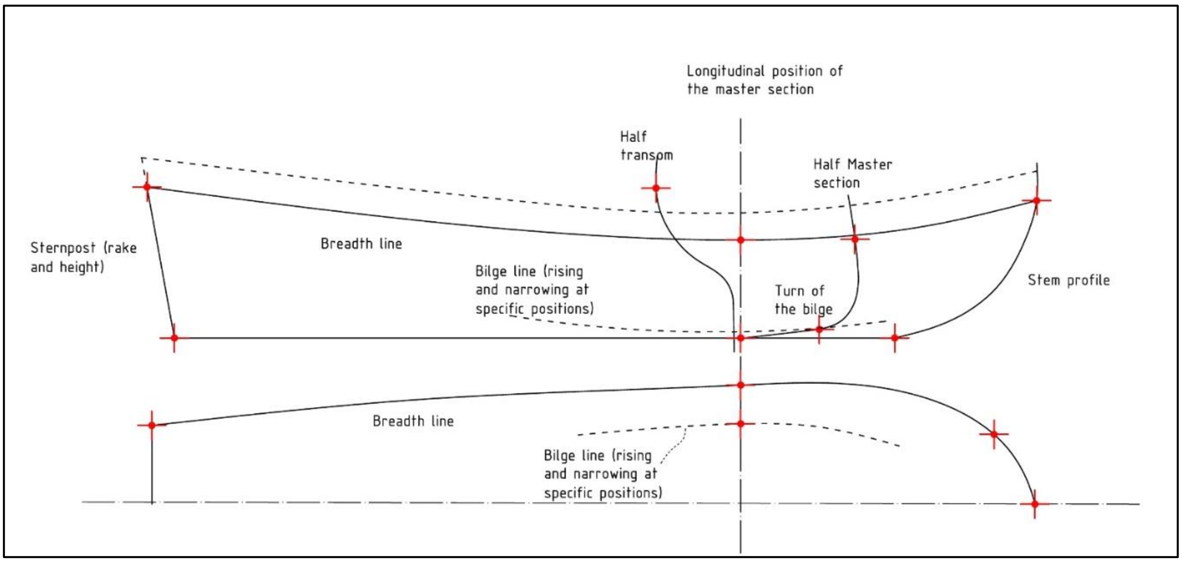


Figure 47 Data included in the specification for a yacht in Witsen's 1671 treatise. The points shown in red are specified by Witsen. The lines shown in the drawing were known by the shipwright. They were either straight lines or they were derived from some of the rules provided by Witsen. (Drawing JPO)

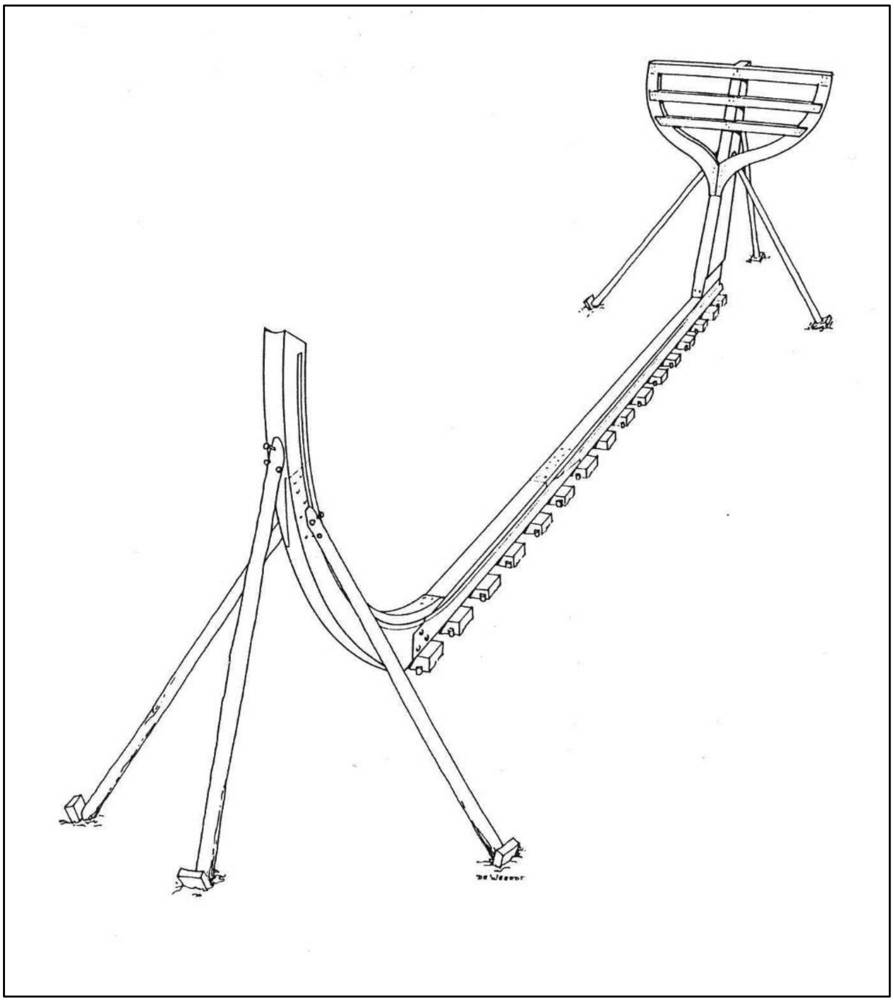


Figure 48 Backbone structure of a typical Dutch ship: Stem, keel and transom-sternpost assembly. (Illustration drawn by Hoving in Hoving, A. 2012. *Nicolaes Witsen and Shipbuilding in the Dutch Golden Age*. p.58-fig 2.42)

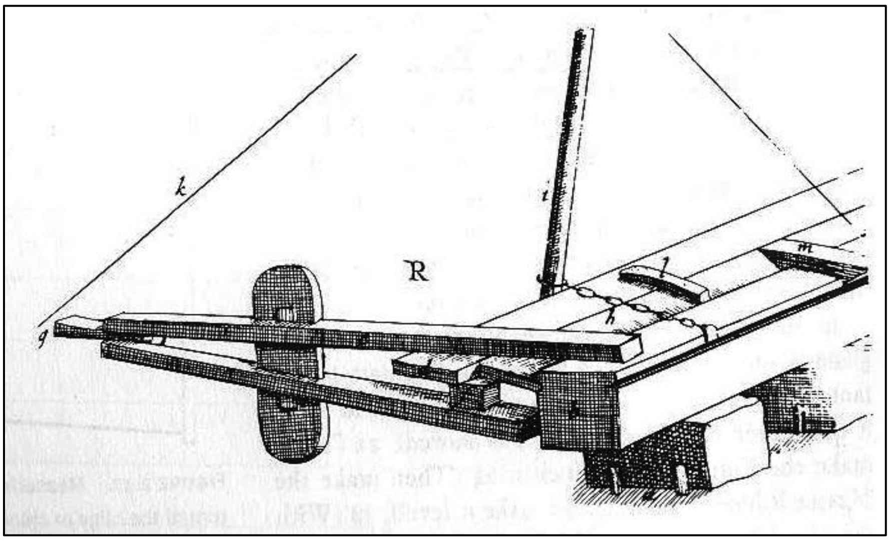


Figure 49 Procedure used to fit the garboard and second plank:
The floor-cleats used to set up the deadrise angle can be seen fixed above the keel, marked (m).

The long wooden clamp holds the second plank to the garboard, and the short wooden cleat nailed to either side of the seam between the garboard and the second plank can be seen above the chain (h).
(Original figure from Witsen 1671 shown in Hoving, A. 2012. *Nicolaes Witsen and Shipbuilding in the Dutch Golden Age*. p.61-fig 2.45)

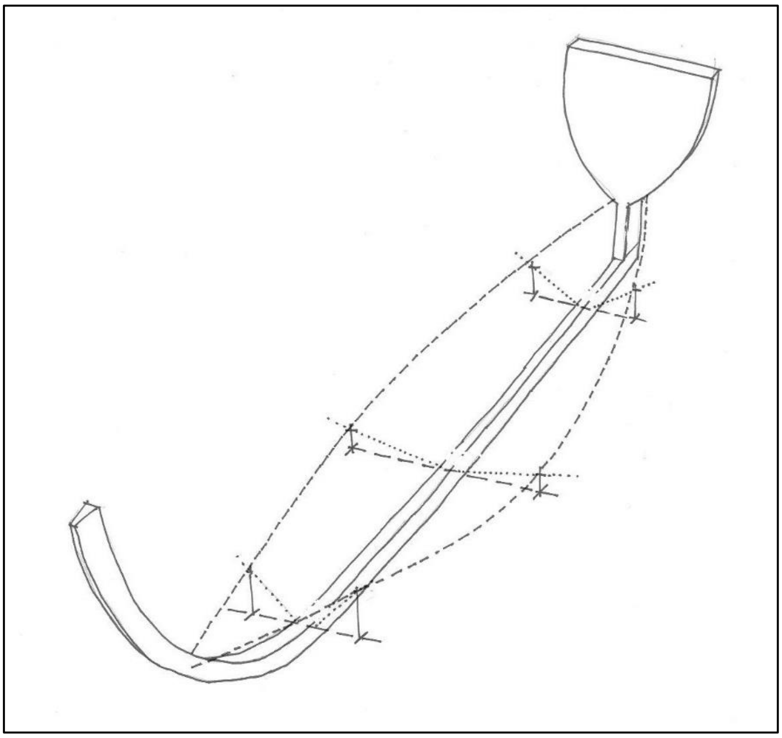


Figure 50 This figure shows in schematic form the information required by Dutch shipwrights to shape the bottoms of their hulls. It can be seen that by defining the breadth and deadrise angles at three points the form of the bottom can be defined. (Drawing JPO)

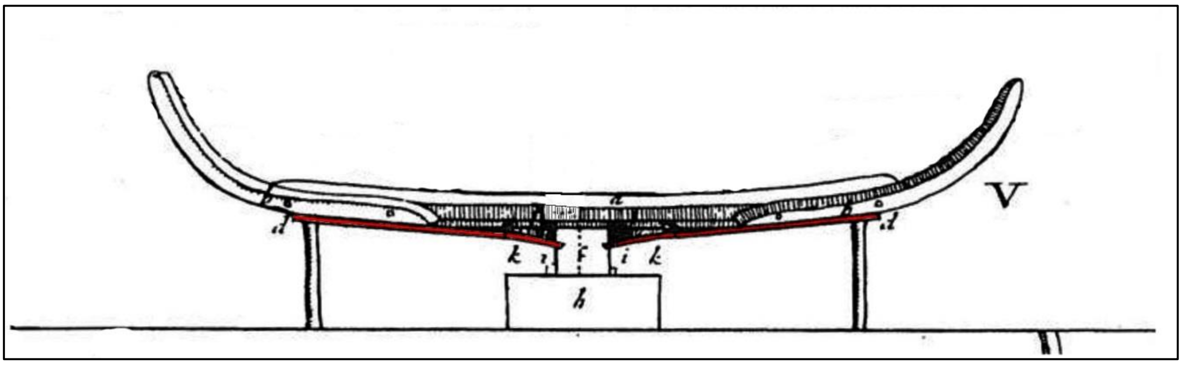


Figure 51 This figure shows the stage that follows the process described in figure 49. Once the bottom is planked (shown in red) up to the start of the bilge, the master frame is positioned into the ship (the figure has been edited and some support structure has been removed for

clarity. The original can be seen in figure 55). From this figure it is evident that the floor-futtock assembly must have been shaped following some means of design. (Original figure from Witsen, N. 1671. *Aeloude en Hedendaegse Scheeps-bouw en Bestier*. Plate 6-V. Edited by JPO)

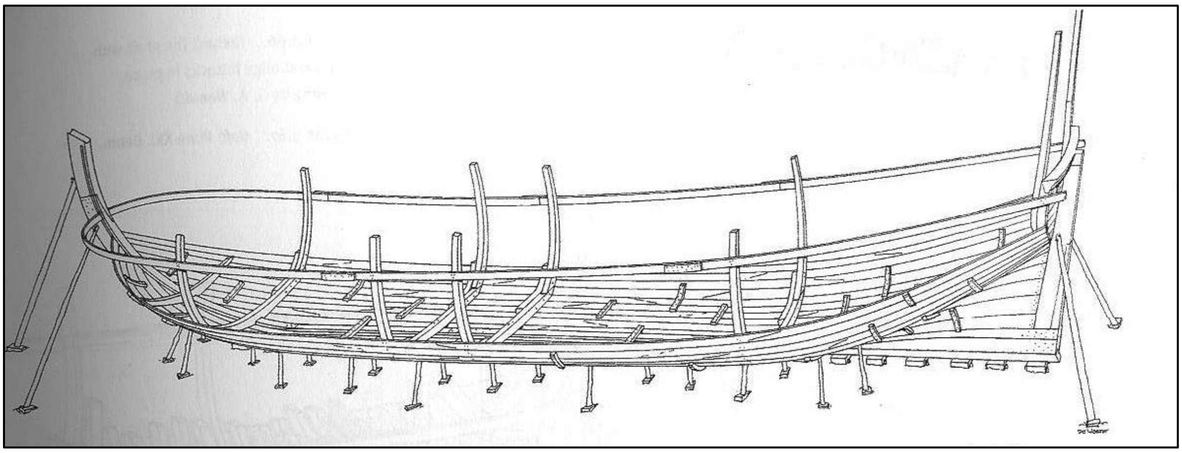


Figure 52 Full frames have been erected after the stage shown in figure 49. The planking and flexible ribbands at specific locations define the shape of the hull. The rest of the frames are made to fit that shape. (Drawn by Hoving in Hoving, A. 2012. *Nicolaes Witsen and Shipbuilding in the Dutch Golden Age*. p.73-Figure 2.63)

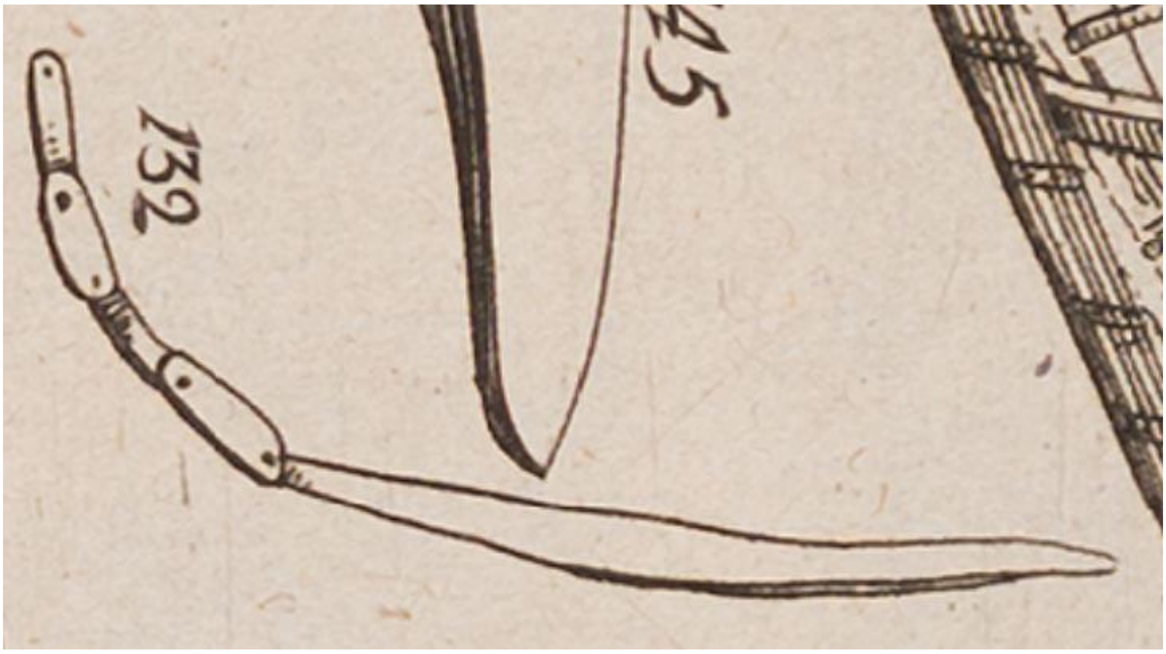


Figure 53 Extract Plate I Rålamb's treatise. It shows the tool used to derive the shape of the frames from the shape of the pre-erected bottom and the ribbands. The tool is made of a rigid section and a chain-like section that can be distorted. In order to use the tool, the shipwright would place the adjustable part of the tool against the bilge area of the planking and would leave

the rigid part protruding upwards against the ribbands (figure 52). The chain-like section would adapt to the sides of the bilge. This way the shipwright could obtain the shape of the frames between the pre-erected frames in figure 52. (Rålamb, A. 1691. *Skeps Byggerij Eller Adelig Öfnings Tionde Tom.* Plate I)

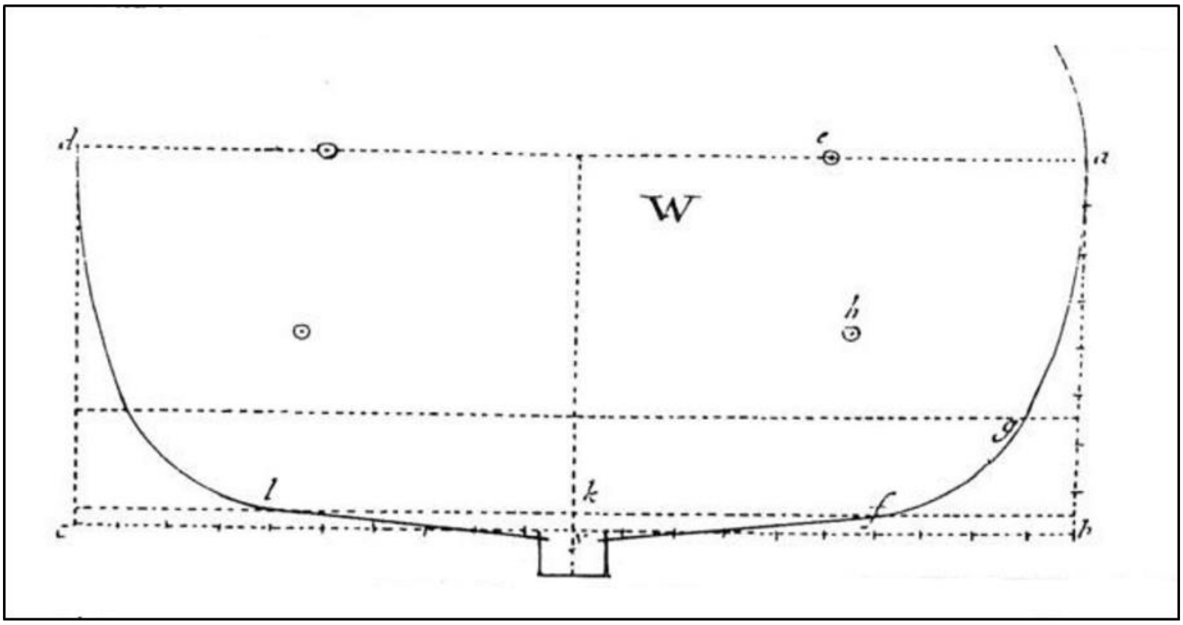


Figure 54 Geometrical construction shown by Witsen to design the shape of the master frame. (Detail from original figure from Witsen, N. 1671. *Aeloude en Hedendaegse Scheeps-bouw en Bestier*. Plate 6-W. Edited by JPO)

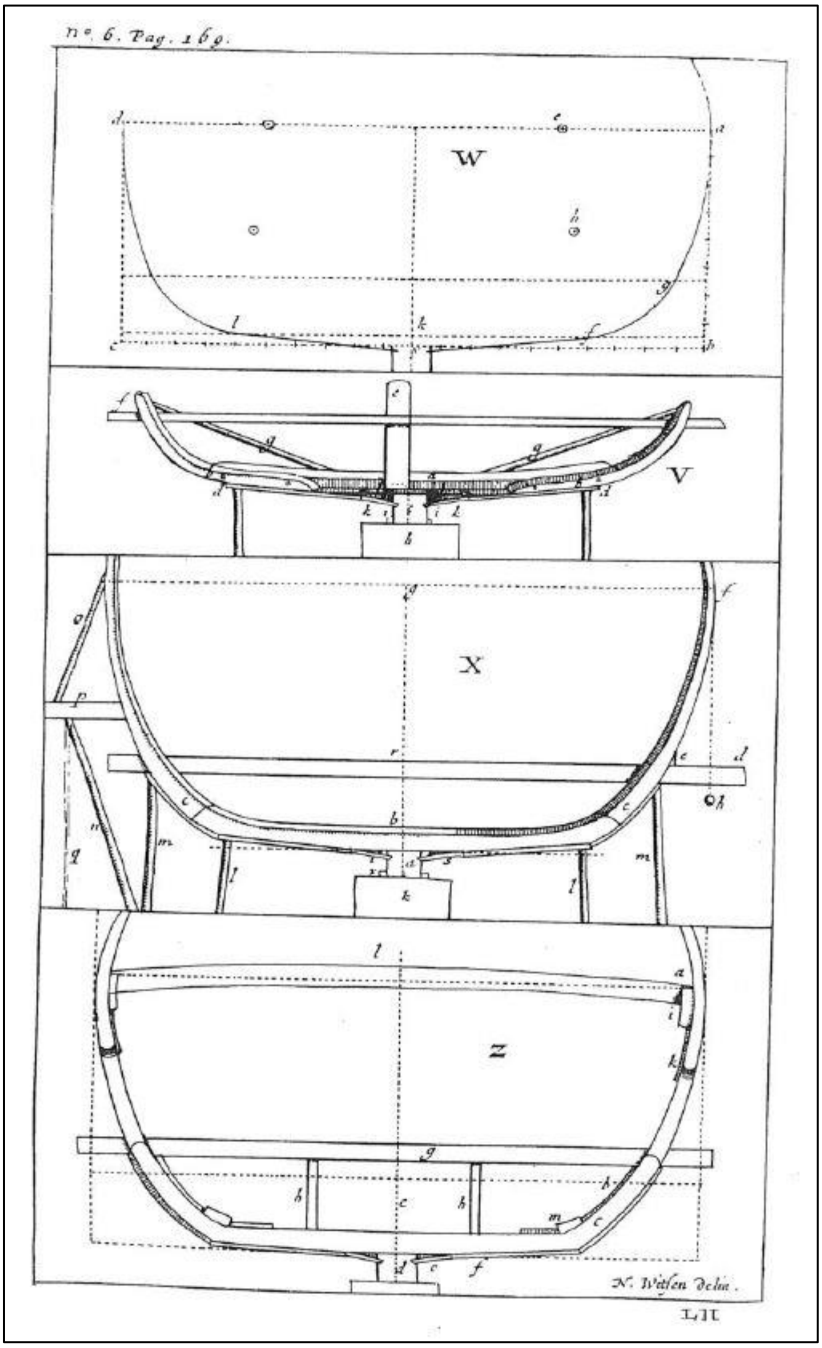


Figure 55 Plate No. 6 as published by Witsen. Plate W and V have been shown above. In plate X the futtocks have been installed in order to define the sides of the ship (Original figure from Witsen, N. 1671. *Aeloude en Hedendaegse Scheeps-bouw en Bestier*. Plate 6)

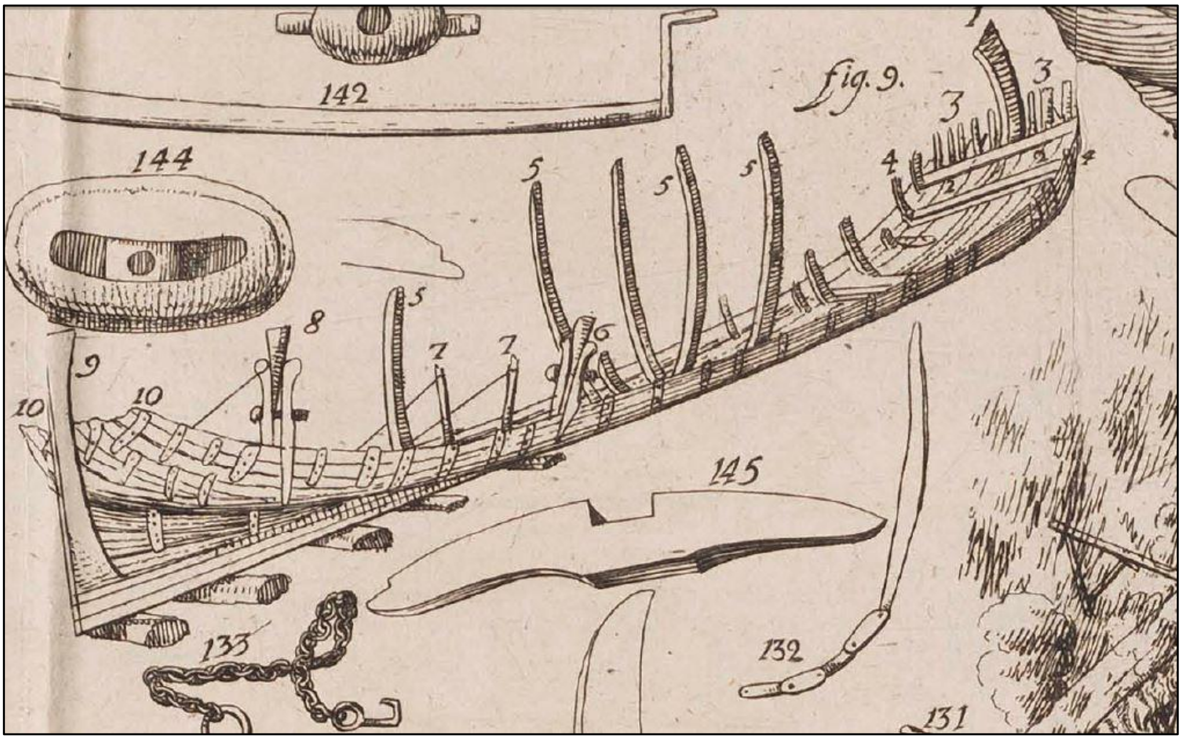


Figure 56 Extract from an illustration from Rålamb 1691. It depicts a ship being built in Sweden by Dutch shipwrights following the methods described by Witsen and Arnoul. The fully erected frames can be seen. There is another frame in the process of being assembled, having only one futtock up.
The tool marked 132 (detail in figure 53) is a tool used to define the shape of the futtock. The chain like part of the tool is used to adapt to the curvature of the pre-planked bilge area, while the top solid part would have been pre-made to the shape of the protruding futtocks. With this tool the shipwright could obtain the shape of any futtock (marked 5 in the illustration) from the hull. Probably a few ribbands as in figure-52 would be of assistance in the process. (Rålamb, A. 1691. *Skeps Byggerij Eller Adelig Öfnings Tionde Tom.* Extract of plate I)

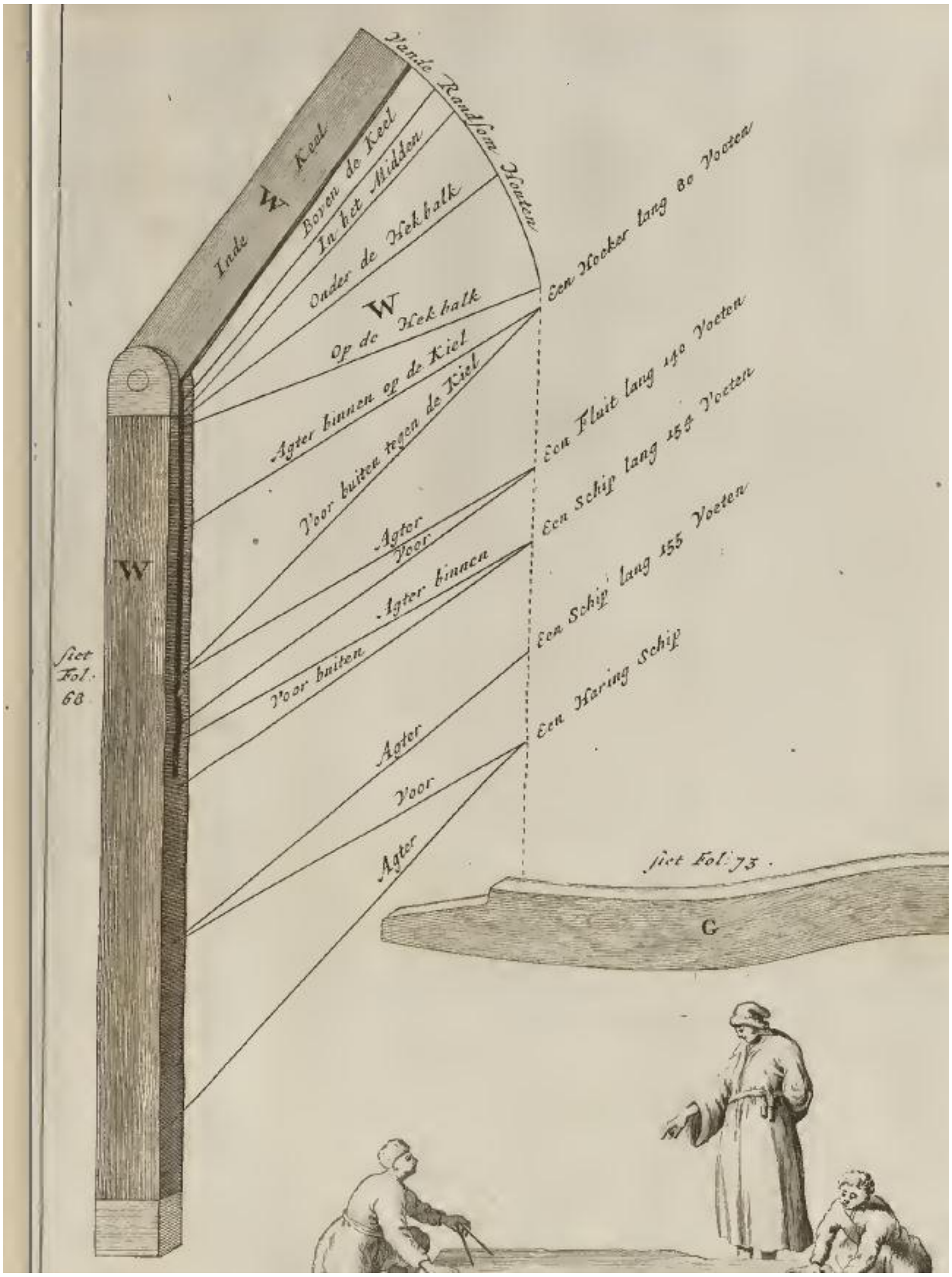


Figure 57 Detail of a figure from Van Yk's treatise where the bevel angles of the bottom of the ship at two specific positions along its length are specified. This idea is similar to those described by Arnoul and Witsen. The information is given for five different ship types. (After Van Yk, C. 1697. *De Nederlandse Scheeps-bouw-konst.* p.72)

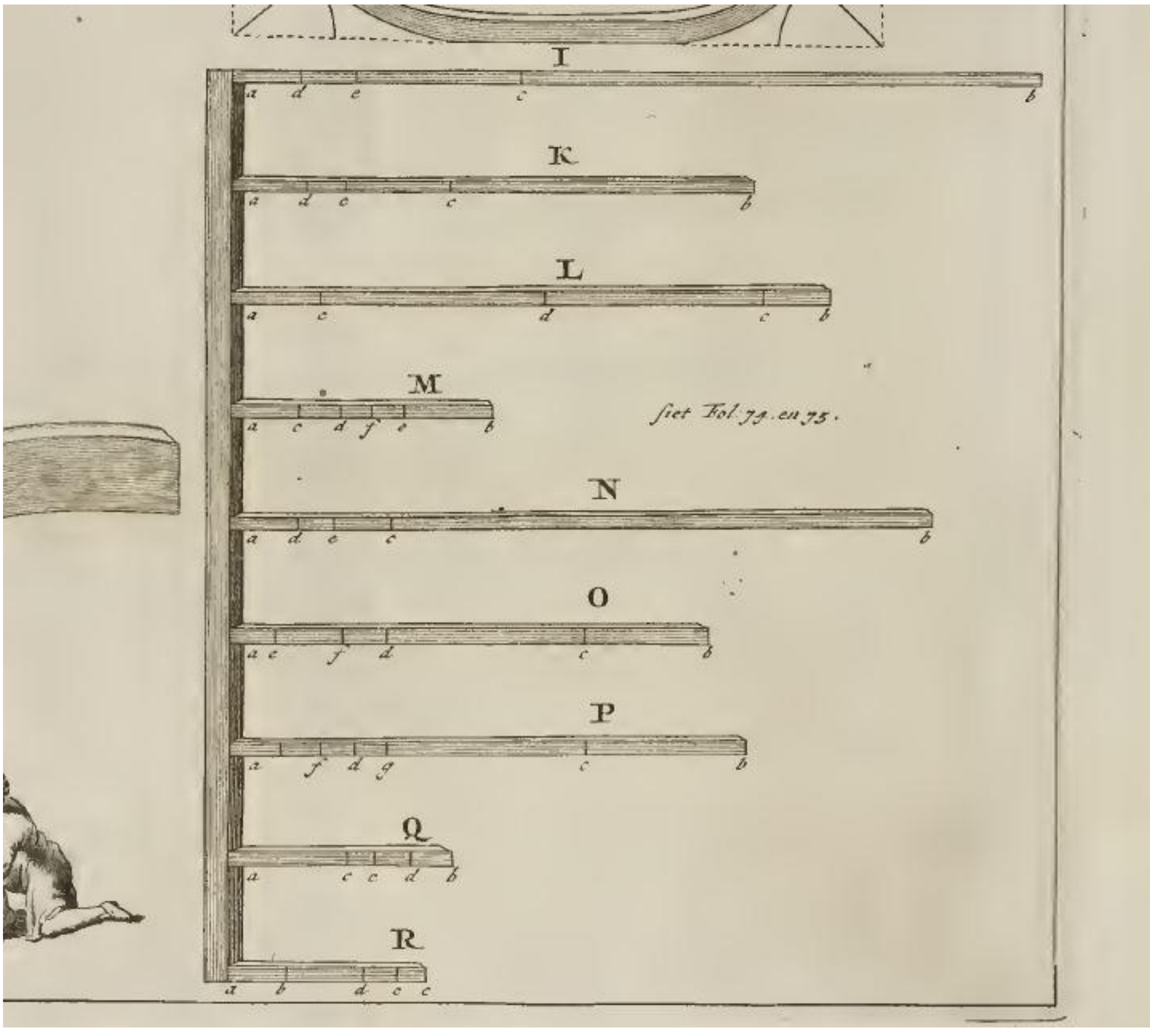
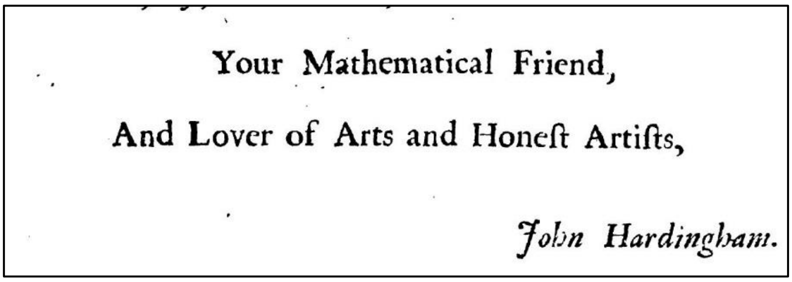


Figure 58 Wooden staffs where the heights of the breadth line at specific points along the length of the hull are marked for nine different ships (After Van Yk, C. 1697. De Nederlandse Scheeps-bouw-konst. p.72)


Your Mathematical Friend,

And Lover of Arts and Honeſt Artiſts,

John Hardingham.

Figure 59 John Hardingham's ‘signature’ in his address to the reader of his treatise (Hardingham, J. 1706. *The Accomplish'd Ship-Wright and Mariner.* To the Reader*)*

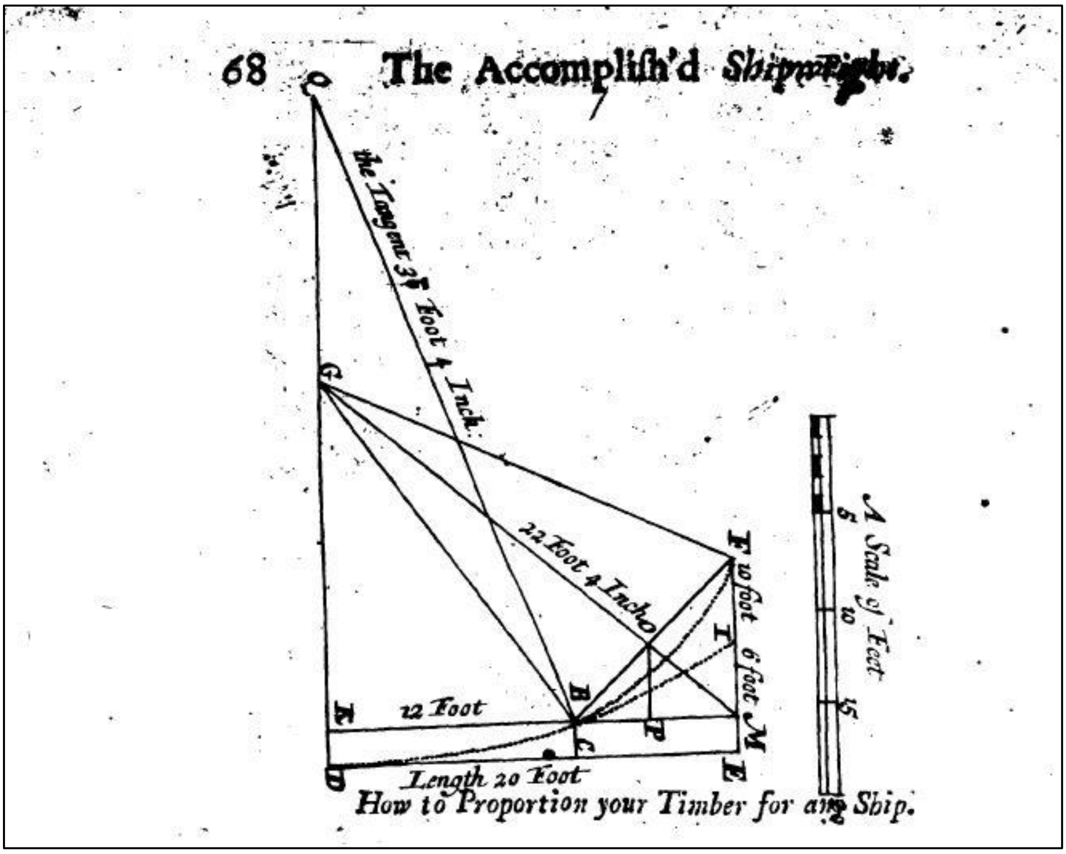
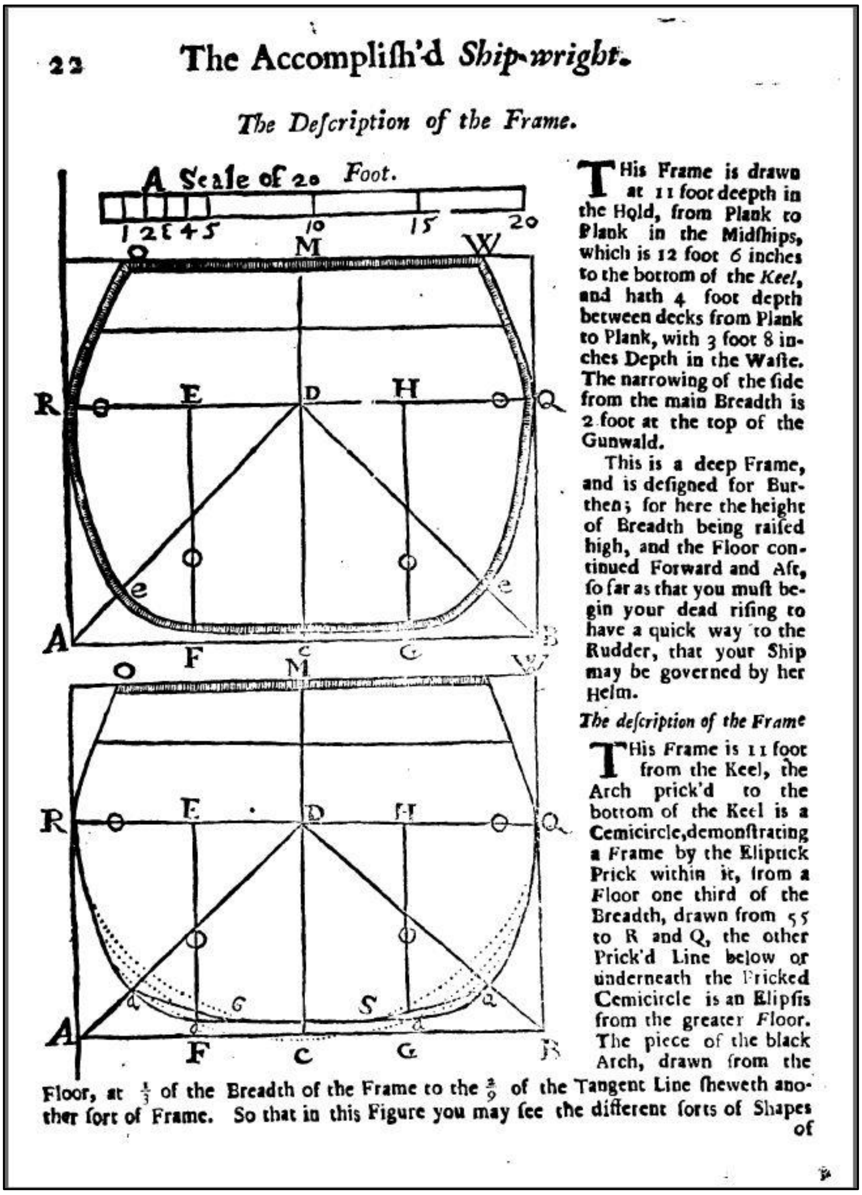


Figure 60 Geometrical construction used to define a rising curve when a full end is desired. This is done by using two arcs instead of a single arc. Note the similarities in the drawing when it is compared to Bushnell's example in figure 37 above. (Hardingham, J. 1706. *The Accomplish'd Ship-Wright and Mariner*. p.68)



22 The Accomplish'd *Ship-wright*.

The Description of the Frame.

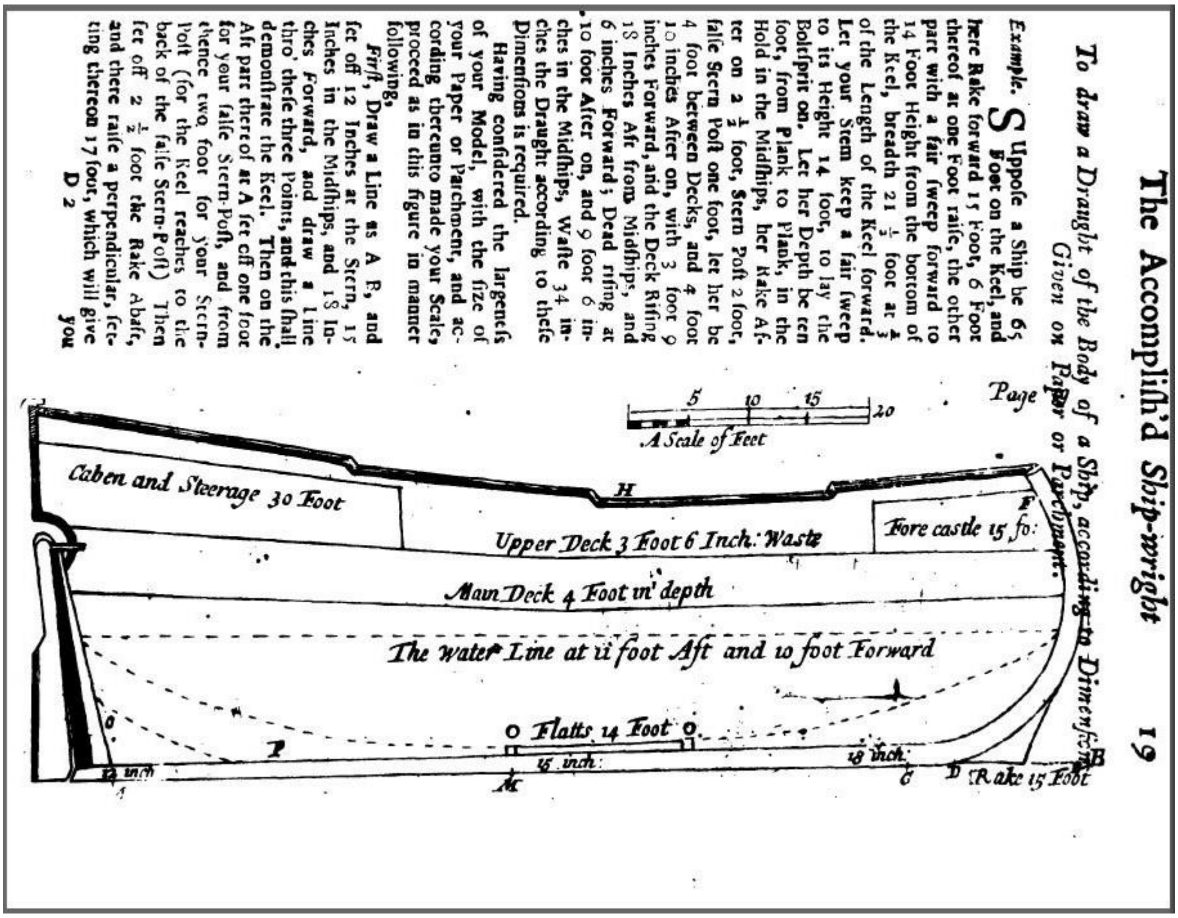
THis Frame is drawn at 11 foot deepth in the Hold, from Plank to Plank in the Midships, which is 12 foot 6 inches to the bottom of the *Keel*, and hath 4 foot depth between decks from Plank to Plank, with 3 foot 8 inches Depth in the Waste. The narrowing of the side from the main Breadth is 2 foot at the top of the Gunwald.

This is a deep Frame, and is designed for Burthen; for here the height of Breadth being raised high, and the Floor continued Forward and Aft, so far as that you must begin your dead rising to have a quick way to the Rudder, that your Ship may be governed by her Helm.

The description of the Frame

THis Frame is 11 foot from the Keel, the Arch prick'd to the bottom of the Keel is a Cemicircle, demonstrating a Frame by the Eliptick Prick within it, from a Floor one third of the Breadth, drawn from 55 to R and Q, the other Prick'd Line below or underneath the Pricked Cemicircle is an Elipsis from the greater Floor. The piece of the black Arch, drawn from the Floor, at $\frac{1}{3}$ of the Breadth of the Frame to the $\frac{2}{9}$ of the Tangent Line sheweth another sort of Frame. So that in this Figure you may see the different sorts of Shapes of

Figure 61 Master section by Hardingham with explanations on how to alter its shape in order to produce different shapes according to the ship's intended use. (Hardingham, J. 1706. *The Accomplish'd Ship-Wright and Mariner*. p. 22)



The Accomplish'd Ship-wright 19

To draw a Draught of the Body of a Ship, according to Dimensions Given on Paper or Parchment.

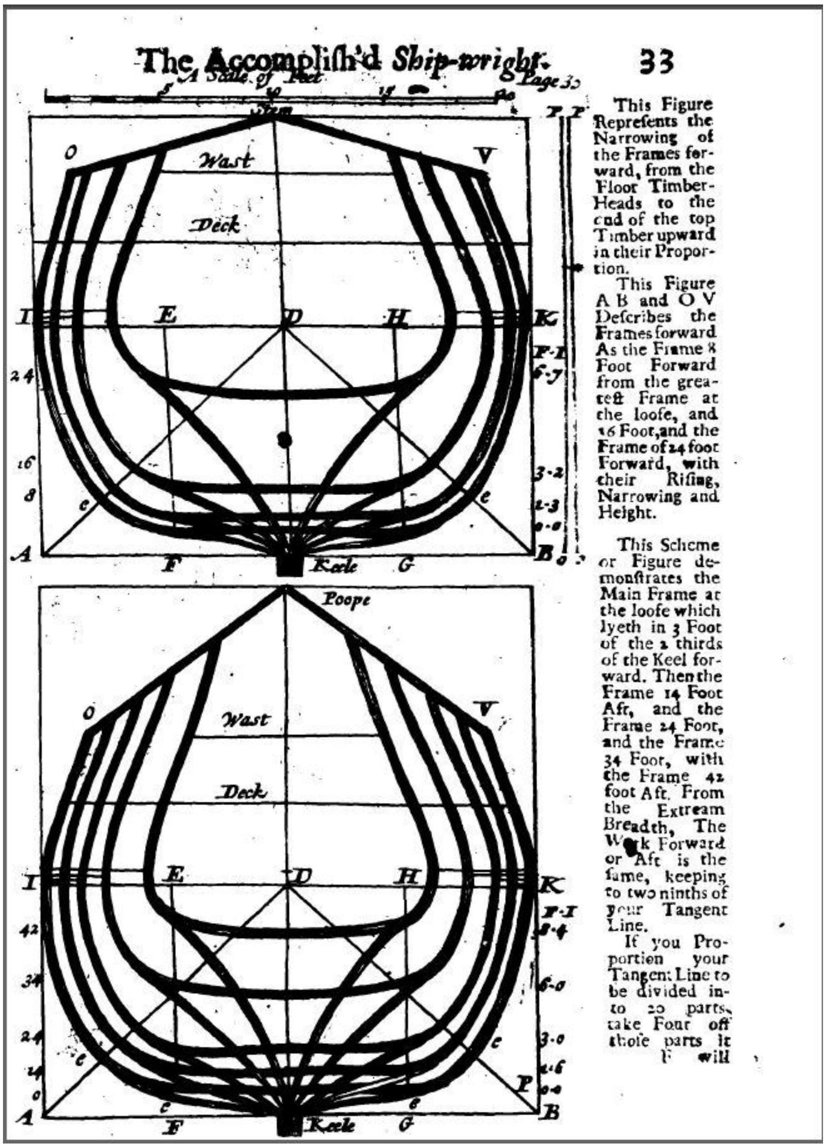
Example. Suppose a Ship be 65 Foot on the Keel, and here Rake forward 15 Foot, 6 Foot thereof at one Foot raise, the other part with a fair sweep forward to 14 Foot Height from the bottom of the Keel, breadth 21 1/2 foot at 1/3 of the Length of the Keel forward. Let your Stem keep a fair sweep to its Height 14 foot, to lay the Boltsprit on. Let her Depth be ten foot, from Plank to Plank, in the Hold in the Midships, her Rake After on 2 1/2 foot, Stern Post 2 foot, false Stern Post one foot, let her be 4 foot between Decks, and 4 foot 10 inches After on, with 3 foot 9 inches Forward, and the Deck Rising 18 Inches Aft from Midships, and 6 inches Forward; Dead rising at 10 foot After on, and 9 foot 6 inches in the Midships, Waste 34 inches the Draught according to these Dimensions is required.

Having considered the largeness of your Model, with the size of your Paper or Parchment, and accordingly thereunto made your Scales, proceed as in this figure in manner following.

First, Draw a Line as A B, and set off 12 Inches at the Stern, 15 Inches in the Midships, and 18 Inches Forward, and draw a Line thro' these three Points, and this shall demonstrate the Keel. Then on the Aft part thereof at A set off one foot for your false Stern-Post, and from thence two foot for your Stern-Post (for the Keel reaches to the back of the false Stern-Post) Then set off 2 1/2 foot the Rake Abaft, and there raise a perpendicular, setting thereon 17 foot, which will give you

D 2

Figure 62 Figure from page 19 used as an aid to understand the process of shaping the hull. (Hardingham, J. 1706. *The Accomplish'd Ship-Wright and Mariner*. p.19).


The Accomplish'd Ship-wright. 33

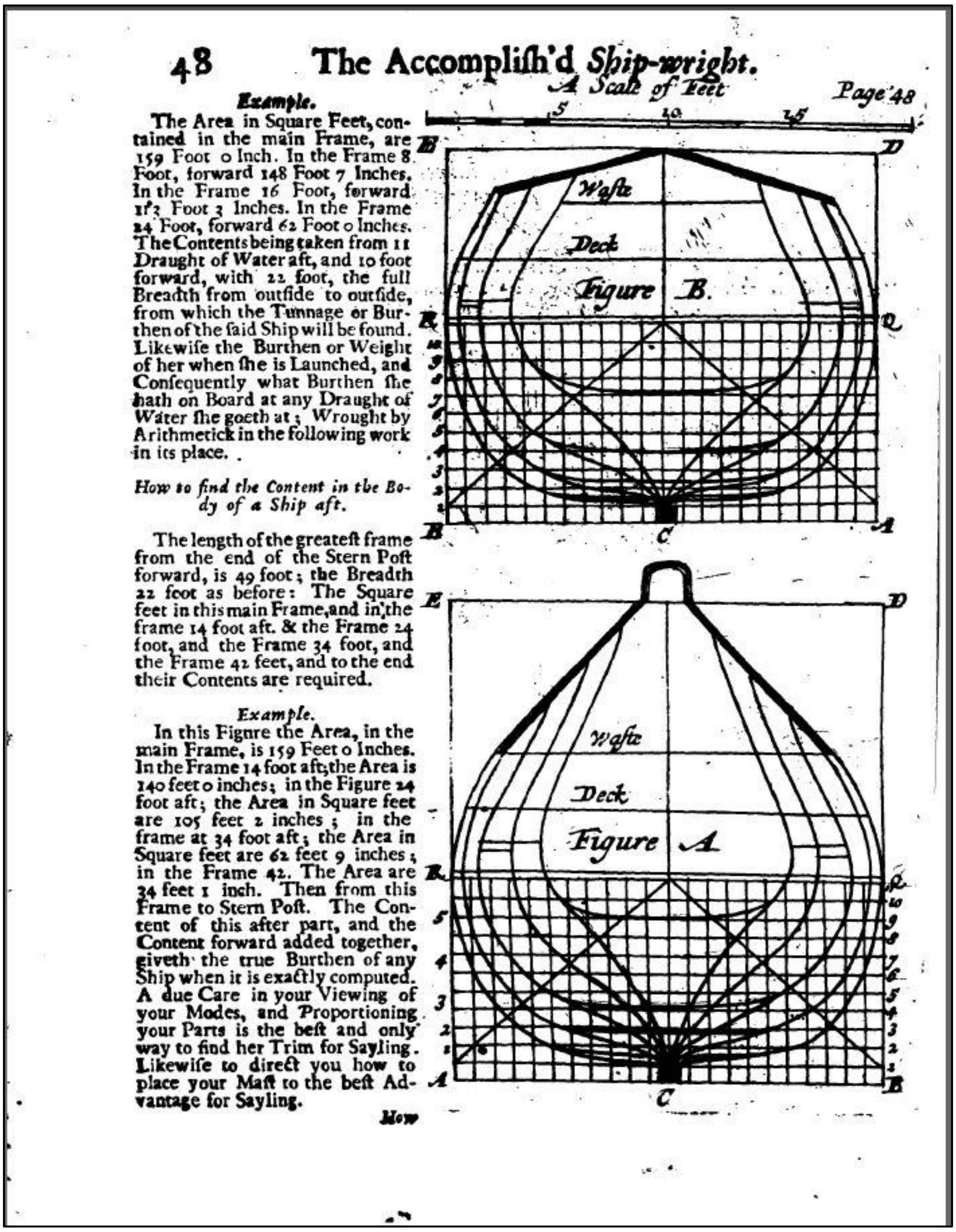
This Figure Represents the Narrowing of the Frames forward, from the Floor Timber-Heads to the end of the top Timber upward in their Proportion.

This Figure A B and O V Describes the Frames forward As the Frame 8 Foot Forward from the greatest Frame at the loofe, and 16 Foot, and the Frame of 24 foot Forward, with their Rising, Narrowing and Height.

This Scheme or Figure demonstrates the Main Frame at the loofe which lyeth in 3 Foot of the 2 thirds of the Keel forward. Then the Frame 14 Foot Aft, and the Frame 24 Foot, and the Frame 34 Foot, with the Frame 42 foot Aft. From the Extream Breadth, The Work Forward or Aft is the same, keeping to two ninths of your Tangent Line.

If you Proportion your Tangent Line to be divided into 20 parts, take Four off those parts it will

Figure 63 Shape of the frames obtained by a process of rising and narrowing of the master section. This plan, is an illustration of the process which, in reality, would be done full-size on a mould loft floor. (Hardingham, J. 1706. *The Accomplish'd Ship-Wright and Mariner*. p. 33)



48 The Accompliſh'd Ship-wright.

Example.

The Area in Square Feet, contained in the main Frame, are 159 Foot o Inch. In the Frame 8 Foot, forward 148 Foot 7 Inches. In the Frame 16 Foot, forward 11f3 Foot 3 Inches. In the Frame 24 Foot, forward 62 Foot o Inches. The Contents being taken from 11 Draught of Water aft, and 10 foot forward, with 22 foot, the full Breadth from outſide to outſide, from which the Tunnage or Burthen of the ſaid Ship will be found. Likewiſe the Burthen or Weight of her when ſhe is Launched, and Conſequently what Burthen ſhe hath on Board at any Draught of Water ſhe goeth at; Wrought by Arithmetick in the following work in its place.

How to find the Content in the Body of a Ship aft.

The length of the greateſt frame from the end of the Stern Poſt forward, is 49 foot; the Breadth 22 foot as before: The Square feet in this main Frame, and in the frame 14 foot aft. & the Frame 24 foot, and the Frame 34 foot, and the Frame 42 feet, and to the end their Contents are required.

Example.

In this Figure the Area, in the main Frame, is 159 Feet o Inches. In the Frame 14 foot aft; the Area is 140 feet o inches; in the Figure 24 foot aft; the Area in Square feet are 105 feet 2 inches; in the frame at 34 foot aft; the Area in Square feet are 62 feet 9 inches; in the Frame 42. The Area are 34 feet 1 inch. Then from this Frame to Stern Poſt. The Content of this after part, and the Content forward added together, giveth the true Burthen of any Ship when it is exactly computed. A due Care in your Viewing of your Modes, and Proportioning your Parts is the beſt and only way to find her Trim for Sayling. Likewiſe to direct you how to place your Maſt to the beſt Advantage for Sayling.

How

Figure 64 Grid superimposed to the transversal sections used to calculate the areas of each of the sections and, from these, the volume of the underwater portion of the hull. (Hardingham, J. 1706. *The Accomplish'd Ship-Wright and Mariner*. p. 48)

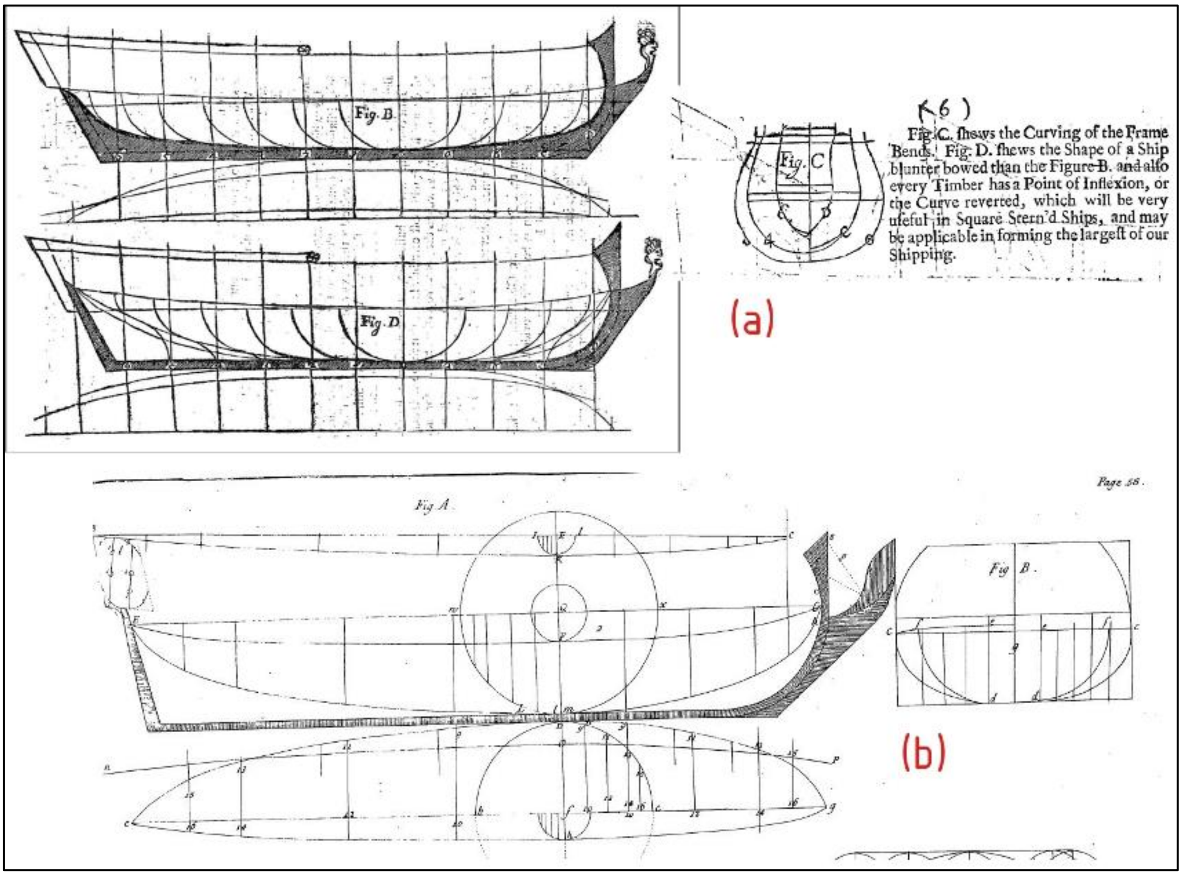


Figure 65 Sutherland's illustrations showing the main lines that define the shape of the ship, shown in a schematic manner. They are shown by Sutherland as a means of conveying the general concept. (Sutherland, W. 1711. *The Ship Builders Assistant*. p.5, 56)

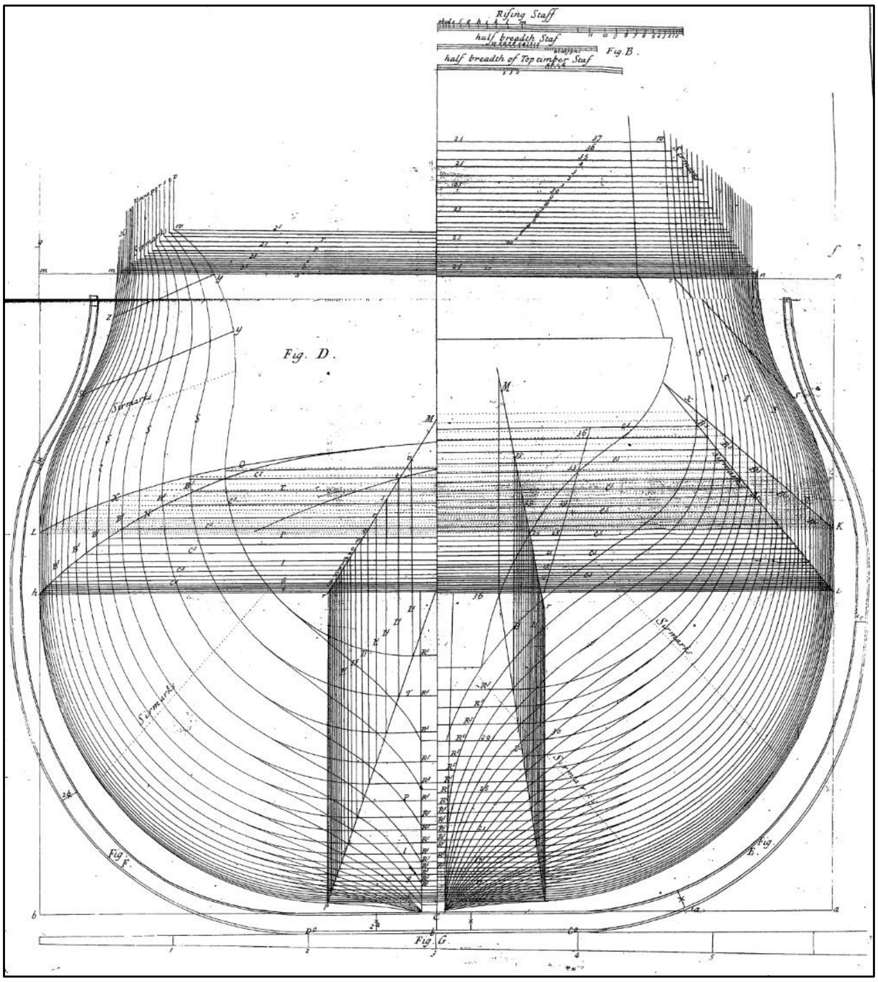


Figure 66 Finished Body-plan used by Sutherland to explain the process of defining the body plan of the hull by rising and narrowing the centre position of each of the arcs which define the shape of the master sections. (Sutherland, W. 1711. *The Ship Builders Assistant*. p.83)

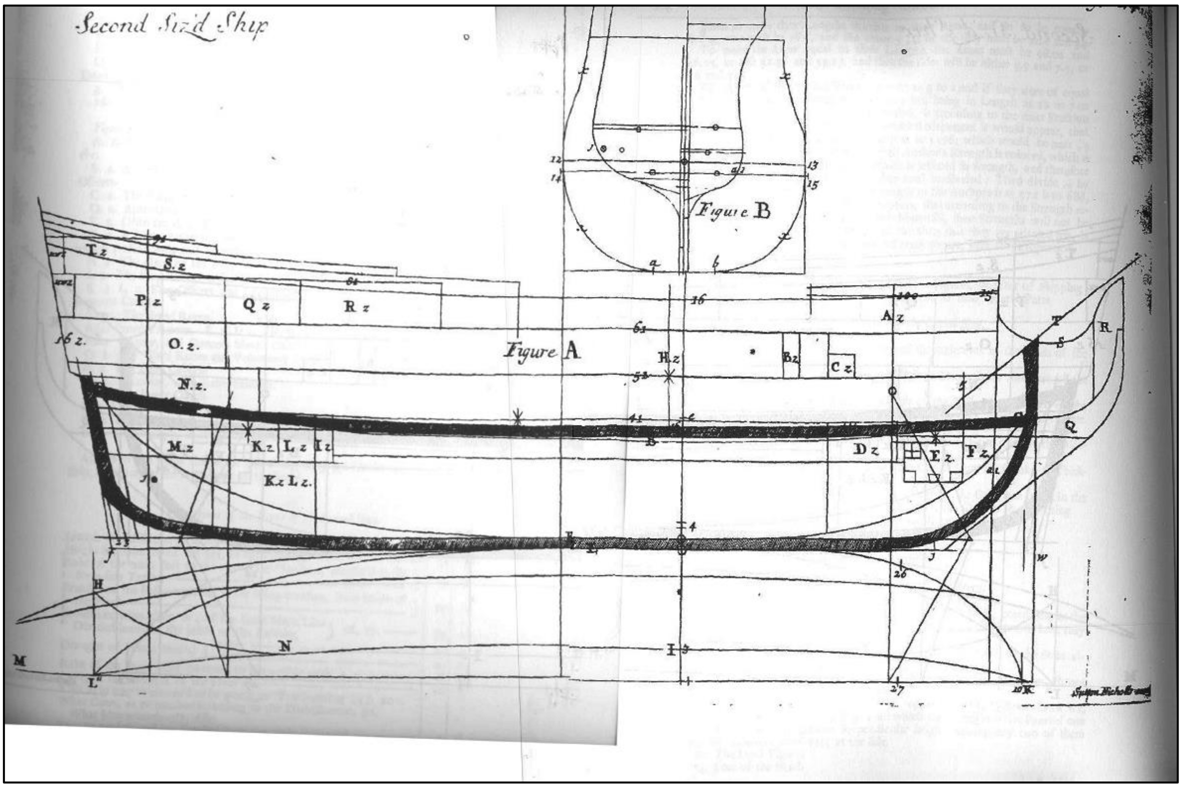
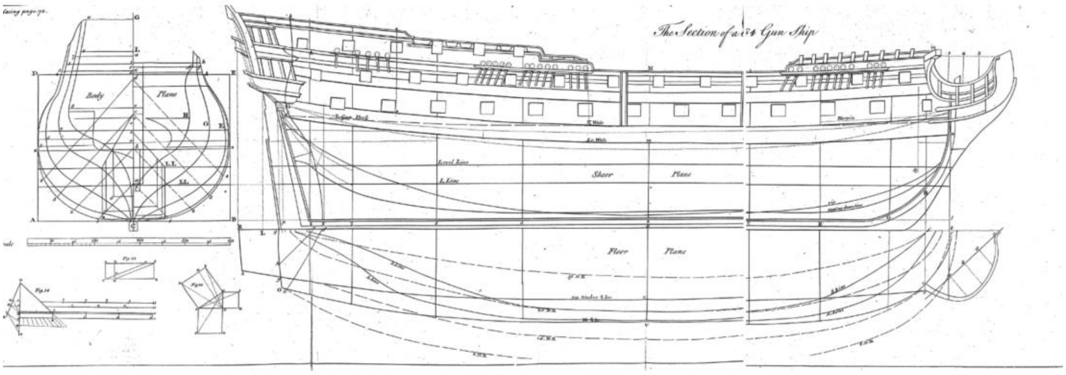
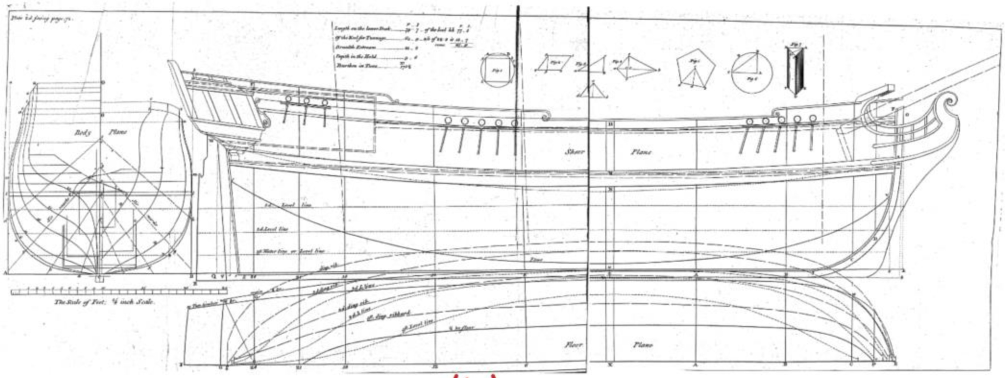


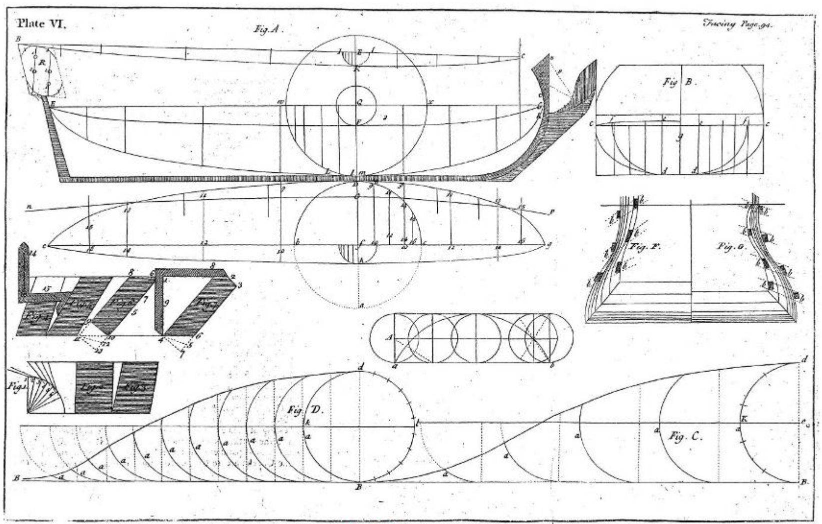
Figure 67 'Lines that shape the body' for a 'Second size' ship. These lines show the rising and narrowing lines, the breadth line and the profile of the ship. It also shown the master section and two sections one forward and one aft. The accompanying text define the main parameters that help the shipwright describe the shape of these curves. (Sutherland, W. 1717. *Britain's Glory: or Ship-Building Unvail'd*. p.24)



(a)



(b)



(c)

Figure 68 Different styles of plan shown by Sutherland in his 1784 edition. Plate 3d (figure (a))and plate 2d (figure (b)) show plans that are very similar to a modern lines plan. They show the shape of the surface of the hull. Plate VI (figure (c)), on the other hand, shows the curves that are used by the design recipe to shape the three-dimensional surface of the hull. They are shown schematically as part of the explanation in the text. (Sutherland, W. 1794. *The Ship Builders Assistant.* p. 72, 78 and 94) s'appelle l'*arcaſſe.*

XVI.

Des Liſſes de l'Arriere. Pl. XIII.

L'eſtain & l'alonge de corniere étant tracés, on tire une ligne droite du point m (qui marque l'élévation des façons de l'arriere) au point a qui indique l'extrêmité de la varangue ; *c'eſt la liſſe des façons* : puis de ſ, extrêmité de la liſſe de hourdi, en S, extrêmité de la ligne du creux, on tire la liſſe du fort S ſ ; entre ces deux liſſes on en place deux autres, de façon qu'elles partagent la courbe a S & l'eſtain m ſ en trois parties égales ; *ce ſont les liſſes intermédiaires* : on partage enſuite l'alonge de revers au maître couple, en deux parties égales au point & ; on porte l'ouverture S & ſur l'eſtain, de ſ en c, & on tire la liſſe & c ; on fait c A égal à & B, & des points B A, on tire la liſſe du plat-bord B A, *fig.* 1 ; ces liſſes qui ſont au deſſus de la liſſe de hourdi, ſe nomment *les liſſes d'accaſtillage*

REMARQUE.

Au lieu de deux liſſes intermédiaires entre la liſſe des façons & celle du fort, pluſieurs conſtructeurs en mettent trois ou quatre ; & plus on en met, plus on a de facilité à tracer la courbure des membres. A l'égard des liſſes d'accaſtillage, elles ſont peu importantes : néanmoins nous en parlerons dans la ſuite.

On ſçait que les liſſes ſont des regles de bois minces & flexibles, qu'on ſuppoſe clouées à différentes hauteurs ſur le maître couple & ſur l'étambot.

Une de ces regles qui répond ſur l'étambot au point où on

Figure 69 One of the many instances where Duhamel du Monceau introduces alternatives to the methods explained in the text. (Duhamel du Monceau. 1758. *Élémens de l'Architecture Navale*. p.224)

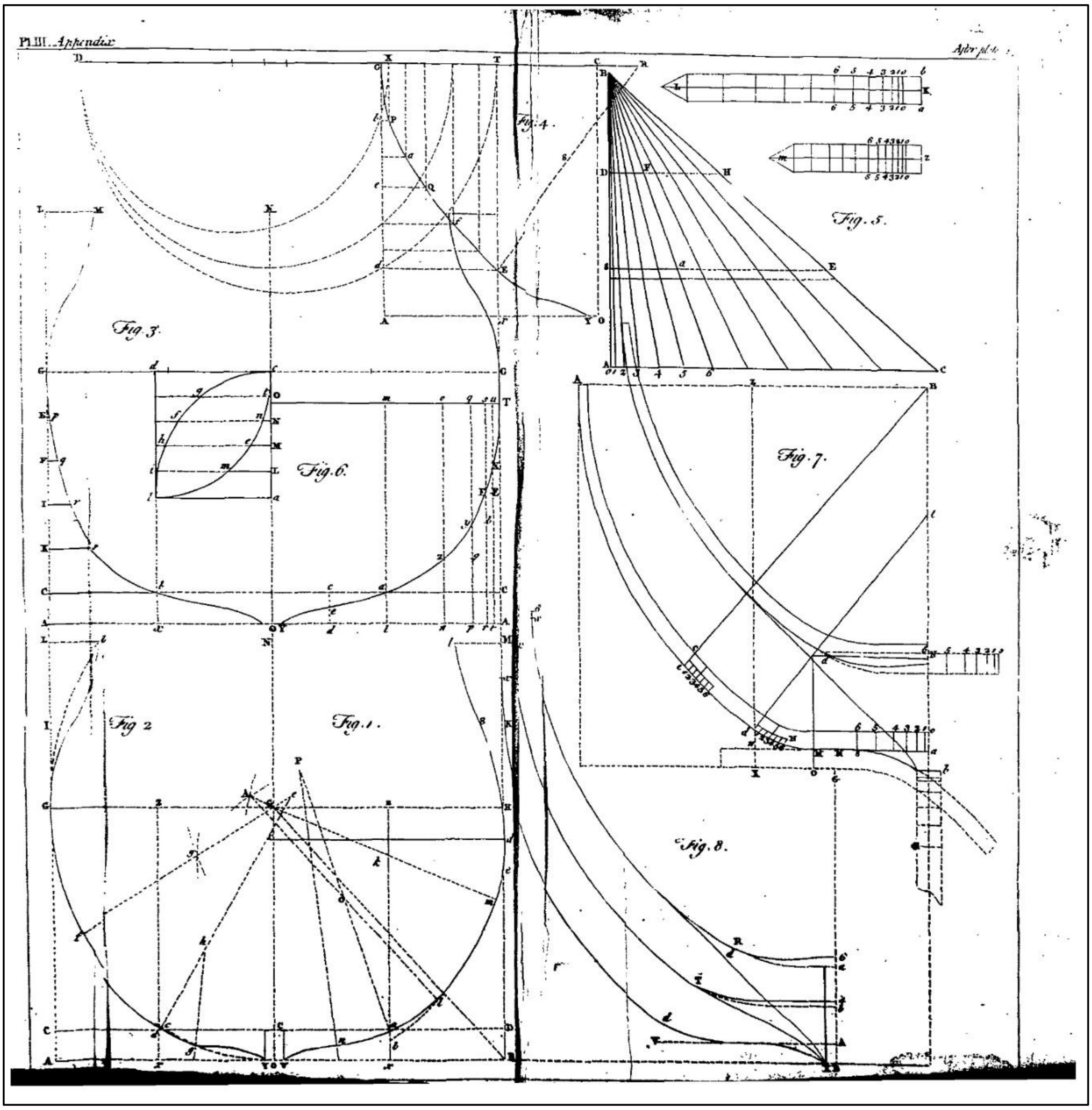


Figure 70 Four different methods for drawing a master section (each half of the master section is a different method). On the right hand side there is a representation of the process of whole moulding. With this technique the body of the ship is defined with a physical mould, in a similar manner to the treatises described in the previous chapter.
Note: this illustration is taken from the English translation of *Elémens de l'Architecture Navale* by Mungo Murray (see main text). The figures in the original copy of the French version were identical but of insufficient quality.

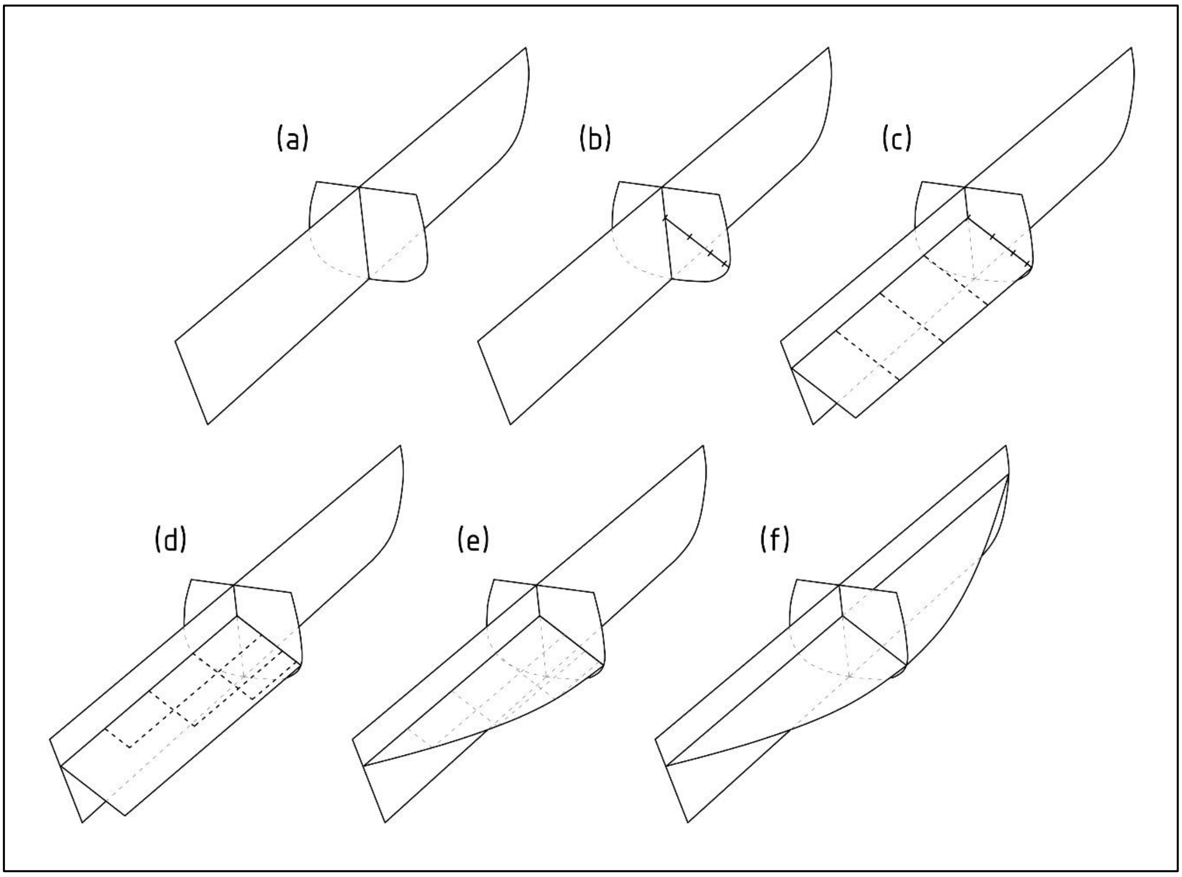


Figure 71 Schematic description of the process of 'reduction' along diagonal planes. The tail frames have not been shown in this illustration for clarity. The designer specifies a curve along a diagonal plane (e) which is obtained by simple geometric constructions (a) to (d). Only one diagonal curve is shown. Figure 72 shows a plan drawn using this technique and 4 diagonals (Drawing JPO).

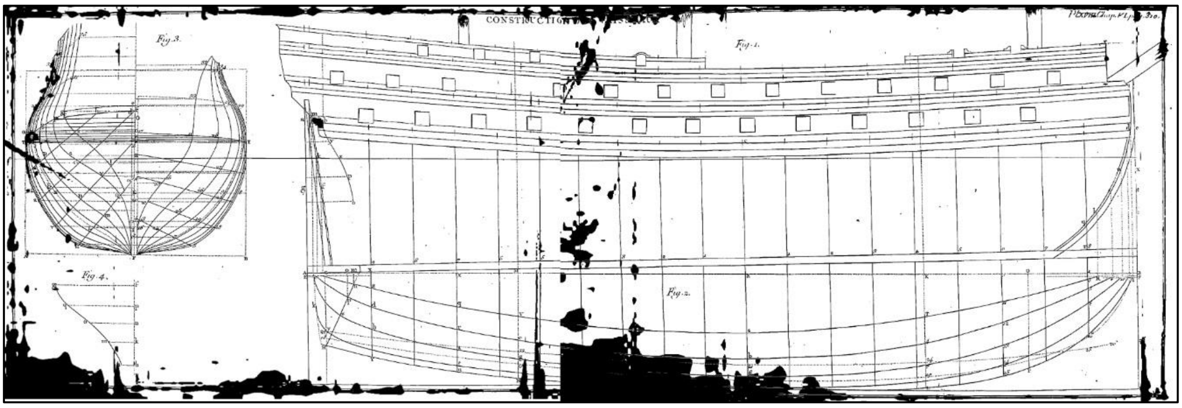


Figure 72 Plate XVIII (Duhamel du Monceau. 1758. *Élémens de l'Architecture Navale*. p.320)

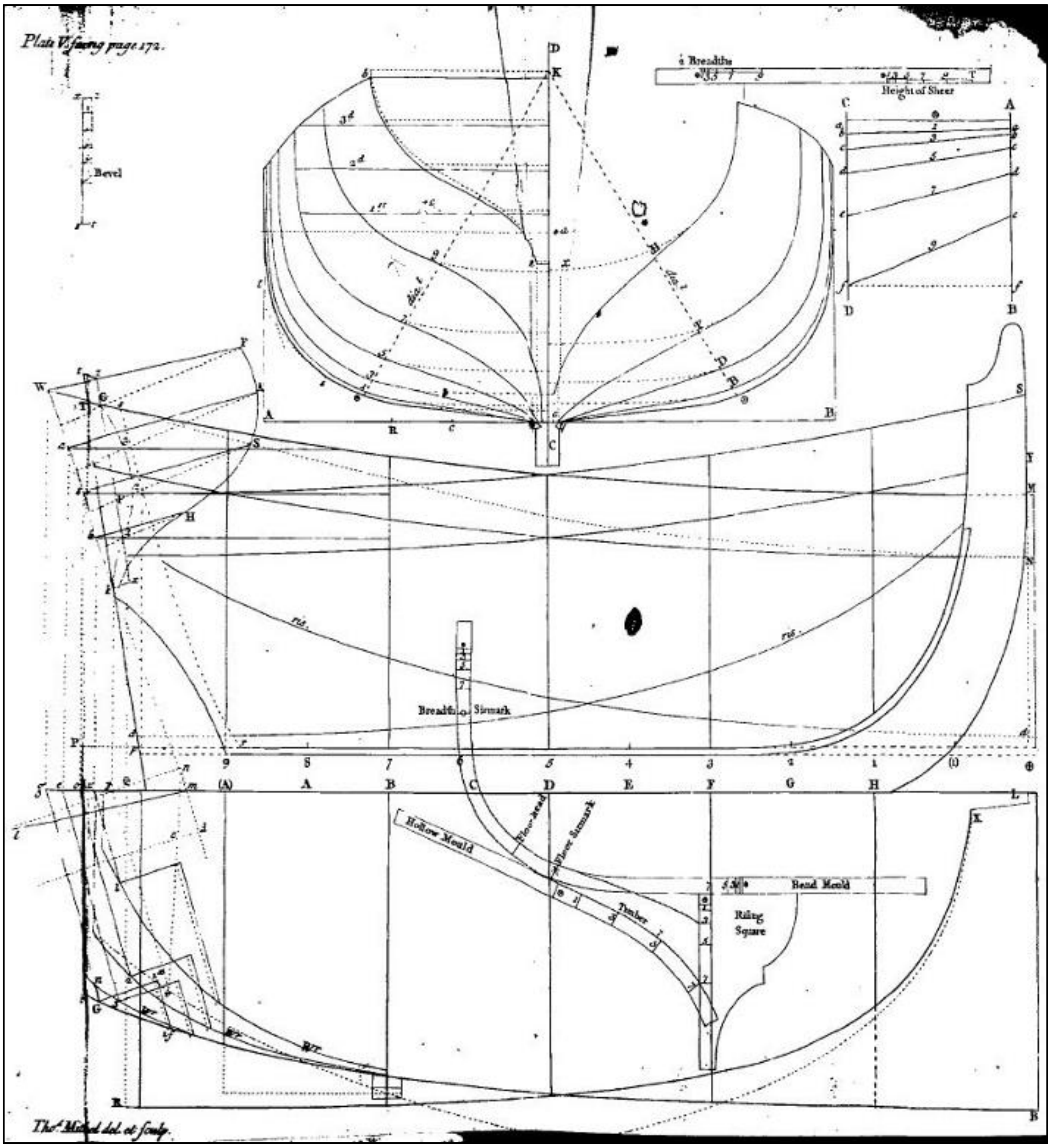


Figure 73 Plate V showing the process of whole moulding. In order to save space, the boat is shown split in half longitudinally. Both ends are shown superimposed. The bow is on the right and the stern on the left of the drawing. (Murray, M. 1764. *A Treatise on Ship-Building and Navigation*. Plate V, p.172)

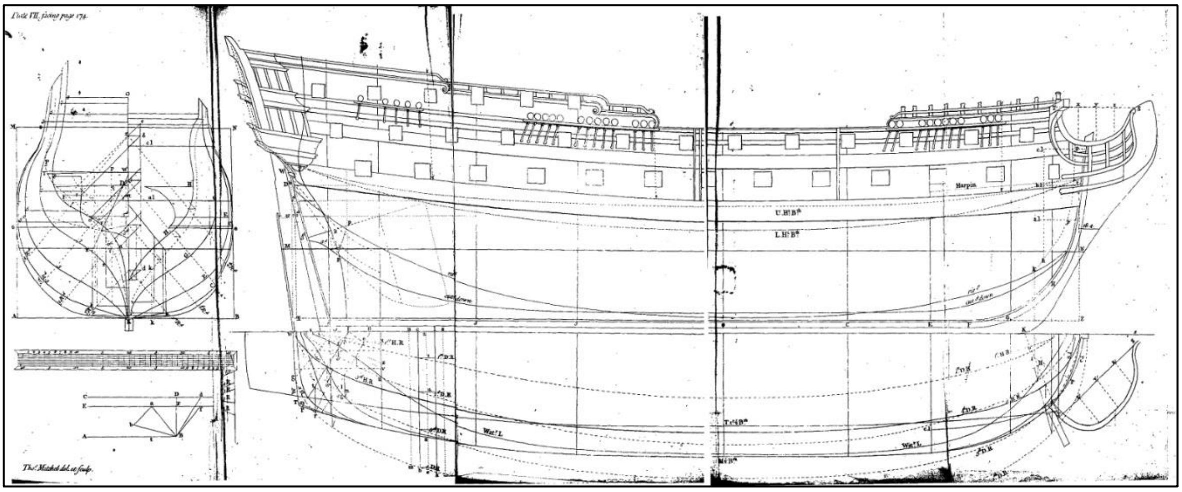


Figure 74 Plate VII. (Murray, M. 1764. *A Treatise on Ship-Building and Navigation*. p.174)

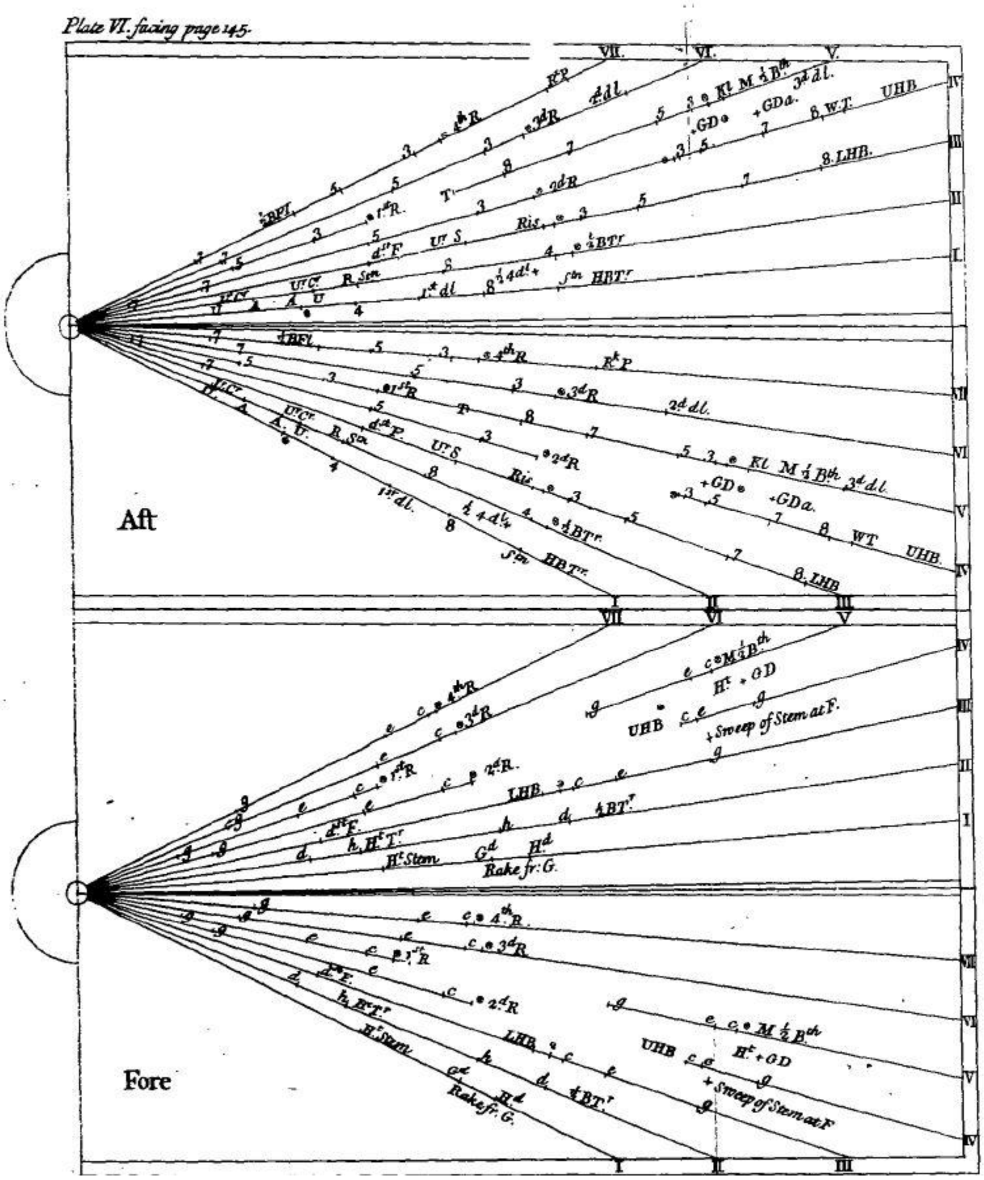


Figure 75 Information required to make a sector which will allow its user to draw ships of the form contained in the sector. (Murray, M. 1764. *A Treatise on Ship-Building and Navigation*. plate VI. p.145)

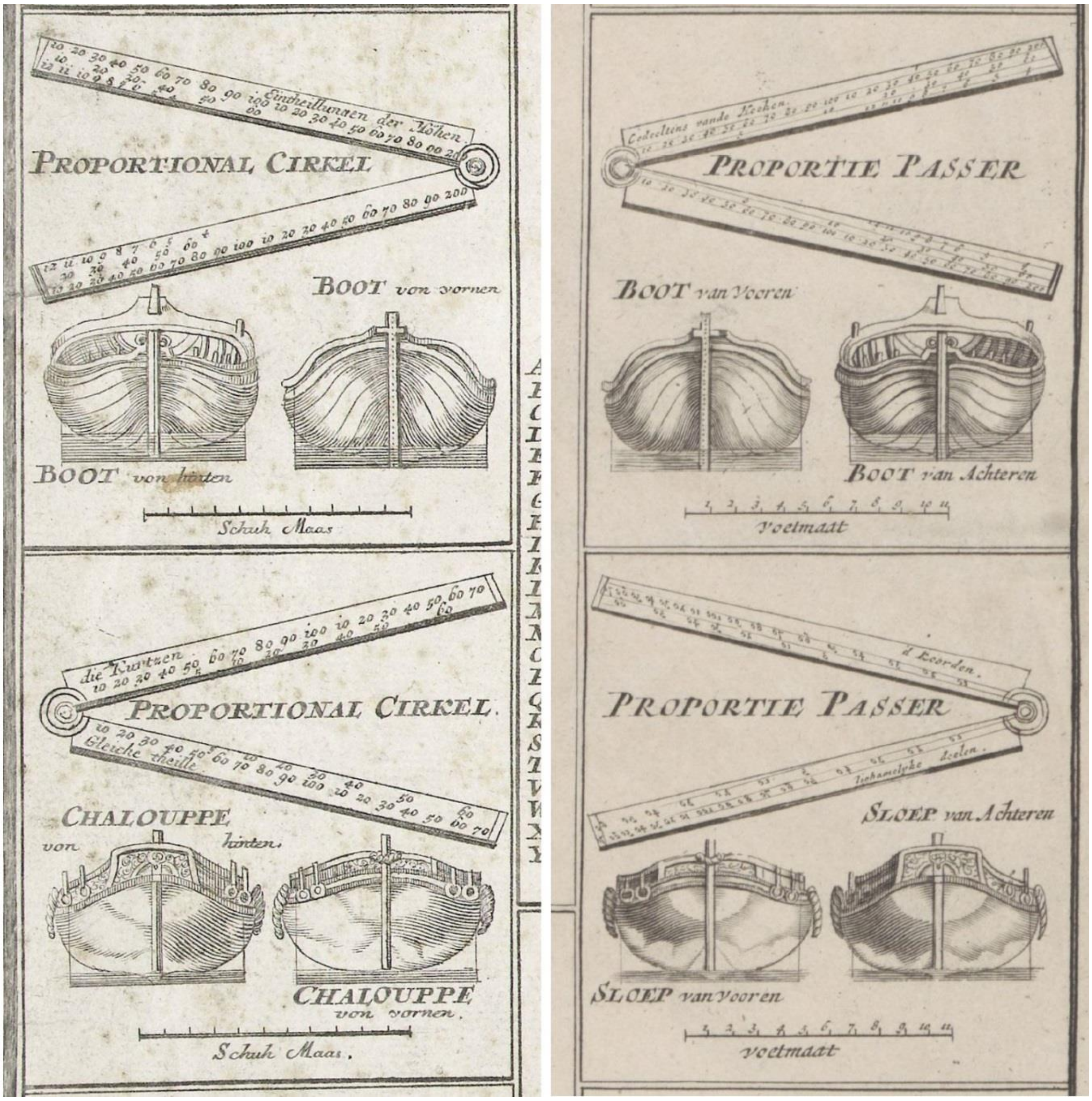


Figure 76 Sectors in the ship-design environment. Details of posters that describe different ship types of the Netherlands. (Left: https://www.rijksmuseum.nl/nl/collectie/RP-P-OB-82.956. Right: https://www.rijksmuseum.nl/nl/collectie/RP-P-1903-A-23539)

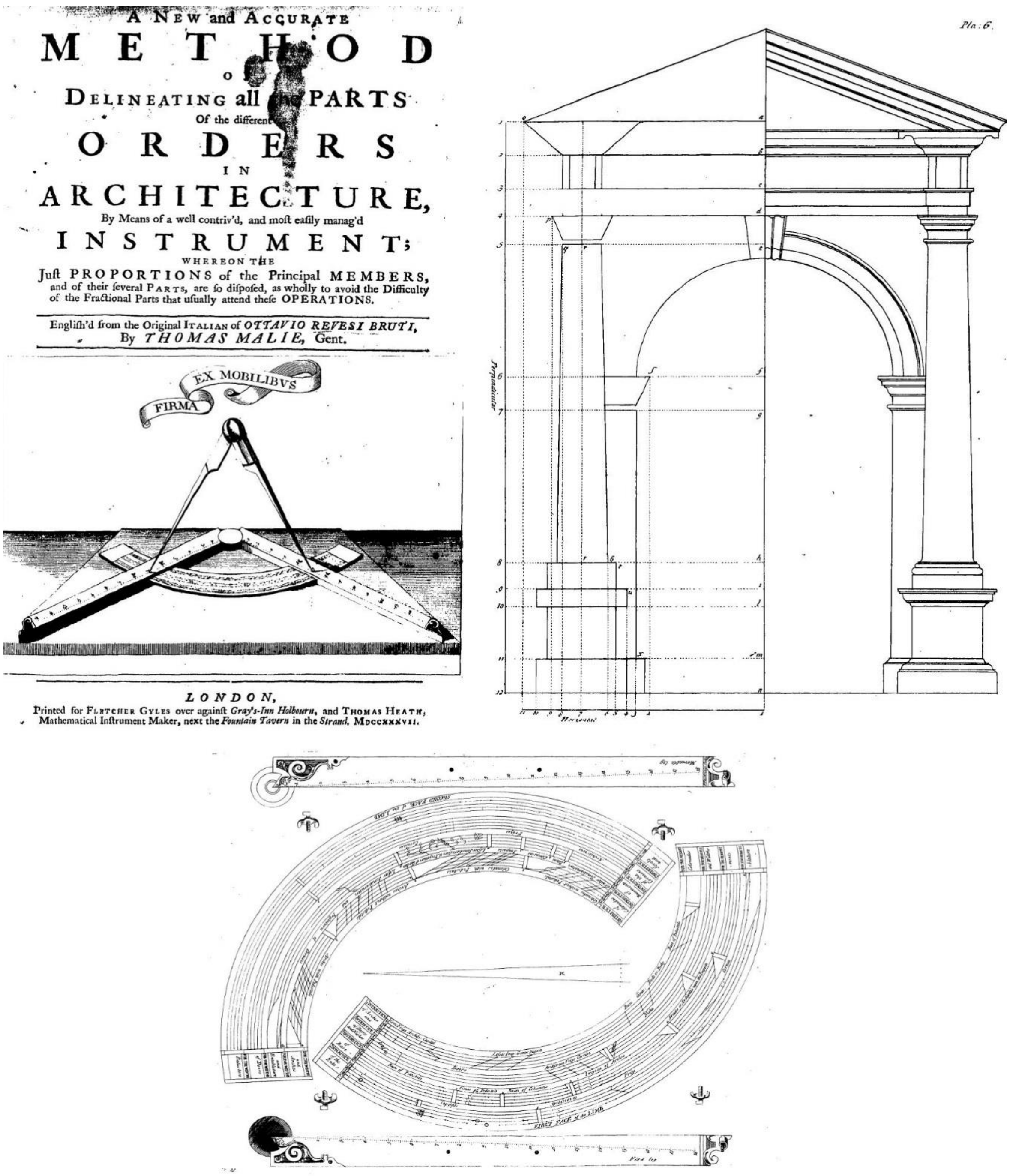


Figure 77 Sectors used in architecture to store the shape of the different orders in classic architecture. The cover of the treatise shows the sector in use (top left). From it, the user can lift proportional relations between the different elements that define the style of a particular architectural order. The top right figure shows the Tuscan order (right) and the information that can be obtained from the sector to set the proportions of the architectonical elements correctly. At the bottom the information contained in the sector is shown. Each part of the sector is shown full size to allow the reader to make a sector for their own use. (Combined image by JPO after Revesi Brutti, O., 1737. *A new and Accurate Method*)

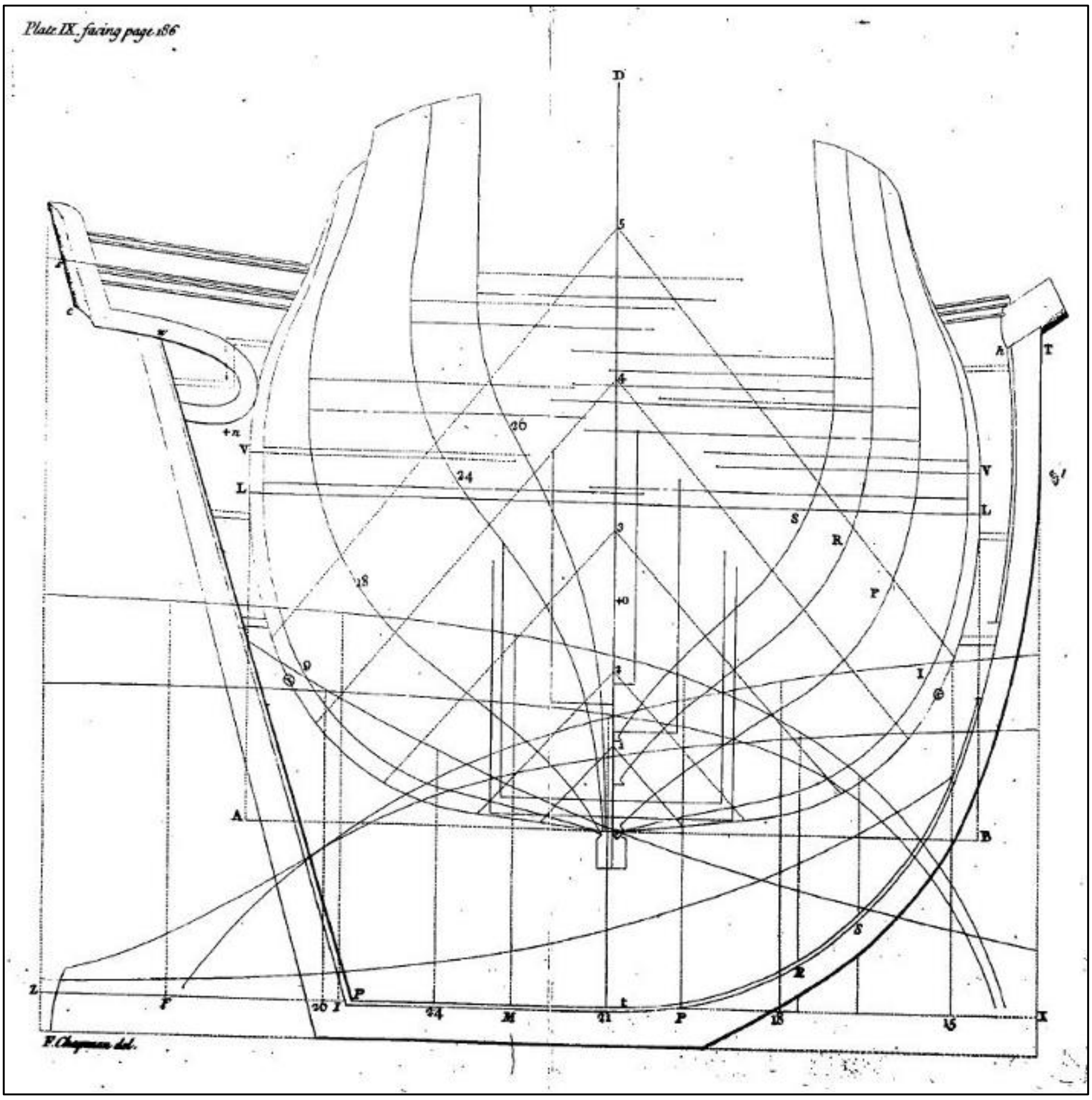


Figure 78 Reduced lines plan of a ship. The figure shows the shape of the hull by overlapping the body plan and the ends of the profile view only. The centre section is missing from the profile view. This shows that the idea of this plan is to convey the information about the lines that shape the hull more than its shape itself. With this plan the shape of the waterlines cannot be judged visually. (Murray, M. 1764. *A Treatise on Ship-Building and Navigation*. Plate IX. p.186)

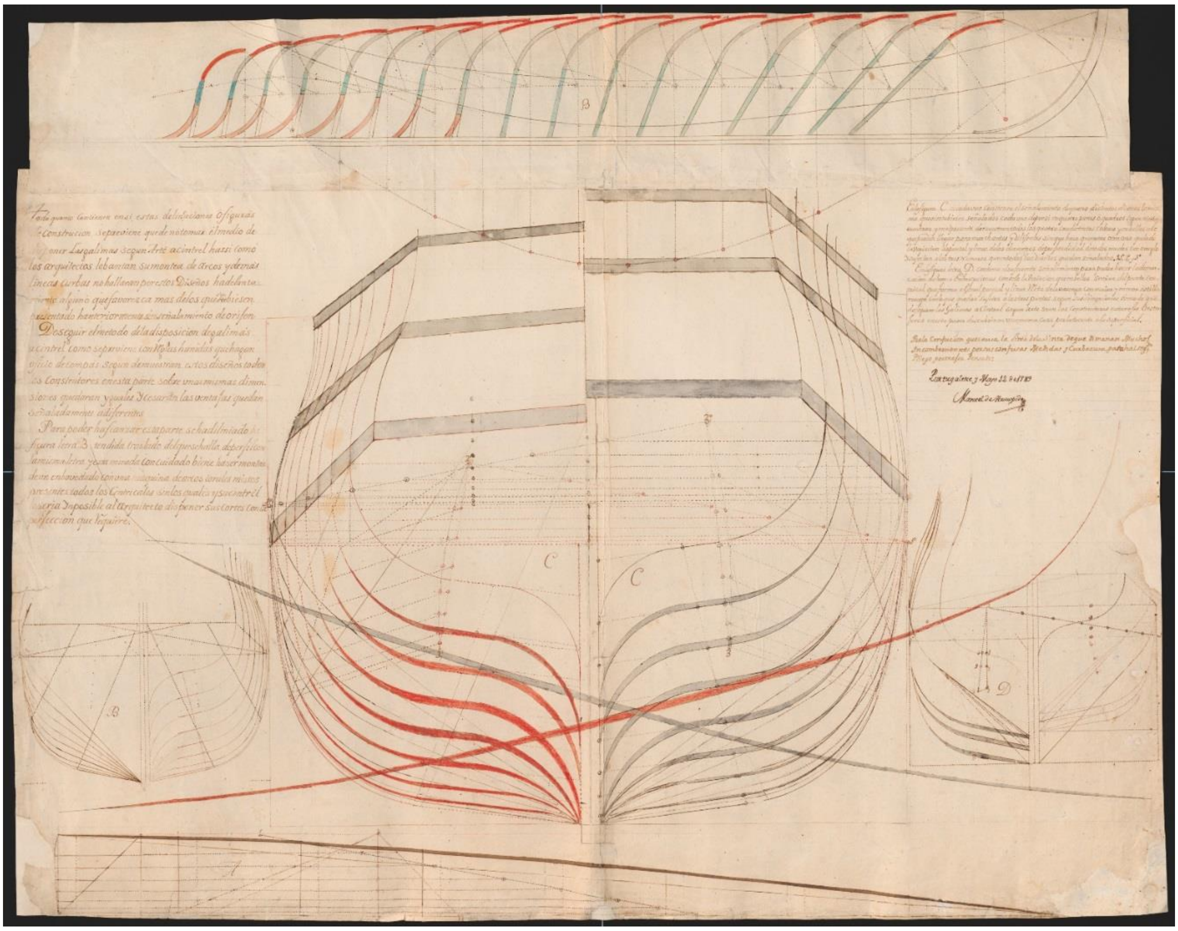


Figure 79 *Delineaciones o figuras de construcción* by Manuel de Arrospide 1789. (Plan mnm_pb_0047 from the Museo Naval of Madrid, Spain)

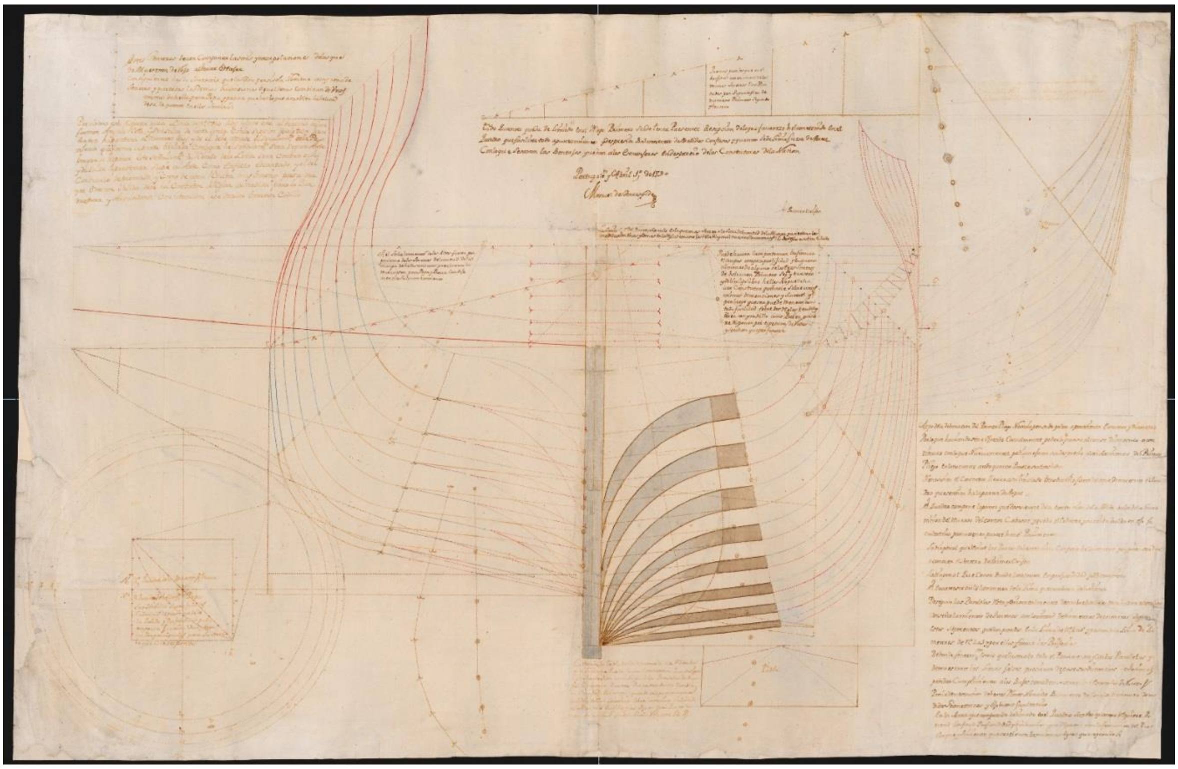


Figure 80 *Delineaciones o figuras de construcción* by Manuel de Arrospide, 1790. (Plan mnm_pb_0048 from the Museo Naval of Madrid, Spain)

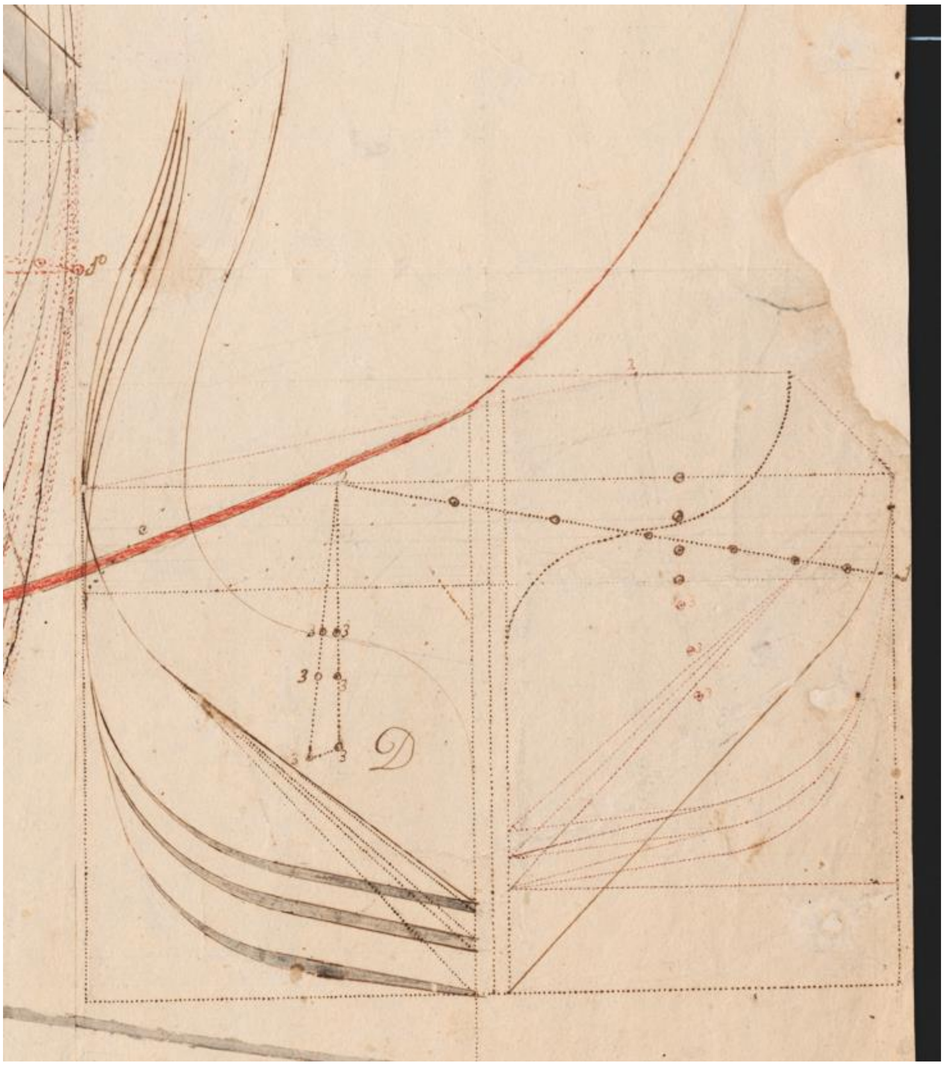


Figure 81 Detail of *Delineaciones o figuras de construcción* by Manuel de Arrospide, 1789. (Plan mnm_pb_0047 from the Museo Naval of Madrid, Spain)

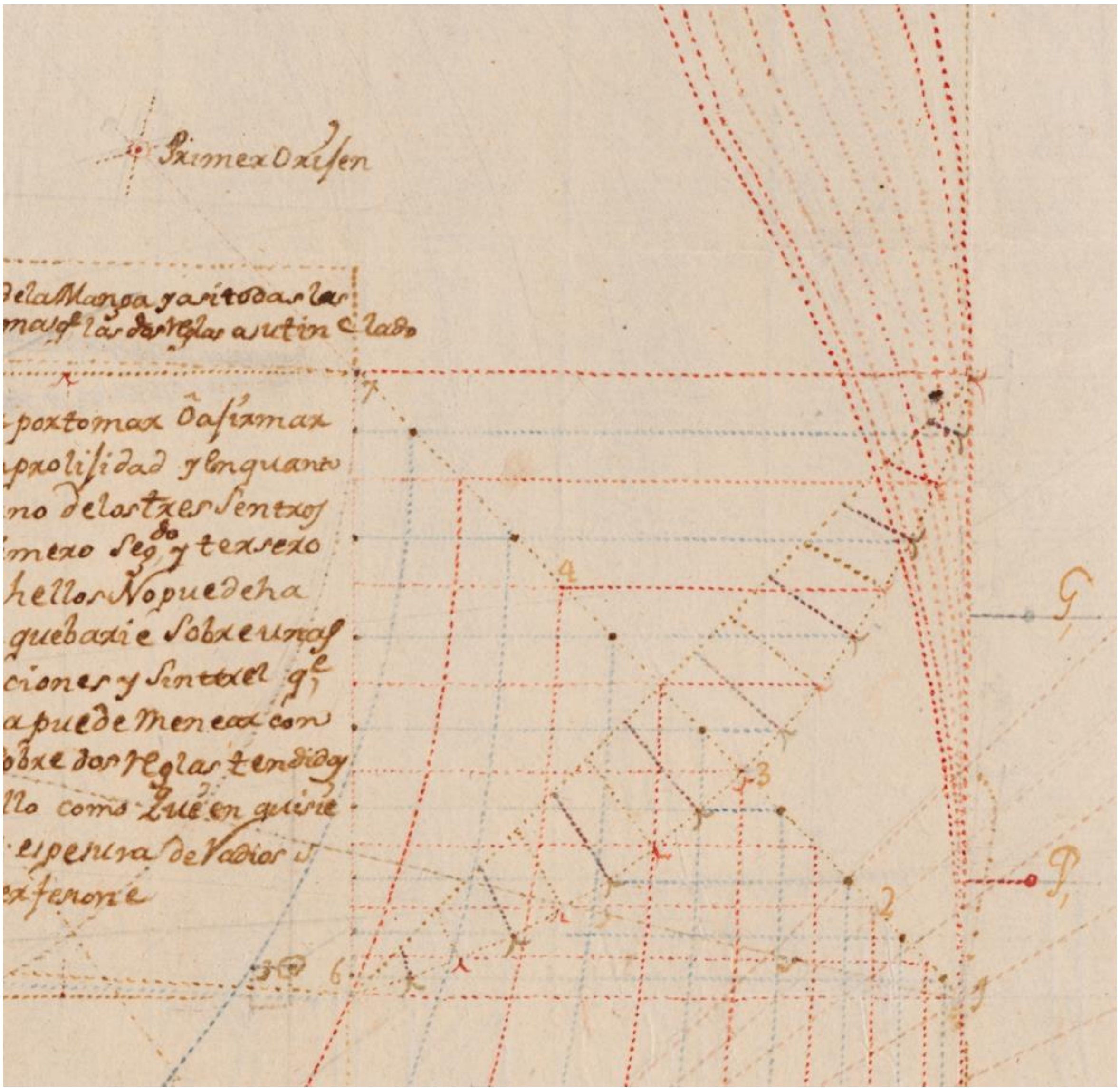


Figure 82 Detail of *Delineaciones o figuras de construcción* by Manuel de Arrospide, 1790. (Plan mnm_pb_0048 from the Museo Naval of Madrid, Spain)

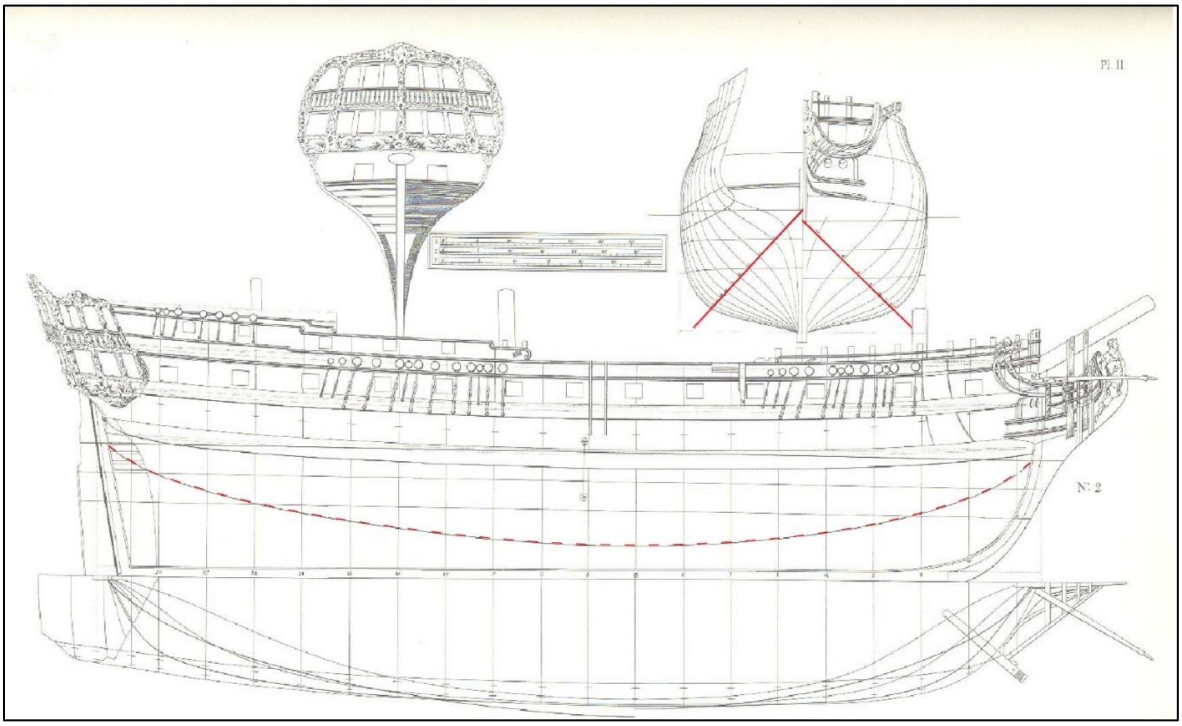


Figure 83 Plate II from Chapman's Architectura navalis Mercatoria. The diagonal has been highlighted in red. This line performs a similar role as the rising and narrowing lines, or the diagonals in Duhamel du Monceau's treatise. (Edited by JPO after Chapman, F.H. 1768. *Architectura Navalis Mercatoria*. 2006 ed. Plate 2)

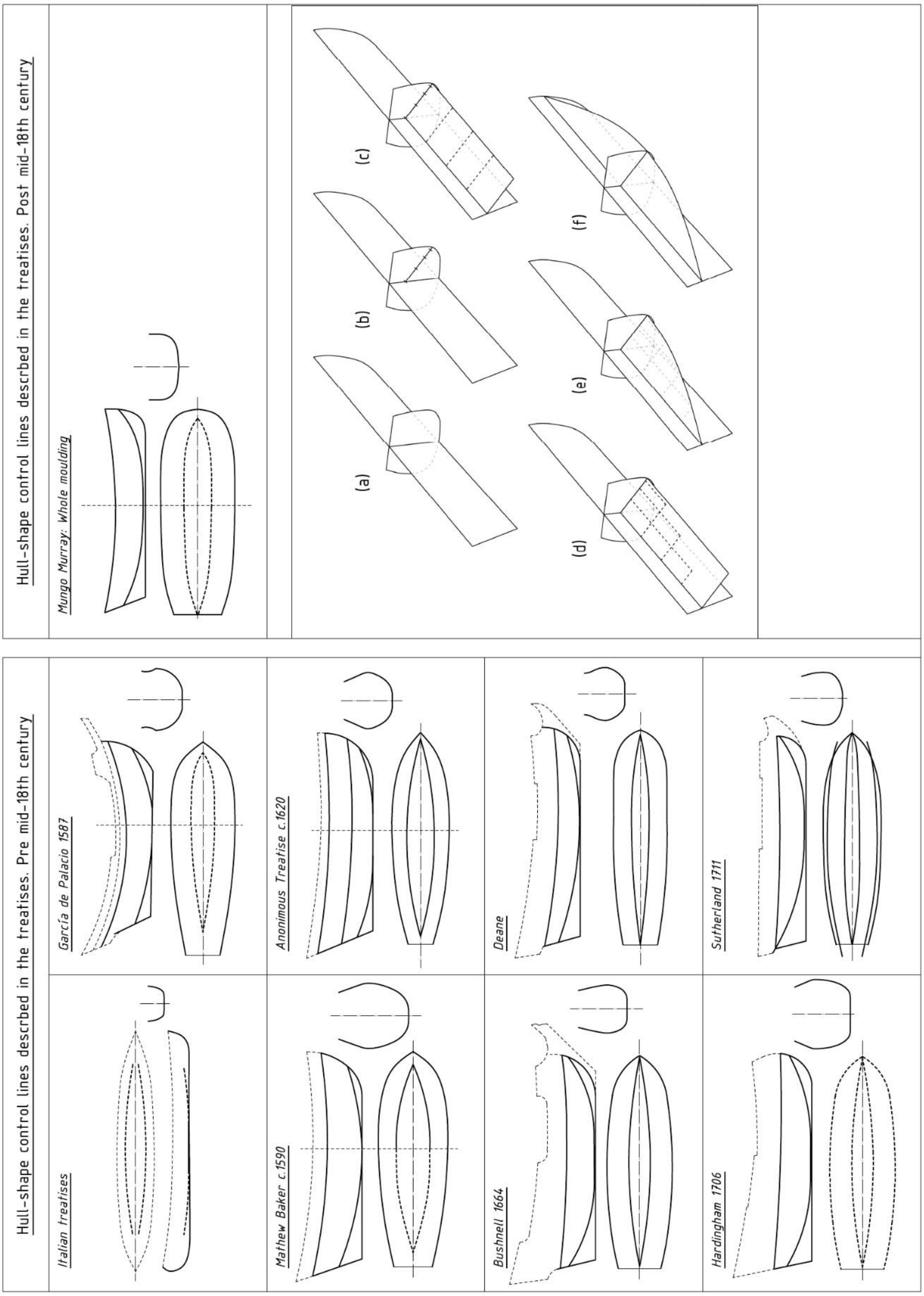
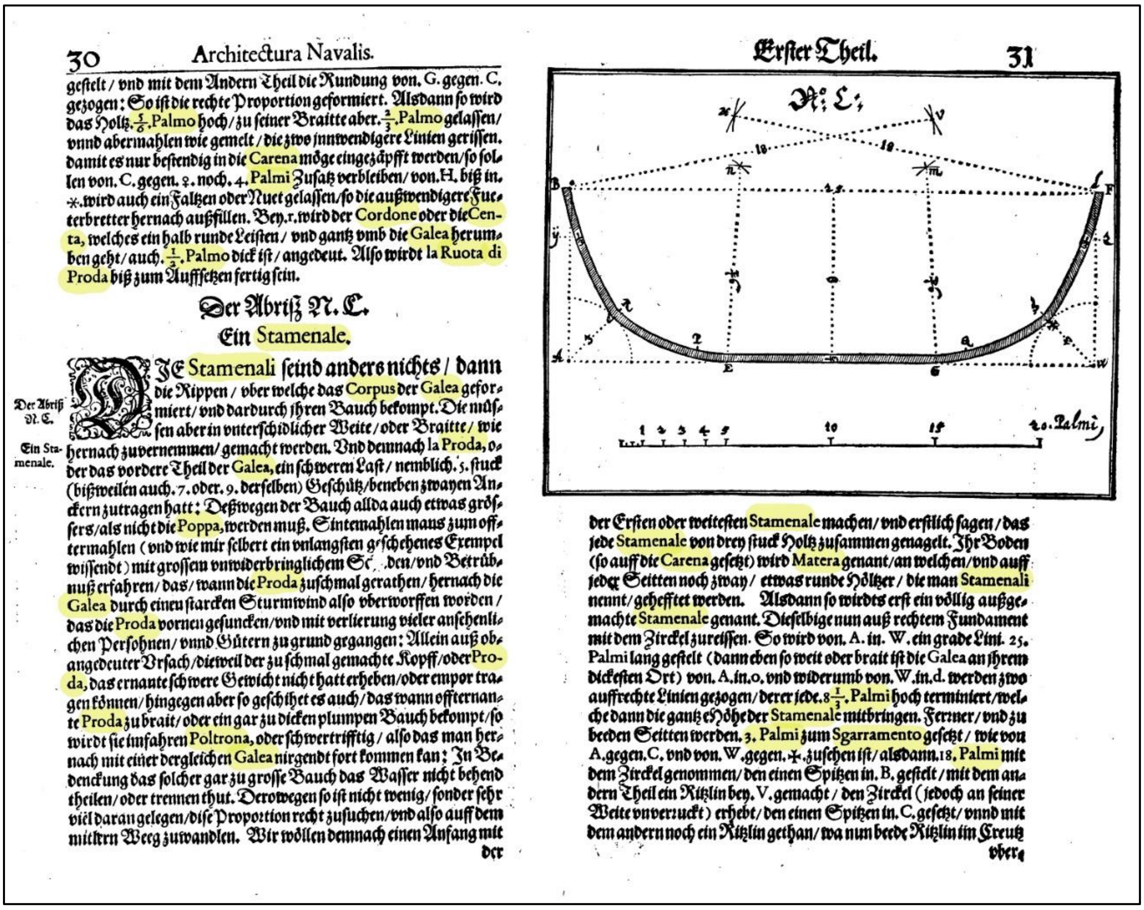


Figure 84 Lines defined by the design-recipe according to each of the treatises. The figure shows that all the treatises use the same conceptual approach to hull-design. The master section and longitudinal rising and narrowing lines define the three-dimensional shape of the hull. (Drawing JPO)



30 Architectura Navalis.

gestelt / vnd mit dem Andern Theil die Rundung von. G. gegen. C. gezogen: So ist die rechte Proportion geformiert. Alsdann so wird das Holtz. $\frac{5}{6}$. Palmo hoch / zu seiner Braitte aber. $\frac{2}{3}$. Palmo gelassen / vnnd abermahlen wie gemelt / die zwo innwendigere Linien gerissen. damit es nur bestendig in die Carena möge eingezäpfft werden / so sollen von. C. gegen. ♀. noch. 4. Palmi Zusatz verbleiben / von. H. biß in. ✱. wird auch ein Faltzen oder Nuet gelassen / so die außwendigere Fuetterbretter hernach außfillen. Bey. r. wird der Cordone oder die Centa, welches ein halb runde Leisten / vnd gantz vmb die Galea herumben geht / auch. $\frac{1}{2}$. Palmo dick ist / angedeut. Also wirdt la Ruota di Proda biß zum Aufffetzen fertig sein.

Der Abriß N. C.

Ein Stamenale.

Der Abriß N. C.

Ein Stamenale.

DIE Stamenali seind anders nichts / dann die Rippen / vber welche das Corpus der Galea geformiert / vnd dardurch jhren Bauch bekompt. Die müssen aber in vnterschidlicher Weite / oder Braitte / wie hernach zuvernemmen / gemacht werden. Vnd demnach la Proda, oder das vordere Theil der Galea, ein schweren Last / nemblich. 5. stuck (bißweilen auch. 7. oder. 9. derselben) Geschütz / beneben zwayen Ancker zutragen hatt: Deßwegen der Bauch allda auch etwas grösser / als nicht die Poppa, werden muß. Sintemahlen maus zum offtermahlen (vnd wie mir selbert ein vnlangsten geschehenes Exempel wissendt) mit grossem vnwiderbringlichem Sc... den / vnd Betrübnuß erfahren / das / wann die Proda zuschmal gerathen / hernach die Galea durch einen starcken Sturmwind also vberworffen worden / das die Proda vornen gesuncken / vnd mit verlierung vieler ansehenlichen Persohnen / vnnd Gütern zu grund gegangen: Allein auß obangedeuter Vrsach / dieweil der zu schmal gemachte Kopff / oder Proda, das ernante schwere Gewicht nicht hatt erheben / oder empor tragen können / hingegen aber so geschihet es auch / das wann offternante Proda zu brait / oder ein gar zu dicken plumpen Bauch bekompt / so wirdt sie im fahren Poltrona, oder schwertrifftig / also das man hernach mit einer dergleichen Galea nirgendt fort kommen kan: In Bedenckung das solcher gar zu grosse Bauch das Wasser nicht behend theilen / oder trennen thut. Derowegen so ist nicht wenig / sonder sehr viel daran gelegen / dise Proportion recht zusuchen / vnd also auff dem mitlern Weeg zuwandlen. Wir wöllen demnach einen Anfang mit

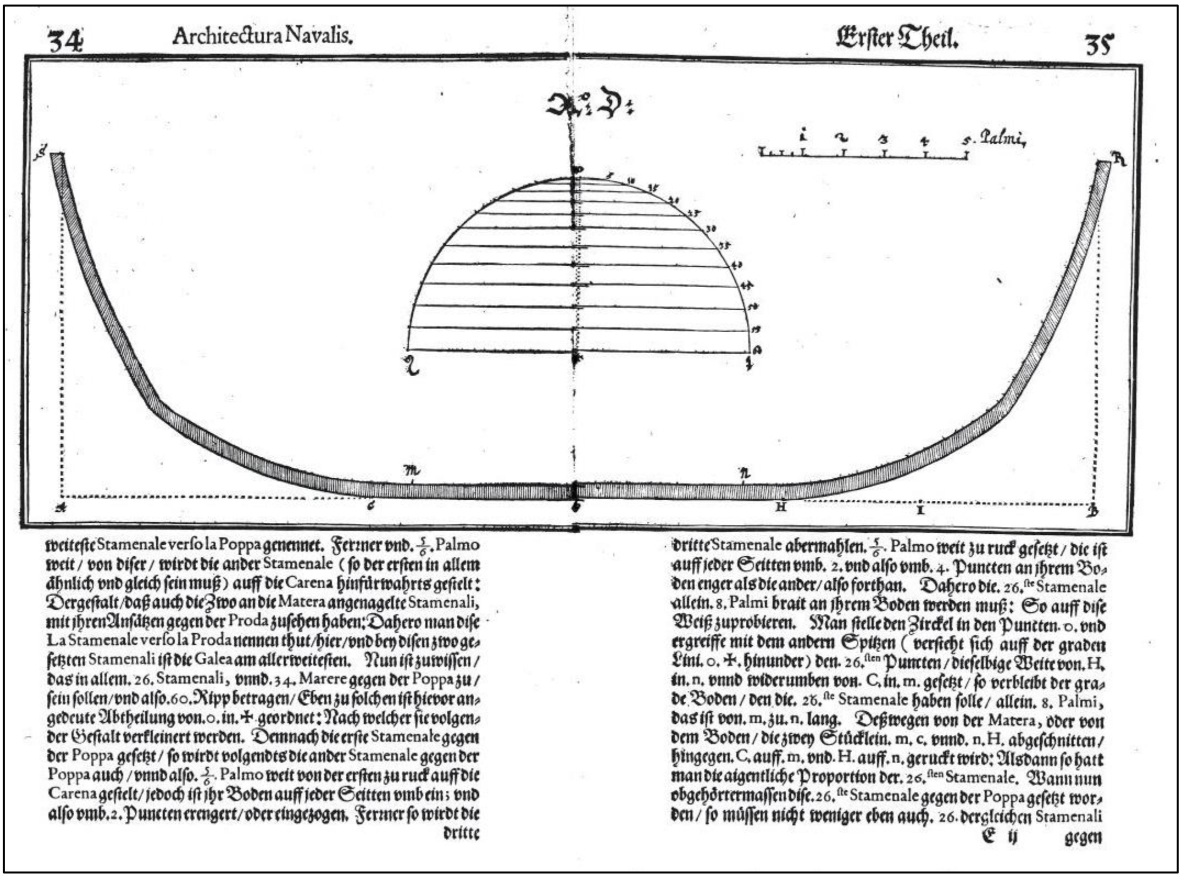
der

Erster Theil. 31

der Ersten oder weitesten Stamenale machen / vnd erstlich sagen / das jede Stamenale von drey stuck Holtz zusammen genagelt. Jhr Boden (so auff die Carena gesetzt) wird Matera genant / an welchen / vnd auff jeder Seitten noch zway / etwas runde Höltzer / die man Stamenali nennt / gehefftet werden. Alsdann so wirdts erst ein völlig außgemachte Stamenale genant. Dieselbige nun auß rechtem Fundament mit dem Zirckel zureissen. So wird von. A. in. W. ein grade Lini. 25. Palmi lang gestelt (dann eben so weit oder brait ist die Galea an jhrem dickesten Ort) von. A. in. o. vnd widerumb von. W. in. d. werden zwo auffrechte Linien gezogen / derer jede. 8$\frac{1}{3}$. Palmi hoch terminiert / welche dann die gantze Höhe der Stamenale mitbringen. Ferner / vnd zu beeden Seitten werden. 3. Palmi zum Sgarramento gesetzt / wie von A. gegen. C. vnd von. W. gegen. ✱. zusehen ist / alsdann. 18. Palmi mit dem Zirckel genommen / den einen Spitzen in. B. gestelt / mit dem andern Theil ein Ritzlin bey. V. gemacht / den Zirckel (jedoch an seiner Weite vnverruckt) erhebt / den einen Spitzen in. C. gesetzt / vnnd mit dem andern noch ein Ritzlin gethan / wa nun beede Ritzlin im Creutz

vber=

Figure 85 Combined image showing pages 30 and 31 of *Architectura Navalis*, written by Joseph Furttenbach in 1629. Despite being written in German, the text describes the design procedures of Mediterranean ships. Interestingly, Italian terms are used throughout the text to refer to technical terminology. Here, the terms in Italian have been highlighted in yellow. This actual page describes the design procedure of the master section of a galley. (Combined image by JPO after Furttenbach, J. 1629. *Architectura Navalis*. p.30-31)



34 Architectura Navalis. Erster Theil. 35

weiteſte Stamenale verſo la Poppa genennet. Ferꝛner vnd. $\frac{5}{6}$. Palmo weit / von diſer / wirdt die ander Stamenale (ſo der erſten in allem ähnlich vnd gleich ſein muß) auff die Carena hinfürwahrts geſtelt: Dergeſtalt / daß auch die Zwo an die Matera angenagelte Stamenali, mit jhren Anſätzen gegen der Proda zuſehen haben; Dahero man diſe La Stamenale verſo la Proda nennen thut / hier / vnd bey diſen zwo geſetzten Stamenali iſt die Galea am allerweiteſten. Nun iſt zuwiſſen / das in allem. 26. Stamenali, vnnd. 34. Marere gegen der Poppa zu / ſein ſollen / vnd alſo. 60. Ripp betragen / Eben zu ſolchen iſt hievor angedeute Abtheilung von. o. in. + geordnet; Nach welcher ſie volgender Geſtalt verkleinert werden. Demnach die erſte Stamenale gegen der Poppa geſetzt / ſo wirdt volgendts die ander Stamenale gegen der Poppa auch / vnnd alſo. $\frac{5}{6}$. Palmo weit von der erſten zu ruck auff die Carena geſtelt / jedoch iſt jhr Boden auff jeder Seitten vmb ein; vnd alſo vmb. 2. Puncten erengert / oder eingezogen. Ferꝛner ſo wirdt die dritte Stamenale abermahlen. $\frac{5}{6}$. Palmo weit zu ruck geſetzt / die iſt auff jeder Seitten vmb. 2. vnd alſo vmb. 4. Puncten an jhrem Boden enger als die ander / alſo forthan. Dahero die. 26.ſte Stamenale allein. 8. Palmi brait an jhrem Boden werden muß: So auff diſe Weiß zuprobieren. Man ſtelle den Zirckel in den Puncten. o. vnd ergreiffe mit dem andern Spitzen (verſteht ſich auff der graden Lini. o. +. hinunder) den. 26.ſten Puncten / dieſelbige Weite von. H. in. n. vnnd widerumben von. C. in. m. geſetzt / ſo verbleibt der grade Boden / den die. 26.ſte Stamenale haben ſolle / allein. 8. Palmi, das iſt von. m. zu. n. lang. Deßwegen von der Matera, oder von dem Boden / die zwey Stücklein. m. c. vnnd. n. H. abgeſchnitten / hingegen. C. auff. m. vnd. H. auff. n. geruckt wird; Alsdann ſo hatt man die aigentliche Proportion der. 26.ſten Stamenale. Wann nun obgehörtermaſſen diſe. 26.ſte Stamenale gegen der Poppa geſetzt worden / ſo müſſen nicht weniger eben auch. 26. dergleichen Stamenali

E ij gegen

Figure 86 Extract of pages 34 and 35 of *Architectura Navalis*. It shows the template of the master section, and the geometric construction which allows the builder to modify the rising and narrowing in incremental steps in order to obtain the shape of the rest of the frames. (Furttenbach, J. 1629. *Architectura Navalis*. p. 34-35)

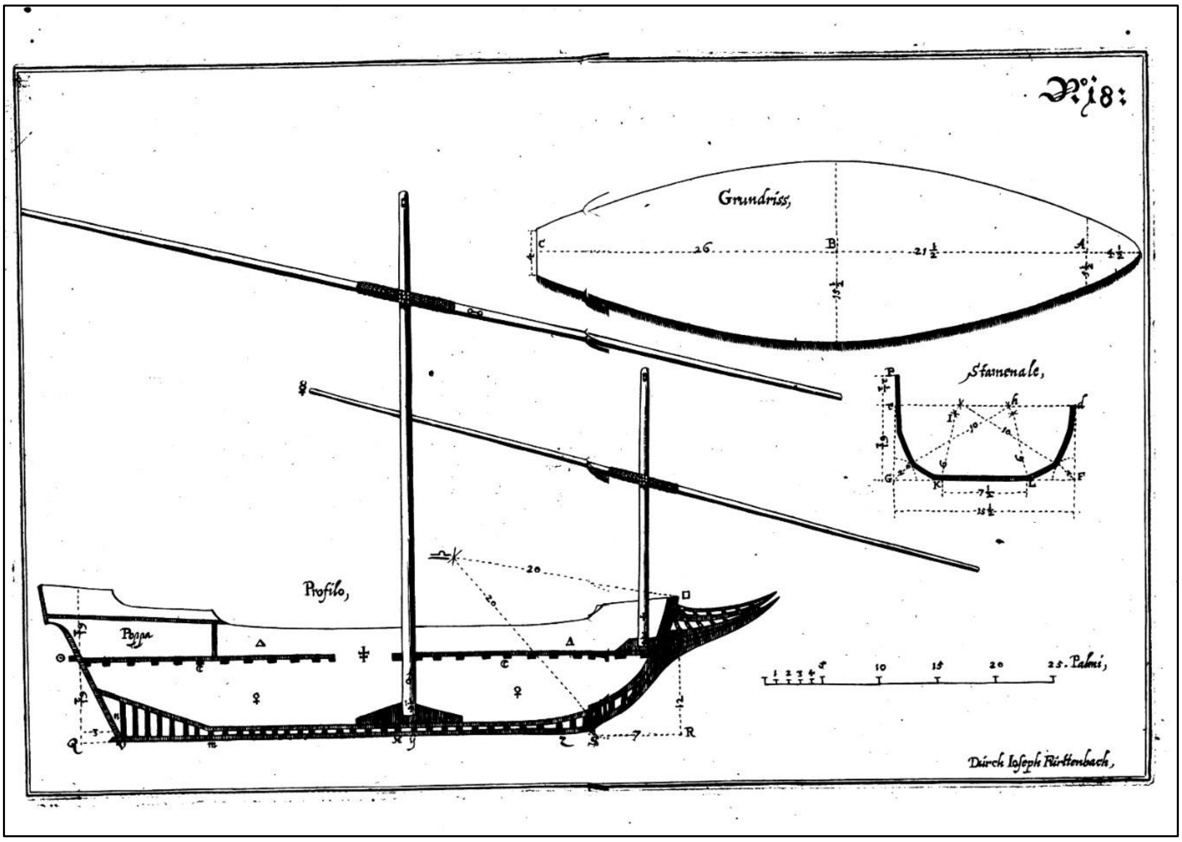


Figure 87 Plate 18 of *Architectura Navalis*. The main parameters of a ship are clearly indicated. The shape and geometric construction of the master section are given. Also, the rake of the sternpost and the curvature of the stem, thus the shape of the backbone. And finally, a series of breadths that define the curvature of the main breadth line are indicated. Interestingly, the geometric construction used to define the shape of the master section does not produce a fair curve. Some of the treatises analysed also show unfair curves, which perhaps indicate that the shipwright could easily fair the curves during construction. (Furttenbach, J. 1629. *Architectura Navalis*. Plate 18)

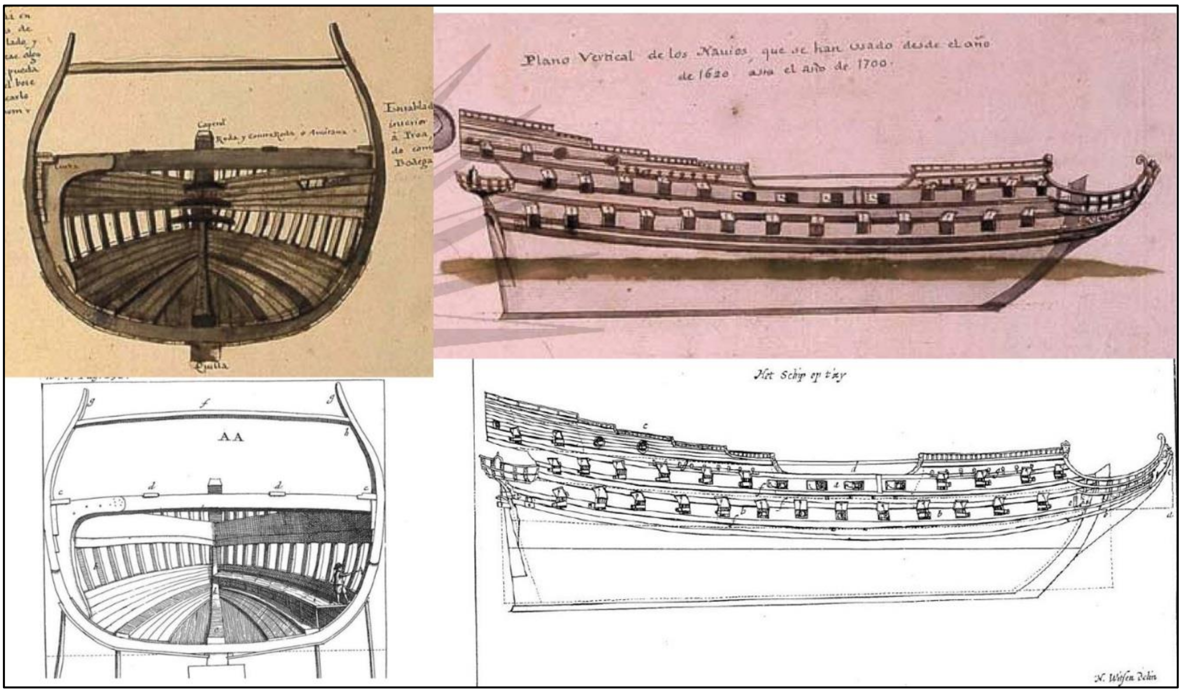


Figure 88 Comparison between Witsen's original figures (below) and Marqués de la Victoria's copies. It is obvious that these figures shown in the *Album del Marqués de la Victoria* are copies of the originals in Witsen.

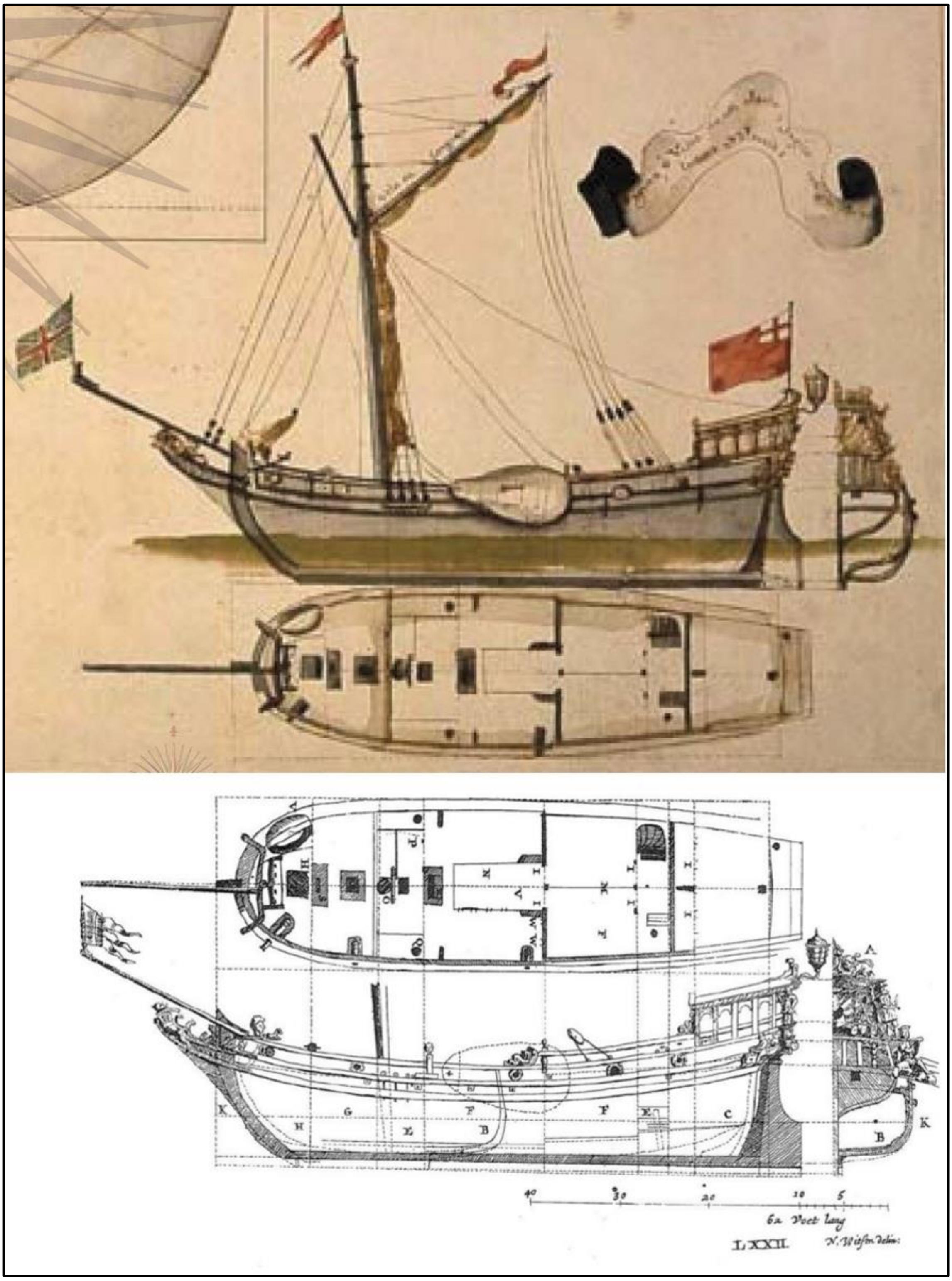


Figure 89 Comparison of two yachts shown in the *Album del Marqués de la Victoria* (above) and Witsen's treatise (below). Clearly the yacht drawn by the Marqués de la Victoria is a copy of Witsen's.

It is interesting to note that in the illustration by the Marqués de la Victoria, two flags are shown that would seem to suggest that the figure corresponds to an English or British yacht. However, in the original by Witsen, the illustration refers to a Dutch yacht.

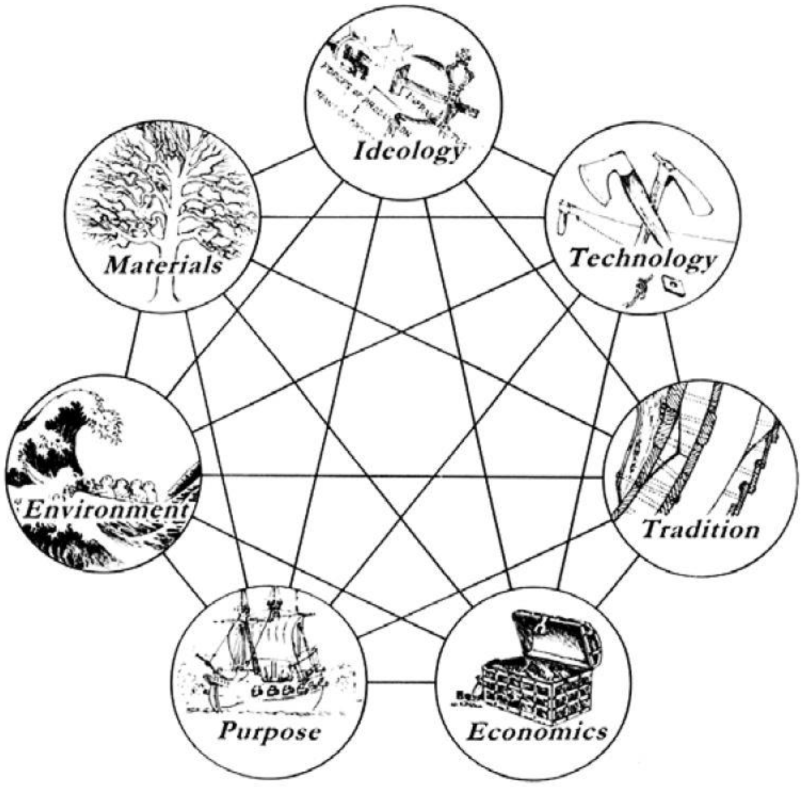


Figure 90 This figure could be used to represents the multiple stakeholders and factors that help, in this particular case, shape the shipbuilding/design industry. (Adams, J. 2013. *A Maritime Archaeology of Ships.* Figure 2.1 p.23)

Figure 91 A satisfactory design: The figure illustrates to perfection that there are as many ideas about what constitutes a valid ship as there are users. Probably most mariners would consider this an overloaded ship. However, it can be seen motoring along in the waters of Ha Long Bay, Vietnam. (Photograph downloaded from: http://matesich.blogspot.co.uk/2011_04_01_archive.html . Last Accessed 10-Sept-2017)

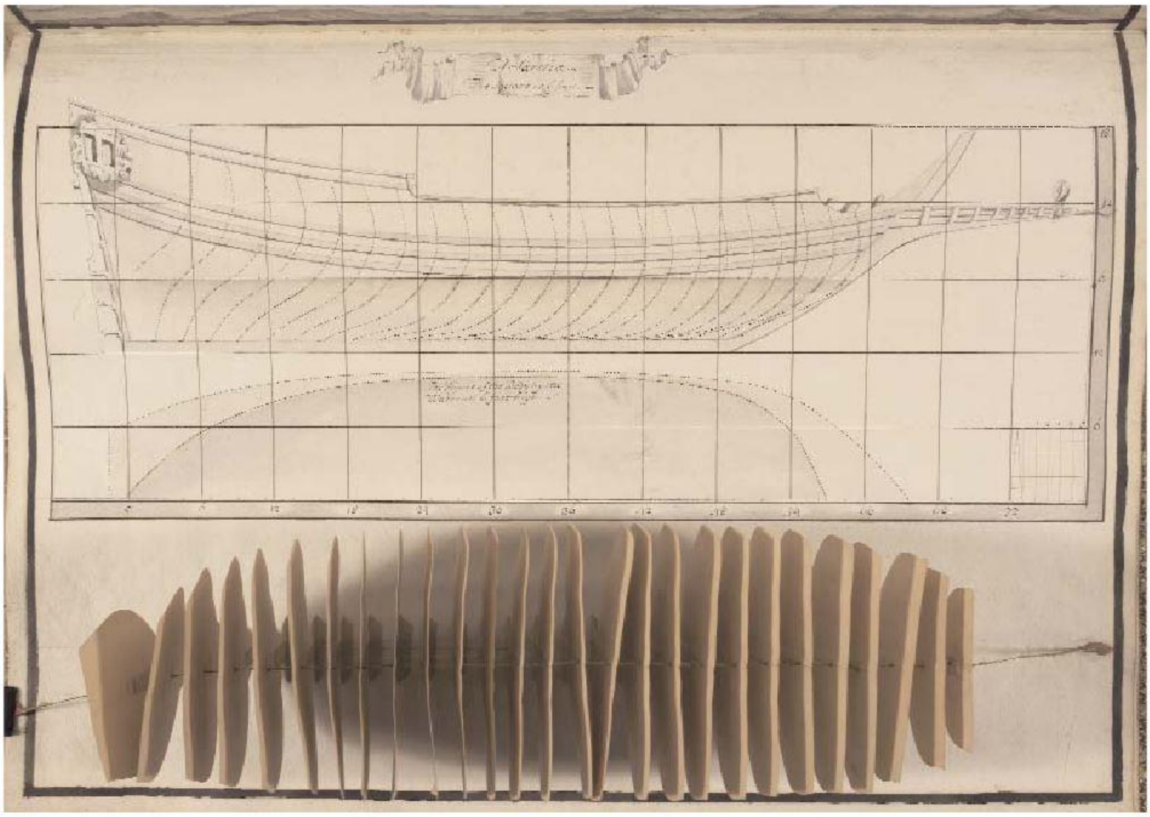


Fig. 10b. A Saettia. King's MS. 40, f. 82

Figure 92 Two alternative methods to convey three-dimensional shape. Above, a drafted plan showing a profile view of the ship with a series of transversal sections at the top. Below a plan view of the ship where the line of maximum breadth and the waterline are shown. Underneath the drafted plan, a model made up of 28 cardboard sections hinged at the surface of the page are shown. A thread joins them, so that when the thread is pulled, all sections pop up and show the three-dimensional shape of a hull. (Fox, C., 2008. The Ingenious Mr Dummer: Rationalizing the Royal Navy in Late Seventeenth Century England. p.21)

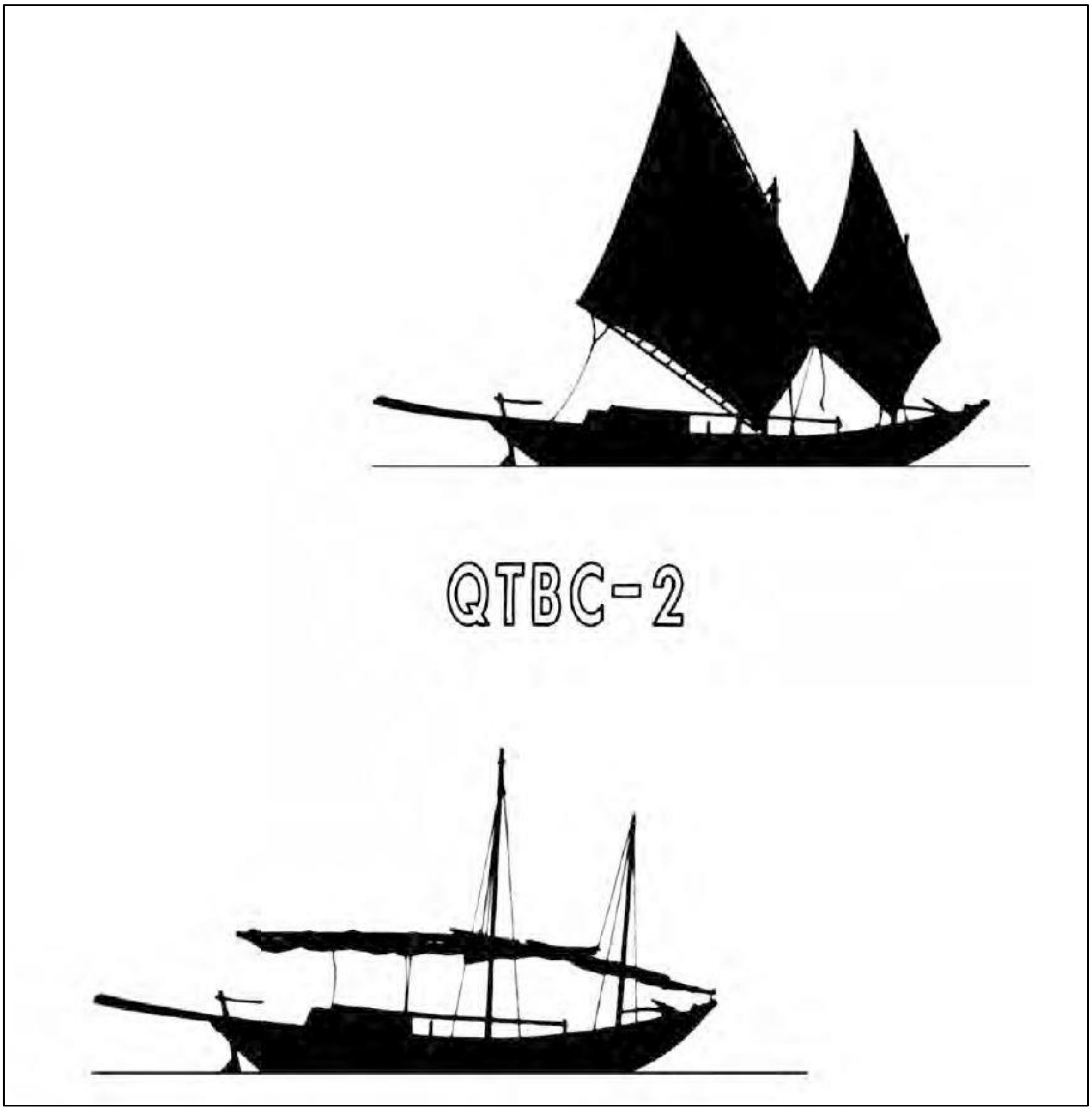


Figure 93 Extract from *The Junk Blue Book*, published by the US army during the Vietnam War to aid in the identification of local craft. Each boat type is described quite extensively in photographs and text. However, the basic tool for recognition are silhouettes for each of the boat types. In this case a QTBC-2 type. (*The Junk Blue Book*. US Government. 1962)

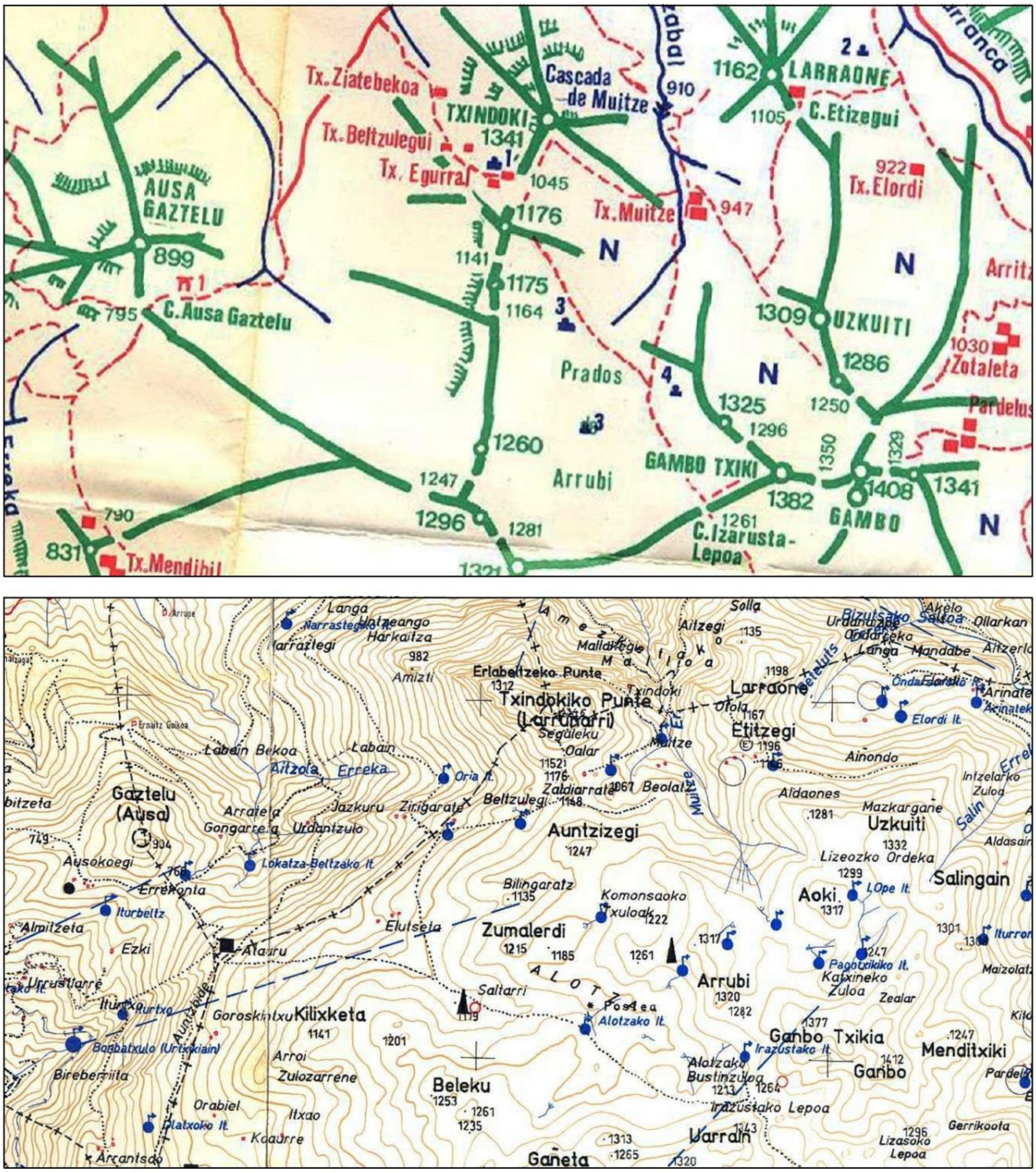


Figure 94 Two forms of showing three-dimensional shape in a map. Both cover the same area of the mountains in the Basque region.
Below, is the common method of showing relief by 'slicing' the terrain by horizontal planes which are spaced equidistantly. The projection of those slices gives an accurate, if not immediately obvious, representation of relief.

The figure above, shows a totally different approach to showing relief. It is based on the ability of humans to recognise the contours of an object. Therefore, the mapmaker has indicated the ridges and mountain tops only (represented by green lines). It does not give as much information as the map below. But, for this author in his youth, who used to walk in these mountains and required information to get general directions, without specific details of slope, it provided sufficient information without the information overload of the map below. It is a type of information that identifies the features which the human brain will identify in the mountains: their contours as marked by the ridges and mountain tops. (JPO after Malo Iciar, J. 1975. *Aralar* and Goikoetxea, I. 1990. Aralar)

Figure 95 End view of a fishing boat at the beach in Deal, UK. (Photograph JPO)

Figure 96 Side view of a fishing boat at the beach in Deal, UK. (Photograph JPO)

Figure 97 *The Shipwright and his Wife* (Rembrandt 1633). This painting shows Jan Rijcksen and his wife Griet Jans. Rijcksen was a master shipbuilder for the Dutch East India Company. In the painting, he is shown working at his desk, holding a document which shows clearly the information required to convey three-dimensional shape. This is shown in detail in figure 98. ("The Shipbuilder and his Wife": Jan Rijcksen (1560/2-1637) and his Wife, Griet Jans 1633. *RCIN 405533*. Picture Gallery, Buckingham Palace. https://www.royalcollection.org.uk)

Figure 98 Detail from *The Shipwright and his Wife* (Rembrandt 1633). It shows the manner in which the contours of the ship are used to convey three-dimensional shape in Dutch shipbuilding. The shape of the backbone is clearly recognisable, showing the stem, keel, and sternpost. Similarly, the shape of the master section is shown. Also, the shape of the transom. Finally, a larger detail drawing could represent the shape of the stem shown upside down. The information contained in this drawing is notably similar to that shown in figure 18 and to some extent in figure 78. ("The Shipbuilder and his Wife": Jan Rijcksen (1560/2-1637) and his Wife, Griet Jans 1633. *RCIN 405533*. Picture Gallery, Buckingham Palace. https://www.royalcollection.org.uk)

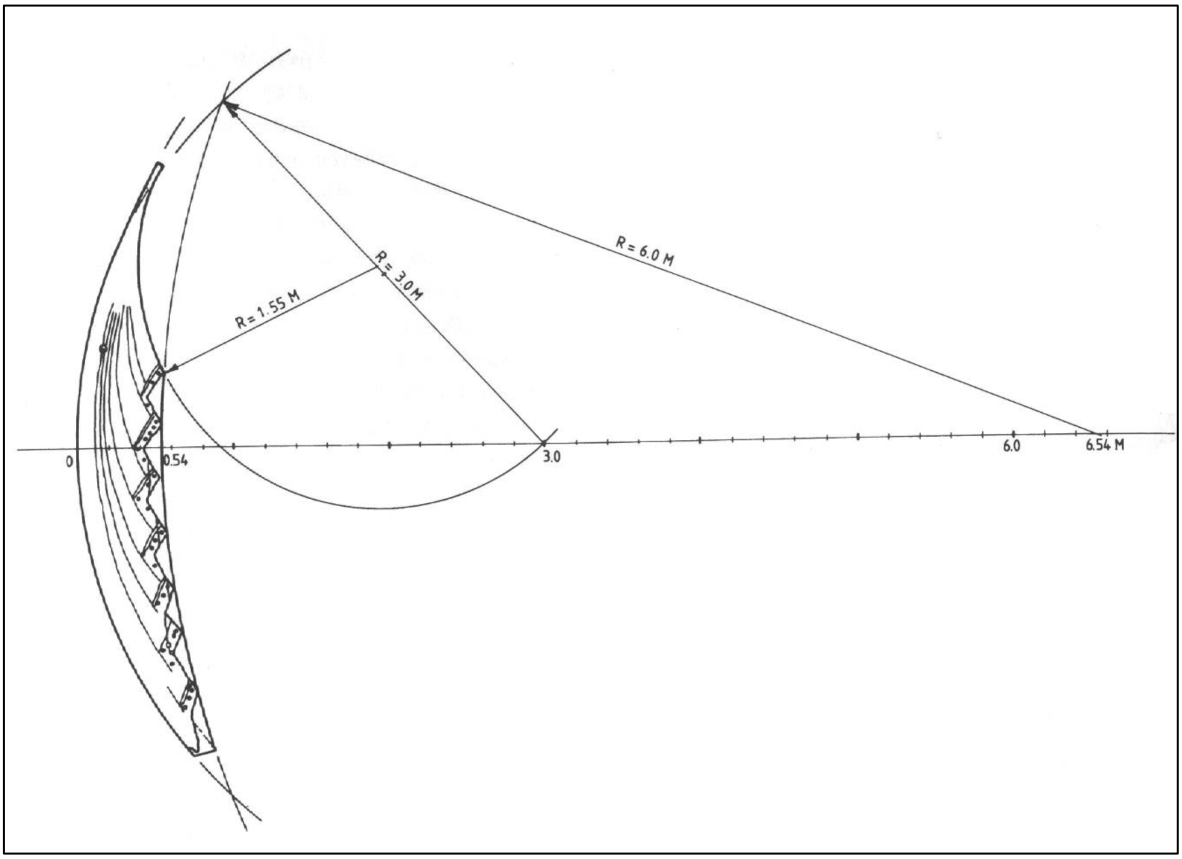


Figure 99 Design of the stem of the Skuldelev 3 ship. (Crumlin-Pedersen, O. & Olsen, O. 2002, *The Skuldelev Ships I.* p.235–8)

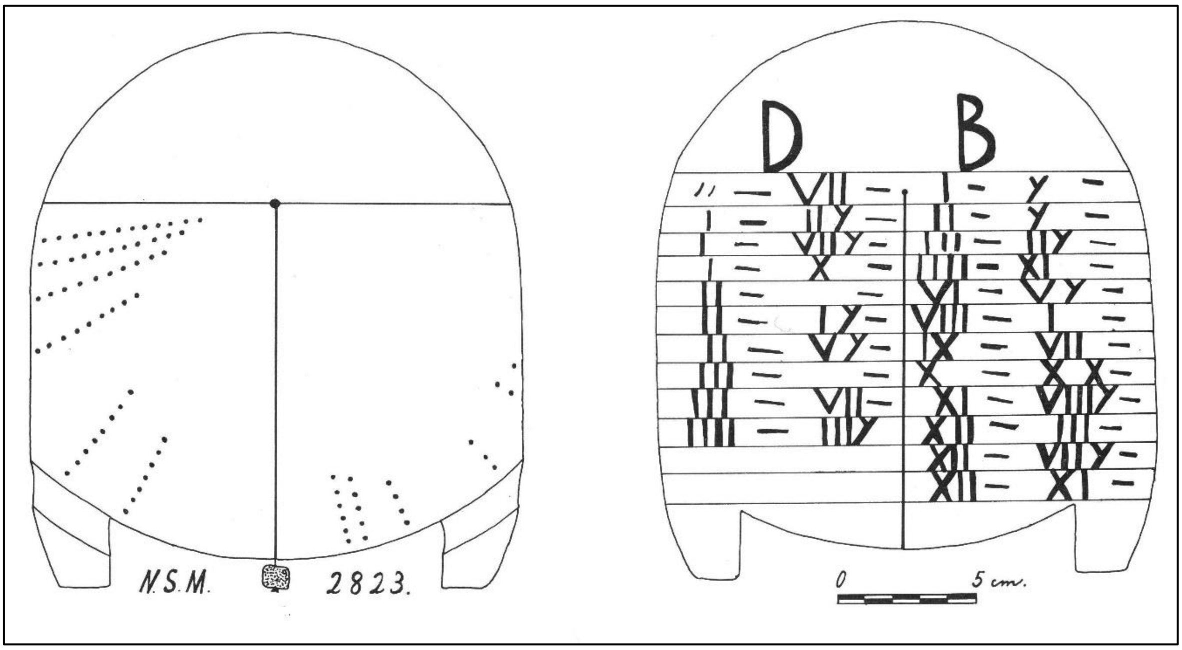


Figure 100 Bevel-board from Hvaler, Østfold in the Norwegian Maritime Museum (N.S.M. 2823). Left: It is a record of the shape of the midship section of a boat made up of 12 planks. The bevel angles of each of the planks is marked with respect to the vertical plane (see figure 101). Right: the other side gives additional information about the 12 planks forward and aft. However,

the original reference does not elaborate on that information. (Christensen, A.E., 19782. Boatbuilding Tools and the Process of Learning. p.240–1)

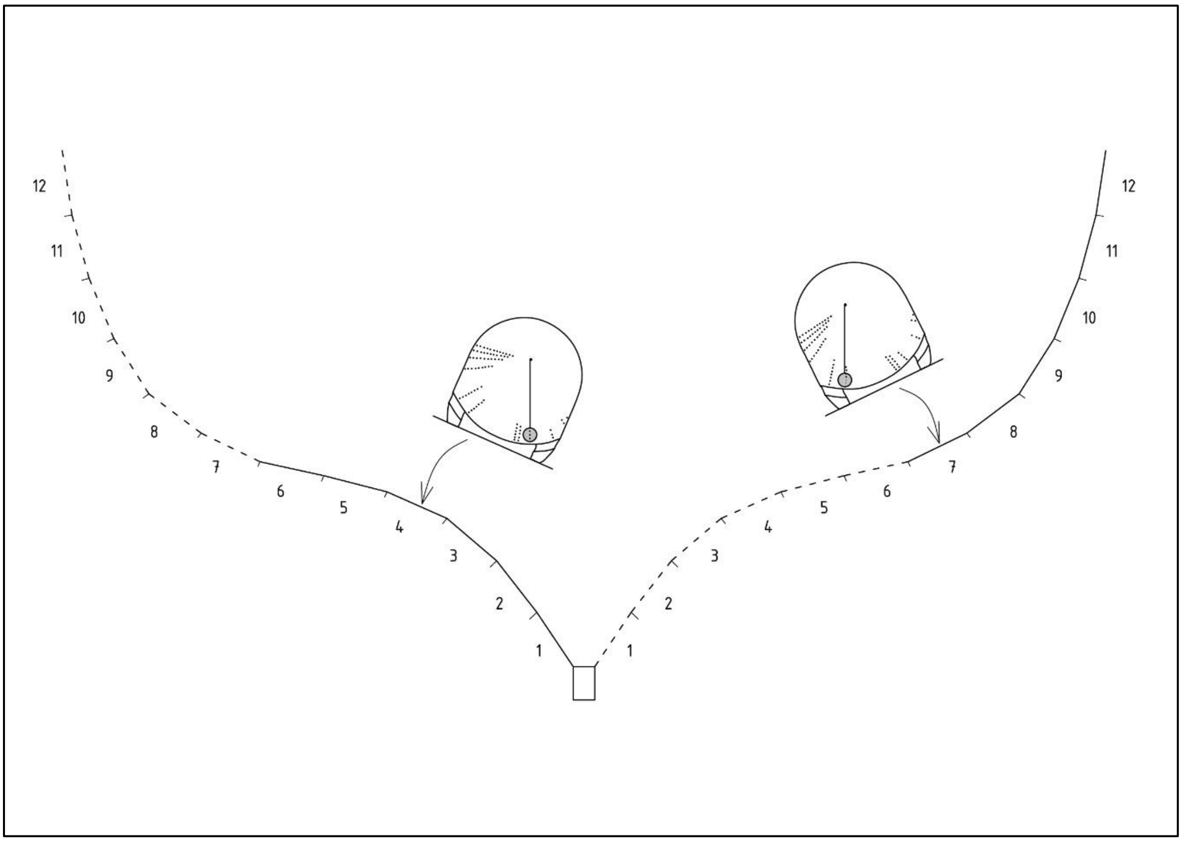


Figure 101 Shape of the midship section contained in the boat bevel-board shown in figure 100. In order to draw the shape it has been assumed that all 12 planks had the same breadth. It is probable that the shipwright would have varied the widths of the planks. These widths would have been recorded or committed to memory, or even a rule of thumb. However, assuming constant breadths as in this example does not invalidate the argument. The tool is a record of a transversal section through the main section. (Drawing JPO).

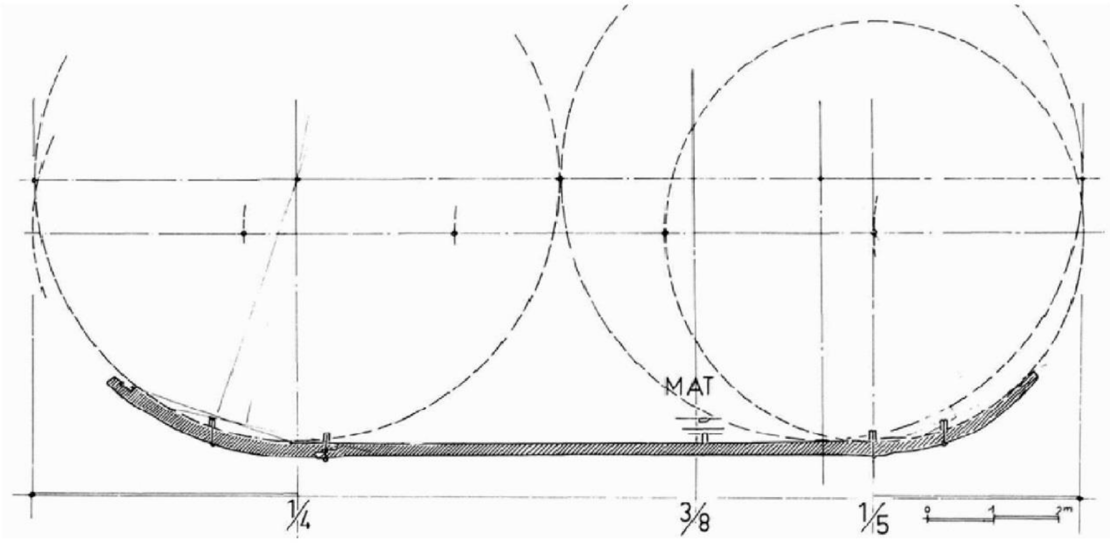


Figure 102 Geometric construction identified in the backbone structure of the 2 AD Roman ship found in Laurons, France. (Gassend *et al*., 1984. L'épave 2 de l'anse des Laurons. p.104)

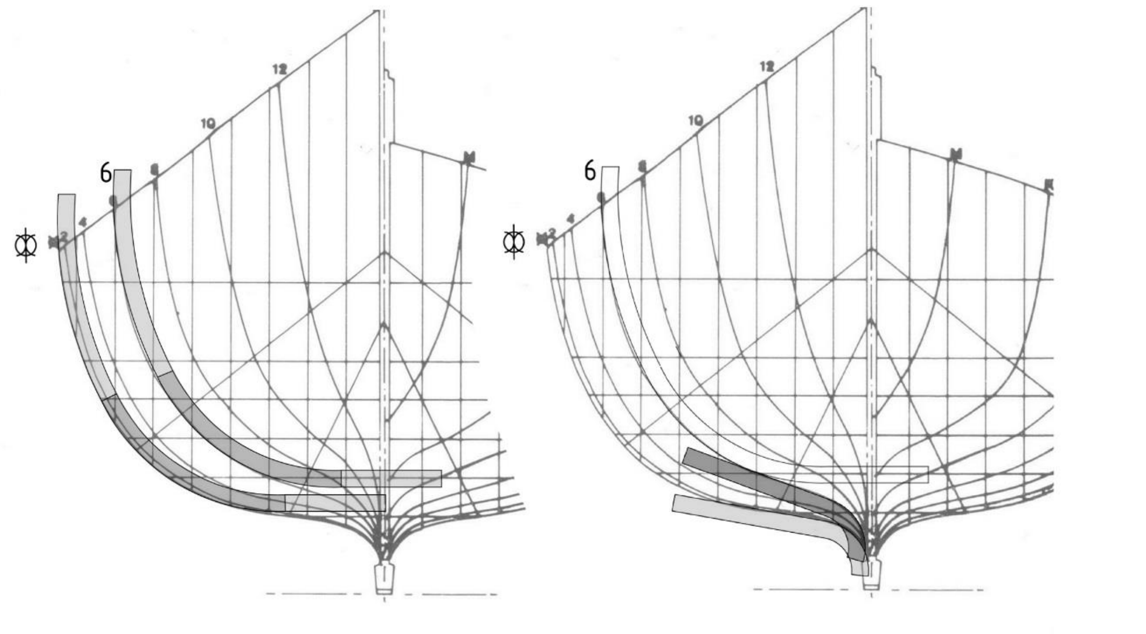


Figure 103 Moulding process as identified in the Kyrenia ship of Hellenistic origin (4BC). A single mould can be used to define the shape of the hull by a process of rising and narrowing of a simple template. (Drawn by author over plan from Steffy, R., 1994. *Wooden Ship Building and the Interpretation of Shipwrecks*. p. 55)

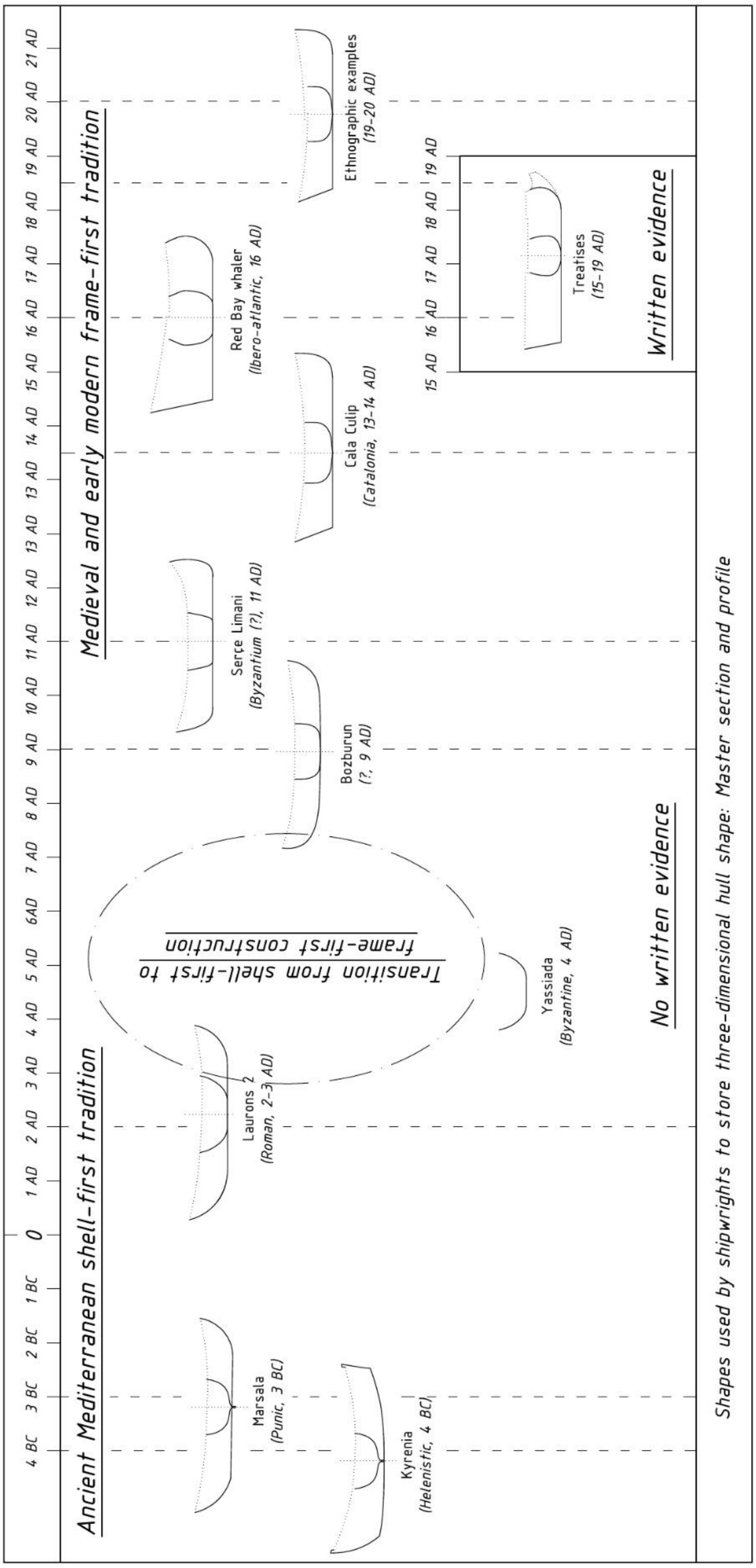


Figure 104 Continuity of the design paradigm from antiquity to the 19th century. It has been suggested that the transversal sections of these ships (with the exception of the 4 AD Yassiada wreck) were obtained from the transformation by controlled risings and narrowings of a template

of the master section. In the case of the Yassiada ship, there is compelling evidence to suggest that means of controlling the transversal shape of the hull were used despite being built on a mainly shell-based approach (Drawing JPO).

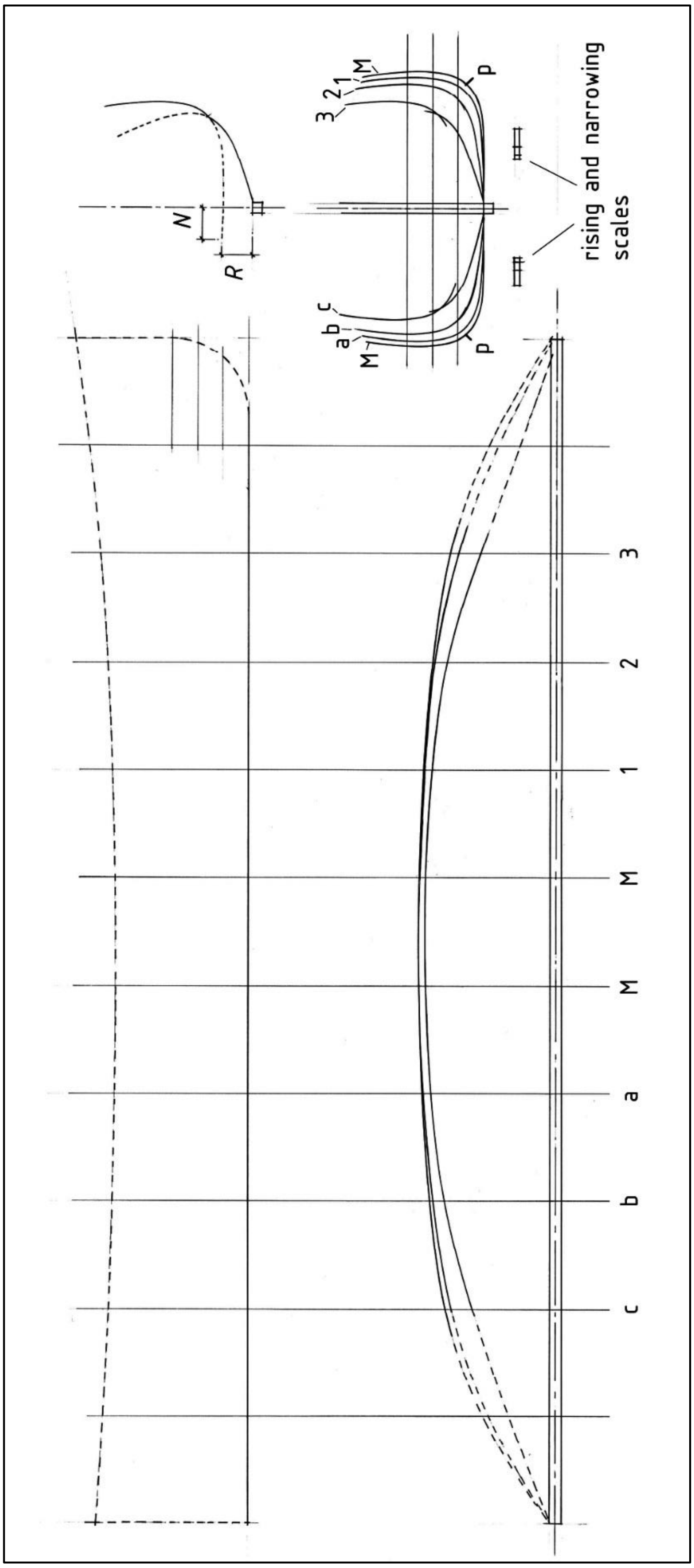


Figure 105 Simple plan of a 'fishing boat' drawn by rising and narrowing a template of the master section. The whole design-decisions were taken while drawing the body plan where the seven section are shown. This process produces a fair hull automatically, in less than 30 minutes. The rest of the drawing (plan and profile) was drawn as a check to see what type of shapes had been produced. The shape is automatically fair, so the design process is quick and automatic.

However, it is based on the body plan only, thus, the ends are not defined. Therefore they are shown discontinuous lines, their shape being determined by the ends of the hull. (Drawing JPO)

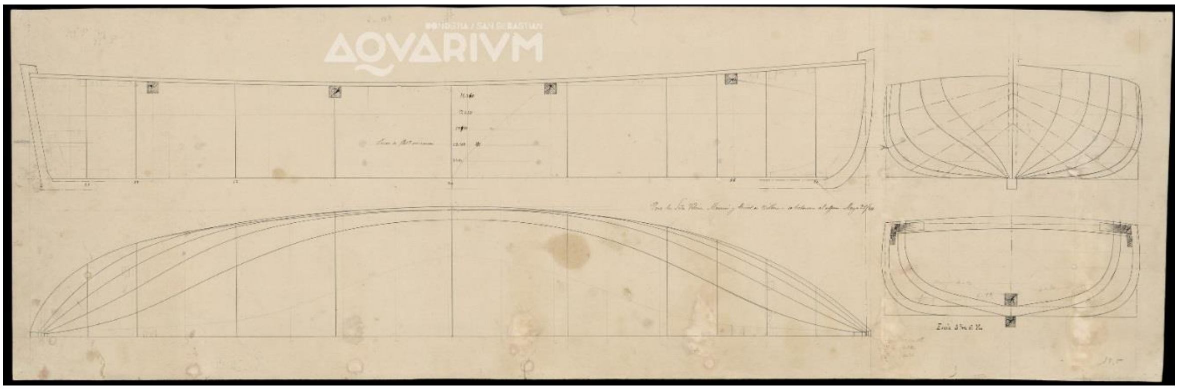


Figure 106 Plan from the Mutiozabal shipyard in Orio, Spain drawn in 1880. It shows the shape of a traditional fishing boat. The transversal sections have been drawn using a template of the master section. (Plan.6227 Colección Mutiozabal, Sociedad Oceanográfica de Gipuzkoa)

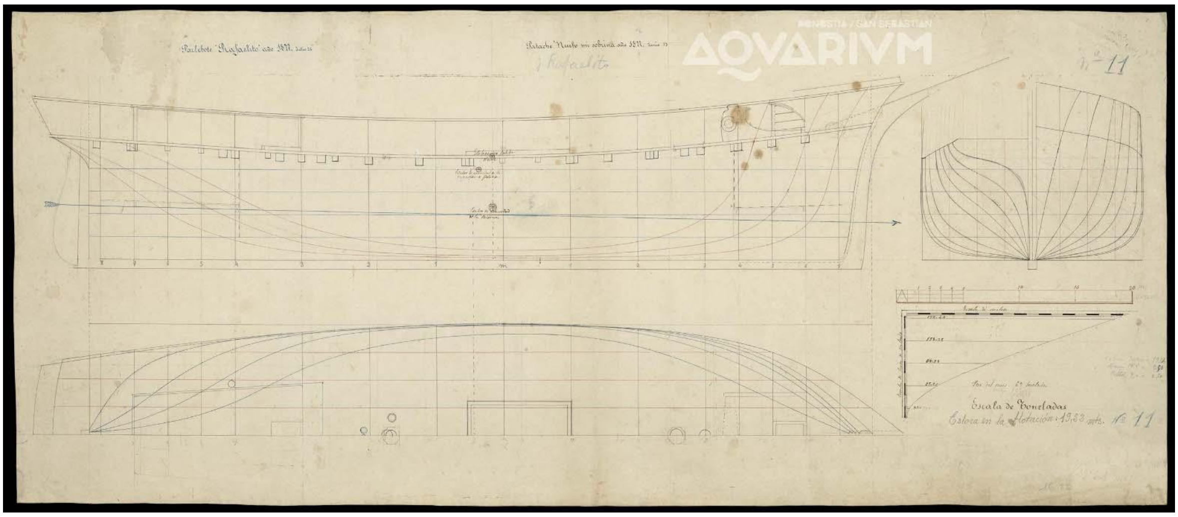


Figure 107 This plan drawn in 1877 is contemporary to figure 106. However, it shows a cargo ship drawn feely, without following a recipe based on the transformation of the master frame. Additional plans for this ship indicate that hydrostatic calculations mhave been carried out during the design of this ship. (Plan.6299 Colección Mutiozabal, Sociedad Oceanográfica de Gipuzkoa)

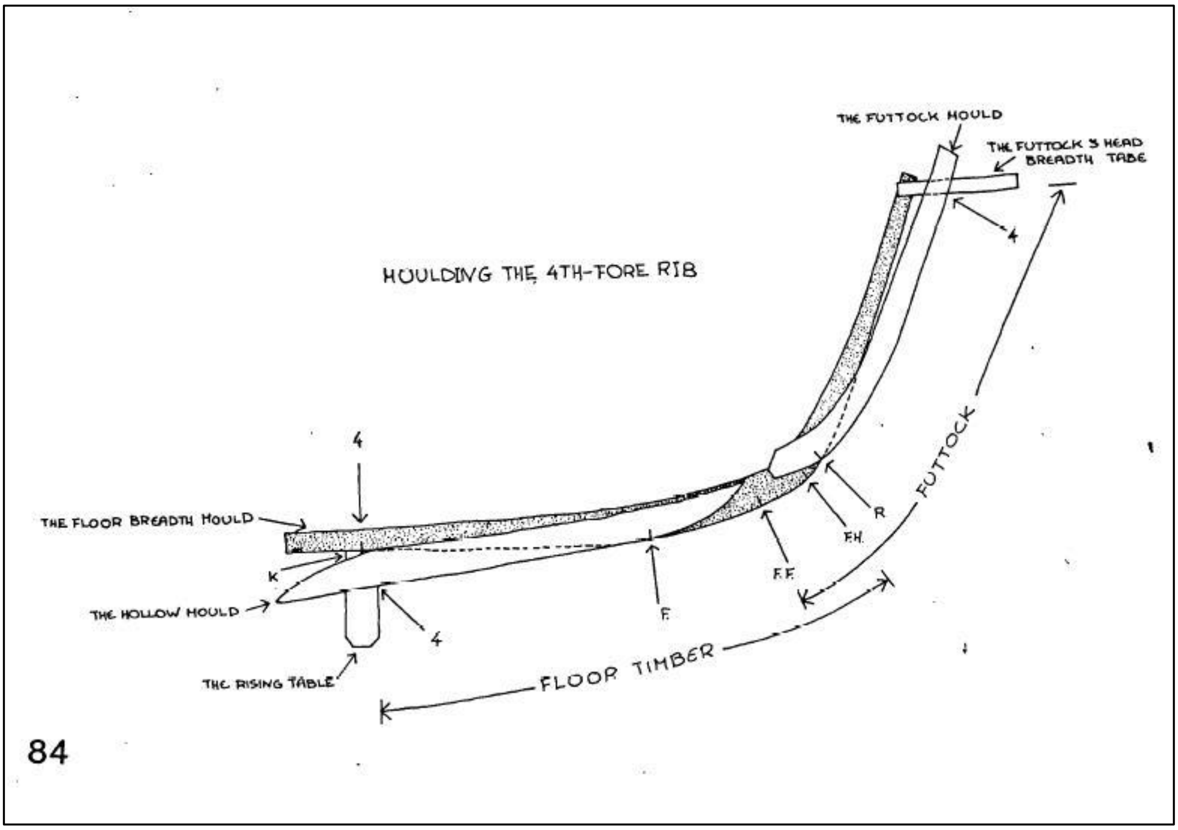


Figure 108 Three part mould used in Greece to design the shape of traditional fishing boats during the second half of the 20th century. (Damianidis, K., 1991. *Vernacular boats and boatbuilding in Greece*. p.84)

Figure 109 Tunisian boatbuilder of the late 20th century drawing the shapes of the frames using a template of the master mould and a rising staff. By arranging both elements, the rising and narrowing of each frame can be adjusted. (Rieth, E., 2016. *Navires et Construction Navale au Moyen Age,* p.257)

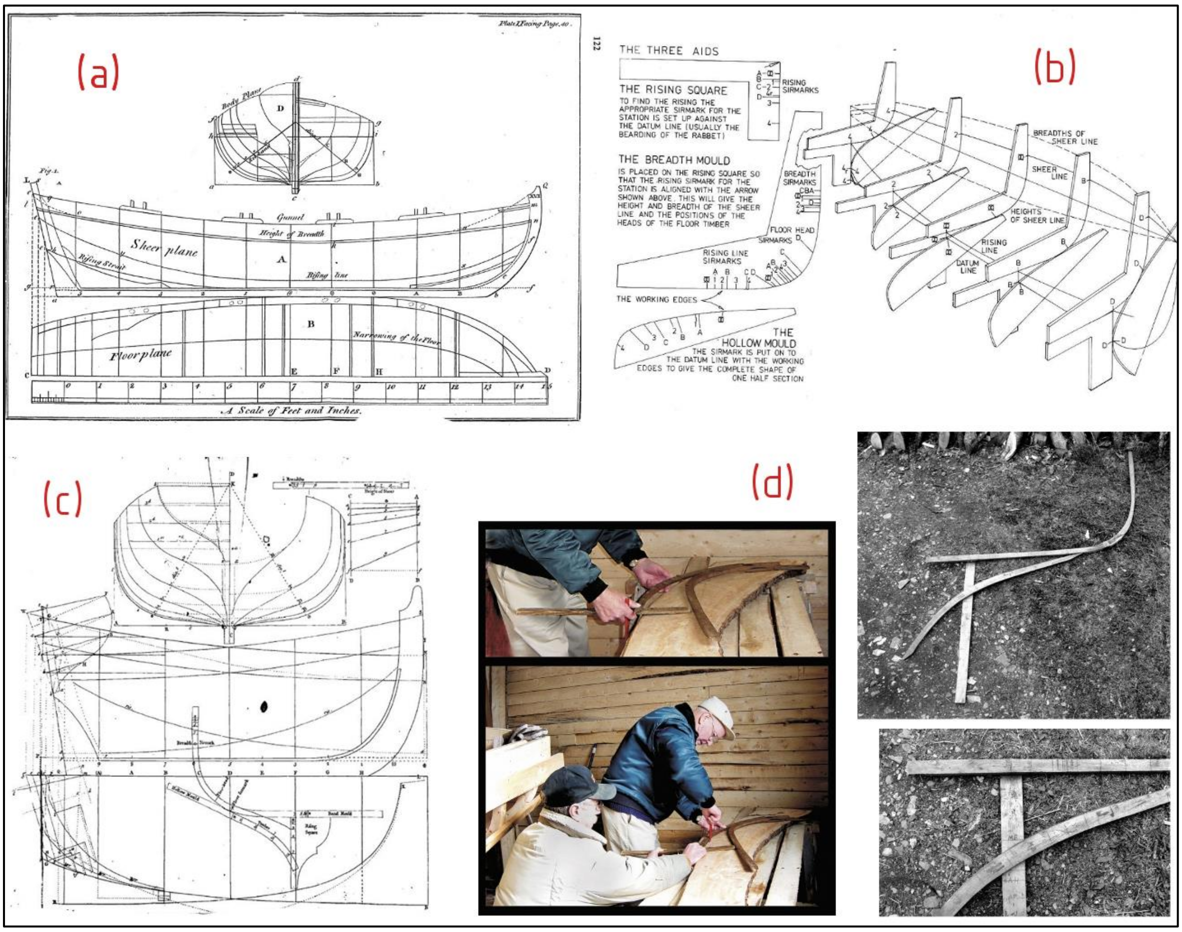


Figure 110 Whole moulding. Figures (a) and (c) show the process of whole moulding as described by Mungo Murray and Sutherland. The drawings look technically advanced. They give the impression of a highly sophisticated design procedure. However, the reality of the process, and its simplicity, becomes evident when practitioners using this procedure, and their tools, are observed next to them. The boat builders in the photograph (figure (d)) are demonstrating the manner in which the three part mould is used, controlled by a series of marks scribed on them. The process does not require any previous drafted plan. It is very simple to execute, but visually very complex if it is drawn on paper. Finally, figure (b) shows the same procedure, again, shown in perspective. Once again, the observer may conclude that the process is complex and elaborate, when it is nothing more that the representation on paper of the practical process being shown by the boat builders in the photograph. ((a) Sutherland, W. 1794. The Ship Builders Assistant. Plate I; (b) McKee, E. 1983. *Working Boats of Britain*. p.122; (c) (Murray, M. 1764. *A Treatise on Ship-Building and Navigation*. Plate V, p.172; (d) Boatbuilders: http://www.virtualmuseum.ca/ Three-part mould: Taylor, D. A., 1982. *Boat Building in Winterton*. p.51, figure 4.2)

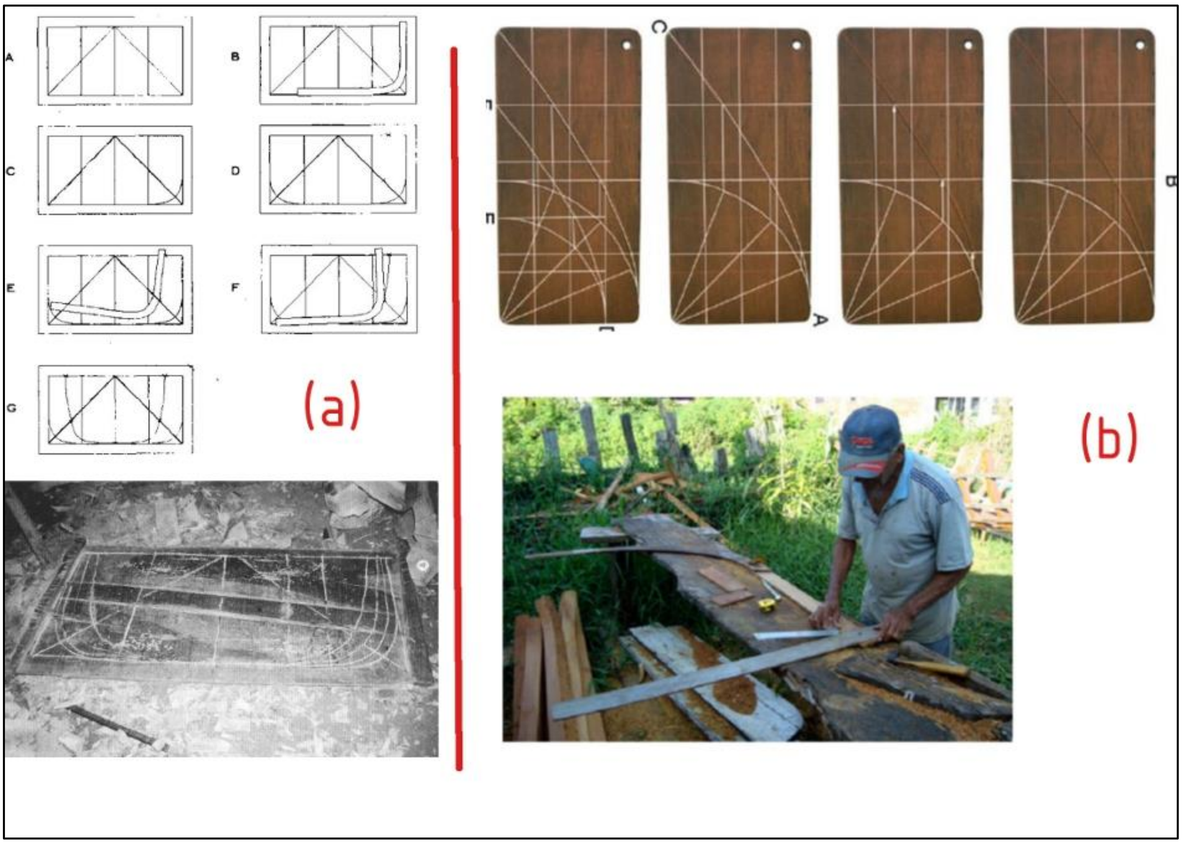


Figure 111 Traditional design methods in use in India and Brazil; both of European origin. These methods are simpler to apply on practice that their graphical representation would suggest, therefore, making them suitable to be transmitted orally. Similarly their simplicity makes them suitable to be stored by recording the information on simple tools or even by committing it to memory. ((a) McGrail, S. 2001-b. Portuguese-derived ship design methods in southern India?; (b) Castro, F. & Gomes-Dias, D., 2015. Moulds, Graminhos and Ribbands)

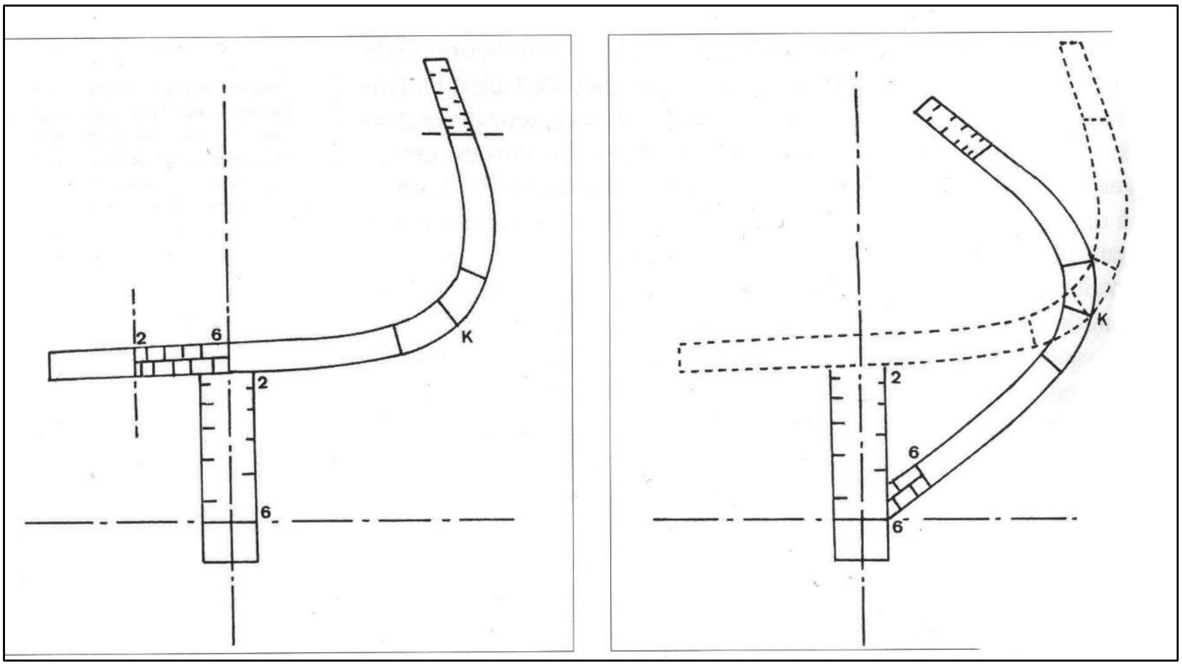


Figure 112 19th century master frame template and rising staff used to design traditional boats in the french Mediterranean called *Gabarit de Saint-Joseph*. (Rieth, E., 1996, *Le Maître-Gabarit la Tablette et le Trébuchet.* p.170)

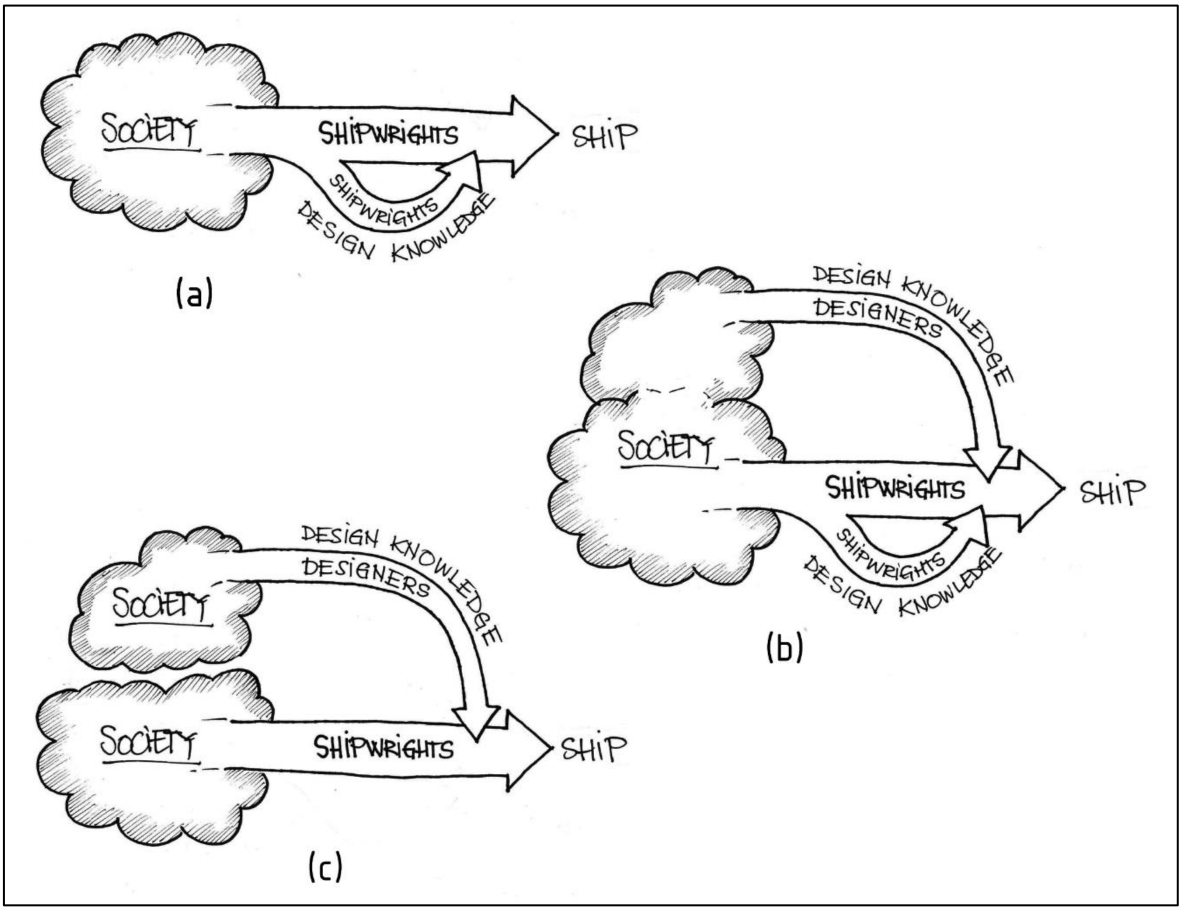


Figure 113 The figure illustrates the manner in which design knowledge was acquired and applied by *(a)* the shipwright in a traditional pre-literate (pre-treatises) group, *(b)* by shipwrights and ship-designers in the early modern period when treatises and traditional methods coexisted and by *(c)* ship-designers in the post-19th century industrial setting. Cases (a) and (b) can acquire knowledge through an apprenticeship on the job. By contrast, the knowledge of post-19th-century ship designers (naval architects) cannot be acquired through making. It involves a deeper theoretical base that must be acquired through a formal process of instruction. (Drawing JPO)

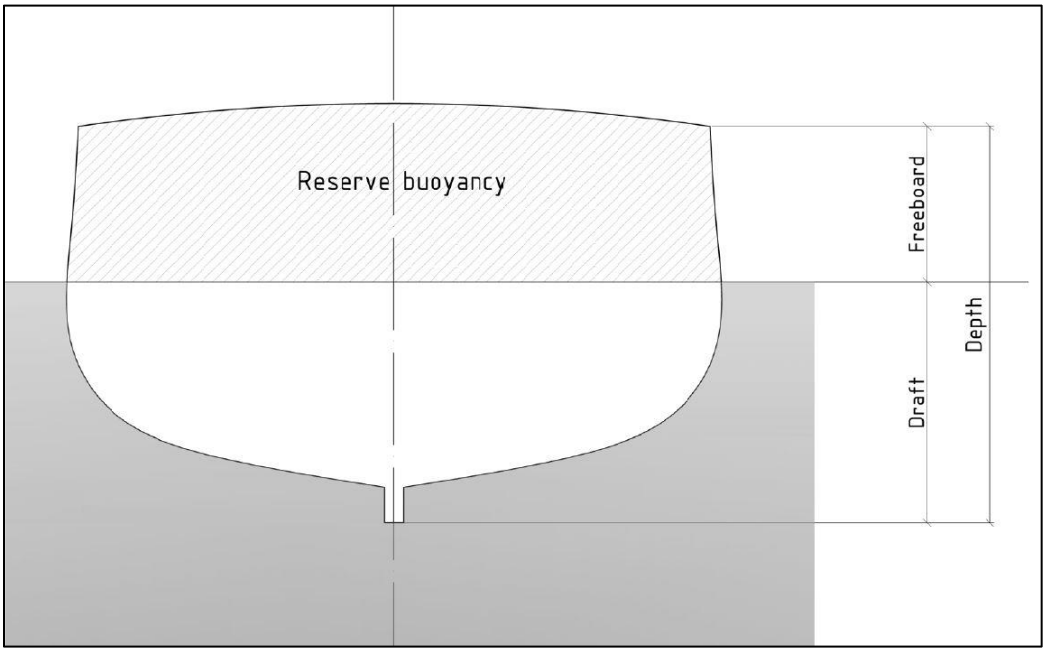


Figure 114 Relation between ship's depth, draft and freeboard. (Drawing JPO)

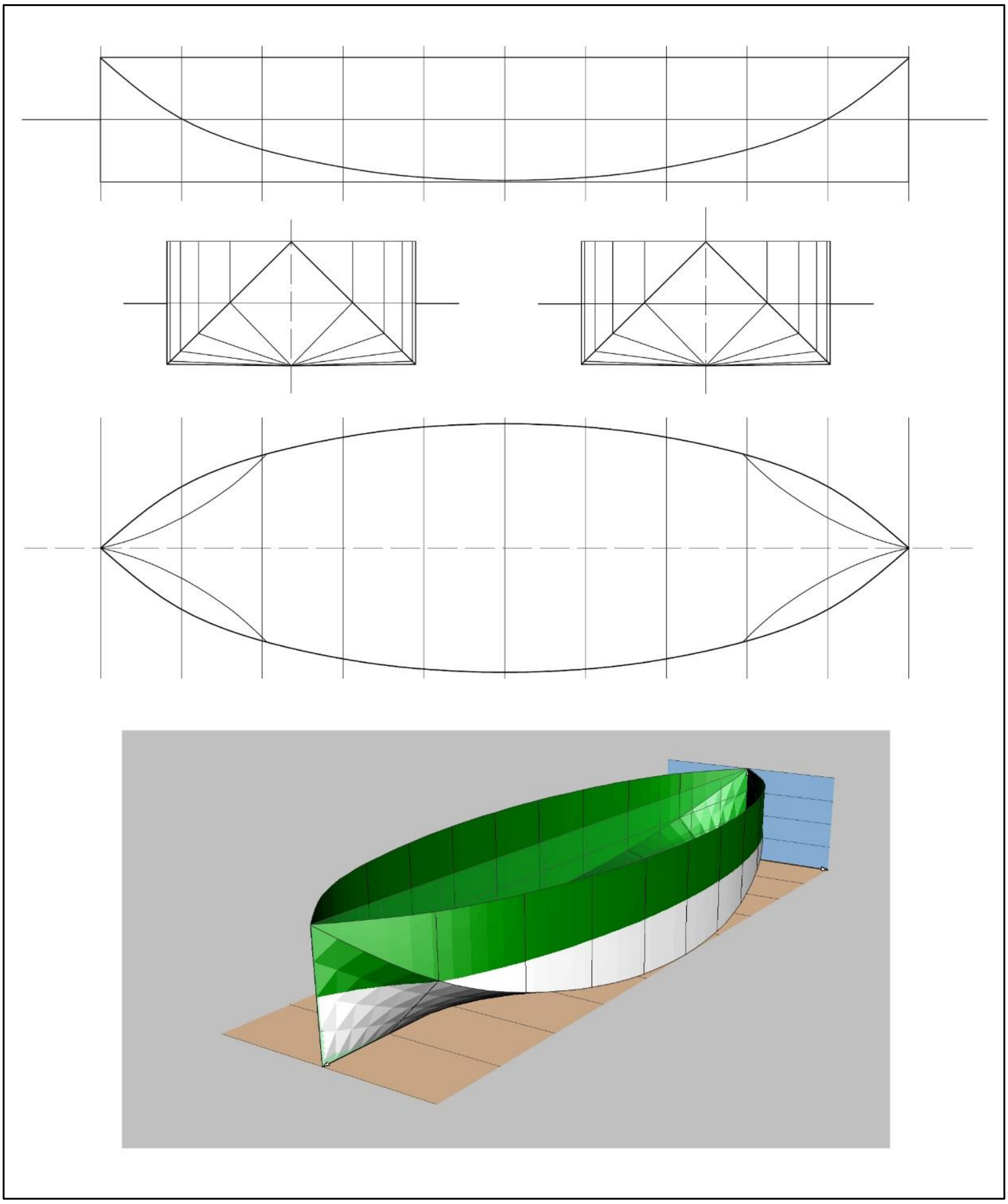


Figure 115 Base model for the test: Model A. (Drawing JPO)

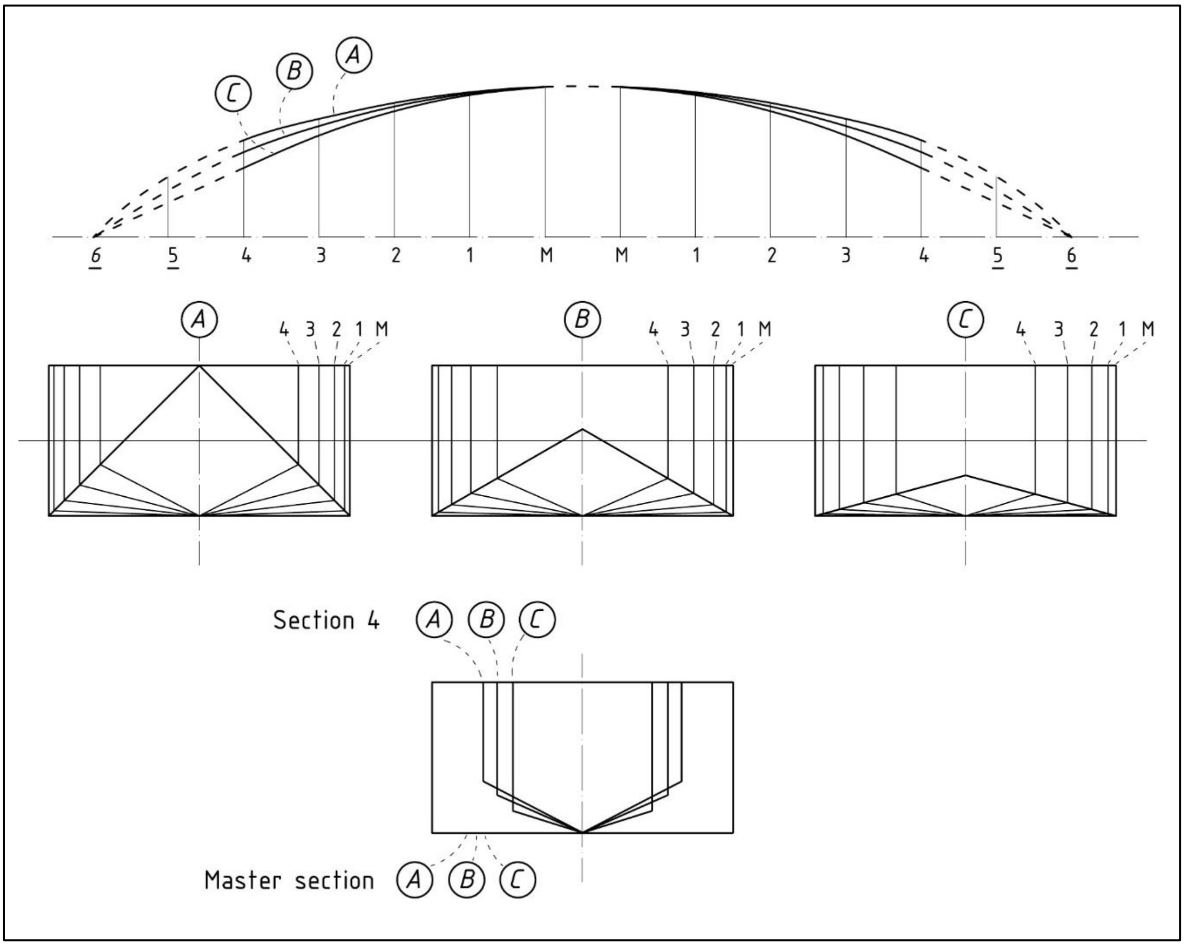
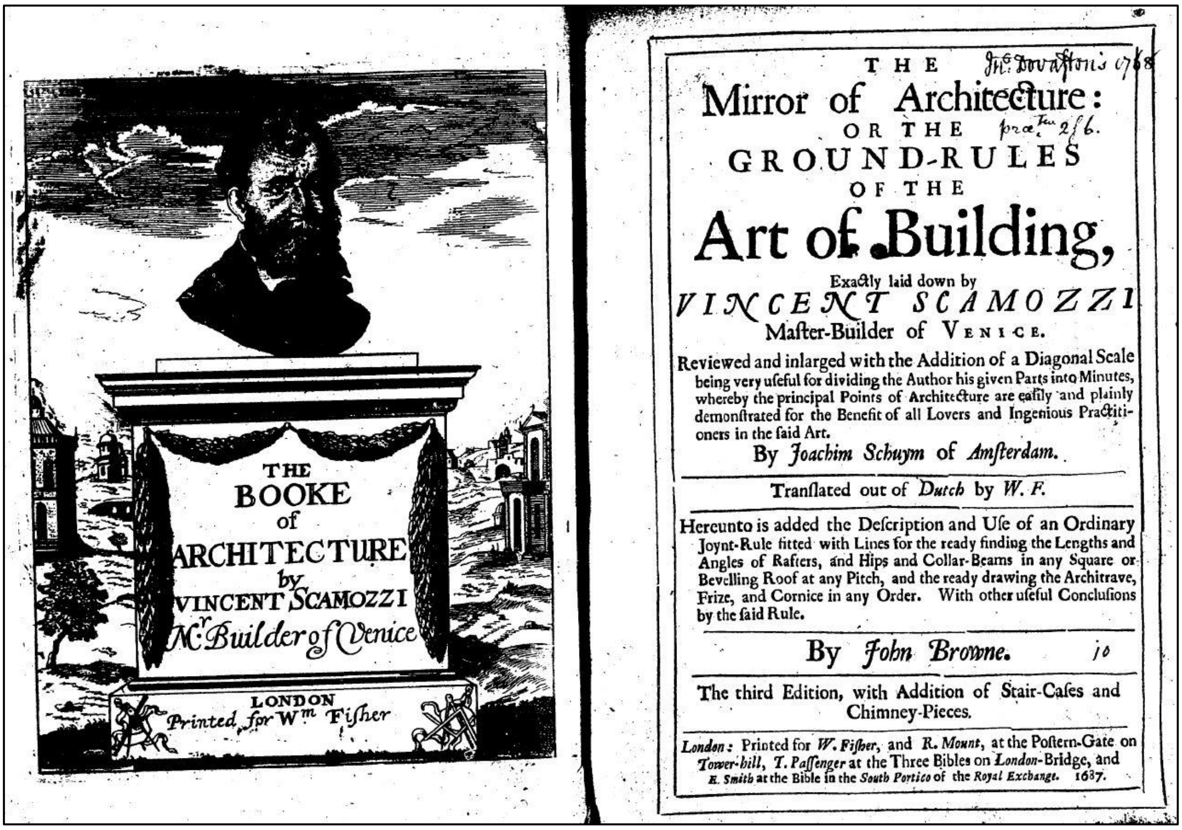


Figure 116 Three models used in the test. The figure at the bottom shows section 4 of each of the hulls. All have the same master section but it is visually apparent that the shape of their ends are markedly different. (Drawing JPO)



THE BOOKE of ARCHITECTURE by VINCENT SCAMOZZI Mr. Builder of Venice

LONDON Printed for Wm Fisher

THE Mirror of Architecture: OR THE GROUND-RULES OF THE Art of Building, Exactly laid down by VINCENT SCAMOZZI Master-Builder of VENICE.

Reviewed and inlarged with the Addition of a Diagonal Scale being very useful for dividing the Author his given Parts into Minutes, whereby the principal Points of Architecture are easily and plainly demonstrated for the Benefit of all Lovers and Ingenious Practitioners in the said Art.

By Joachim Schuym of Amsterdam.

Translated out of Dutch by W. F.

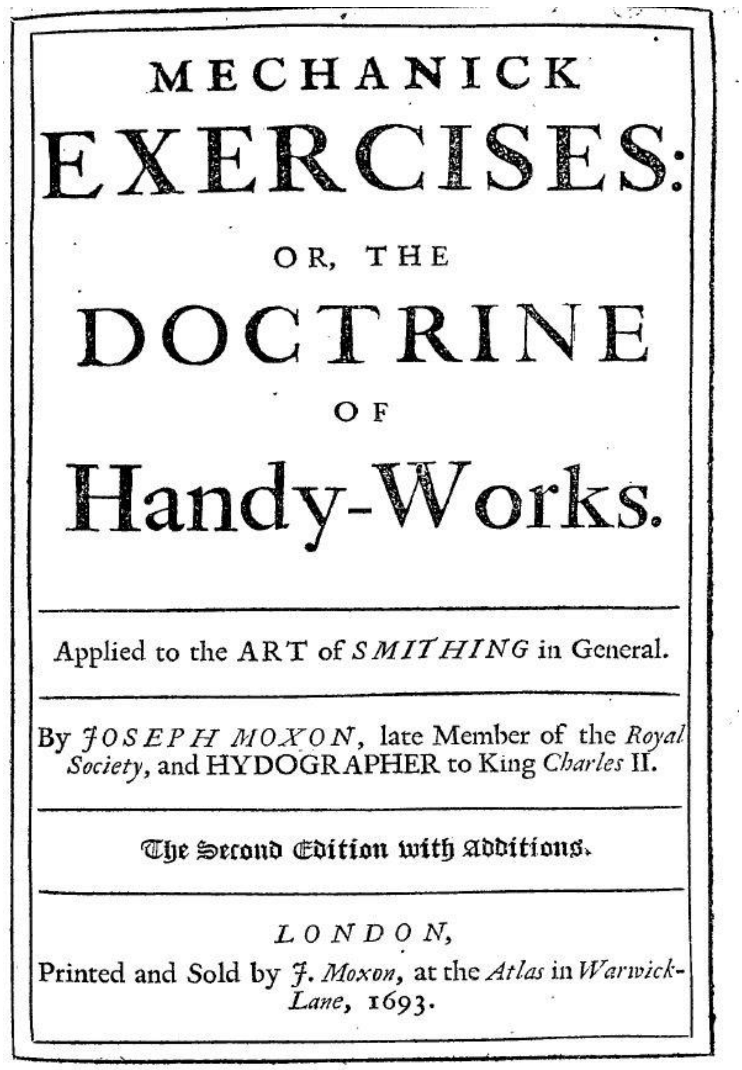
Hereunto is added the Description and Use of an Ordinary Joynt-Rule fitted with Lines for the ready finding the Lengths and Angles of Rafters, and Hips and Collar-Beams in any Square or Bevelling Roof at any Pitch, and the ready drawing the Architrave, Frize, and Cornice in any Order. With other useful Conclusions by the said Rule.

By John Browne.

The third Edition, with Addition of Stair-Cases and Chimney-Pieces.

London: Printed for W. Fisher, and R. Mount, at the Postern-Gate on Tower-hill, T. Passenger at the Three Bibles on London-Bridge, and E. Smith at the Bible in the South Portico of the Royal Exchange. 1687.

Figure 117 Cover and title page of a *The Booke of Architecture* (1637), destined for a learned readership



MECHANICK
EXERCISES:
OR, THE
DOCTRINE
OF
Handy-Works.

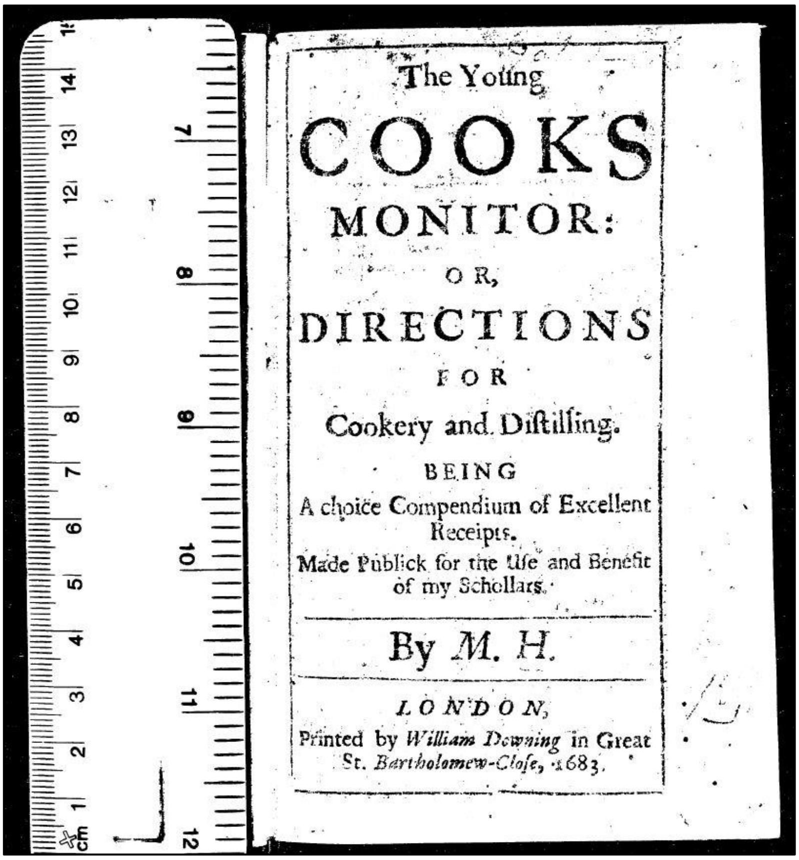
Applied to the ART of *SMITHING* in General.

By *JOSEPH MOXON*, late Member of the *Royal Society*, and HYDOGRAPHER to King *Charles* II.

The Second Edition with Additions.

LONDON,
Printed and Sold by *J. Moxon*, at the *Atlas* in *Warwick-Lane*, 1693.

Figure 118 Joseph Moxon's *Mechanick Exercises* (1693) written for a readership of practical craftsmen. It is covers a wide array of subjects, without theoretical disquisitions. Its contents would have been of use for anyone with sufficient practical knowledge who wanted to have a better knowledge of some of the craft described on it: Smithing, house carpentry, bricklaying, etc.

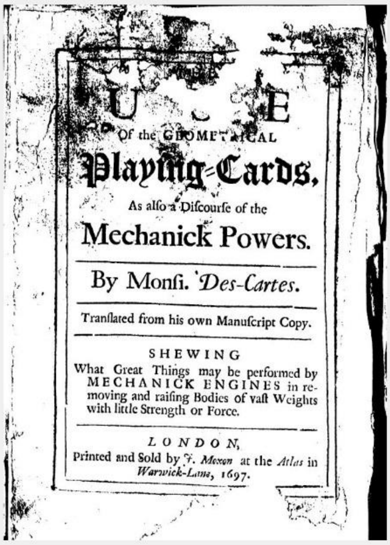


The Young
COOKS
MONITOR:
OR,
DIRECTIONS
FOR
Cookery and Diftilling.
BEING
A choice Compendium of Excellent Receipts.
Made Publick for the Ufe and Benefit of my Schollars.

By *M. H.*

LONDON,
Printed by *William Downing* in Great St. *Bartholomew-Clofe*, 1683.

Figure 119 The young *Cooks Monitor* (1683), written for young students



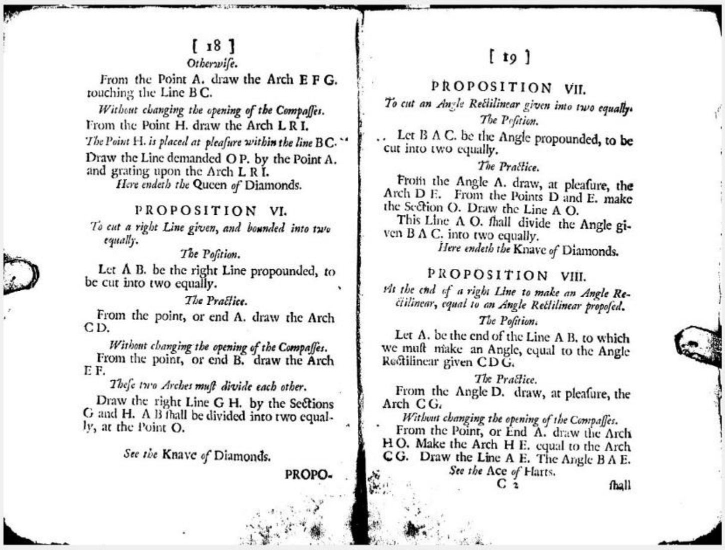
USE
Of the GEOMETRICAL
Playing-Cards,
As also a Discourse of the
Mechanick Powers.

By Monsi. Des-Cartes.

Translated from his own Manuscript Copy.

SHEWING
What Great Things may be performed by MECHANICK ENGINES in removing and raising Bodies of vast Weights with little Strength or Force.

LONDON,
Printed and Sold by J. Moxon at the Atlas in Warwick-Lane, 1697.



[18]

Otherwise.

From the Point A. draw the Arch E F G. touching the Line B C.

Without changing the opening of the Compasses.

From the Point H. draw the Arch L R I.

The Point H. is placed at pleasure within the line B C.

Draw the Line demanded O P. by the Point A. and grating upon the Arch L R I.

Here endeth the Queen *of* Diamonds.

PROPOSITION VI.

To cut a right Line given, and bounded into two equally.

The Position.

Let A B. be the right Line propounded, to be cut into two equally.

The Practice.

From the point, or end A. draw the Arch C D.

Without changing the opening of the Compasses.

From the point, or end B. draw the Arch E F.

These two Arches must divide each other.

Draw the right Line G H. by the Sections G and H. A B shall be divided into two equally, at the Point O.

See the Knave *of* Diamonds.

PROPO-

[19]

PROPOSITION VII.

To cut an Angle Rectilinear given into two equally.

The Position.

Let B A C. be the Angle propounded, to be cut into two equally.

The Practice.

From the Angle A. draw, at pleasure, the Arch D E. From the Points D and E. make the Section O. Draw the Line A O.

This Line A O. shall divide the Angle given B A C. into two equally.

Here endeth the Knave *of* Diamonds.

PROPOSITION VIII.

At the end of a right Line to make an Angle Rectilinear, equal to an Angle Rectilinear proposed.

The Position.

Let A. be the end of the Line A B. to which we must make an Angle, equal to the Angle Rectilinear given C D G.

The Practice.

From the Angle D. draw, at pleasure, the Arch C G.

Without changing the opening of the Compasses.

From the Point, or End A. draw the Arch H O. Make the Arch H E. equal to the Arch C G. Draw the Line A E. The Angle B A E.

See the Ace *of* Harts.

C 2 shall

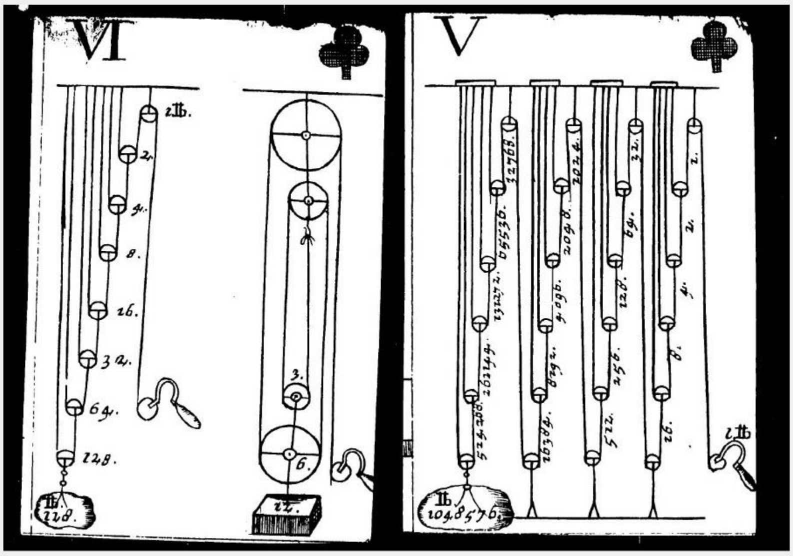
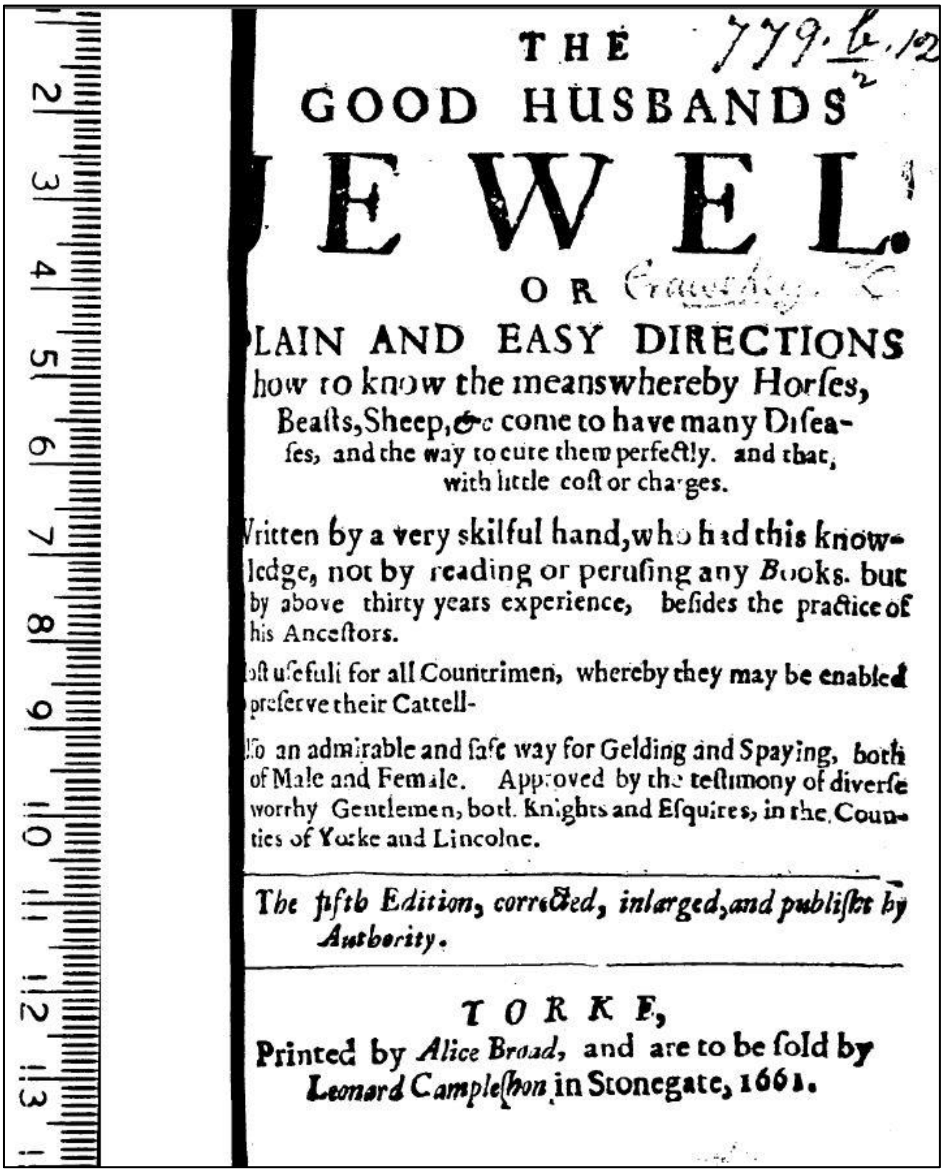


Figure 120 *Geometrical Playing Cards* (1697). This is an interesting combination of complex text destined to a learned readership and lighter material focusing to a wider audience. The text is a translation of Descartes' work. Therefore, it is highly theoretical and with abstract language. In order to make it more useful to craftsmen who might not be accustomed to this type of language, playing cards are supplied. Each card shows a practical example of the ideas expressed in the text. In this example, the use of pulleys to multiply lifting power



THE
GOOD HUSBANDS
JEWEL.
OR
[P]LAIN AND EASY DIRECTIONS
how to know the meanswhereby Horſes,
Beaſts, Sheep, &c come to have many Diſea-
ſes, and the way to cure them perfectly. and that,
with little coſt or charges.

[W]ritten by a very skilful hand, who had this know-
ledge, not by reading or peruſing any Books. but
by above thirty years experience, beſides the practice of
his Anceſtors.

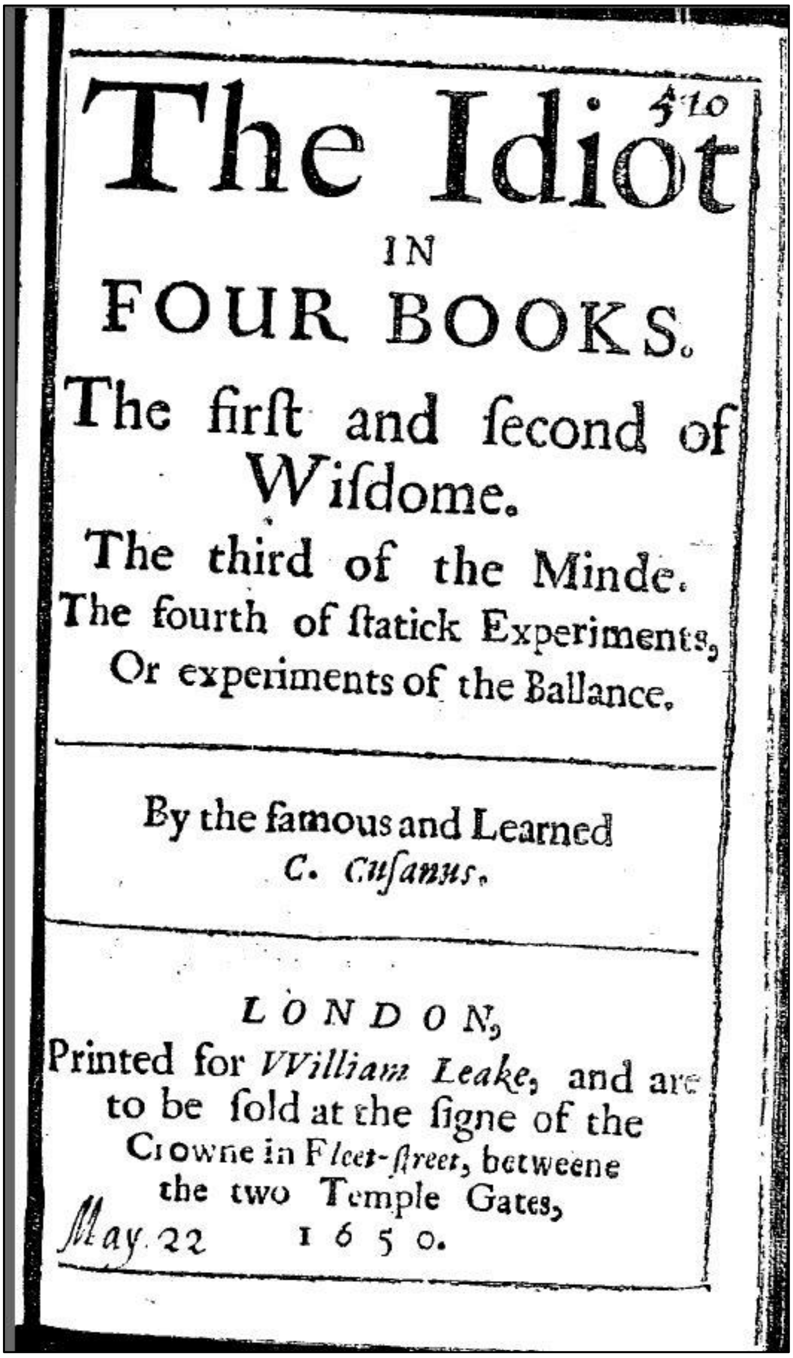
[M]oſt uſefull for all Countrimen, whereby they may be enabled
[to] preſerve their Cattell-

[Al]ſo an admirable and ſafe way for Gelding and Spaying, both
of Male and Female. Approved by the teſtimony of diverſe
worthy Gentlemen, both Knights and Eſquires, in the Coun-
ties of Yorke and Lincolne.

The fifth Edition, corrected, inlarged, and publiſht by Authority.

YORKE,
Printed by *Alice Broad*, and are to be ſold by
Leonard Campleſhon in Stonegate, 1661.

Figure 121 Book on animal husbandry written by an unnamed author who warns the reader in the cover that his knowledge comes from his experience of more than thirty years and not from reading books



The Idiot 410

IN

FOUR BOOKS.

The firſt and ſecond of Wiſdome.

The third of the Minde.

The fourth of ſtatick Experiments,

Or experiments of the Ballance.

By the famous and Learned

C. Cuſanus.

LONDON,

Printed for *VVilliam Leake*, and are to be ſold at the ſigne of the Crowne in *Fleet-ſtreet*, betweene the two Temple Gates,

May 22 1650.

Figure 122 *The Idiot in Four Books* (1650). The so called ‘idiot’ is used by the author to show the strength of ideas based on common sense as opposed to abstract scholarship based on pure reason

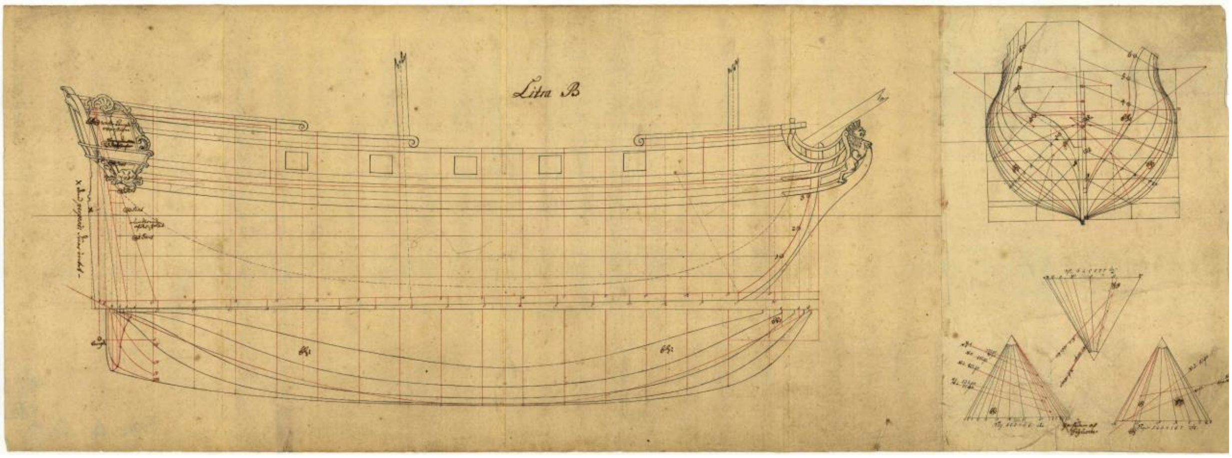


Figure 123 Danish plans of the 18th century. They show the geometric constructions (triangles) used to obtain the transformation of the diagonal planes, following the methods described by Duhamel du Monceau. A written explanation of the process illustrates the shipwrights thought when designing this ship.[1] (https://www.sa.dk/ao-soegesider/da/billedviser?epid=17149179#207772,39521250)

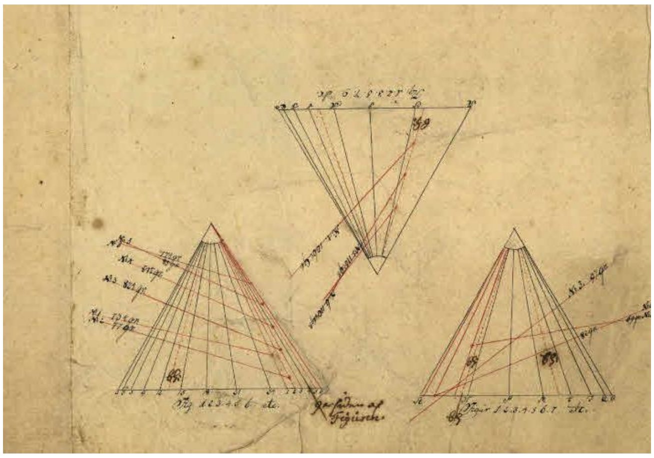


Figure 124 Detail of the triangles used to obtain the lines that control the gradual transformation of the diagonals

[1] I have to thank Rolf Warming for reading the original Danish text and giving his impressions on it.

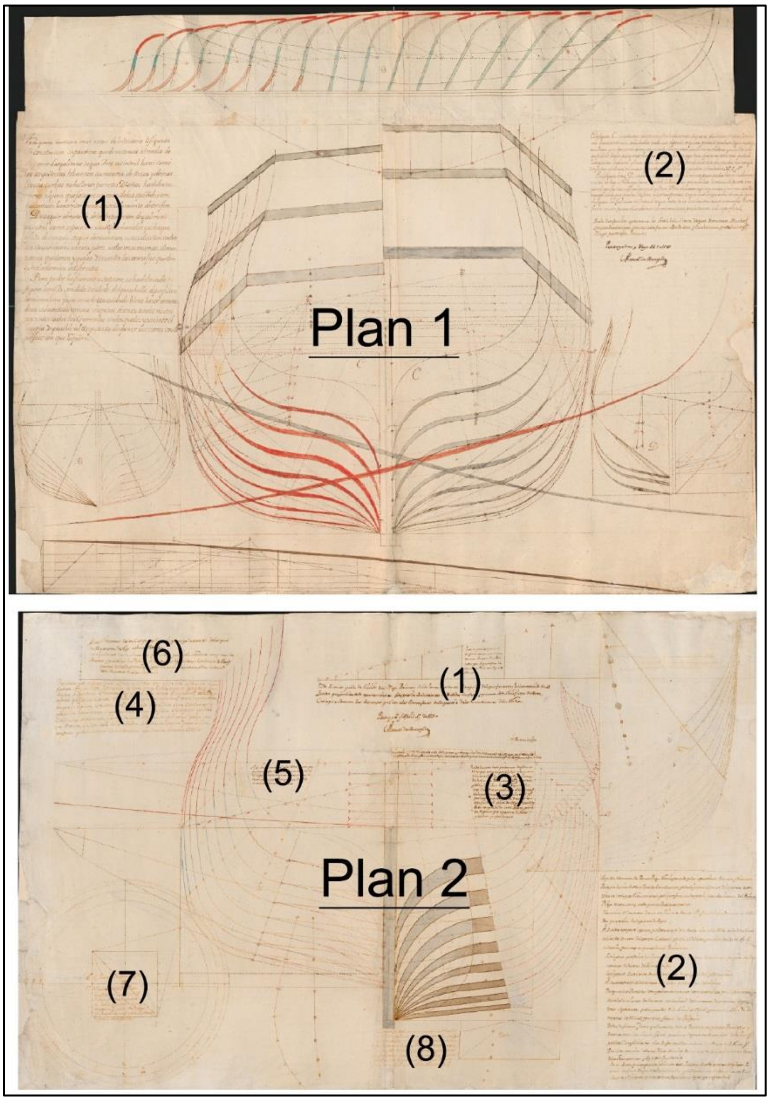


Figure 125 Numbering system used to identify individual blocks of text in the plans

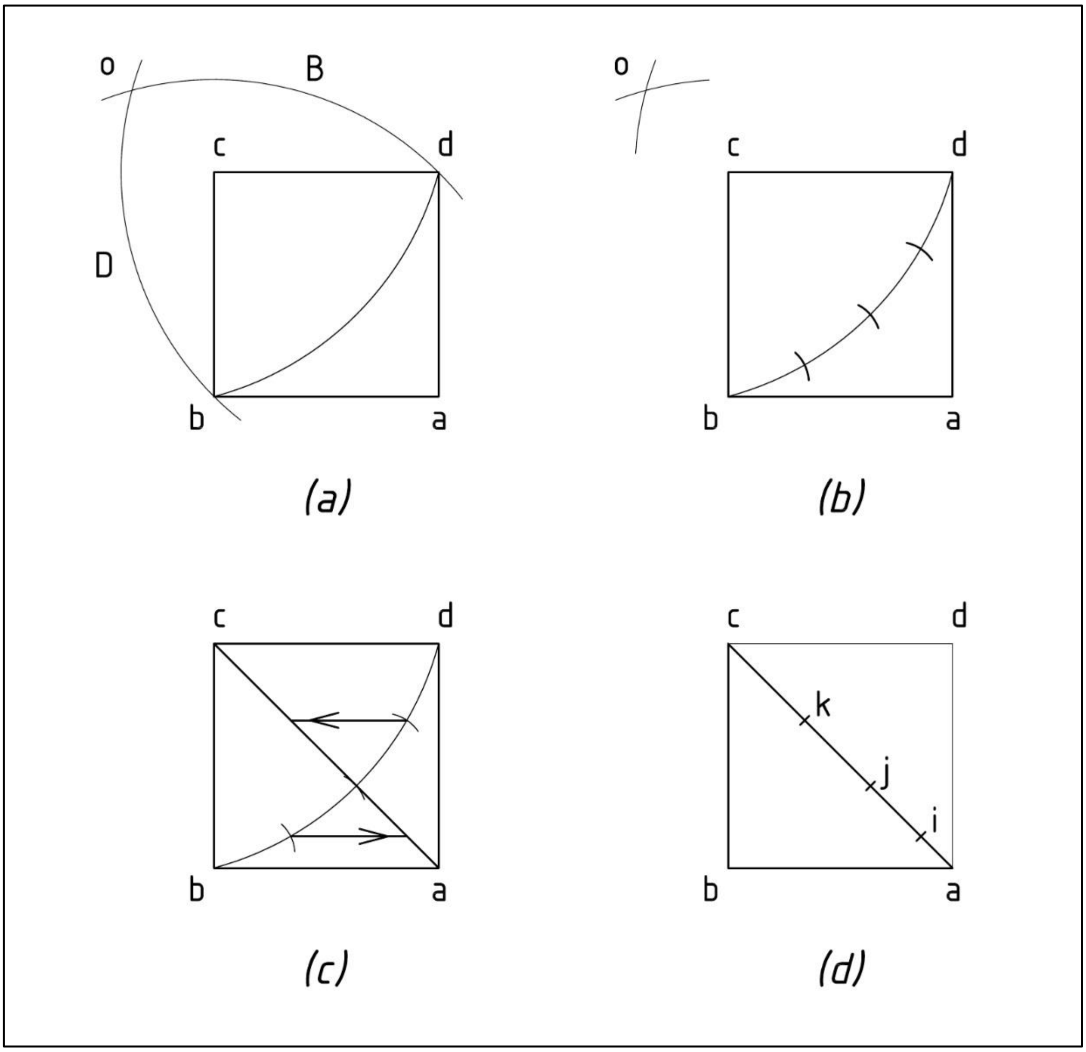


Figure 126 Method to design the quadrant described by Arrospide. It determines the three-dimensional shape of the hull. (Drawing JPO)

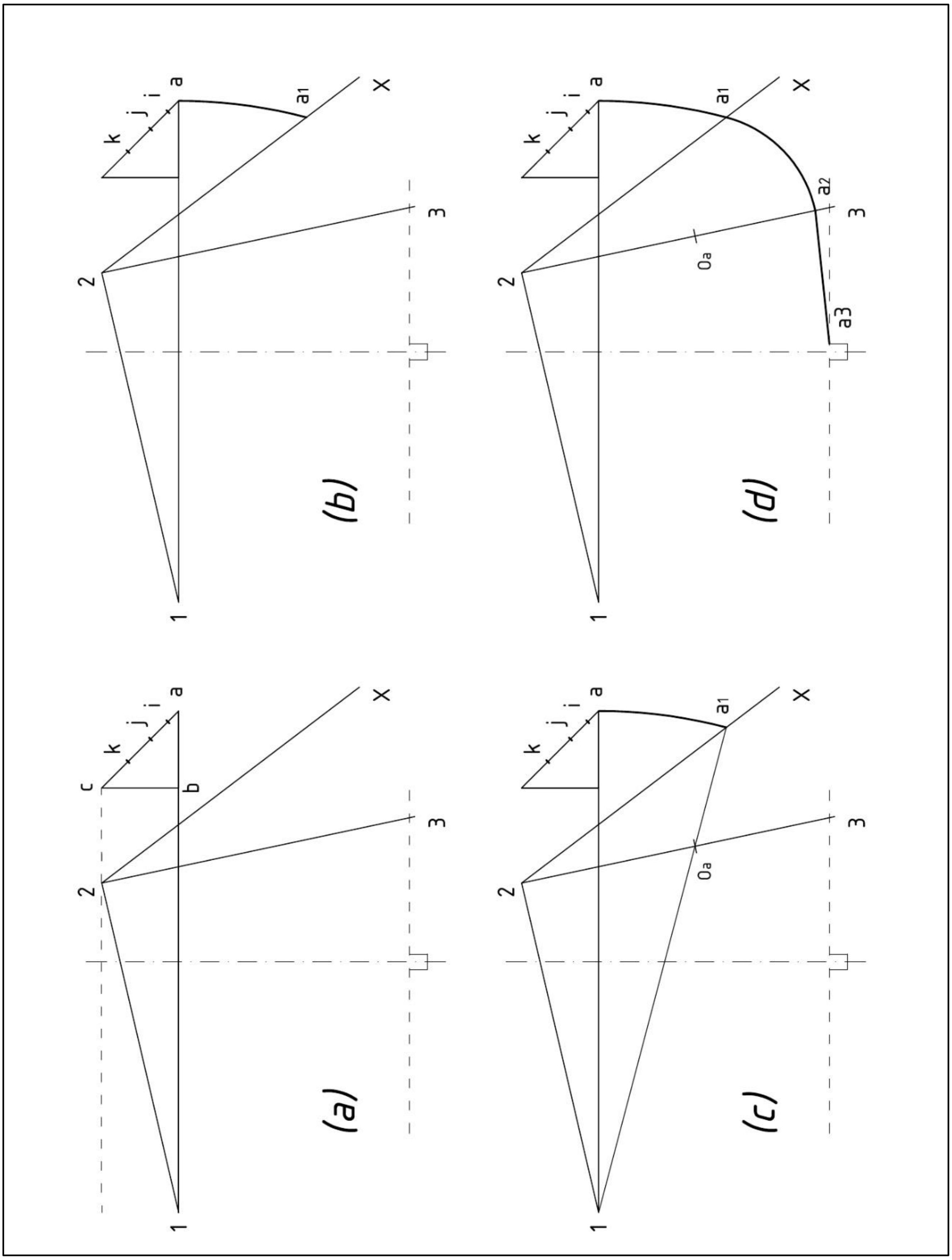


Figure 127 Arrospide's method of drawing a master section from the quadrant. (Drawing JPO)

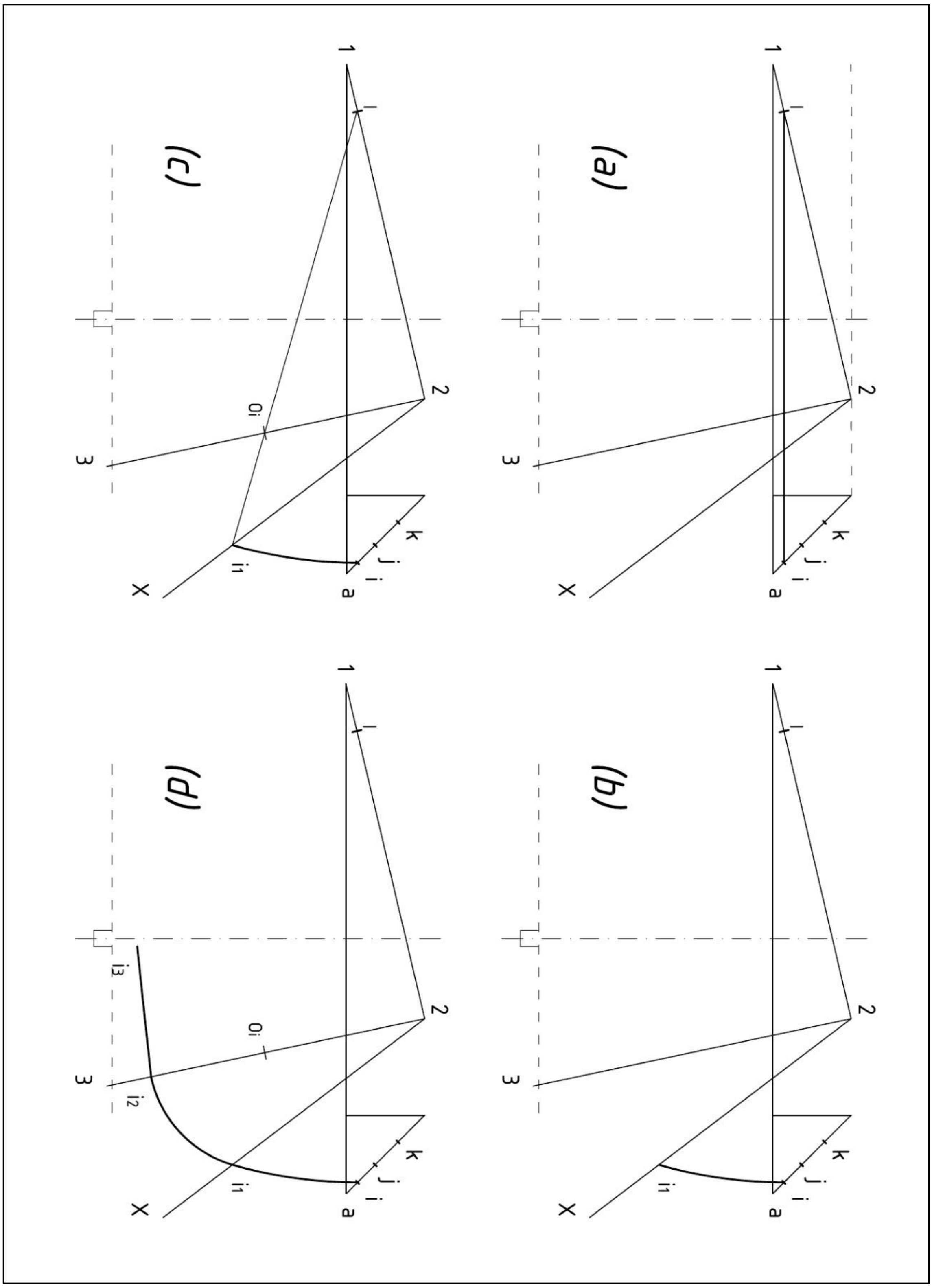


Figure 128 Arrospide's method of drawing *section-i* from the quadrant. (Drawing JPO)

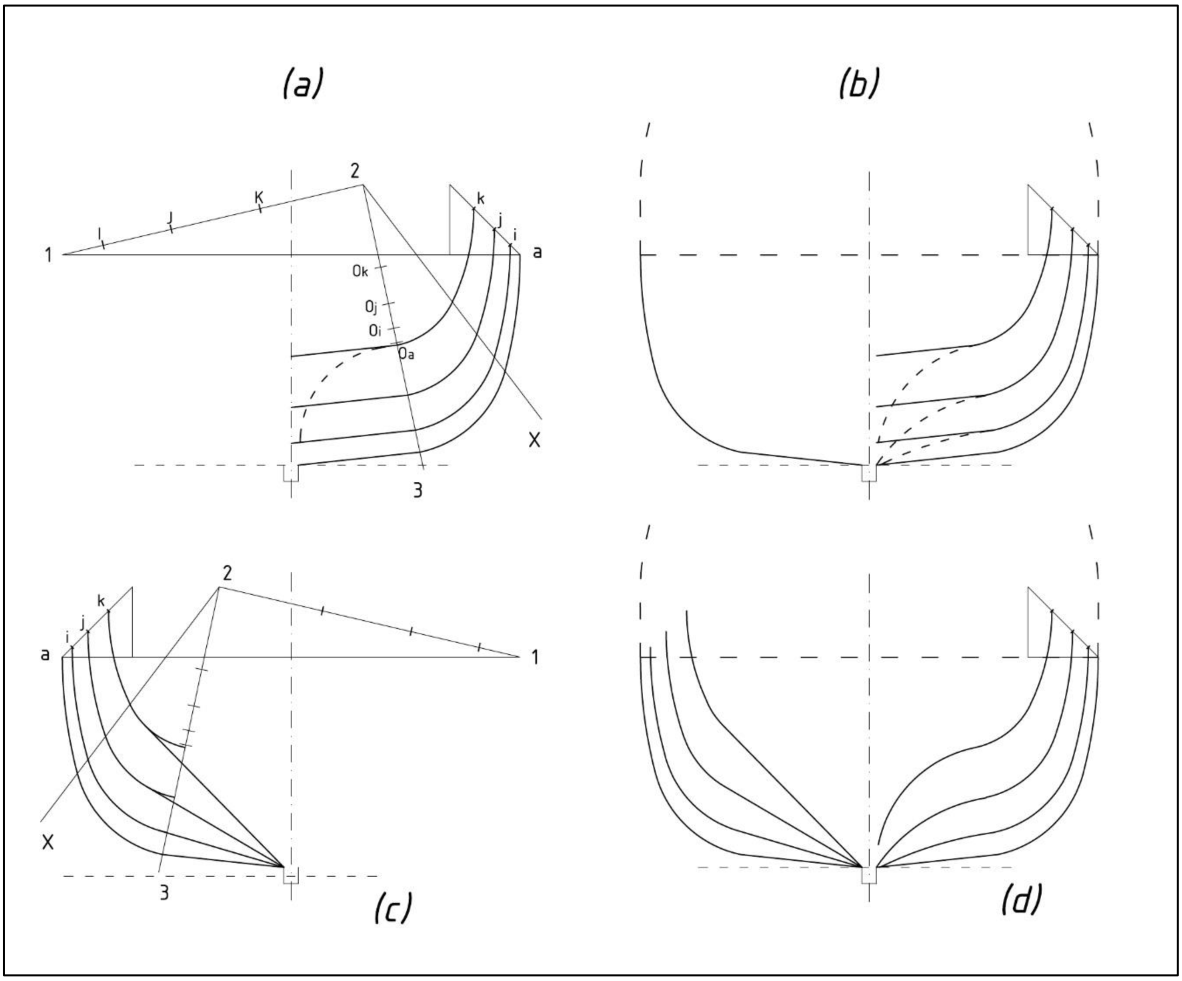


Figure 129 Arrospide's method forward and aft, and final body plan. (Drawing JPO).

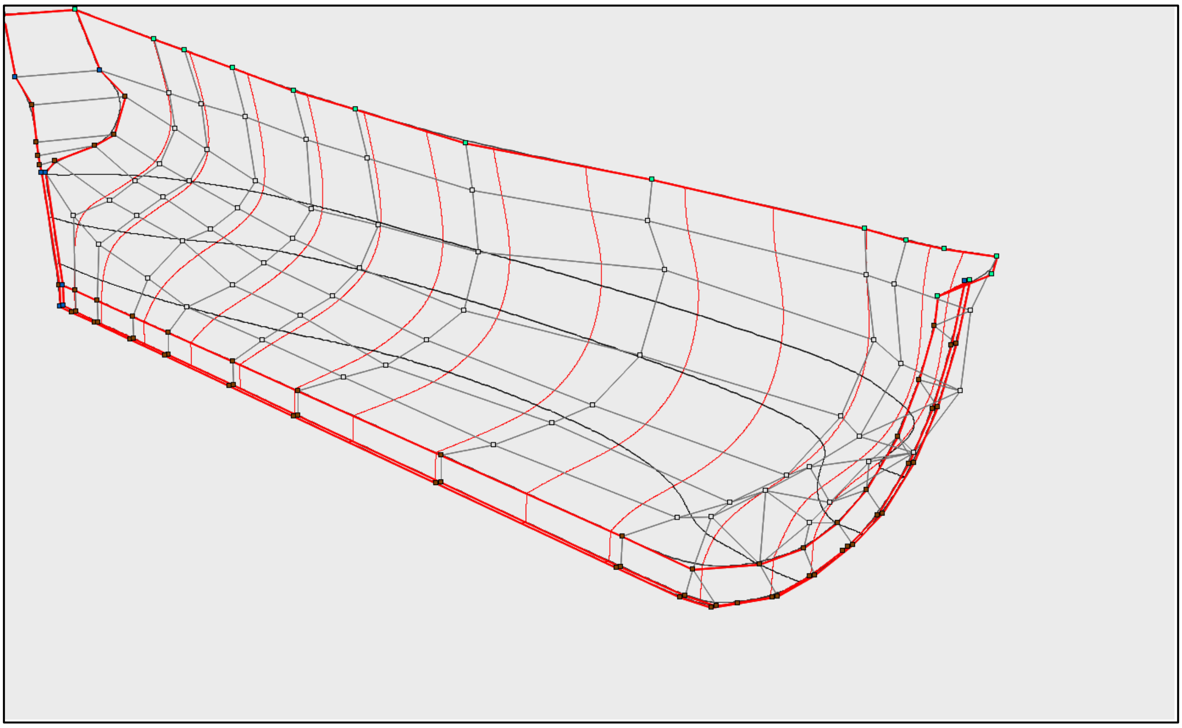


Figure 130 Perspective view showing the control network of nodes used by DelftSHIP to define the three-dimensional surface of a ship. (Drawing JPO)

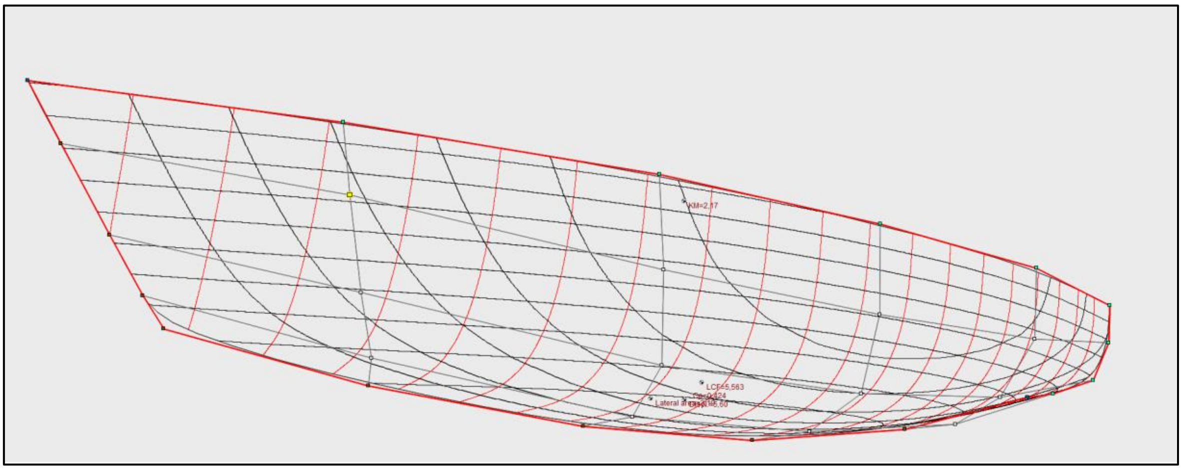


Figure 131 Control mesh in the shape of a modern yacht created automatically by DelftShip. (Drawing JPO)

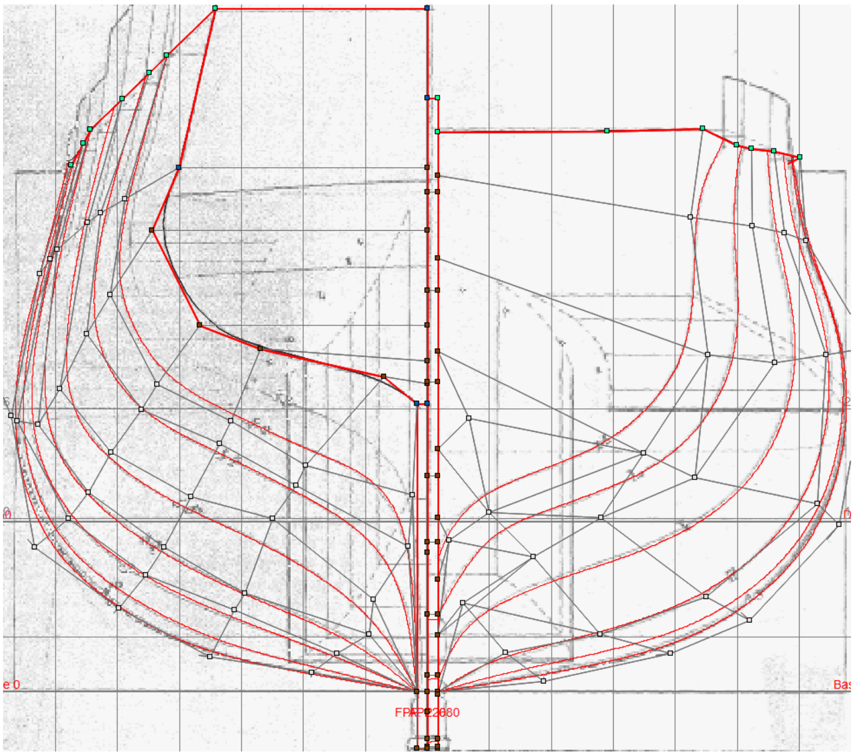


Figure 132 Body plan showing the network of control points and the sections (shown in red) at the same locations as in the original plan in the background. (Drawing JPO)

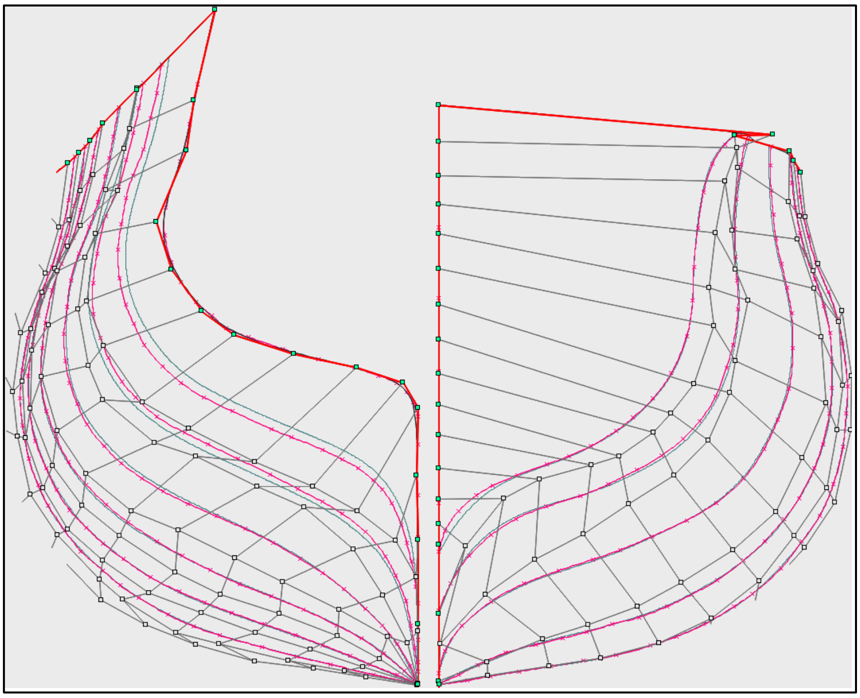


Figure 133 Hull surface and control-node network created by DELFTship automatically. The digitised sections introduced as a table of offsets are shown by DELFTship as a series of marker sections shown in red in the figure. (Drawing JPO)

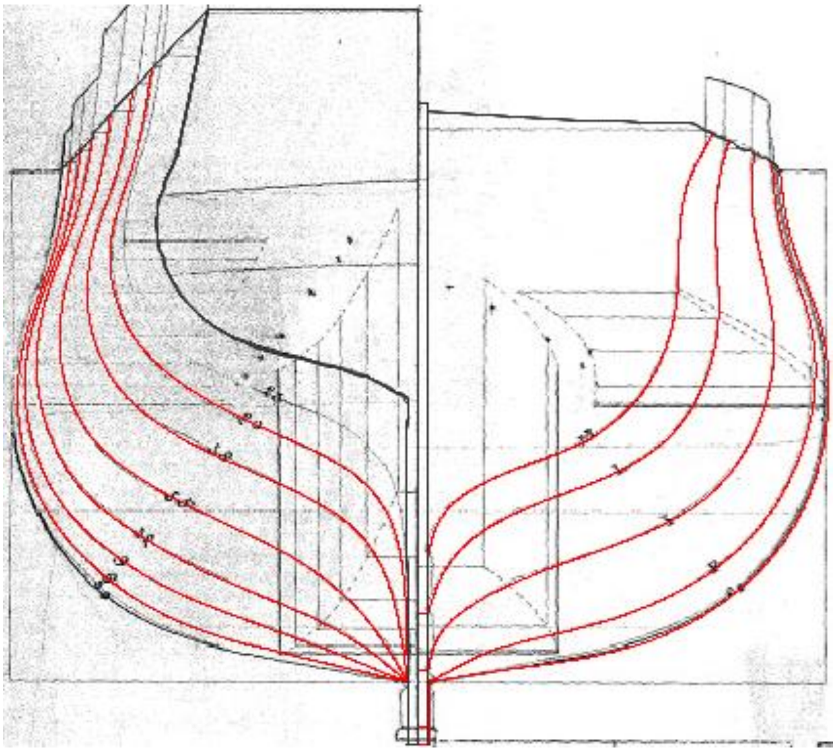


Figure 134 Same body plan as in figure 133, with the control network removed. The automatic hull surface created by DELFTship from the digitised table of offsets has been faired

using the background image as a guide. The red sections show the faired stations, which match very closely the original plan in the background. (Drawing JPO)

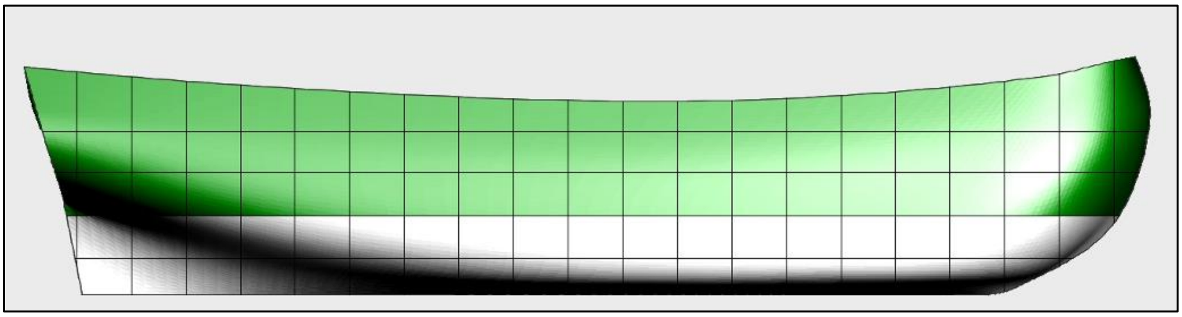


Figure 135 Original *Mary*: three-dimensional hypothetical profile view. (drawing JPO)

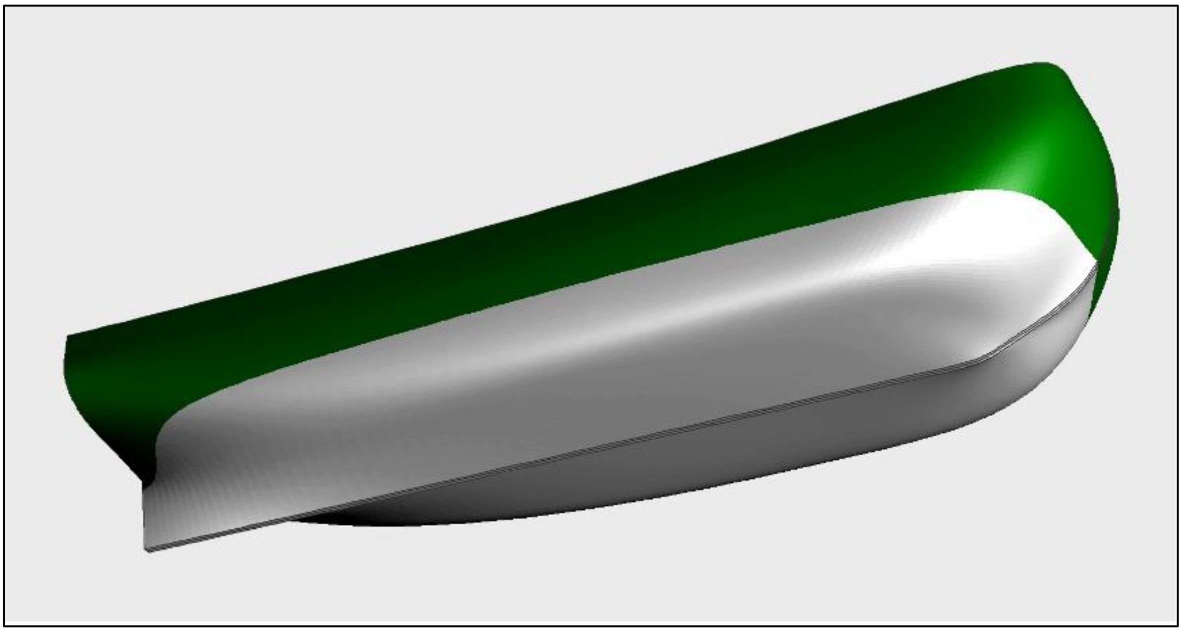


Figure 136 Original *Mary*: three dimensional hypothetical rendering of the. This view shows the typical bluff bow of a Dutch ship of the period. (Drawing JPO)

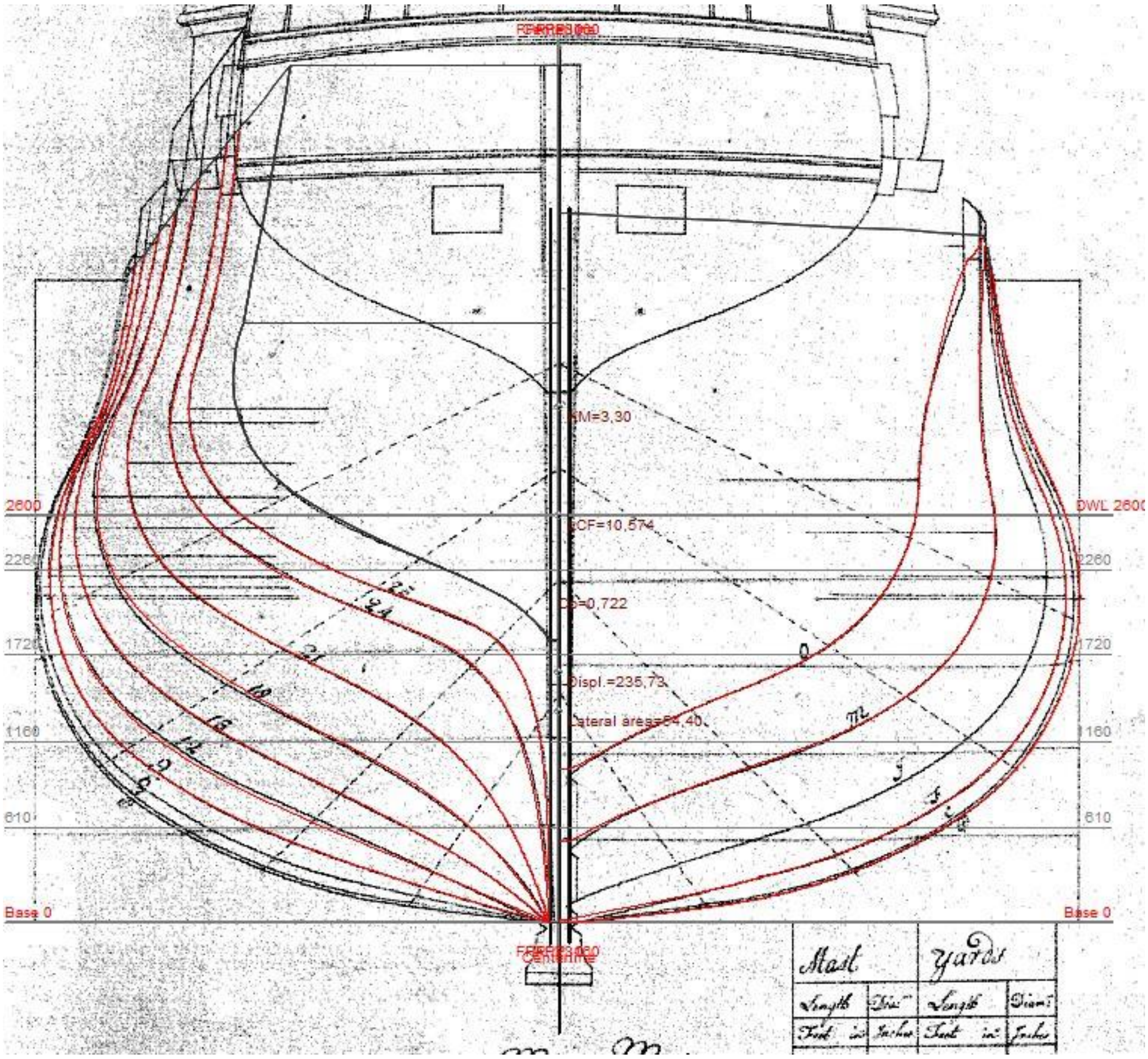


Figure 137 *Katherine* yacht: original body plan of the Katherine with the body plan obtained in DELFTship (in red) superimposed. (Drawing JPO)

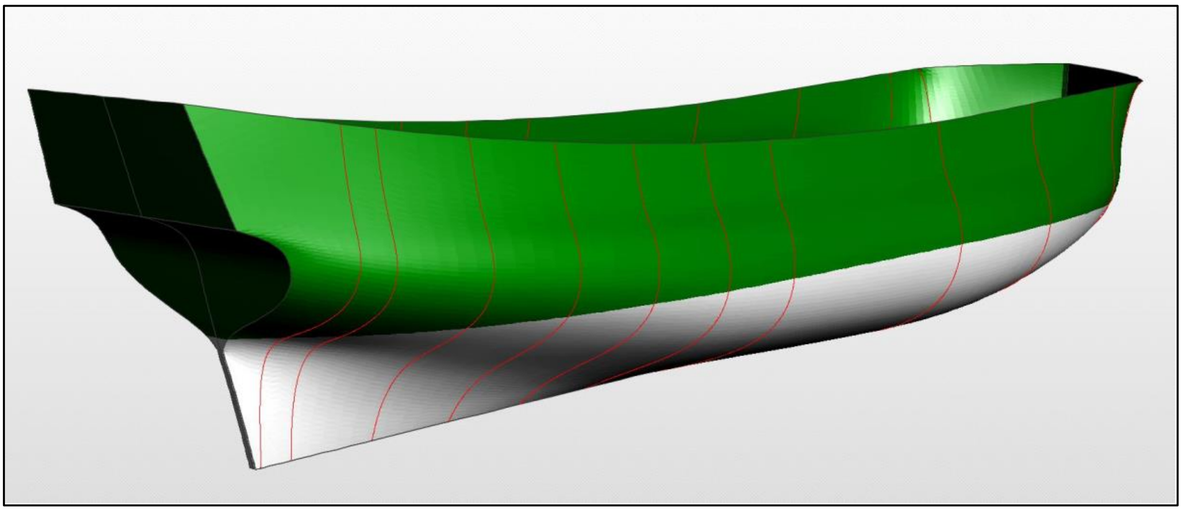


Figure 138 *Katherine* yacht: three-dimensional view. (Drawing JPO)

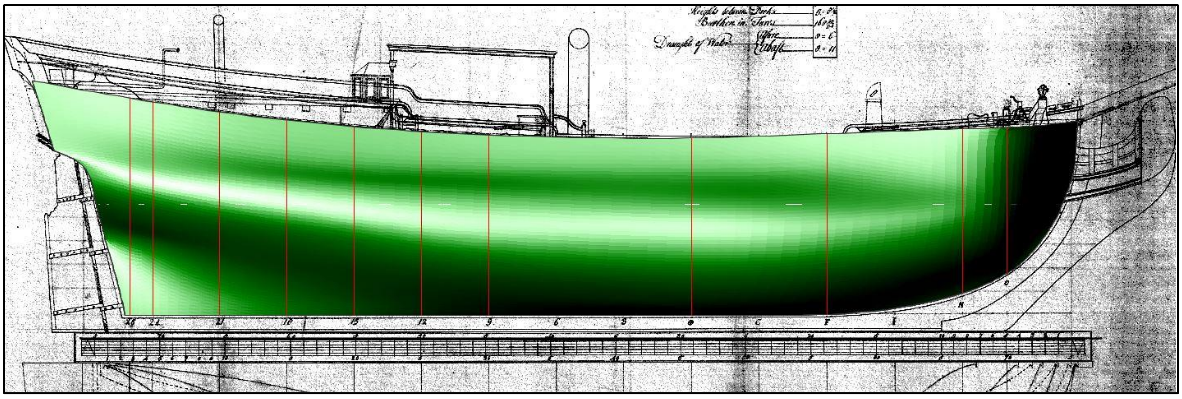


Figure 139 *Katherine* yacht: overlay of the 3-D model onto the original profile drawing. Note that the stem and keel have not been modelled at this stage. (Drawing JPO)

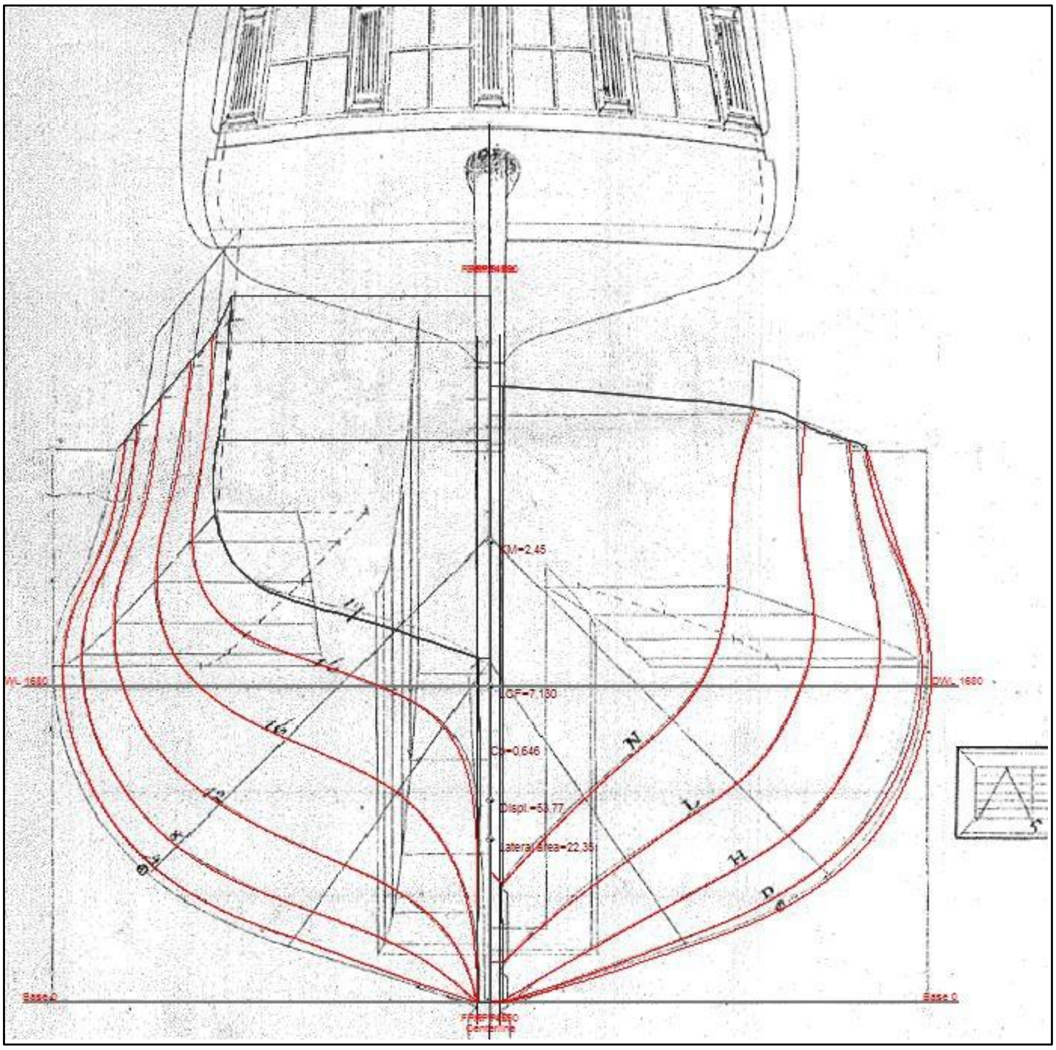


Figure 140 *Queenborough* yacht: original body plan of the Katherine with the body plan obtained in DELFTship (in red) superimposed. (Drawing JPO)

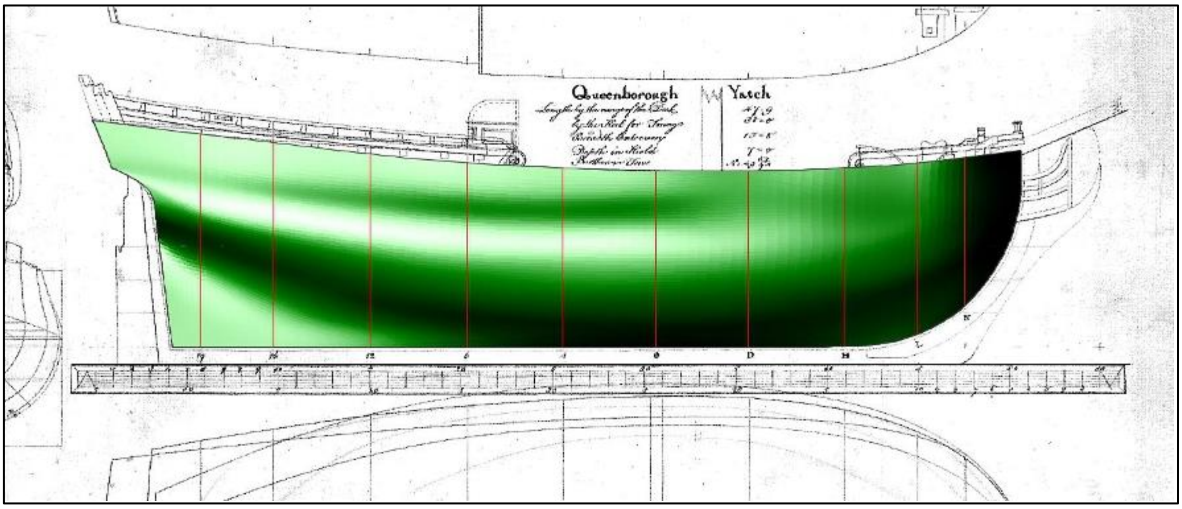


Figure 141 *Queenborough* yacht: overlay of the 3-D model onto the original profile drawing. (Drawing JPO)

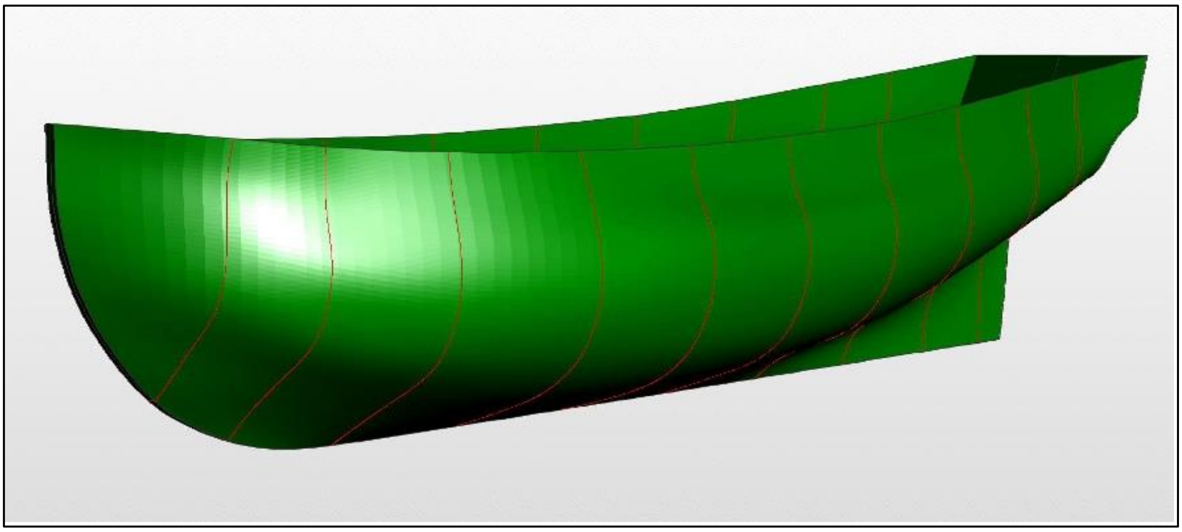


Figure 142 *Queenborough* yacht: three-dimensional view. (Drawing JPO)

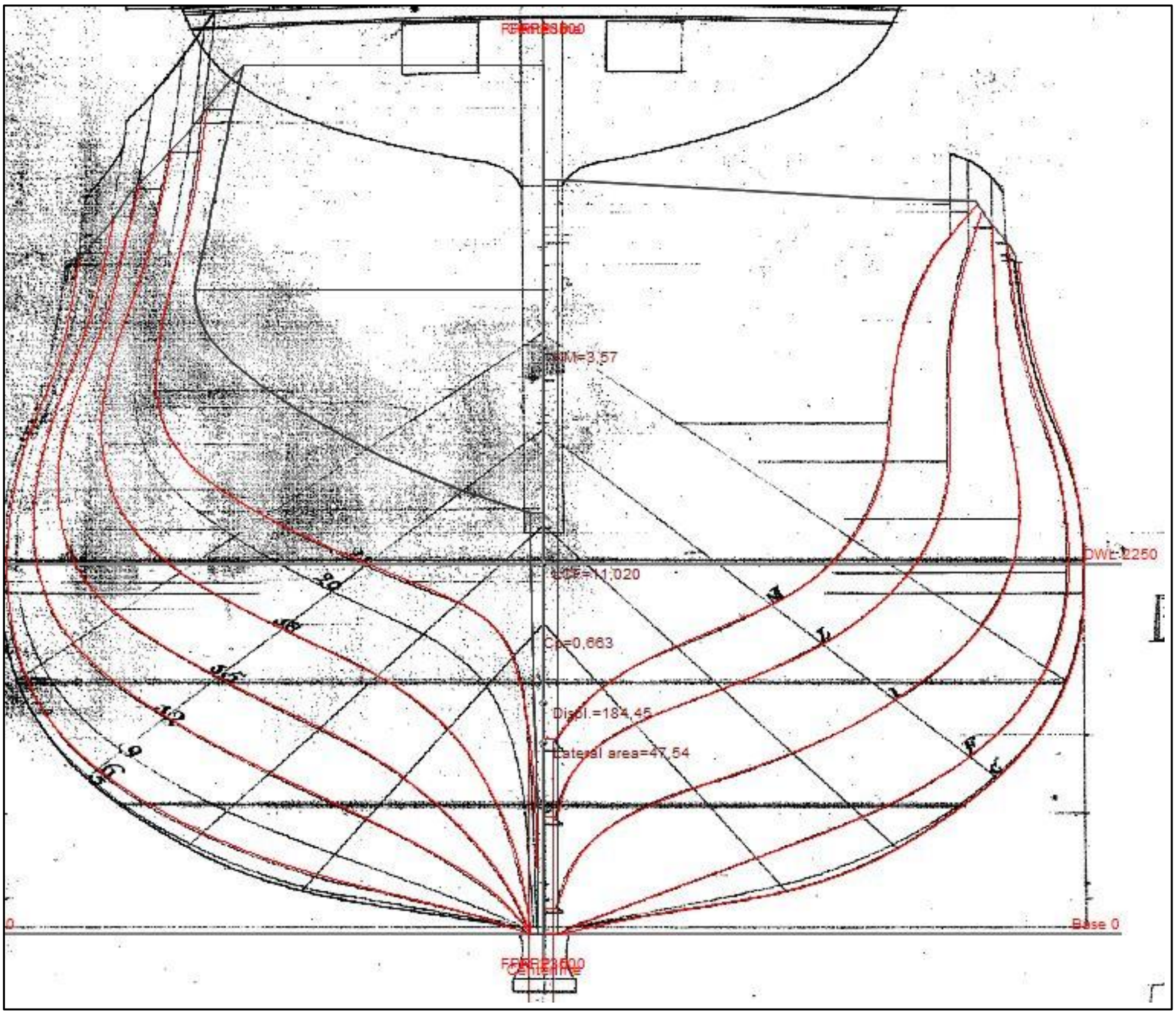


Figure 143 *Mary, 1764*: original body plan of the Katherine with the body plan obtained in DELFTship (in red) superimposed. (Drawing JPO)

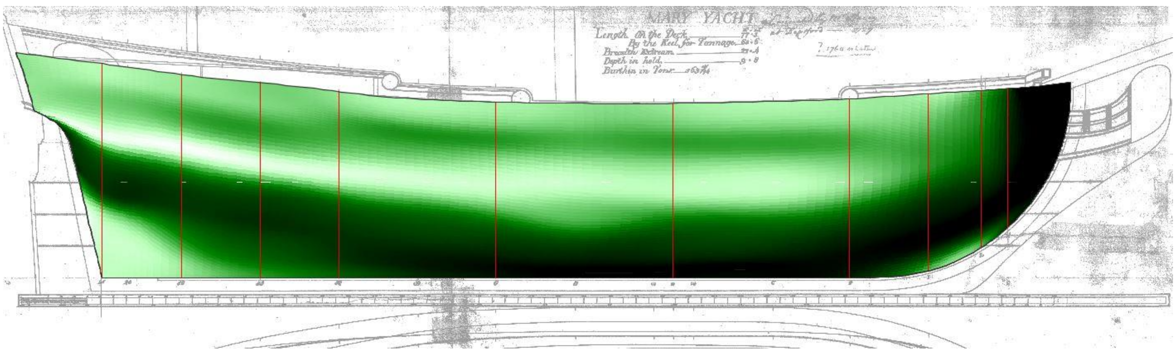


Figure 144 *Mary, 1764:* Overlay of the 3-D model onto the original profile drawing. (Drawing JPO)

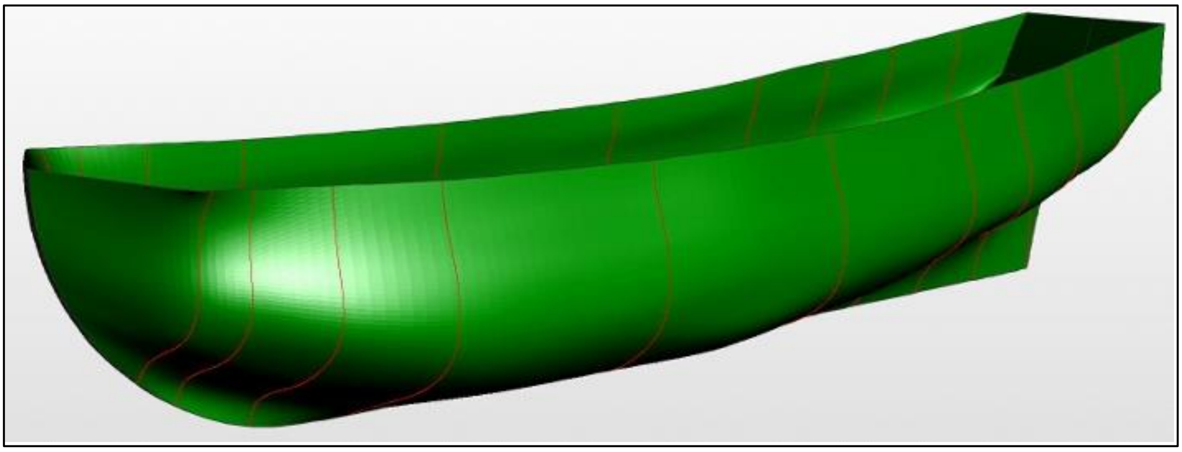


Figure 145 *Mary, 1764:* Three-dimensional rendering. (Drawing JPO)

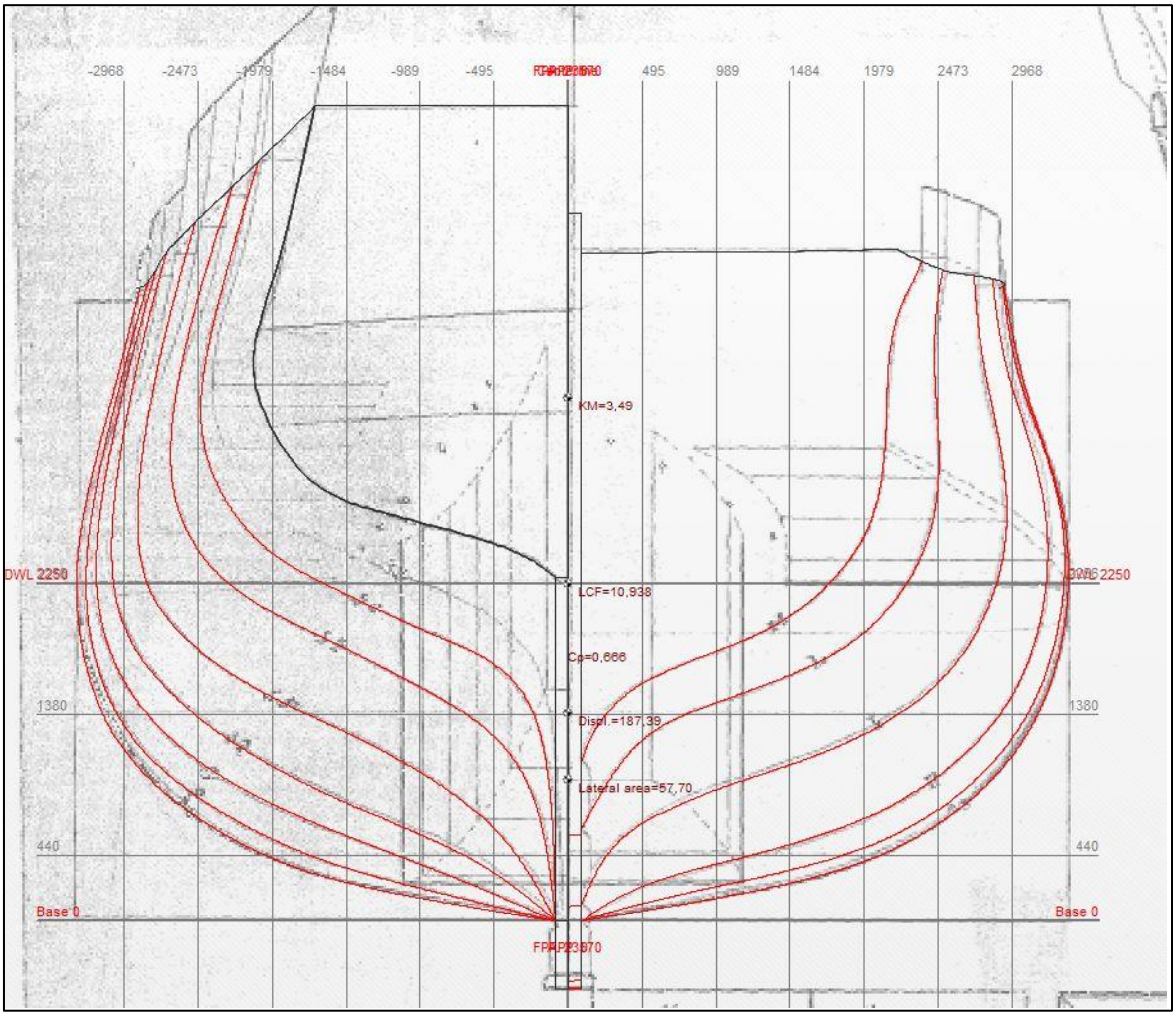


Figure 146 *Mary, 1772:* original body plan of the Katherine with the body plan obtained in DELFTship (in red) superimposed. (Drawing JPO)

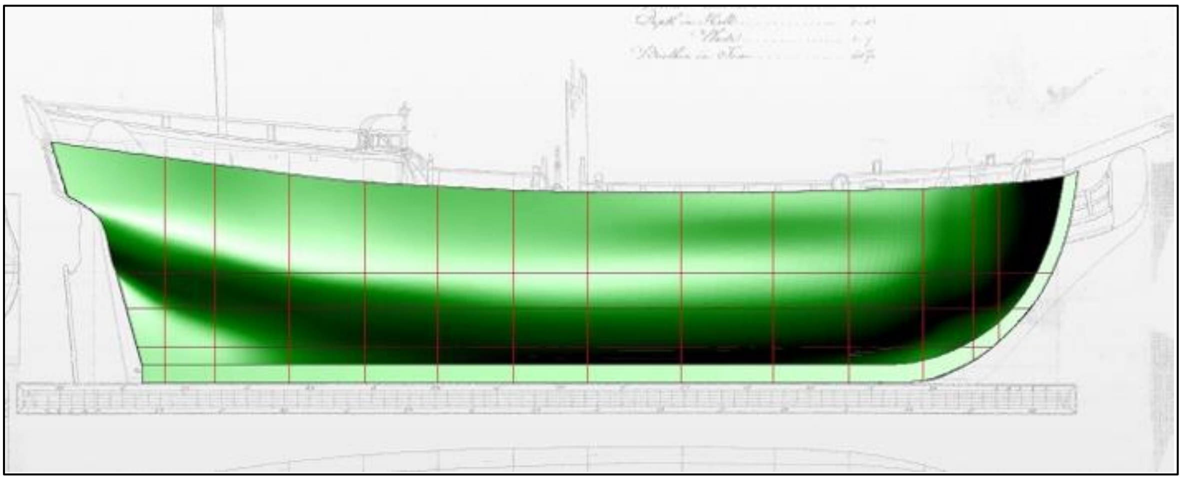


Figure 147 *Mary, 1772:* Overlay of the 3-D model onto the original profile drawing. (Drawing JPO)

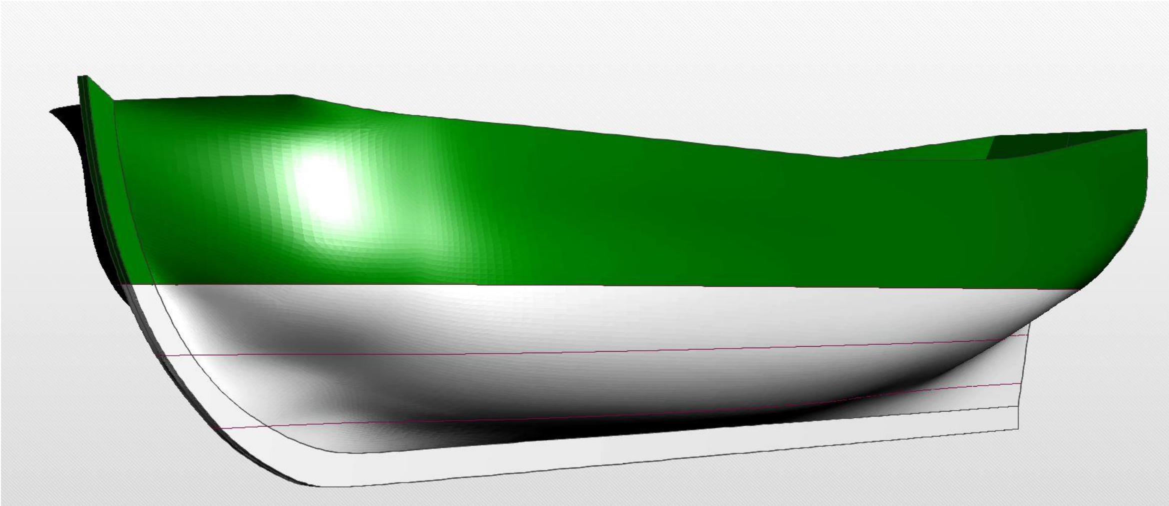


Figure 148 *Mary 1772:* three dimensional view from ahead of the. (Drawing JPO)

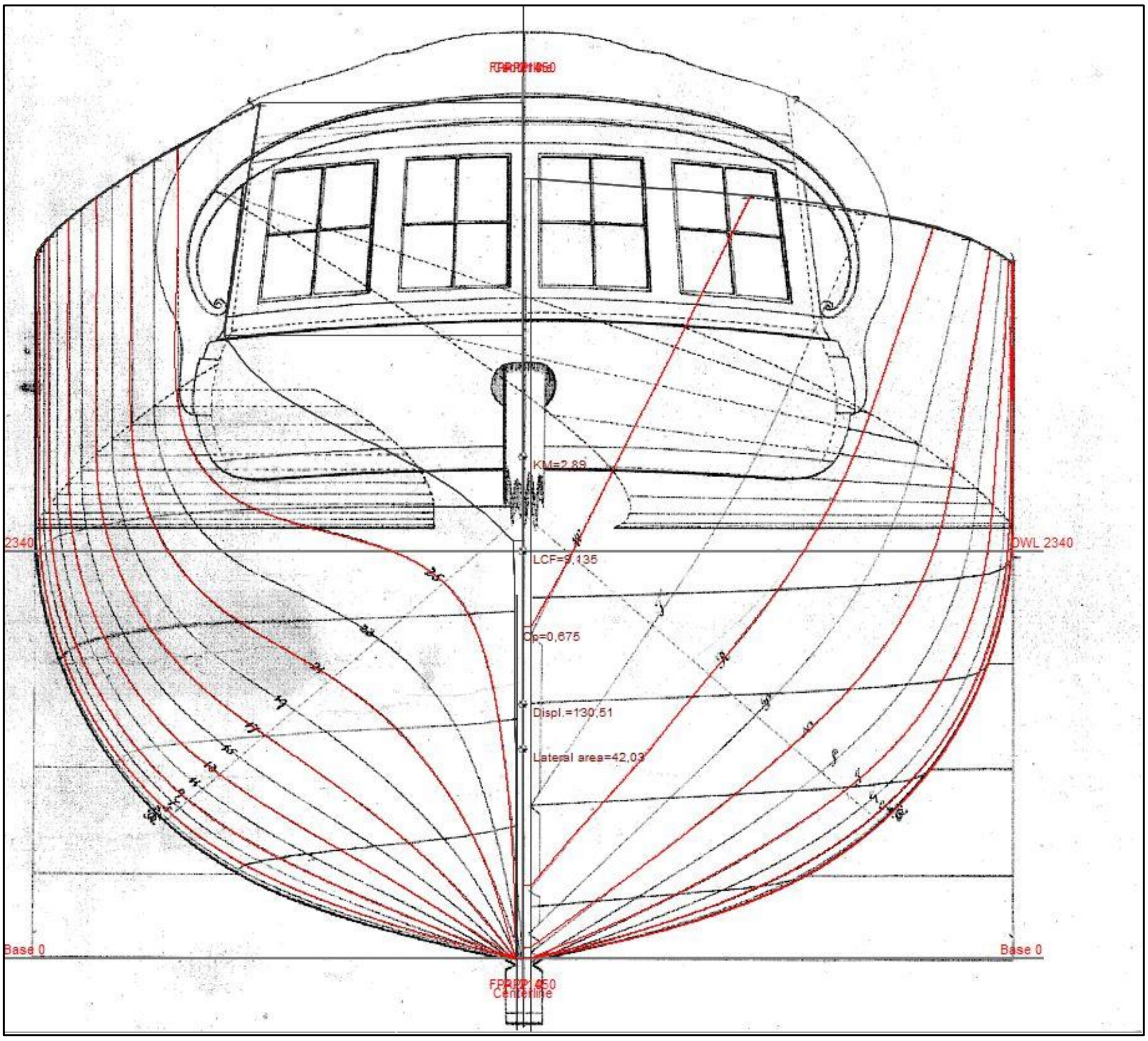


Figure 149 *The Commissioner's Yacht*: original body plan of the Katherine with the body plan obtained in DELFTship (in red) superimposed. (Drawing JPO)

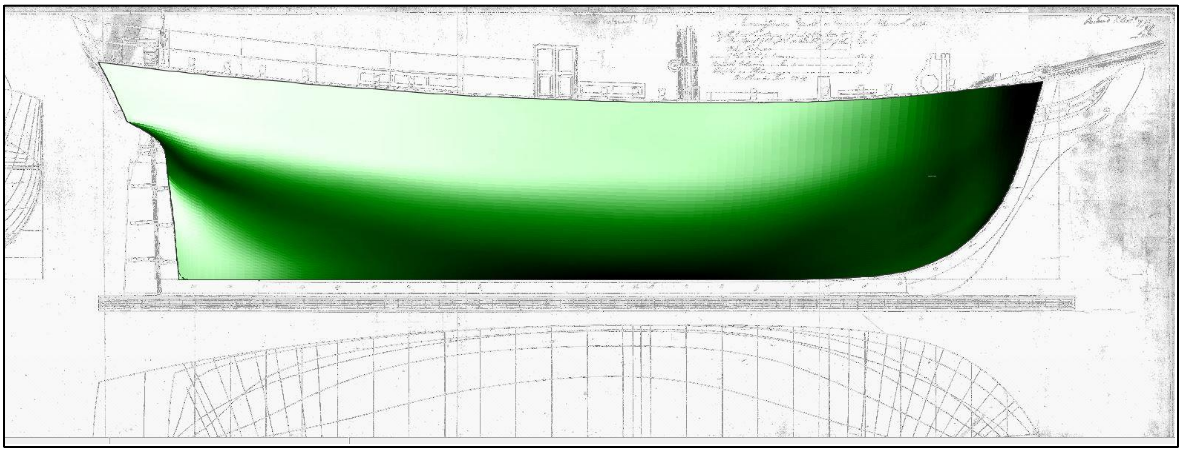


Figure 150 *The Commissioner's Yacht:* overlay of the 3-D model onto the original profile drawing. (Drawing JPO)

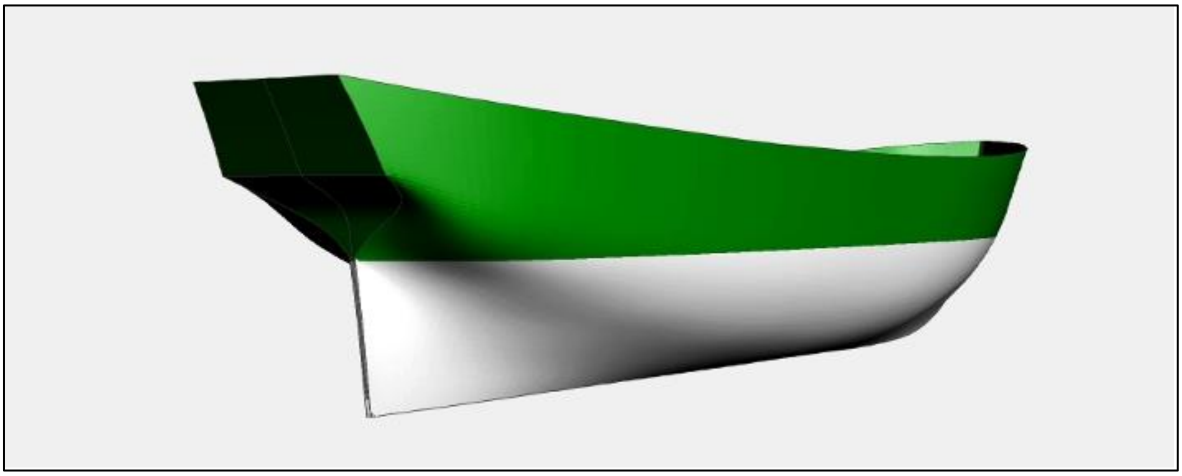


Figure 151 *The Commissioner's Yacht:* view from the starboard quarter. (Drawing JPO)

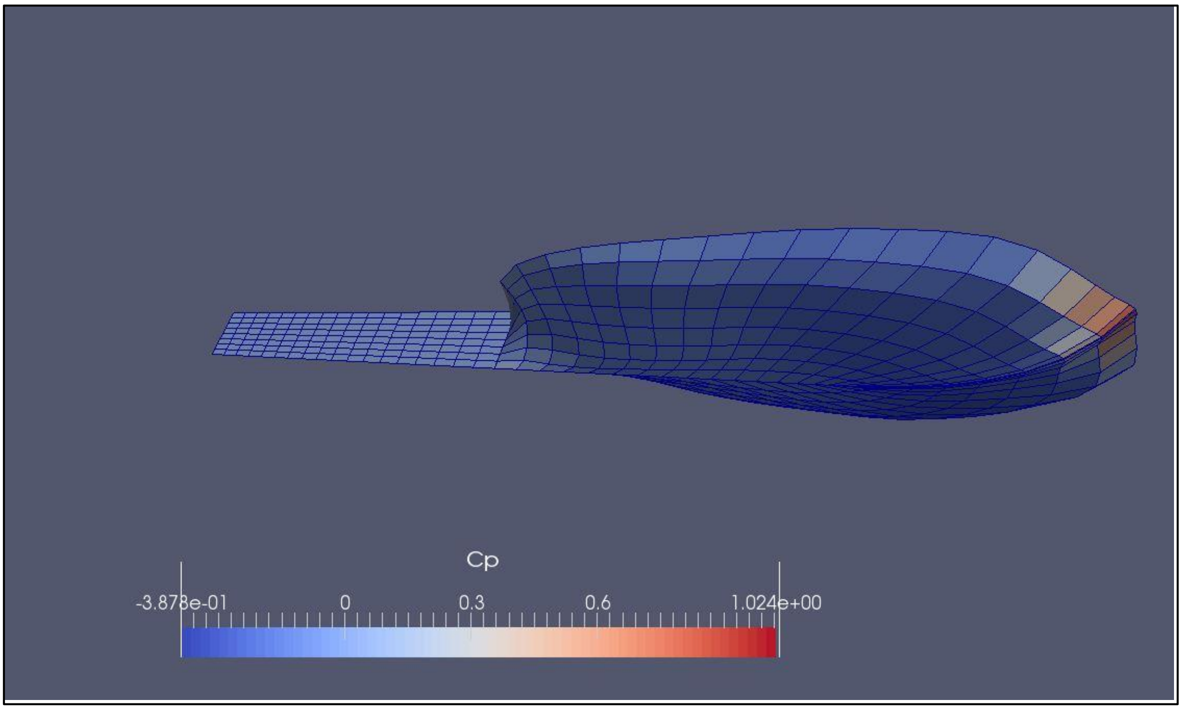


Figure 152 Panels in which PALISUPAN divides the underwater surface of the hull and wake. The colours represent the pressure (in non-dimensional coefficient form). Higher values are shown in red and lower values in blue. A free software called Paraview has been used in order to produce this image and visualise the output data produced by PALISUPAN. (figure JPO)

Chapter 2: Tables

Table 1 16th and 17th century ship design treatises analysed in this thesis.

16th AND 17th CENTURY TREATISES			Language	Design	Construction	Rigging
1578	*A Booke Called the Treasure for Travellers, ...*	W. Bourne	English	✓		
1587	*Instruccion nautica para el buen uso y regimiento de las naos, su traza.....*	D. Garcia de Palacio	Spanish	✓	✓	✓
c.1580	*Fragments of English Shipwrightry*	M. Baker	English	✓		✓
c.1620	*A treatise on Shipbuilding*	Wells (?)	English	✓		
1643	*Hydrographie contenant la Theorie et la practique de toutes les parties de la navigation*	G. Fournier	French	✓	✓	✓
1664	*Compleat Shipwright*	E. Bushnell	English	✓		✓
1670	*Deane's Doctrine*	A. Deane	English	✓	✓	✓
1671	*Aeloude en hedendaegsche scheepsbouw en bestier*	N. Witsen	Dutch	✓	✓	✓
1697	*De Nederlandse Scheeps-bouw-konst. Open Gestelt*	C. van Yk	Dutch	✓	✓	

Table 2 18th century ship design treatises analysed in this thesis.

18th CENTURY TREATISES			Language	Design	Construction	Rigging
1706	The Accomplish'd Ship-Wright and Mariner	J. Hardingham	English	✓		✓
1711	The Ship-builders Assistant	W. Sutherland	English	✓	✓	✓
1717	Britains Glory or Shipbuilding Unvail'd	W. Sutherland	English	✓	✓	✓
1717	The Prices of the Labour	W. Sutherland	English			
c.1732	Oservaziones que se Pratican para la Delineacion de Navios	G, Aizpurua	Spanish	✓	✓	✓
1755	The Ship Builder's Assistant or Marine Architecture	W. Sutherland	English	✓	✓	✓
1758	Élémens de l'Architecture Navale	D. du Monceau	French	✓	✓	✓
1765	A Treatise on Ship-building and Navigation in Three Parts	M. Murray	English	✓	✓	
1789-90	Delineaciones o figuras de construcción	M. Arrospide	Spanish	✓		
1768	Architectura Navalis Mercatoria	F. Chapman	Swedish (English translation)	✓		

Table 3 Royal yachts (JPO, compiled from Madge, T. 1997. *Royal Yachts of the World*. p. 182)

Charles II yachts			Principal dimensions						
Name	**Built**	**Lost**	**Length ft**	length **m**	**Beam ft**	beam **m**	**Draught ft**	draugt **m**	**Approx tonnage**
Mary	1660	1675	52	15,85	19	5,79	8	2,44	100
Royal Escape	--	--	30	9,14	15	4,57	7	2,13	34
Anne	1661		52	15,85	19	5,79	7	2,13	100
Bezan	1661		34	10,36	14	4,27	7	2,13	35
Katherine (1)	1661		49	14,94	19	5,79	7	2,13	94
Minion	--	--	28	8,53	12	3,66	5	1,52	22
Charles (1)	1662		36	10,97	14	4,27	7	2,13	38
Jemmy	1662		31	9,45	13	3,96	6	1,83	25
Henrietta	1663		52	15,85	19	5,79	7	2,13	104
Merlin	1666		53	16,15	20	6,1	6	1,83	109
Monmouth	1666		52	15,85	20	6,1	8	2,44	103
Navy	1666		48	14,63	18	5,49	8	2,44	74
Saudadoes	1670		50	15,24	18	5,49	8	2,44	86
Cleveland	1671		53	16,15	21	6,4	8	2,44	107
Queenborough	1671		30	9,14	13	3,96	7	2,13	29
Deale	1673		32	9,75	13	3,96	6	1,83	28
Isle of Wight	1673		33	10,06	13	3,96	6	1,83	30
Kitchen	1674		52	15,85	20	6,1	9	2,74	103
Katherine (2)	1674		56 (36)	17,07	21	6,4	9	2,74	135
Portsmouth (1)	1674		57	17,37	21	6,4	7	2,13	133
Charles (2)	1675		54	16,46	21	6,4	8	2,44	120
Charlot	1677		62	18,9	21	6,4	9	2,74	142
Mary (2)	1677		67	20,42	22	6,71	9	2,74	166
Henrietta (2)	1679		65	19,81	22	6,71	8	2,44	162
Izabella Bezan	1680		46	14,02	16	4,88		0	52
Fubbs	1682		63	19,2	21	6,4	10	3,05	148
Isabella	1683		60	18,29	19	5,79	12	3,66	144

Table 4 Principal dimensions of the yachts of Charles II of English made for which there are near-contemporary plans. Dimensions obtained from plans (JPO).

Yacht		Length	Keel length	Max Beam	Depth of hold	Burthen in Tuns	Displacement (metric tonnes) [1]
Katherine	Feet	75' 11"	62' 7"	22' 6"	9' 1/2"	168 12/94	---
	m	23.14	19.1	6.85	2.75	---	182.98
Queenborough	Feet	47' 9"	38' 0"	15' 8"	7' 0"	49 57/94	---
	m	14.55	11.58	4.77	2.13	---	53.72
Mary 1764	Feet	77' 1"	61' 6"	22' 4"	9' 8"	163 14/94	---
	m	23.5	18.75	6.81	2.95	---	184.45
Mary 1772	Feet	77' 4"	62' 9 5/8"	22' 5 1/4"	10' 10 1/2"	168 18/94	---
	m	23.57	19.14	6.84	3.31	---	187.39
Mary 1783	Feet	77' 4"	62' 9 5/8"	22' 5 1/4"	10' 10 1/2"	168 18/94	---
	m	23.57	19.14	6.84	3.31	---	---
Commissioner's Yacht	Feet	67' 1"	53' 9"	18' 11"	11' 8"	102 18/94	---
	m	20.45	16.38	5.76	3.56	---	130.51
	[1]	The displacement has been calculated to an estimated waterline situated at the point of maximum breadth. It likely that the real draft would be lower than this.					

Table 5 Different aspects in which this thesis has studied hull conception. The core information would have a string innate component, thus it is common to all traditions. On the other hand, the storage mechanisms and the strategies to develop 3-D hull surface represent cultural choices, particular to the technological trajectory of each tradition (Table JPO)

	Core information stored for the conception of hull shape		Mechanism used to store information				Strategy to develop 3-D hull surface	
			Backbone		Master section			
	Backbone	Master section	Geometry	(2) Physical tool	(1) Geometry	(2) Physical tool	Geometry Rising and narrowing	Longitudinal fairing
Early modern frame-first	✓	✓	✓		✓	(2)	✓	✓
Ancient Mediterranean shell-first	✓	✓	✓		✓	(2)	✓	✓
Early modern bottom-based	✓	✓	✓		✓	✓		✓
Northern European clinker-tradition	✓	✓	✓		(3)	✓		✓

(1) This is either an implicit rule, recorded in writting, or explicitly derived from archaeological material.
(2) This could be a full sized template or a tool in which shape is stored. For example a boat-level, a story stick or similar device
(3) Although methods to define the shape of the master section based on constructive-geometry have not been identified in the archaeological or ethnographic record, simple geometric procedured based on the control of bevel angles have been suggested in the literature

Table 6 Results of test in 8.2.1. The results show that the differences in displacement and hull area are small enough to be negligible. However, the reduction of GM by 16.69% and 31.86% would have a significant impact on the initial stability of the ship (Table JPO)

Hull	(a)	(b)	(c)
Displacement (U^3)	31495	32034	31721
% difference in displacement with respect to hull (a)	–	1.71	0.72
Area of Hull + Deck (U^2)	12310.8	12169	11875.2
% difference in total area with respect to hull (a)	–	-1.15	-3.54
GM (assuming Centre of Gravity at waterplane) (U)	7.25	6.04	4.94
% difference in GM with respect to hull (a)	–	-16.69	-31.86

Note: these figures should be used for comparison only.

Dimensions of the hulls:

Length: 130 Units
Beam: 40 Units
Draft: 10 Units

Appendix A Arnoul's description of Dutch ship construction and its influence in the current narrative

The aim of this appendix is to analyse the manner in which Arnoul's account of 17th century Dutch shipbuilding practices was translated and interpreted by Hasslöf's in his influential papers which helped establish the current narrative which explains the manner in which Dutch bottom-based builders approached the task of shaping their hulls. It will be argued that the contents of Arnoul's original account were misinterpreted by Hasslöf, leading to an interpretation which is not supported by the evidence.

A.1 Arnoul's account and its relevance

In 1670 a Frenchman, Mr. Arnoul, was sent by the then Minister Colbert to 'spy' the shipbuilding procedures followed in Dutch and English shipyards.[2] He wrote an account that has been used to interpret how Dutch shipyards of the period built their hulls. According to Arnoul's brief account Dutch shipwrights started by building the bottom shell-first and once it had been planked up internal reinforcements (floors and frames) were introduced. The topsides were planked in a frame-first fashion by attaching planking to these pre erected frames.

Arnoul's text was used by Hasslöf in support of his shell-first versus frame-first paradigm, and thus it will be analysed here. The following sections will show that Hasslöf's translation of Arnoul's text is flawed. It will be highlighted that Arnoul's text was used several times by Hasslöf in different publications, and that each time he used different version of the translations. Furthermore, there is a clear evolution in the translations and subsequent references to the text by Hasslöf. In particular, the change of some key words within the text alter the message of the original text, effectively reinforcing and supporting the theories proposed by Hasslöf in his 1957, and 1972 papers.

The following paragraphs will compare the original text and Hasslöf's 1963 and 1972 translations. The analysis will show that the meaning of the original text could have been interpreted very differently to the way that Hasslöf did. It is a very short text. However, its importance as one of the foundations of the shell-first frame-first paradigm justifies the analysis.

[2] Arnoul. 1670. *Remarques Faites par le Sieur Arnoul*

In the following sections the original text and Hasslöf's two translations will be reproduced followed by an analysis and comparison of individual sentences of each of the three texts.

A.2 The original 1670 French text

La premiere que j'y ay remarqué, c'est que pour l'ordinaire en France on commance a poser les varangles immediatement après avour dressé la quille. En Hollande, au contraire, ils commancent par le bordage et netaillent les varangles qu'après avoir posé jusques à dix ou douze bordages. Ils sçavent la largeur qu'ils doivent donner à l'avant, a l'arriere et au milieu, et conduisent ainsi à l'oeil le galbe de leur vaisseau, qu'ils tournent de quelle maniere ils veullent, à cause qu'ils ont la mesme facilité d'agir par le dedans comme par le dehors. Cela fait aussi que le bordage se joint bien mieux l'un contre l'autre. Et quant aux varangles, ils les taillent ensuitte selon le gabary que le bordage leur donne, sans qu'ils soient obligez de faire aucune division pour la couppe. Ce que je trouve de plus avantageux dans cette methode, c'est qu'ils ont le loisir de considerer le galbe de leur bastiment, et qu'ils le peuvent changer, jusques à ce qu'ils n'y trouvent plus rien à redire, au lieu que, quand les varangles sont un fois posées, un charpentier qui ne voit que pour lors son ouvrage ne peut reconnaistre ses deffauts que lorsqu'il n'est plus temps de s'en dedire, ce qui me fait conclurre que leur maniere de faire en ce point est la plus seure et la plus aisée, quoiqu'il semble que les règles dont se servent la pluspart de nos maistres charpentiers pour la coupe de leurs varangles soient plus certaines que l'oeil, qui n'a de fondement que sur la pratique et l'experience qu'il peut avoir acquise.[3]

A.3 Hasslöf's 1963 translation

' [...]. The first thing I have noticed is that as a rule in France one begins to place the floors immediately after laying the keel. In Holland, on the contrary, they begin with the planking and do not shape the floors until they have fitted as many as ten or twelve strakes. They know the width they should give forward, aft and amidships, and thus they get the form of their ship by-eye, shaping it in whichever manner they wish, since they have the same facility of working inside as outside. This also ensures that the planks fit much better against one another. And as to the floors, they then cut them according to the mould which the planking gives them without having to make any allowance for dubbing. The thing I find most advantageous in this method is that they have leisure to consider the shape of their vessel and can change it until they find nothing

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[3] *Arnoul. 1670. Remarques Faites par le Sieur Arnoul*
Hasslöf, O. 1957-8. Carvel Construction Technique, Nature and Origin. p.54

more to alter; whereas, when the floors are once placed, a carpenter who has not seen his work until then cannot recognise its faults until it is too late to rectify them. This makes me conclude that their method of working in this respect is the surest and easiest, though it seems that the rules used by most of our master-carpenters for cutting their floors are more certain than working by-eye, which is only founded on practice and experience'.[4]

A.4 Hasslöf's 1972 translation

[...]. The first thing I noticed was that in France the timbers are usually put up immediately after the keel has been laid. In Holland however, they begin by laying the planks and do not cut the ribs until they have laid ten or twelve planks. The width fore, aft and midships that the planking should have is marked out and they can follow with their eyes the lines of the ship so that they run freely, because they can just as easily make adjustments upwards as downwards. This means that it is easier to join the planks together. As for the ribs, they are cut later on the model that the planking gives them, without having to divide any of the sections. What I find most advantageous about this method is that one is free to judge the lines of the craft and can alter them according to need instead of having a builder who only sees the details of his own job and not his mistakes until it is too late, because the ribs are already in place. The conclusion I draw is that the method of working is in this case the safest and most convenient, although it would seem that the rules that our master craftsmen use for the framework are more reliable than eye measurements.[5]

A.5 Analysis of the text

The text will be divided in separate sections that will be analysed independently. The object of the analysis will be twofold. One objective of the analysis will be to establish if Hasslöf's translations were correct and if they convey the same message as the original did. Additionally, as both Hasslöf's translations were published within a space of 9 years, it will be interesting to observe if both translations convey the same message or, on the contrary, if the changes in the translations introduced changes in the 'flavour' of the message. Following this, a conclusion will be offered to suggest that Hasslöf's interpretation offers a distorted view of the contents of the original text written by Arnoul in 1670.

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4 Hasslöf, O. 1963. Wrecks, Archives and Living Tradition. p.170

5 Hasslöf, O. 1972. Main Principles in the Technology of Ship-Building. pp.59-60

In order to simplify the reading, the three texts will be referred to as: Arnoul 1670, Hasslöf 1963 and Hasslöf 1972. Each of the following sections will first reproduce a few sentences of Arnoul 1670, followed by the same text in both of Hasslöf's translations. Any discrepancies on the translations and their relevance with regards to the accuracy of the interpretation of the original text will be pointed out in this section. Some key-words will be highlighted as necessary.

A.5.1 Sentences 1 and 2 of the original text:

Arnoul 1670:

'La premiere que j'y ay remarqué, c'est que pour l'ordinaire en France on commance a poser les ***varangles*** *immediatement après avour dressé la quille. En Hollande, au contraire, ils commancent par le bordage et netaillent les* ***varangles*** *qu'après avoir posé jusques à dix ou douze bordages.'*

Hasslöf 1963

'The first thing I have noticed is that as a rule in France one begins to place the **floors** immediately after laying the keel. In Holland, on the contrary, they begin with the planking and do not shape the **floors** until they have fitted as many as ten or twelve strakes.'

Hasslöf 1972

'The first thing I noticed was that in France the **timbers** are usually put up immediately after the keel has been laid. In Holland however, they begin by laying the planks and do not cut the **ribs** until they have laid ten or twelve planks.'

Comparison of Hasslöf 1963 and 1972:

The 1963 translation is correct and reflects the contents of the original. However, the 1972 translation is incorrect.

A comparison of the 1963 and 1972 translation shows that in the 1972 translation the word ***varangles*** –correctly translated as **floors** in the 1963 translation–, has been translated as **timbers**, and **ribs**. The introduction of these general, non-specific terms, like **timbers** and **ribs**, instead of the specific **floors** cannot be justified as they introduce a high level of ambiguity to a text that was specific and clear as to the area of the hull it was describing. The meaning of the original text is lost, and instead of reflecting a practice that was specific of a part of the bottom of the ship only, with the 1972 translation, it could refer to any area of the ship that could include the bilges and even the topsides. This is a most important aspect that will be reflected throughout the text in the following analysis. Its importance will be discussed accordingly at the end of the analysis.

A.5.2 Sentence 3 of the original text

Arnoul 1670:

Ils sçavent la largeur qu'ils doivent donner à l'avant, a l'arriere et au milieu, et conduisent ainsi à l'oeil le galbe de leur vaisseau, qu'ils tournent de quelle maniere ils veullent, à cause qu'ils ont la mesme facilité d'agir par le dedans comme par le dehors.

Hasslöf 1963 [6]

(1) They know the width they should give forward, aft and amidships, *(2)* and thus they get the form of their ship by-eye, *(3)* shaping it in whichever manner they wish, since they have the same facility of working inside as outside.

Hasslöf 1972

(1) The width fore, aft and midships that the planking should have is marked out and *(2)* they can follow with their eyes the lines of the ship so that they run freely, *(3)* because they can just as easily make adjustments upwards as downwards

Comparison of Hasslöf 1963 and 1972:

Yet again, a comparison of the 1963 and 1972 translation shows that in the 1972 translation the text has been changed in such a way that introduces ambiguity and reduces the precision of the original text.

Thus, the original (1) ‘ They know the width they should give forward, aft and amidships’ – correctly translated in the 1963 version, conveys a strong sense of pre-determined ideas about the dimensions of the bottom– However, for no clear reasons it is converted in the 1972 version into ‘The width fore, aft and midships that the planking should have is marked out’. The impression of pre-design, of pre-conceived idea of the shape of the bottom, is totally lost in the 1972 translation.

(2) The reference to the ‘eye’ in the 1963 translation does not mean that the shipwright designed the shape of the hull by ‘eye’, without a sense of pre-design. The eye in this case would be a tool to judge that lines were fair and correct, but always within the conceptual design imposed by the pre-determined widths of the bottom specified in part (1) of the sentence.

[6] The analysis is subdivided in three parts numbered **(1)**, **(2)** and **(3)**

However, again, the translation in 1972 of the third part of the sentence is striking. The 1972 translation ‘because they can just as easily make adjustments upwards as downwards’ conveys the idea defended elsewhere by Hasslöf that shell-builders –as the ones described by Arnoul– could modify the shape of the hull as the ship was being constructed. Hence, Hasslöf's reference to making adjustments to the planking by moving it upwards or downwards. According to this translation planks could be tilted up or down to suit the particular wishes of the builder as he laid each plank. However, the original and the 1963 translation describe a different situation. Both describe a particularity of Dutch construction when compared to the French tradition best known by Arnoul. In French shipbuilding as in any other frame-first building tradition, the framing inside the hull make working from within the hull difficult, thus shipwrights must work almost exclusively from the outside in order to plank the hull. The particularities of the Dutch method allowed shipwrights good access to the planking from within the ship as well as from the outside, as there were no floors in the way at this stage that Arnoul is describing: the bottom. Therefore, this noteworthy aspect of Dutch shipbuilding is mentioned in the original and not a non-existing practice of tilting planks up or down at the whim of the shipwright in order to alter the transversal shape of the hull as it is being built as is suggested by Hasslöf's erroneous 1972 translation.

A.5.3 Sentence 4 of the original text

It has not been analysed as it has no especial relevance.

A.5.4 Sentence 5 of the original text

Arnoul 1670:

*(1) Et quant aux **varangles**, ils les taillent ensuitte selon le gabary que le bordage leur donne, (2) sans qu'ils soient obligez de faire aucune division pour la couppe.*

Hasslöf 1963

(1) And as to the **floors**, they then cut them according to the mould which the planking gives them *(2)* without having to make any allowance for dubbing.

Hasslöf 1972

(1) As for the **ribs**, they are cut later on the model that the planking gives them, *(2)* without having to divide any of the sections.

<u>Comparison of Hasslöf 1963 and 1972:</u>

The translation of (1) is correct in the 1963 translation, and incorrect in the 1972 translation. However, the translation of the second part of the sentence (2), is not correct in the 1963 translation. The 1972 translation of this part of the sentence is more accurate, although it's meaning its elusive.

This is again an instance where a precise word –***varengle***, rightly translated as **floor** in the 1963 translation– is translated in the 1972 version using a word that is synonymous with frame: **rib**. The specificity of **floor** and the idea it conveys that the process described refers to the bottom area of the ship only is lost. The 1972 translation could give the impression that this process could refer to the topsides and bilges of the hull as well, as **ribs**, or frames are members that extend to these areas. Once again, the 1972 translation introduces ambiguity –with respect to which area of the hull is being described– in a description where there was none.

A.5.5 Sentence 6 in the original text

Arnoul 1670:

Ce que je trouve de plus avantageux dans cette methode, c'est qu'ils ont le loisir de considerer le galbe de leur bastiment, et qu'ils le peuvent changer, jusques à ce qu'ils n'y trouvent plus rien à redire, au lieu que, quand les ***varangles*** *sont un fois posées, un charpentier qui ne voit que pour lors son ouvrage ne peut reconnaistre ses deffauts que lorsqu'il n'est plus temps de s'en dedire...*

Hasslöf 1963

The thing I find most advantageous in this method is that they have leisure to consider the shape of their vessel and can change it until they find nothing more to alter; whereas, when the **floors** are once placed, a carpenter who has not seen his work until then cannot recognise its faults until it is too late to rectify them.

Hasslöf 1972

What I find most advantageous about this method is that one is free to judge the lines of the craft and can alter them according to need instead of having a builder who only sees the details of his own job and not his mistakes until it is too late, because the **ribs** are already in place.

<u>Comparison of Hasslöf 1963 and 1972:</u>

The 1963 translation is correct. It conveys the idea of the original, stating that shell-builders could rectify their design easier that frame-first builders, who once they had erected the pre-manufactured **floors** could often find out that, especially at the hull's ends, the shapes were unsuitable.

As in the case of previous sentences, the 1972 translation is incorrect.

This is yet another case in which for reasons unknown, Hasslöf changes the perfectly correct and precise translation of 1963 –when he correctly translated ***varangle*** by **floor**– and translates, in 1972, the original ***varangle*** for **rib**, thus changing the message conveyed in the original text. While the original text –and Hasslöf's own 1963 translation– referred to **floors** and thus the bottom of the ship, the new 1972 text converts the **floors** into **ribs**, thus introducing ambiguity as to the area of the ship that the original writer was referring to. Again, the mention of ribs conveys the idea that this description applies to any area of the hull instead of to a small area of the bottom only.

A.5.6 Sentence 7 in the original text:

Arnoul 1670:

(1) *... ce qui me fait conclurre que leur maniere de faire en ce point est la plus seure et la plus aisée,**(2)** quoiqu'il semble que les règles dont se servent **la pluspart de nos maistres charpentiers** pour la coupe de leurs **varangles** soient plus certaines que l'oeil, **(3)** qui n'a de fondement que sur la pratique et l'experience qu'il peut avoir acquise*

Hasslöf 1963

(1) This makes me conclude that their method of working in this respect is the surest and easiest, *(2)* though it seems that the rules used by **most of our master-carpenters** for cutting their **floors** are more certain than working by-eye, *(3)* which is only founded on practice and experience.

Hasslöf 1972

(1) The conclusion I draw is that the method of working is in this case the safest and most convenient, *(2)* although it would seem that the rules that **our master craftsmen** use for the **framework** are more reliable than eye measurements.

<u>Comparison of Hasslöf 1963 and 1972:</u>

The 1963 translation is correct and reflects the contents of the original, while the 1972 is partially incorrect.

The first part (1) of the sentence is translated correctly in both translations and conveys the original message without any undue distortion, however, the same cannot be said of the second part of the sentence.

(2) Here again, it can be seen how an accurate and technically correct term has been wrongly translated in the 1972 translation. As a result the meaning of the original text –correctly

translated in the 1963 version– is distorted. Following with the suspiciously recurrent faulty translation of the original text, once again, the term ***varangles*** has been translated into **framework**, instead of the correct **floors**. As a consequence, and similarly to previous comments, the precision of the original is lost. Therefore, the original text that refers to part of the **bottom** of the ship only –precisely translated in the 1963 translation– loses its precision and becomes, by way of the poor choice of term an ambiguous text which could be applied to any area of the hull of the ship, as framework can refer to bottom, bilges or sides of the ship, including topsides and above deck areas.

It is interesting to note that in the 1972 translation Hasslöf again is influenced by his preconception, and mistranslates Arnoul in part (3) of the sentence when Arnoul is translated as saying that '**our** [French] master craftsmen' follow rules to shape the internal framing of their ships. This reference seems to suggest that according to Arnoul there are no other methods followed by French shipwrights of the time, when in fact this is not the case. The correct 1963 translation clearly conveys the idea that '**most** of our master-carpenters' follow these rules, leaving room for the idea that Arnoul was aware at least some master carpenters building in France were following different shipbuilding procedures, a fact that may not fit well within the paradigm defended by Hasslöf

A.5.7 Conclusions with regard to pre-design by Dutch shipwrights

Reading the original written by Arnoul in 1670 and the 1963 translation by Hasslöf, it could be concluded that Dutch shipwrights building in the Dutch flush traditions had a clear idea of the shape of the hull before its construction began. Thus, the three breadths of the bottom at three key pre-decided positions (forward, midship and aft) would define the shape of the bottom of the hull before the construction started. This may not seem like much in way of pre-design. However, if it is assumed that the method described by Arnoul is necessarily incomplete, as his description only amounts to a few sentences, and that much detail must evidently be lost due to the brevity of the account, the conclusion that it is a method that describes construction by-eye with no idea of pre-design cannot be necessarily inferred as Hasslöf did.

A.6 Conclusions with regards to Hasslöf's interpretation

The result of the analysis of both of Hasslöf's translations is striking. There is little to criticise to the 1963 translation. It conveys the original meaning in an objective manner, using the correct English terms in lieu of the original French terms used in Arnoul's text. However, in his 1963 paper Hasslöf expressed his theory that shell-builders and, thus, Dutch shipwrights had no means of pre-conceiving hull shape prior to the adoption of full frame-first building technique. Thus, although the wording of the translation is correct, Hasslöf used it to support his theory that shell builders had no mean of pre-design; that design happened simultaneously with construction. The previous analysis of the meaning of the original text seems to suggest that this conclusion is not necessarily correct. However, the 1963 paper his 1957 paper set the ground for maritime archaeologists and other scholars for the future. The effects can still be felt in the current literature.[7]

As it has been explained in previous sections, it is evident that Arnoul's text refers to parts of the bottom of the ship only, and from its text one could not conclude that the bottom and bilges and some parts of the sides were planked before internal transverse members –floors and futtocks– were introduced. However, this is precisely what Hasslöf did in his paper published in 1966 where the contents of the 1957 and 1963 papers were condensed. In this paper Hasslöf produced a new, more detailed and nuanced description of Dutch shell-first construction that reinforced his theories that stated that Dutch shipwrights of the period had no method of pre-design, and that most of the hull –not only a part of the bottom– was planked before the internal framing was introduced. Hasslöf did not provide additional evidence to further modify the description published in 1963. Instead, he referred the reader to the material published in the 1963 paper as support of the new, detailed description he was providing which is quoted below:

> '**When the shell below the waterline has been planked,** the lower parts of the **ribs, called the flooring and the futtock** are inserted in this, and are then extended upwards by means of the toptimbers.'(Highlights by JPO).[8]

It is striking that where in the 1963 paper Hasslöf translated the text correctly, in his 1966 paper quoted above he offered an account that cannot be substantiated following Arnoul's description. Nowhere in the original account by Arnoul is it said that the bottom and bilges and part of the sides **up to the waterline** are planked up before the internal floors, futtocks and toptimbers are added. Hasslöf's 1966 account is just not supported by the evidence he tries to put forward to justify it. However, if one does not have the original text at hand to contrast Hasslöf's claim, one is left with the impression that there are contemporary written texts that support his interpretation, when in fact this is not the case.

Hasslöf performed the final twist in his 1972 seminal work on ships and shipbuilding that has influenced maritime archaeology and studies of traditional ship-construction since. In his 1972 description of Dutch shell-first construction –criticised in previous sections– he published his new

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7 *Hasslöf, O. 1957-8. Carvel Construction Technique, Nature and Origin*. p.54

8 Hasslöf, O. 1966. Sources of Maritime History and Method of Research. p.137

translation of the original text by Arnoul which misrepresents the original text. Hasslöf’s new translation changed the contents of the text by ignoring the original references to the floors and wrongly translating them with incorrect terms like timbers, ribs, framework etc. rightly translated in the 1963 translation. The new terms chosen by Hasslöf seem to indicate that the method described a large area of the hull, when only the bottom was being mentioned in the original. Also he introduces the idea that Dutch shipwrights built and conceived simultaneously by tilting planks upwards or downwards at their whim during the building process, based on a mistranslation of the original.

This disparity of translations, and the fact that only the second translation is incorrectly translated in such a way that it shows a strong bias in the part of the translator, probably indicate the influence of his pre-conceived ideas and the weight of the, by then, established scholarship on the matter of hull conception by shell-builders. Irrespective of the causes of the flawed translation, Hasslöf's papers have helped to spread a concept that is based on no evidence at all; or at least, a concept for which Arnoul's account gives no support at all.

Appendix B Delineaciones of Figuras de Construcion[9] (sic). Transcription and English translation

NOTE: The two plans analysed in this appendix are included in the DVD and are identified with their reference number at the Museo Naval of Madrid, Spain.

Plan 1: mnm_pb_0047

Plan 2: mnm_pb_0048

They are included in folder: *Chapter 5/ 10-Delineaciones o figuras de construccion*

Figure 125 identifies the numbering system used in this appendix to refer to individual blocks of text within the plans.

Chapter 5 of this thesis has given a short description of the contents of these two very interesting large-format plans drawn by Manuel de Arrrospide in 1789 and 1790. These two documents provide clear references to tools and the conceptual approach to ship design used in commercial yards at the latter part of the 18th century, away from the pressures of state sponsored shipbuilding processes. They provide sufficient information to be able to describe a method of designing hulls which has no parallel in any of the treatises analysed, with the exception of some similarities with Fournier’s method described more than a century earlier. No method similar to Arrospide’s has been described in the literature. Thus it is explained here for the benefit of students of early modern ship design practices.

The plans have been identified in this thesis with the title *Delineaciones of Figuras de Construcion* (sic). These words appear in the opening sentence of plan 1 (figure 79) (Plan-1 block of text 1) [10] and can be translated as *Plots or Construction Figures*. Despite the reference to *Construction*, they describe the method of designing the three-dimensional shape of the hulls without any mention of construction features or methods. The author mentions several times local builders (see below: Plan-1 block of text 2 and Plan-2 block of text 1). The documents are signed in Portugalete. Therefore, he seems to be describing design practices in the shipyards of Portugalete which is close the city of Bilbao, in the Basque region of Spain. The document is very well drafted and

[9] In correct Spanish it should be spelt ‘Construcción’.

[10] Figure 128 identifies the numbering system used in this appendix to refer to individual blocks of text within the plans.

provides explanations in Spanish which describe the design process, albeit in a rather confused way. Both plans were drawn in consecutive years, the second being an attempt to clarify some of the ideas expressed on the first plan (Plan-2 block of text 1). Unfortunately the author did not specify who the intended readers of the plans were.

As described in chapter 5 the texts of the plans show that the author, Arrospide, had a limited command of the Spanish language, with numerous syntax and grammatical errors to justify this opinion. Moreover some of the expressions used by Arrospide indicates that, in some cases, he was translating literally from the Basque language. As a result some expressions within the text, which are grammatically correct in Spanish convey no real meaning and cannot be understood correctly unless one is familiar with the original Basque expression.[11] For example in Plan-1 block of text 2 (see footnote 22). The lack of punctuation throughout the text complicates further the challenge of interpreting the text.

Although Arrospide is described here as a person with a limited command of the Spanish language it should not be interpreted as meaning that he was uneducated. The quality of his plots and his neat handwriting[12] seem to suggest a certain level of education.[13] His level of Spanish must be understood within a society where Basque was still the predominant language and Spanish would have been reserved for formal communication of an official nature. In such a scenario, Arrospide's level of Spanish would not have been a problem in spoken conversation but would have presented a challenge, as it is shown in the plans, in formal written communication.[14] Arrospide's

[11] The present author's mother languages are both Basque and Spanish. As a consequence, it has been possible to interpret the often confusing syntax and awkward sentences in a way that a non-Basque speaker, most probably, would not have been able to do.

[12] If Arrospide had used someone to write the texts it is expected that the writer would have used some punctuation marks and correct syntax which would have made the text more readable.

[13] In their study *Artistic and Building Activity in the Notaries of Bilbao During the 18th Century* A. Leis Alava and I. Madariaga Varela provide numerous entries in local official documents in which Manuel de Arrospide from Portugalete is described as a Master carpenter. He is shown to be responsible for the construction of the piers in the port of Portugalete (Biscay) and other wooden structures (Leis Alava, A. and Madariaga Varela, I. 2012. Actividad artística y construcción en los notarios de Bilbao durante el siglo XVIII. p. 109, 162, 343, 358

[14] This situation is still commonplace in certain areas of the Basque region where the present author has met many examples of skilled professionals –often running successful businesses– whose basic, 'unlearned', spoken Spanish contained numerous grammatical and syntax errors but did not prevent them from conducting successful professional careers and businesses. However, in most cases, their inability to write correct formal documents in Spanish –like contracts, specifications, estimates, etc.– led them to employing other people for those tasks.

difficulties in writing correct Spanish should be understood as a reflection of the social landscape of the period and not necessarily of the particular author.

In light of these difficulties which prevent translating some parts of the original author's message into correct, comprehensible, Spanish it would appear that this document would be of little value. However, the opposite is true. These documents describe tools and the design method used in commercial yards at the latter part of the 18th century, away from the pressures of state sponsored shipbuilding processes. The design method has no parallel in any of the treatises analysed, with the exception of some similarities with Fournier's method from the previous century. No method similar to Arrospide's has been described in the literature. Thus it is explained here for the benefit of students of early modern ship design practices.

If one were to focus on the quality of the drafted plans, the method may appear totally contemporary with the ones shown in treatises and plans of the late 18th century. On the other hand, if one focuses on the shape of the master section defined by two arcs and a straight line and the manner in which a simple quadrant is used for the transformation of the master section, the resemblance with design methods described a century earlier is apparent. Similarly, the method described in the plans makes no use of waterlines and diagonals which were common at the end of the 18th century, nor does it require drawing any view of the hull besides the body plan (see below for a full explanation of the process). Therefore, again, showing a higher resemblance to methods described in the earliest treatises. These characteristics of the method, make these plans an interesting object of study.

A final reason to study Arrospide's plans is to show that besides manuscript and printed treatises there are other sources of evidence which should be explored to find out about the design methods of the period. Ultimately these should help provide a nuanced picture of who the shipwrights of the period really were. That is, their social extraction, their knowledge landscape, their social strategies in place to store and transmit knowledge. But, more importantly, they should show that, as the authors of the treatises often write, there are still a variety of design methods which are not described in the treatises and yet await to be identified.

The following sections provide, first, a description of the design method described by Arrospide.[15] It is followed by an English translation of the original text. In order to identify the individual blocks of text within the plans a number has been assigned to each block of text as shown in figure 125.

[15] This normally should come as a conclusion after reading the original text. However, as it is a rather confusing text, it is best to show the conclusion first. This way, once the reader is acquainted with the method it will be easier for them to understand the translation of Arrospide's words.

Following the English translation, a transcription of the text is given both in its original form and in an edited form where some punctuation has been added and some text has been edited. However, this has not always been possible, and the present author has been incapable of understanding the meaning of some of the text. Consequently, some of the blocks of text could not be transformed into correct Spanish and, hence, into English. In both the English translation and the edited Spanish version, words added by the present author have been indicated in square brackets. Most of the punctuation marks in the English and edited Spanish versions have been added by this author. They are not shown in square brackets to make the text easier to read. In the few cases where it has not been possible to read a word, or the word written by the original author does not correspond to a word in Spanish, are indicated by the symbol '[?]'. In some cases, notes and comments have been added at the end of the translation of the corresponding block of text. These point at certain noteworthy aspects of the text or provide interpretation of the meaning of the original text which cannot be translated literally but its meaning is clear to the present author. Those cases are indicated in square brackets using italics.

B.1 The design procedure described by Arrospide's

Despite some difficulties of fully understanding the contents of the document (below), the two plans contain sufficient written explanations and carefully drawn diagrams to be able to describe, in general terms the design method described by Arrospide.

The design method describes how to shape a hull, placing the focus of attention on the lower portion of the hull, from the line of maximum breadth to the keel. The topsides, which play a secondary role on the behaviour of the ship as a floating object –as they are well above the waterline– receive little attention in the explanations within the text.

One of the main features in Arrospide's method is that it does not require to draw any longitudinal view of the hull. The ones showing in the plans are drawn to illustrate the explanations given by Arrospide. In practice, a body plan drawn in the loft floor would suffice. The explanation of the design method is accompanied by drawings made by this author which describe the method of designing the body plan, in the same order in which a shipwright would draw them in the loft floor.

The design process starts by designing a quadrant which determines the manner in which the shape of the hull narrows and rises as it nears the ends. Once the quadrant is designed, the three-dimensional shape of the hull is obtained automatically on the full-size plot of the body plan.

The design of the quadrant

The design of the quadrant is the main design choice of Arrospide's method (figure 126). The designer starts by choosing a value of rising and narrowing, which must be equal to each other, for the last frame in which the method will be used. The, a quadrant is drawn with sides equal to the value of rising and narrowing chosen (quadrant *a b c d* in figure 126(a)). Then, point O is found as shown (figure 126(a)). Finally, from O an arc *bd* is drawn. This arc must be divided in as many equal parts as frames are desired (figure 126(b)). These divisions are transferred to the diagonal in the quadrant (figure 126(c)). These intersection points are shown in figure 126(d). They determine the three-dimensional shape of the hull. With them, the bodyplan can be drawn in an automatic manner.

The bodyplan:

The method used by Arrospide to define the shape of any of the sections of the hull is very simple, it relies entirely on simple geometry and is fully automatic. Besides the quadrant described above, the designer must make the following design choices. The maximum breadth of the hull must be chosen (line *1-a* in figure 127(a)). A second design choice would be the depth of the hull, from the baseline to the line of maximum breadth (figure 127). Once this information is drawn in the loft floor, the information obtained from the quadrant is placed on the line of maximum breadth *(1-a)* (figure 127(a)). Then, point *2* is marked in a parallel to the breadth line*(1-a),* drawn at the highest point of the quadrant. The reader is not informed how to choose the position of point *2* along the line. However, it is determinant in the final shape of the hull, as it controls the auxiliary lines that fix the centres of the arcs that make up the sections.

Next, the auxiliary lines *1-2 , 2-3* and *2-X* are drawn. They are used to shape the transversal sections of the hull. Thus, the centres of the side arcs will be placed on line *1-2*. Likewise, the centres of the bilge arcs will be placed on line *2-3*. And, the tangent points between the side and bilge arcs will be placed at line *2-X*. These are considered important control parameters which determine the shape of the hull.[16] All this, in a fully automatic manner.

The reader is informed that line *2-3* should form a square angle to the line *1-2*.[17] It is interesting to note, however, that in the seven instances in which these lines are shown in the two plans, the two lines do not form a 90^{o} angle. Thus, it becomes evident that, in common with most of the treatises analysed in chapters 4-5, the explanations in the text should not be read in a prescriptive

[16] Plan-1 block of text 2 and Plan-2 block of text 4

[17] Plan-2 block of text 4

manner and should be read as an indication of a general method which the designer can use as guidance, being free to depart from it.

The process of drawing a section is shown in figure 127((a) to (d)). As stated, it is fully automatic. The process starts by drawing the side arc (figure (127(b)). Its centre is located at *1*, its radius is the distance *1-a*. It stars at point *a* and finishes where it intersects line *2-X* . For the purpose of this explanation, this point is called *a1*. Next, the centre of the bilge arc must be found by geometric construction (130(c)). Thus, a line is struck from point *a1* to the centre of the side arc at *1*. The centre of the bilge arc will be located at the intersection between this line and line *2-3* and has been identified in the drawing as *Oa*. This geometric construction guarantees that the bilge arc and side arcs will be tangent. In the next step, the bilge arc is struck with centre *Oa* and radius *Oa-a1,* and is extended to a point *a2*, which is found where the arc intersect line 2-3 (figure 127(d)). To end the design of the section, the floor is drawn as a straight line, from *a2* to the top edge of the keel at *a3*. The simplicity of the method is striking, as it is fully automatic.

The rest of the sections are obtained in exactly the same manner as shown in figure 128 with the example of *section-i*. To obtain section-i, the designer must, first, locate the centre of the side arc at point *I* in line *1-2* (figure 128(a)). The centre is obtained from extending a parallel line from point *i* in the quadrant until it intersects line *1-2*. From this centre, *I*, the side arc is drawn with a radius *I-i* (figure 128(b)). The rest of the process is identical to the master section, with the exception of the floor. Initially the floor is drawn as a parallel line to the floor of the master section (figure 128(d)). However, later, it is faired with a reverse curve as shown in figure 129(a) and (b). However, the method of fairing is not explained in the text nor is it evident from the drawings. Although a second quadrant may be used to determine the radii of the reverse arcs. Figure 129(c) shows how to obtain the shape of the sections forward of amidships, which are obtained by drawing the floor tangent to the bilge arc. The result of the design process is shown in figure 129(d).

Final thoughts on Arrospide's method

(Some of these conclusions can only be justified if the English translation below is read. However, it is placed here, so as not to break the flow of the argument from the explanation of the method above. It was felt that the sometimes obscure translation might result in an image of a difficult and confusing method which has been shown to be simple and easy to learn).

These two plans provide a partially complete description of a design method used to design the three-dimensional shape of merchantmen and fast ships in the latter years of the 18^{th} century.

Despite its shortcomings, there is sufficient information in the plans to describe, in general terms the design method described by their author, Arrospide.

It is clear that it is a method which is relatively simpler than other methods described in other treatises in chapters 4-5. Moreover, the differences become more obvious when the method described in the two plans is compared with other contemporary methods of the second half of the 18th century. The main difference is that Arrospide's method does not require, nor does it use, a drafted scale plan. It is a design method which is followed directly on the loft floor. The shipwright draws the shape of the transversal sections from simple geometric constructions and using a single quadrant to obtain the necessary control in shaping the hull. In contrast, contemporary design methods would, often, produce a scale plan, to different levels of sophistication, which would allow the shipwright to check the suitability of the shapes of the finished design.

The lack of a graphical description of the hull-shape to scale from which to judge, visually, the suitability of the finished shape might be seen as a shortcoming of the design method. However, it seems to be well suited for the design of merchantmen. It is a simple procedure, based on a limited set of control parameters, and a nearly automatic design procedure. Consequently, it would have resulted in an economical design process leading to the production of reliable shapes of known performance.

These two plans show that in order to understand the transformation that took part from the early adoption of moulding techniques based on the transformation of a template by rising and narrowing to the final adoption of design methods based on engineering knowledge, other sources of evidence can be used to produce a better narrative of this technological trajectory. This section has described the geometric method. The translation provides extra information about the use of the methods and the tools needed.

B.2 English translation

B.2.1 Plan-1: Block of text 1

[With respect to] everything contained in these plots or construction figures, it is warned that unless the means are provided to define the sections[18] following the art of the compass[19] –just like architects loft their arches and other curved lines full-size on the floor[20]–, [followers of these] drawings will find no improvement [in the designs of hulls] over those [hulls] previously obtained without indication of origin.

If this method of obtaining the curves with a compass, as shown in the drawings, is followed –using two straight-edges joined to each other to act as a compass[21]–, all builders here will agree on a common set of dimensions and will abandon the perceived advantages of using different sets of dimensions.

In order to clarify this part [of the explanation] figure B has been drawn in plan-view from the body-plan [also labelled with a letter B]. If this [plan-view] is observed carefully, it shows the lofted figure of a vault shape –made up of a series of mixed *tori*– where all the centres are shown. Without these [centres], and the compass, it would be impossible for the architect to define the sections with the precision that is required.

B.2.2 Plan 1: Block of text 2

Figure C shows the drawing of four different designs, as if they were shown in four individual drawings as it is customary. In the present plan the four designs –shown in different colours– illustrate the different shapes that can be obtained for merchant vessels or fast ships. It must be highlighted that all that is required is to adjust the depth of the ship and the line of the futtock

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[18] In the original the author uses the word *'galima'* which according to the dictionary is a term used to describe a curved timber, or the curve defined by it. *Fernández de Navarrete, M., 1831. Diccionario Marítimo Español.*

[19] In the original the author uses the word 'cintrel'. This is a term used to describe a string or straightedge which is fixed –by one of its ends– to the centre of an arch, vault or dome, and is used to position, radially, the courses of bricks of stone.

[20] In the original the author uses the word 'Montea'. This term was used to describe the full size drawing on a floor of the true shape of a hull from. This drawing enabled the builder to obtain the necessary full-sized templates to assist in the making of the various construction elements of the ship. *Fernández de Navarrete, M., 1831. Diccionario Marítimo Español.*

[21] Such a solid compass is called a beam-compass or trammel in English.

arcs, always with respect to the lines marked 1º, 2º and 3º with which the four designs have been drafted.

Figure D contains the necessary information to allow the definition of a variety[22] of ships by only varying the position of the centre of the futtock arc and the straight part of the floor, with more or less deadrise. Thus they are fixed by these three points. As a result, if the ship's sections are obtained by the art of the compass, local and foreign[23] shipwrights will produce identical hull shapes.

Due to the confusion created by the breadth line with its confusing measurements and curvature, refer to the second plan which is better thought.

Portugalete, 12th May 1789

Manuel de Arrospide

B.2.3 Plan 2: Block of text 1

Everything included in the first plan must be taken into consideration, except the [information included in this plan] which facilitates the [drafting process] and negates the [value] of disorganised dimensions[24] and anything that is drafted without the art. Then, the advantageous consideration of foreign[25] [ships] and the contempt for local builders will cease.

Portugalete, 1st April 1790

Manuel de Arrospide

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[22] In the text Arrospide says literally that the information given will allow the drafting of hull shapes for **eleven** vessels. The text is written in Spanish, thus the word eleven could be interpreted (as it would be in English) to mean the actual number 11, as opposed to any other number of hulls. However, this choice of word, eleven, describes the author, Arrospide. In the Basque language the word eleven can mean the actual number 11 or it can also be used to mean a **variable number** of something. For example, just like in English one could say 'I have told you **a hundred** times....' meaning numerous times, in Basque the expression would be 'I have told you **eleven** times ...'. Therefore, if the word eleven is understood as a literal translation from Basque, to mean a variety, the figure and the reference to eleven hulls (in the original) becomes clearer. The figure pretends to illustrate that the method is suitable to produce shapes for a variety of ships; that the method is adjustable.

[23] Foreign: from other distant lands, not necessarily in a foreign country. During this period the word foreign (*'extranjero'*) could be used in Spain to describe distant areas within the Spain. (See Terreros y Pando, E., 1787, *Diccionario castellano con las voces de ciencias y artes y sus correspondientes en las tres lenguas francesa, latina e italiana [...]*. Tomo segundo. Madrid, Viuda de Ibarra, 1787. pag 137,2

[24] He is probably speaking about dimensions which are inherited or obtained with no known method.

[25] See footnote 18 above

B.2.4 Plan 2: Block of text 2

[When] the first plan was plotted I had not thought about the possibility of approximating the centre and diameter. *[Note: it is unclear what is meant by centre and diameter in this sentence]*

Having given the chance of doing that, it will be shown next. This will allow to improve the explanation [given in the first plan] which should not be [disregarded]. Thus, about [all this matter] I say:

The shipwright does not require to take into his shipyard any other drawing which is not shown in the figure that shows the stern part [of the ship].[26]

The figure shows the part [of the ship] that [shows the reduction] of the master frame towards the stern-post. The stern post and its rake are left to the good eye of the builder as they do not take part on the loft-floor.[27]

The diagonal which receives the extension points, makes up the diameter[28] which allows to find the centre of the first origin. *[Note: This sentence refers to the quadrant used to define the shape of the maximum breadth line where a point called 'first origin' is labelled.[29] Section B.1 describes how to draw this quadrant and the significance of the diagonal].*

The diagonal which crosses [the quadrant] divides the depth and elevation. [*Note: in other words. The diagonal is used to obtain the heights of the breadth line at each frame, following a very simple geometric construction. This is explained in Section B.1].*

The [quadrant] is the [plot used to shape] the maximum breadth line.

By extending [the divisions obtained in the quadrant] horizontally [across the ship's breadth until they touch line 1 to 2] the centres [of the breadth arcs] can be found. [These can be struck] and stop [where they intersect] line 2 to X. [Then bilge arcs are struck from their centres at line 2 to 3 to connect with the breadth arcs] thus forming the surface of the hull. *[Note: see Section B.1 for an explanation of the process]*

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[26] In other words, all the information required by the shipwright is contained in the body plan.

[27] Once again Arrospide seems to indicate that the profile view of the ship, where the sternpost and its rake would be represented, was not necessary. The rake would be placed, by-eye, or at least not from a drawing by the shipwright, directly on the ship as it constructed.

[28] Arrospide means to say radius. See figure 129(a)

[29] This point has been labelled point O in figure 129 (a) and (b)

[With] these lines [and] the parallel lines[30] shown as auxiliary lines the contour of the hull is closed. [The distances between the parallel auxiliary lines] define the bottom of the hulls as seen in the diminishing [reverse floor arcs].

In the drafting of these plots no geometric scale has been used, [nor] the practiced eye [of the author].

In the plot, everything related to the strength[31], length, depth, and graduation required to form the bottom of the ship is shown [...].

B.2.5 Plan 2: Block of text 3

Line 6 to 7 in the [quadrant] is the one which is most often[32] [used to define] the half breadth line. In this manner, all dimensions agree *[Note: probably meaning that all lines are fair]*. The measurements in the diagonal are transferred into a straight-edge which is all that is required to transfer [the information] to the shipyard together with a second straight-edge. *[Note: The information contained in the second straight-edge is not specified, however, presumably it would contain the length of the side of the square. With it, and the dimensions marked in the diagonal, the breadth and height at each section can be marked (Section B.1)].*

[Note: an additional paragraph warns about the errors that may result from not being careful when drafting the arcs full-sized on the floor. The author explains that a trammel, made up of two straightedges can be used as a compass, however long this may be. This must be held firmly in order to describe the centres and lines of the plan.]

B.2.6 Plan 2: Block of text 4

Finally, it must be warned that line one to two and from this to three must form a square angle. *[Note: in the plot this line is drawn at 86^o. Thus, contradicting the accompanying text, as it is not a square angle. Similarly in Plan-1 this line is shown in five examples and none is a true 90^o angle]*.

---

[30] Here Arrospide is referring to the straight lines that define the deadrise at each section, which are all represented by parallel lines for the rear sections of the hull shown in the body plan. In the case of the sections forward of amidships the deadrise is variable (see section C.1).

[31] The plans do not show any structural details, therefore, in this case strength could refer to ship stability. In present day Basque the term used to describe the resistance of a ship to heeling is *'indarra'* which literally translates into Spanish as strength.

[32] It is noteworthy that Arrospide indicates that this is the most common method. Thus, as indicated in most treatises the author acknowledges that there are other methods in use which differ from the one shown in the document.

Without leaving this line, for every section, point number three will be marked. From it, the exterior shape of the hull which defines the oval part will be struck [with the compass]. [In this manner] the [definition of the shape] will be according to the art [of ship design]. Because, if the shape is defined at the inverse side of the line, [the hull] will be misshapen. *[Note: The following sentence is obscure and not fully comprehensible. It describes the problems of substituting an approximate method to define the shape of the section instead of using the art. This is explained using an analogy to two buildings with walls sloping inwards or overhanging outwards. The final sentence, which is difficult to translate, again, describes that the bilge radius, struck from point three, must be dimensioned with regard to the point marking the turn of the bilge, in a proportion to the volume required from the hull and its rigging.]*

B.2.7 Plan 2: Block of text 5

[Note: This text is another example of the obscure language used by the author which is impossible to translate without having to rewrite the text fully. Therefore, only an interpretation will be given. The text describes a similar idea as the Plan-2 block of text 3*, although in this case it refers to the left hand side of the body plan which shows a ship with a slightly different shape to the one shown in the right hand side. The text, which is placed in the drawing next to the line which defines the point of maximum breadth in the body plan, can be interpreted as saying that the heights at each section on the maximum breadth line can be obtained directly from the quadrant (Section B.1)].*

B.2.8 Plan 2: Block of text 6

[Note: It is a short text of unclear meaning in which the author seems to be referring to the idea that the sections of the hull are based on the master section.]

B.2.9 Plan 2: Block of text 7

[Note: The text is placed above a quadrant to which it is related. It makes some references to the master frame, the bow and stern, the keel and the depth. However, it cannot be translated.]

B.2.10 Plan 2: Block of text 8

[Note: This block of text placed next to the keel makes some references to the floors, the run of the ship, the turn of the bilge and the perimeter of the section, to finally mention the sides of the hull. The text, of unclear meaning, refers to a 'tabla' [plank or table in Spanish] which seems to be used to check the straight part of the floors. Next to the text a simple figure labelled 'tabla' seems to be part of the explanation. Unfortunately, the text cannot be interpreted.]

B.3 Spanish text

This section is provided to facilitate the access to the original information to those interested in the original source.

Each of the blocks of text is shown in two versions. First, the original, unedited version is shown. Interconnected words in the original text have not been separated. Line breaks are indicated by the symbol '/'. Wherever a word could not be read is shown as '?'. In some cases where the interpretation of a word is dubious, it has been shown by following the suggested word by the symbol '(?)'.

The edited version is shown in italics with any word that has been added shown in square brackets. Words have been separated and the spelling has been corrected. Additionally, some punctuation has been added for clarity. Similarly the order of some sentences has been altered in a way that reflects the original message while respecting the correct syntax in Spanish.

B.3.1 Plan-1: Block of text 1

Original text:

Todo quanto Contienen ensi estas delinaciones ofiguras / de Construcion sepreviene quedenotomar elmedio de / disponer lasgalimas segun Arte acintrel hassi como / los arquitectos lebantan sumontea de arcos ydemas / lineas curbas nohallaranporestos Diseños hadelanta- / miento alguno quefavorezca mas delos queseubiesen / presentado hanteriormente sin señalamiento de orijen

Deseguir elmetodo deladisposicion degalimas / acintrel como sepreviene con reglas hunidas quehagan / oficio decompas segun demuestran estos diseños todos / los Constructores enesta parte sobre unasmismas dimen- / siones quedaran yguales Y cesaran las ventajas quedan / señaladamente adiferentes

Para poder hafianzar estaparte sehadilimitado la / figura letra B tendida traslado delquesehalla deperfilcon / lamisma letra yesta mirada con cuidado biene haser montea / deun enbovedado conuna maquina dearcos torales mistos / presentes todos los Centricales sinlos quales ysucintrel / leseria Ynposible al arquitecto disponer sus cortes con la / perfeccion que Requiere.

<u>*Edited text:*</u>

[En] todo cuanto contienen en si estas delineaciones o figuras de construcción se previene que de no tomar el medio de disponer las galimas según arte a cintrel, así como los arquitectos levantan su montea de arcos y demás líneas curvas, no hallarán por estos diseños adelantamiento alguno que favorezca más de los que se hubiesen presentado anteriormente sin señalamiento de origen.

De seguir el método de la disposición de galimas a cintrel como se previene, con reglas unidas que hagan oficio de compás, según demuestran estos diseños, todos los constructores en esta parte sobre unas mismas dimensiones quedarán iguales y cesaran las ventajas que dan señaladamente a diferentes.

Para poder afianzar esta parte se ha delimitado la figura letra B tendida, [que es] traslado de la que se halla de perfil con la misma letra y esta, mirada con cuidado, viene a ser montea de un embovedado con una máquina de arcos torales mixtos presentes todos los [centros] sin los cuales y su cintrel le sería imposible al arquitecto disponer sus cortes con la perfección que requiere.

B.3.2 Plan-1: Block of text 2

<u>*Original text:*</u>

En lafigura C. decada uno contienen elseñalamiento dequatro distintos disenos lomis- / mo quesiestubiesen señalados cada uno deporsi enquatro partes o quadros segun acos- / tumbran yenelpresente demuestran todos los quatro condistintas colores yenhellos alo / quepueden llegar para marchantes y dilijentes sinque haia quenotar otra cosa quelade- / lavariacion depuntal ylinea delos diametros deprofundidad detodos modos con arreglo / ysujecion alos tres Numeros queentodos los diseños quedan señalados. ? 1º, 23, y3º

Enlafigura letra D contiene elsuficiente señalamiento para poder hacer lademar- / cacion de honce Enbarcaciones consolo la Variacion que en hellossemira delpunto cen- / trical que forma eljenol puntal y linea Recta delavarenga conmaior y menor astilla / muerta conloque quedan sujetos alostres puntos segun susdimensiones demodo que / defigurar las Galimas a Cintrel segun arte sean los constructores naturales Oestran- / jeros enesta parte descubriran unamisma cosa porlotocante a lo superficial.

Por confucion quecausa la Linia dela Sinta deque dimanan Muchos / Incombenientes porsus confusas Medidas y Curbatura pasahal segdo / Pliego pormejor Pensado:

Portugalette y Mayo 12 de1789

Manuel de Arrospide

<u>*Edited text:*</u>

La figura C. contienen el señalamiento de cuatro diseños distintos, en cuatro partes o cuadros según acostumbran, lo mismo que si estuviesen señalados cada uno de por sí. En el presente [plano se] demuestran los cuatro con distintos colores y en ellos a lo que pueden llegar para marchantes y diligentes, sin que haya que notar otra cosa que la de la variación de puntal y linea de los diámetros de profundidad, [siempre] con arreglo y sujeción a los tres números que en todos los diseños quedan señalados. ? 1º, 2º, y3º

La figura letra D contiene el suficiente señalamiento para poder hacer la demarcación de once embarcaciones con solo la variación que en ella se mira del punto central que forma el genol puntal y linea recta de la varenga con mayor y menor astilla muerta con lo que quedan sujetos a los tres puntos según sus dimensiones de modo que de figurar las galimas a cintrel según arte sean los constructores naturales o estranjeros en esta parte descubrirán una misma cosa por lo tocante a lo superficial.

Por la confusión que causa la línea de la cinta de que dimanan muchos inconvenientes por sus confusas medidas y curvatura pasa al segundo pliego por mejor pensado:

Portugalete y Mayo 12 de1789

Manuel de Arrospide

B.3.3 Plan-2: Block of text 1

<u>*Original text:*</u>

Provas (pruebas) paralosque en el / ôrijinal conozen en delos / mismos Sentros tras Ran / tados por Separasion de / numero Primero segundo / ytersero

Todo Quanto queda de Liniado enel Pliego Primero seade tener Presentte âeaepcion deloquefavoreze helcontenido enel / Quadro quefasilitta todo apuntamiento y despresia Balementto deMedidas confusa y quanto Sedeliniafuera deArtte / Conloque sesaran las Bentajas quedan alas estranjeras endesprecio delos Construtores dela Nacion

Portugalete y Abril 1º, de1790

Manuel de Arrospide

<u>*Edited text:*</u>

Todo cuanto queda delineado en el pliego primero se ha de tener presente, a excepción de lo que favorece el contenido del cuadro que facilita todo apuntamiento y desprecia la utilidad de medidas confusas y cuanto se delinea fuera del arte. Con ello cesarán las ventajas que dan a las [embarcaciones] extranjeras en desprecio de los constructores de la nación.

Portugalete y Abril 1º, de1790

Manuel de Arrospide

B.3.4 Plan-2: Block of text 2

Original text:

Atpo [al tiempo(?)] dela deliniacion del Primer Pliego Noavia pensado poder aproximar elsentro y diametro / Porloque haviendoseme Ofresido Casualmente poderlograrsualcanse diomotralo acon / tinuar conloque Nuevamente podriamejorar sindesprecio alseñalamiento del Primer / Pliego enlotocante a todo quanto Parezesertraslado:

Nonesesita el Construtor llevarasutinclado ôtrodizeño fueradeloquedemuestra el qua / dro quesemira alapartte dePopas

El Quadro compone lapartte quedesmereze dela extencion dela Mtra [Maestra] aala_dela Guar / nicion del reverso delcontra Codaste yqueda elCodaste ysucaida halbuenojo fa / cultativo pornottener partte henel Pavimento

Ladiagonal queRecive los Puntos dehesttencion Compone heldiametro porquien seadar / aconozer el senttro delPrimerOrijen

Ladiagonal QueCrusa divide lotocantte emprofundidad y Helevacion / el Quarttosirculo lamonttea dela Linia quenombran delaSintta / Deseguir las Paralelas desta(?) yOrisontalmentte descubredondeles tocahazer mencion / conseñalamientto desenttros conlamitad dediamettros deprimeras [?] / estos Segmenttos quedan parados enla Linia de nº,2 a5 ypasan ala Linia de ...[Dia] / metros de nº, 2a3 ypor ellos forma las periferias

Dedondefenezen con esttas quedaserado todo el Pavimentto yConlas Paralelas q / demuestran las linias falsas quesirven depaso susdistancias deSesion [?] / paradar Cumplimentto alos Bajos comodemuestran sus escaseados de [?] / Parademostracion dehestos Planes Noavido Balimento deEscala diminuta dem / didas Geometricas y ôjobueno facultativo

Enla Area que comprende deliniado enel Quadro AzeVer quantto Requiere For / titud Longitud Profundidad y Graduacion que Requiere parala formacion del Puer(?) / Obuque ySimiento quesostienen lasmismas Agoas quesepara de Si

Edited text:

[Al tiempo] de la delineación del primer pliego no había pensado poder aproximar el centro y diámetro.

Por lo que habiéndoseme ofrecido casualmente poder lograr[lo], [se] demostrar[á] a continua[ción]. Con [ello] nuevamente podría mejorar [la demostración] sin desprecio al señalamiento del primer pliego. En lo tocante a todo cuanto parece ser, traslado:

No necesita el constructor llevar a su tinglado otro diseño fuera de lo que muestra el cuadro que se mira a la parte de popa.

El cuadro compone la parte que desmerece de la extensión dela [Maestra] a la de la guarnición del reverso del contra codaste. [Q]ueda el codaste y su caída al buen ojo facultativo por no tener parte en el pavimento.

La diagonal que recibe los puntos de extensión compone el diámetro por [el cual] se ha dar a conocer el centro del primer origen.

La diagonal que cruza divide lo tocante en profundidad y elevación

El cuarto [de] círculo [es] la montea de la línea que nombran de la cinta.

[Siguiendo] las paralelas de esta horizontalmente descubre donde [intersectan la línea 1 a 2] [definiendo de esa manera] los centros de los [radios] de los [genoles del costado] primeras. Estos segmentos [de arco terminan en la línea 2 a 5] y [se extienden a línea de [diá]metros de nº, 2 a 3 y por ellos forma las periferias [de cada sección].

De donde fenecen con estas queda cerrado todo el pavimento. [Las distancias entre las líneas auxiliares paralelas] sirven para dar [forma] a los bajos como demuestran [los finos de popa en reducción].

Para la demostración de estos planes no [ha] habido [ayuda] de escala diminuta de medidas geométricas y [¿ni?] ojo bueno facultativo

En el área [delineada] en el cuadro [se muestra todo lo relacionado con la] fortitud, longitud, profundidad y graduación que requiere para la formación del [...] buque y [el] cimiento que sostiene las mismas aguas que [las] separa de sí.

B.3.5 Plan-2: Block of text 3

Original text:

La Linia 6 y 7 del Quarto sirculo es laquemas seazer ala Liniadelamitad delaManga yasitodas las / medidasson Vnas ytomas enlaregledemano lasdela diagonal nosesita_llevar_mas_qe las dosreglas asutinclado

Puedehacer Eror [error?] portomar ôafirmar / el compás compocaprolijidad y encuanto / almenos dealguno delostres Sentros / de heleccion Primero Segdo y tersero / ydelinias Sobre hellos No puede ha / ver Construtor quebarie sobre unas / mismas dimenciones y Sintrel qe / porlargo quesea puede menear con / toda fasilidad sobre dos reglas tendidas / ôbien conyradillo como quien quisie / re disponer por espesura de Radios / ySerchon queperfesione

Edited text:

La linea 6 y 7 del cuarto de circulo es la que más se hace a la linea de la mitad de la manga y así todas las medidas son unas. Tomando en la regla de mano las [medidas] de la diagonal no necesita llevar más que las dos reglas a su tinglado.

Puede [errar] por tomar o afirmar el compás con poca prolijidad y en cuanto al menos de alguno de los tres centros de elección primero, segundo y tercero y de líneas sobre ellos no puede haber constructor que varíe sobre unas mismas dimensiones y cintrel. [Por largo que sea el cintrel], puede menear[lo] con toda facilidad sobre dos reglas tendidas o bien con yradillo como quien quisiere disponer por espesura de radios y cerchon2 que perfeccione.

B.3.6 Plan-2: Block of text 4

Original text:

Por ultimo esde adbertir quela Linia de nº, Vno ados ylade este altercero deben / formar Angulo recto, ysinsalir de hesta linia conla sepcion queletoca hasu / tanteo hapuntara el numero tres y de el debe azerse el senalamto, dela Pe- / riferia queforma laparte ôbalada conloque helseñalamto, sera segun Arte / porque de disponer esteseñalamto, âlreberso dela Linia sera contra echo / ydesalir âprosimar suple al Arte como edificio escarpado yeldel / Contrario desplomado, y como de aqui resulta mas ômenos porsu ma / yor ômenor salida debe hel Construtor ãreglar la medida para la Qua / dratura y Arboladura con atencion asu maior ômenor codillo

Edited text:

Por ultimo [hay que] advertir que la línea de nº, uno a dos y la de este al tercero deben formar ángulo recto. Sin salir de esta línea, con la sección que le toca a su tanteo, apuntará el número tres y de él debe hacerse el señalamiento de la periferia que forma la parte ovalada. [De esta manera] el señalamiento será según arte porque, de disponer este señalamiento al reverso dela línea será contrahecho, y de salir aproximar suple al arte como edificio escarpado y el del contrario *desplomado, y como de aquí resulta más o menos por su mayor o menor salida debe el constructor arreglar la medida para la cuadratura y arboladura con atención a su mayor o menor codillo.*

B.3.7 Plan-2: Block of text 5

Original text:

Siel señalamiento delos Altor fuesen por / govierno delos Sentros delamitad dela / manga dehellosmismos prezisara se / resolviesen para Popa y Proua condife / rienciasulevantamiento

Edited text:

Si el señalamiento de las alturas fuesen por gobierno de los centros de la mitad de la manga, de ellos mismos precisara [que] se resolviesen para popa y proa con diferencia su levantamiento.

B.3.8 Plan-2: Block of text 6

Original text:

Estos Centros deven Componer lasmismas ynterpolaciones delasqueel / deMuestran derojo aserar orecojer / consiguiente hes de advertir que laMta porsisola Notiene compamade(?) / Sentro y quetodas lasdemas Guamerones(?) Ogualderas(?) Combinan de Vnos mismos dehella para Popa y proua quehes loque acredita ladelica / desa de quanto enellas semire:

B.3.9 Plan-2: Block of text 7

Original text:

Nº 4º, Quadra dela Maestra pa Proua / Nº, 4 Quadradehella pa, Popa / Sus Medidas superficiales / Cadauna deporsi conlade / la Quilla y Profundidad pareze / componen Juntada Una y otra / Las Proporsionales ysera Sumetad / la que corresponde

B.3.10 Plan-8: Block of text 8

Original text:

Colocada la tabla donde leacomode ala Vista(?) hal / que Govierna Puede Saver consertesia Quandosigue / la embarcacion conelGolpe delas Paralelas de Baren / gas Orisontales Quesera Presentandosele tambien / la Linia Roja Orisontal yquando selepresenttareasi / laLinia azul Costruira(?) sobre lamaior Salida / dela Periferia Ôcodillo y las Aguas enel Portalo / com enla Lra [letra] G yladela Linia Roja como Lra [letra] P

Appendix B: Delineaciones of Figuras de Construcion

Appendix C The digital modelling process

This appendix will outline the digital modelling and testing process followed in this research, and will give the main reasons which justify that this part of the research was pursued only partially during the development of this thesis. There are several reasons for this. Firstly, that very soon in the research it was felt that a more worthwhile pursuit would be to try to study the ship design-knowledge of early modern shipwrights. This, in turn, would help understand early modern society better and, also, would offer the opportunity to assess and criticise the manner in which such knowledge is interpreted in the current academic literature. All this is discussed in the main body of this thesis. A second consideration would be the difficulties of creating a model that could be guaranteed to represent in an accurate manner the yachts of this period. And, the final and main reason would be the difficulties of performing a digital test of the performance of the theoretically modelled hulls, with the limited analytical tools available for it during this research.

The section will start by describing the purpose of the modelling and the choice of modelling program.

C.1 Purpose of modelling

The main objective of the theoretical modelling and testing of Charles Ii’s yachts was to study their performance. The definition of hull form and rig configuration is a basic requirement for this analysis. Hydrostatic calculations and hydrodynamic characteristics established by computer software are only representative of the data introduced in the calculations. Thus, if the model created were truthful to the real ships, it could be expected that the results would represent the characteristics of the real ships. However, if the models did not truly represent the original ships, the results would, likewise, be irrelevant in order to characterise the performance and hydrostatic characteristics of the real ships. Therefore it was required that, in order for this exercise to produce meaningful results, the shapes of the hulls had to reflect the real shape of the ships, as accurately as possible.

This was made easier by the existence of near contemporary plans for four of Charles II's yachts in the archives of the National Maritime Museum in Greenwich. However, the plans were hand drafted following the design methods described in chapters 4 and 5, therefore, had to be converted first to a format that could be input into the software used for the analysis. One of the initial objectives in the research became to evaluate different computer software packages which would allow to reproduce the shape of the hulls of Charles II’s yachts easily and accurately. The software should allow to create an easy communication with specialised software which was going to be used for the hydrostatic and hydrodynamic calculations used in this research. In addition, it was considered interesting to find a set up that may benefit other researchers who might not be familiar with modelling software, and especially with specialised naval architecture software.[33]

C.2 The choice of 3D modelling program

The main requirements from the program chosen for the purpose of modelling the original hull shapes would be accuracy and, secondly, user-friendliness. Two hull design software packages were tried for this process: ShipShape, a commercial hull design software developed by the Wolfson Unit from the University of Southampton, and DELFTship, a commercial hull design software. After a series of comparative tests between ShipShape and DELFTship the latter was chosen for its precision of the modelling process, reliability and ease of operation.

DELFTship is a modern, up to date, hull design program that in its most basic form is available free. Besides very extensive hull modelling capabilities, described below, the free version of DELFTship provides hydrostatics calculations capabilities, albeit for the upright condition only, which provides sufficient information to a non-trained naval architect. However, the free version of DELFTship used for this research had the capability of exporting the hull's geometry on several file formats that could be input into commercial hydrostatics calculation programs (e.g. GHS files), available in the University's computer network. With these it would be possible to obtain the necessary hydrostatic data for the hulls at different angles of heel. This, of course, would not be necessary if a fully licensed version of DELFTship was used for this research.

There are other modelling programs which have the possibility of adding hydrostatic calculation modules (e.g. Rhinoceros and Orca 3D) however, being generic modelling programs they have extensive capabilities which, as a result require a longer learning process. In contrast, Delftship is a hull-design program and, as such, its numerous modelling tools are directed towards the shaping of hull shapes. This reduces the effort required to learn its use. Additionally, one of the most interesting feature of DELFTship, is that an existing lines plan is very easy to reproduce following the process described below.

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[33] For example, the suitability of the program chosen for the modelling and hydrostatic analysis, DelftShip, was shown by my colleague Thomas Dhoop in his research on medieval Winchelsea. Without previous knowledge of modelling programs or of hydrostatics analytical software, he modelled and calculated the displacement, internal volumes and basic hydrostatic data of a series of medieval hulls (Dhoop, T. 2017. Shaped by Ships and Storms: A Maritime Archaeology of Medieval Winchelsea, University of Southampton, Faculty of Humanities, Archaeology, PhD Thesis).

C.2.1 The hull surface in DELFTship

In contrast to other hull design software that use B-Spline or NURB surfaces, DELFTship uses a type of mathematical surface called subdivision surfaces to define mathematically the surface of the hull. Subdivision surfaces share the same mathematical background as NURB and B-spline surfaces with some advantageous features. The mathematical algorithms do not restrict the surface to a rectangular definition of points and, thus, any point configuration can be used.[34] In practice, the hull surface is controlled in DELFTship by a series of control nodes which define a control mesh. The mesh is not in the actual hull surface, and any change to the position of the control nodes, and therefore the mesh defined by them, directly affects the shape of the hull (figure 130). Not having the control points on the actual hull surface may, at first, seem a disadvantage. However, the control of the shape of the surface is very intuitive, and matching it to the original plan very easy.

C.2.2 Modelling a pre-existing shape

In the process of reproducing a hull shape starting from a pre-existing lines plan DELFTship has an important advantage over other hull design software. It allows the user to have the original lines plan as a background image in any of the display windows in DELFTship. This background image can be used to edit the hull surface defined by DELFTship until it matches the original hull shown in the plan as explained below.

The process would start by inputting the ship's principal dimensions. DELFTship uses those dimensions to produce a network of control points that define a hull surface shaped like a yacht (figure 131). The user, then, inserts the original plan as a background image in any of the three orthogonal view windows: body, sheer and half-breadth views. Following this the control network is manipulated in the three views, by adjusting the nodes using the mouse or keyboard arrows, until the shape of the hull matches the original plan in the background. A means of checking the match between the surface created in the computer and the drafted plan is by specifying transverse stations and waterlines in DELFTship at the same positions as in the original plan. The body plan sections and waterlines produced by the program should overlap those shown on the original plan used as a background image (figure 132). This method has certain advantages. The shape of the specified stations and waterlines vary in real time to the movements of the nodes in the network, and thus, the modelling is a visual process that happens in real time on the screen. However, this simple method has an important disadvantage. The hull generated automatically by

[34]DELFTship BV. 2008. User Manual. p. 8-9

the program from the ship's main dimensions is shaped like a modern yacht which must be altered extensively to reproduce the shape of the 17th century ship. In order to achieve an accurate result extra nodes must be added in the ends of the hull (especially at the forefoot) making the control mesh less 'tidy' and its control less intuitive. This problem can be minimised if the user takes advantage of additional tools available in DELFTship.

DELFTship has another tool with great potential for an accurate modelling of pre-existing hull. The program can automatically 'wrap' a hull surface around a user defined series of sections. These sections can be transverse, longitudinal or a combination of both and are entered in DELFTship as a table of offsets that define the spacial X, Y, Z coordinates of points within those sections. These coordinates can be obtained by hand measuring coordinates of points from a scale plan or, more conveniently, by digitising points on the original plan using a number of freely available digitising software packages. The ensemble of points obtained must be collected in a text file containing the X, Y, Z coordinates for each point; again, easily done with a simple text editor or word processor. When the formatted text file is input in DELFTship it automatically creates a hull surface that matches closely the surface on the original hand drafted plan (figures 133). However, a perfect match is not always possible and there might be areas that might require to be faired at a subsequent step.

In order to fair those regions of small discrepancy between the original shape and the shape produced by DELFTship when wrapping the surface to the points defined by the user, the original plan can be used as background image in order to finish fairing the hull following the method described above. The great advantage of this combined method is that the network of control nodes created by DELFTship is optimally distributed according to the shape of the digitised hull. This allows for an efficient and simple fairing of the small discrepancies with the original body plan in just a few iterations by the user.

The end result is a hull that matches the original lines plan very accurately (figure 134).

C.3 Charles II's yachts

This section shows the results of the modelling process for six royal yachts. In order to help identify the yachts called *Mary*, the yacht given as a present by the Dutch will be called here the original *Mary*', while its replacement built in England will be called the 'second *Mary*'.

The shape of the original *Mary* has been developed from its original dimensions, and hand drawn sketches in which Witsen's main design parameters were drawn. These sketches were used as background images for the process of hypothetical modelling in DELFTship.

Plans for the following royal yachts were available at the National Maritime Museum in Greenwich (date of the plan in brackets): *Katherine* (undated), *Queenborough* (undated), second *Mary* (1764, 1772, 1783) and *Commissioner's yacht* (1794). These plans were used to model the hulls shown in them following the process described in the previous section. As it can be noted there are three sets of plans for the second *Mary*. The dimensions of the second *Mary* indicated on the plans dated 1772 and 1783 are identical. There is a small difference in measurements between these dimensions and the ones shown in the plan dated 1764. The difference is less that 1.5% in overall length, keel length and burthen in tons. There is a 5% difference in the dimension given for the depth in the hold, however. In all dimensions the 1764 plan gives the smallest values. The differences are small enough to consider them within the tolerances that could be expected when taking measurements by hand. As a further check, the 1764 plan and the 1772 have been superimposed in an image-manipulation software. The superimposed image shows that the stations on both plans show small differences which again, allow to conclude that both ships represented in the plans are the same *Mary*.

One characteristic of the plans is that they are either not dated, or the date shown in them is c.100 years later than the date those ships were originally built. However, it is not unheard that ships could be in service during very extended periods of time, being extensively repaired and rebuilt in the process. For example Endsor describes the case of the *Lenox* built in 1677, rebuilt in 1701 and 1723, and finally sunk in 1756.[35] Another example of a ship with a long service life would be one of the royal yachts, the *Fubbs*, that was built in 1682 and remained in service until 1781. A life of 99 years during which it was rebuilt in 1701, 1729, 1749.[36] As a result of this, and as their provenance suggests, there is a high degree of confidence that the yachts depicted in the original plans represent ships that belonged to Charles II.

The following sections show some images obtained after the modelling process and basic hydrostatics data obtained in DELFTship for each of the ships. The purpose of the exercise was to obtain an accurate definition of the three dimensional shape defined by the original plans, aimed at an analysis of their performance. Thus, areas of the hulls which do not have a relevance for such an analysis, such as the shape of the sheer etc. were been ignored at this stage. In all cases transversal sections were defined to coincide with the locations of the sections in the original plans shown in the background. Thus it is possible to see the good match between the original

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[35] Endsor, R. 2009. The Restoration Warship. p.7

[36] Crabtree, R. 1975. *Royal Yachts of Europe*. p. 18

Madge, T. 1997. *Royal Yachts of the World*. p.35

plan and the shape of the hull reproduced in DELFTship. Additionally, basic renderings of the hulls show their three-dimensional shapes.

Table 1 shows the principal dimensions of the yachts obtained from the original plans. The displacement in metric tonnes has been obtained in DELFTship.

C.4 Hydrodynamic modelling in PALISUPAN (985)

. This section will described the aero-hydrodynamic analysis of the royal yachts and the reasons that led to not pursuing this route to its final aim.

The analysis of the aero-hydrodynamic characteristics of the original *Mary* and other yachts belonging to Charles II required choosing an appropriate computer software. There were several options at the University. The most accurate choice could have been the use of modern, up to date, fluid dynamics software ,CFD, that produce very accurate results by modelling the flow around hull and rig in a very realistic manner. However, the accuracy of the results would have been negated by the fact that the input data would necessarily be a theoretical approximation to the real configuration of Charles II's yachts. Moreover, at the time of starting this research, these software packages required the use of specialised, powerful, computers and could not be run on a personal computer. Therefore it was decided that a less precise programme that could produce reasonable results from the limited data available was preferred. The program supplied by the University to that end is called PALISUPAN, and was written by professor Turnock of the University of Southampton to study the interaction between a rudder and a propeller. However, it had been used for the analysis of the hydrodynamic characteristics of a hull in the past. Therefore it was expected that it could provide results which could be used to compare the performance of the yachts modelled above.[37] This proved not to be the case.

PALISUPAN is a lifting surface panel code that considers the flow of a fluid around a body, by simplifying the characteristics of the fluid and flow, so that the fluid is considered inviscid, incompressible and irrotational.[38] Ignoring these aspects of real fluids, the computational power needed is reduced, and the program can be run in any personal computer. In order to run, the user must produce a geometry file and a command file that PALISUPAN reads and executes.

[37] Gibbard. A.M.J. 2012. Development of a Hull and Performance Model for One of Charles II's Royal Yachts.
Evans. C. 2002. A Theoretical Study into the Upwind Sailing Performance of the Hanse Cog of 1380.

[38] Turnock. S.R. 2000. *PALISUPAN. User Guide.* p5

The geometry file contains information about hull shape and fluid flow properties. The shape of the hull is defined as a series of horizontal sections (parallel waterlines) which the program uses to recreate a closed surface defined by parametric cubic splines as an accurate approximation of the real three-dimensional shape of the hull.[39] Additionally, the user must specify other characteristics of the fluid flow field such as fluid properties, fluid velocity, wake geometry, constants to present data in non-dimensional form etc. All this data must be organised in a hierarchical text file, where each piece of data has its correct position and format. Any diversion from the expected format will result in the program crashing unexpectedly or running in an infinite loop.

The command file –also a text file– contains information that allows PALISUPAN to read the appropriate geometry file, allows multiple runs of the same geometry under varying flow conditions –for example different angles of attack–, and produces output files, all specified by the user. As in the case of the geometry file the data must be organised in a hierarchical text file where any diversion from the expected format will result in the program crashing.

PALISUPAN reads the command file and geometry files and breaks down the surface of the body in a user specified number of rectangular panels (figure 152). The pressure distribution over each panel is calculated by PALISUPAN, and by integrating (adding) the pressure distribution of each individual panel PALISUPAN can estimate the forces of the fluid on the hull on both the direction of the fluid flow and transverse to it.[40] Hence hydrodynamic resistance and side force are calculated by the program. Similarly to the hull, the geometry of sails could be specified, and therefore the drag and side-force produced by it could be obtained from PALISUPAN. However, PALISUPAN was developed to study the hydrodynamics of rudders behind a propeller. As such, it has some limitations when it is used to analyse a hull's hydrodynamics.

The first limitation of PALISUPAN is that the program ignores the water-air interface, as it is not relevant for the analysis of fully submerged rudders for which it was originally written. However, a ship is an object that moves through a two fluid interface, air-and-water, and the movement of the ship through this air-water interface produces a series of waves on the surface of the water that are not taken into consideration by PALISUPAN. The presence of these waves has a direct consequence on the resistance of the hull, and therefore, ignoring the air-water interface results in an underestimation of the resistance of the hull. However, at the relative slow speeds at which these hulls moved, wave resistance represents a small proportion of total resistance, so it was

[39] Turnock. S.R. 2000. *PALISUPAN. User Guide.* p.11

[40] Turnock. S.R. 2000. *PALISUPAN. User Guide.* p.16

decided that this limitation could be overcome. Other numerical approximations would be used to evaluate the increment in drag due to the creation of waves.

A second limitation of PALISUPAN is that it does not consider the side-force and resistance of the hull when heeled, as it has no means to 'heel' the hull in PALISUPAN. Therefore, if the effects of heel in hull resistance were to be investigated, a new geometry file, containing the shape of a heeled hull will be needed for each case. However past research published in the literature had shown that heeled resistance and upright resistance for this type of hull may not vary significantly. For example, Hubregtse found that the side-force and resistance of the replica of a 17th century Dutch ship, the *Amsterdam*, built in the 1980s, were independent of heel angle.[41] This would indicate that the increase in resistance due to heel angle could be ignored, or estimated to be relatively small. However, this should be evaluated properly, as it might be not be necessarily true to all hulls.

Thus, two components of hull resistance had to be evaluated by empirical means. If the program proved to be practical in its calculations, these limitations would not have proved to be unsurmountable, as the final goal of the exercise was to compare performances, rather than obtaining absolute values of performance. It seemed reasonable to assume that the overestimation or underestimation of the forces due to these two limitations would affect all yachts equally and, consequently, their relative performances would stay the same. However, the shapes of the hulls proved to be too extreme for PALISUPAN.

The main object of 'running' the hulls in PALISUPAN was to obtain the resistance and side forces created by the hull at different speeds at various angles of incidence to the flow. Similarly the same would have to be calculated for the rigs. With all this data a simple velocity prediction program can be written that finds the equilibrium between the following pairs of forces: propulsive force against resistance; sail side force against hull side force; heeling moments[42] against righting moments. The VPP takes all the forces and moments into consideration by following an iterative process that looks for an equilibrium amongst all.[43] However, in order for the VPP to produce results, it must know, first, the forces created by the hull and by the rig at

[41] Hubregtse, A.H. 1990. The V.O.C. ship Amsterdam: A velocity prediction. p.160

[42] A moment is a force times a distance. In this case, the side-force of the sails time its distance to the opposing side force generated by the hull.

[43] The modelling of the forces did not advance to this stage, therefore a more technically advanced explanations not needed here. However, to know more: Fossati, F.2009. *Aero-Hydrodinamics and the Performance of Sailing Yachts.The science behind sailing yachts and their design*. London: Adlar Coles Nautical. p. 268.

different flow conditions. That is at different speeds and angles of incidence. However, after an arduous period of testing the models of the hulls, it was found out that PALISUPAN could not cope with the flow around their extreme shapes if compared to the lifting foils for which the program had originally been built. Simplified shapes were tried, but with no success. They were already very different from the original shapes. Therefore, it was decided that this route would not produce meaningful results, and the hydrodynamic analysis of the hulls was abandoned.

In parallel with the computer modelling of the hydrodynamic characteristics of the hulls, the research on the ship treatises and the design-knowledge of the period developed. This, by contrast, proved to be a most gratifying research.

Appendix D Glossary

Backbone: Longitudinal structure running through the centreline of the ship. It is made up of the stem, the keel and the sternpost (figure 48).

Beam: Breadth of the ship at its widest point.

Bilge: The bilge is the area of the hull between the bottom and the sides.

Bow: Front end of the ship.

Depth: Height within the inside of the ship, from the top of the keel to the underside of the deck (figure 114).

Displacement: Volume of water that the ship displaces while floating freely. Its weight is equivalent to the weight of the ship. Consequently, sometimes the term displacement is also used to describe the weight of the ship.

Draught (draft): Distance measured from the surface of the water to the lowest point of the ship inside the water. It obviously varies depending on the weights placed within the ship (figure 114).

Fair: A fair curve is one which has no unsightly humps and hollows. Ships' and boat's hulls are normally fair. Their surfaces run describing smooth clean lines that show curvatures that gradually change shape without any local distortions in curvature.

Floor: Lower part of a frame, although it can also exist on its own. It is a transversal element that is placed on top of the keel, fixed to the inside of the hull's planking. Normally, it is also attached to the top of the keel. It reinforces the keel to frames or keel to skin connection.

Frames: Transversal structural elements placed within the hull, against the inside face of the surface of the hull. They are normally made up in parts. Each part is called a futtock, with the exception of the lower section which is called a floor.

Freeboard: distance from the surface of the water to the deck of the ship (figure 114).

Furring: To 'furr' a ship parts of its planking was removed allowing access to the frames. These were supplemented, thus creating a new outer shape. Then new planking was fixed to the new frame shapes. This transformed the underwater shape of the hull and its stability characteristics (see *Girdling*).

Futtock: each of the segment of which a frame is made of.

Girdling: Girdling a ship consisted in adding a thick layer of planking around its waterplane, to increase beam and thus solve problems of stability (see *Furring*).

Heel (to): to incline. Ships heel due to waves, uneven loads, wind etc.

Keel: Strong central element of the bottom structure of the ship, running longitudinally, at its centreline. The construction of ships normally starts by laying the keel and the rest of the elements of the backbone (figure 48).

Planking (plank): wooden boards, running longitudinally, which make up the outer skin of the ship.

Ribband: long flexible wooden battens. They can be bent around pre erected elements of the hull, or provisional supports, to help the shipwright judge curvature visually. In the case of this thesis the curvature of the still un-defined hull's surface (figure 52).

Ship-designer: in the case of this research, someone who has been trained, specifically, to design ships. This is in opposition to the shipwright who may be someone who, obviously, is engaged in the construction of ships but, also, in the case of some shipwrights with specialised knowledge, may also be responsible for defining the design of the ship.

Shipwright: in the case of this research, someone who is engaged in the construction of ships. Some shipwrights with specialised knowledge, may also be responsible for defining the design of the ship.

Stability: ability of a ship to stay upright whilst floating. When a stable ship is disrupted from its equilibrium position by inclining it to some heeling angle (by wind forces, waves, uneven loading, etc.) once the disrupting force is removed it will return to its initial position. However, most ships will have a maximum heeling angle which once exceeded, the ship will not have the ability to return to the vertical and will continue rolling until it capsizes.

Stem: Structural element in the front end of the backbone (figure 48).

Sternpost: Structural element in the after end of the backbone (figure 48).

Tail-frame: Two frames either side of the master frame, placed towards the ends of the ship. They limit the area of the hull in which traditional methods of rising and narrowing were used to define the transversal shapes of the hull.

Transom: transversal surface of the ships skin, at its aftermost end (figure 48).

Weatherly: ability to sail into the wind. Sailing ships cannot sail directly into the wind. They do it by sailing in a zig-zag fashion that allows them to sail towards the direction from which the wind is coming. Depending on the configuration of the ship, some will be very weatherly, thus will sail quite close to the wind, while others might not be able to advance into the wind.