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Materials and Structures Research Thrusts: Recommendations for the Maritime Environment

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[dstl]

Materials and Structures Research Thrusts: Recommendations for the Maritime Environment

Results of an International Workshop held Southampton

16th to 18th November 2005

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Approval

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Professor P Curtis .....

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Executive Summary

This report summarises the finding of an international workshop held in Southampton on the 16th-18th November 2005 to explore Materials and Structures long-term Research and Development requirements for the maritime environment.

Fifty subject area experts were drawn from eights countries to identify R&D needs in the areas of:

- Modelling and Simulation
- Materials and Structures
- Above Water Environment
- Below Water Environment.

A fifth area entitled "Complex Design Risk Reduction" was also considered as selected by the attendees during the workshop.

The resulting recommendations, provided in section 3, are to be supplied to the attendees, various funding bodies including the UK's MOD, Dti and the Research Councils.

Further collaboration embracing teams drawn from academia, research laboratories, manufacturing industry and regulatory authorities, both national and international, was seen as being vital to ensure continued materials and structures innovation in the maritime sector,.

Cross sector working was also considered a high priority where complimentary technologies should be jointly researched to reduce risk and accelerate technology insertion.

1 Background

1.1 The purpose of this report is to provide guidance to funding agencies for long term structures and materials research requirements for the maritime environment through an experts workshop held between the 16th and 18th November 2005 under the auspices of the University of Southampton and the UK's Ministry of Defence.

1.2 This report and workshop were funded via three agencies, namely the UK Ministry of Defence (MOD) via the Research Acquisition Agency (RAO), the Dti via the National Composites Network (NCN) and the US Office of Naval Research (ONR). The workshop was supported by fifty key technical experts in the marine/naval community drawn from eight countries with two keynote addresses from:

- Dr Jeffery Beach, Technical Operations Manager, Naval Surface Warfare Centre, Carderock, US DoD.
- Professor John van Griethuysen, Head of Sea Technology Group, UK MOD.

1.3 The principal funding agencies towards which this report is directed include:

- The Research Acquisition Organisation of the UK MOD
- The Department of Trade and Industry (Dti) via the Materials and Structures National Advisory Committee and the Marine and Materials Innovation Growth Teams
- The Engineering and Physical Sciences (EPSRC) Research Council
- US Department of Defence, principally the Office of Naval Research
- European Union, including the European Defence Agency and Framework VII
- The marine industry through such bodies as the Shipbuilders and Ship Repairers (SSA), British Marine Federation, etc.

1.4 It is also hoped that the report will stimulate new opportunities for collaborative research across the various funding bodies (e.g. inter-government departments) and further the already excellent international collaborations that exist within the marine community.

1.5 Details of the workshop structure and principal outcomes are summarised in the following chapters, with comprehensive reference details offered in Annexes A to H.

2 Workshop Details

2.1 The raison d'etre for the workshop arose from the UK MOD's Research Acquisition Organisation's Capability and Technical Advisors within Dstl to assist in identifying long-term research requirements in the field of materials and structures for the UK naval community.

2.2 In recent years several UK MOD departments have sponsored a number of research and development programmes to explore the use of innovative or emerging materials and structures technologies for both the above and below water environments. In a number of projects MOD funding has been supplemented with industrial private venture funding.

2.3 Collaborative research has also featured extensively in recent years and has been at both national and international level, with the most notable international collaborations being European Union (e.g EUCLIDs and EUROPAs) and US based.

2.4 This research has embraced activities such as:

- Further use of advanced composites for a range of naval applications including propulsors, rudders, hyroplanes, top-sides, doors/hatches, etc
- NDE methods, damage tolerance and repair of naval composites
- Composite patch repairs for steel structure
- Improved welding technologies for reduced distortion
- Application of high energy beam processes for the welding of non-ferrous wrought alloys for sea-water systems
- Use of novel structural topologies (viz. sandwich panels) for ship application

2.5 Much of this R&D has been stimulated via the need to; reduce ownership costs, including procurement costs; reduce structural mass without sacrificing platform durability or survivability; enhancing survivability though structural or manufacture features; improve signature management.

2.6 As much of this research is cutting edge, including the use of fibre-optic sensors for example for structural health monitoring of submarine composite components, the longer term research needs for the marine community were less obvious. Discussions with various academic institutions and industry also resulted in a less than clear view for long term R&D needs.

2.7 Following discussions between technical staff at Dstl and academics at the University of Southampton's School of Engineering Science, it was decided that to assist in long-term maritime R&D planning the University of Southampton would hold an international experts workshop. Initially to be funded by the UK MOD, subsequent discussions with the Dti's Materials and Structures NAC indicated that support from the Dti was possible to assist in its technology

programme calls. Dti funding was supplied via the National Composite Network (NCN), given the increasing use of such materials in the marine industry. Discussions with the European Office of ONR led to ONR offering funding support given its international theme.

2.1 Workshop Structure

2.1.1 To provide the maximum opportunity for the development of long-term research ideas and requirements, the workshop was structured as follow:

- Two keynote strategic speakers were invited to provide national overviews of long-term naval requirements taking into account changes in operational needs, social, political and environmental issues and declining defence budgets. These speakers were:
  - Professor John van Griethuysen, Head of the MOD's Sea Technology Group
  - Dr Jeffrey Beach, Technical Operations Manager, Naval Surface Warfare Centre, Carderock, US DoD.
- Three further personal perspective presentations were presented by Professor B Hayman, Dr Paul Frieze of PAFA and Professor Mark Spearing of the University of Southampton.

2.1.2 This was then followed by four workshop brain-storming sessions of 60 minutes duration on the following themes:

- Modelling and simulation
- Materials and structures
- Above water environment
- Underwater environment

2.1.3 Each session was sub-divided into four delegate groups comprising a maximum of 12 delegates with two session facilitators. Facilitators also provided topics for consideration prior to each session, plus recorded the principal outcomes. Full details of the workshop format are given in Annex A. Each delegate was also requested to complete a delegate's record sheet (Annex B), comprising initial and final thoughts of each session. Finally each group provided a summary of their key points in a session plenary. The key issues arising from each session are provided in Annexes C to F respectively.

2.1.4 A further "un-themed" session was also held, with the theme being identified by the delegates at the end of the four earlier sessions. This offered scope to revisit previous sessions or to introduce a subject area based on the attendee's views on a subject of importance. This resulted in a fifth session entitled:

- Complex Design Risk Reduction

2.1.5 The key issues arising from this session are presented in Annex G.

2.1.6 The workshop was then concluded with a closure plenary session. The outcome of this session is provided in Annex H.

3 Principal Technical Recommendations

3.1 As to be anticipated the workshop generated significant information as evident in Annexes C to H. To refine the workshop outcome, the principal fund holders and facilitators held a meeting on the final day to agree a research priority list for each of the workshop session areas. These priority areas are summarised below:

i. Modelling and Simulation

- **Accurate Load Prediction.** Despite the availability of very comprehensive computational structural design capabilities, load prediction in a number of key areas is poorly understood, namely slamming and shock for various hull forms and even wave shape. Further work in this area is seen as a priority.

- **Integration and Validation of Complex Ship Design Models.** A critical need exists to increasingly move to multi-physics approach, whereby computational fluid dynamics, motions, structural analysis, material models, structural health monitoring (SHM), survivability, etc are brought together as an integrated process. These are usually looked at separately, leading to inefficient or time consuming designs and processes.

- **Design for Manufacture and Operation.** Modelling of manufacture must be further improved, combined with prediction of fabrication effects on structural performance and platform lifing, etc.

- **Systems Engineering Approach**. With the increasing move to system approaches, there is an urgent need not to overlook the structural/materials aspects, as has been done in the past in other systems. Quantify and treat risk via a systematic approach such that ownership costs are reduced at acceptable risk levels.

ii. Materials and Structures

- **Multi-functional Structures.** Future structures activities should focus on multi-functionality (i.e. stealth, structural health monitoring, fire protection, etc) and adaptive (morphing) concepts. Novel topology including further exploitation of sandwich construction, plus use of layered/hybrid structures require further investment activities combined with the recognition of increasing environmentally friendly legislation.

- **Rapid Technology Insertion.** A means of accelerating new technologies within the maritime community is urgently required while accepting regulatory requirements. Use of improved material models (particularly but not exclusively composites) taking into account environmental effects will assist.

Likewise improved knowledge of loading, limitations of advanced structural computational codes, and a greater ability to manage risk within the design process.

- **Relevant and Reliable Material Design Information.** There is an urgent need to re-visit and maintain a valid materials data base for emerging or new materials. It is recognised that considerable material data exists, but is frequently unavailable to a wider community through lack of need to release, commercial issues, etc. Not only hindering technology insertion, the absence of design information frequently results in repeated testing of similar materials at a considerable cost burden.

- **Lightweight and Environmentally Friendly Structures.** Increasing need to move to lighter weight, low maintenance and "green" materials with minimal, ideally improved, impact on platform operations.

iii. Above Water Environment

Lightweight Survivable Platforms. Future military needs will require faster, but also survivable platforms. Further integrated research exploiting:

- light weight low signature materials
- novel hull forms
- modularity
- structural topologies

are of high priority.

Re-examination of Structural Topology. Important need to assess the benefits (reduced weight, greater survivability and whole life cost) of incorporating secondary structure as part of the prime structure, for example integral piping or ducting.

Technology Enablers for Reduced Manning. Pressure to reduce manning for significant defence cost savings, combined with modular platforms and high survivability, is seen to offer excellent opportunities for innovative ship design. Technology enablers that require further R&D as a high priority include:

- High safety jettisonable crew modules
- Increasing use of sensor damage/fire sensors
- Automated damage control & firefighting systems,
- Removal of many existing crew limiting restraints including fire, smoke and toxicity aspects, life support, etc,
- Use of foaming agents for fire suppression/buoyancy

iv. Underwater Environment

- **Platform Longevity.** The longevity of existing platforms requires further research to reduce ownership costs using alternative materials with the ability to meet new and unanticipated roles at the original design concept while maintaining platform durability and survivability. Considerations shall include:
    - Addition of new materials with old to extend platform life
    - Ability of structural design to permit enabling technologies during the life of the platform in a cost effective manner
    - The contribution of the materials selection to the reduction of maintenance required by the platform

- **Novel Pressure Hull Designs.** Work must investigate the potential of new materials to permit novel hull designs for any underwater platform considering:
    - Challenging the use of ring stiffened designs for new materials
    - Investigating the benefits of pre-stressing
    - Exploring the impact of pressure hull penetrations on the potential of new materials designs
    - Explore potential of filament winding

- **Unmanned Underwater Vessels.** Increasing use of Unmanned Underwater Vessels (UUVs) requires further R&D investment to examine:
    - Improved deployment and recoverability
    - Modularity concepts
    - Materials for construction combined with structural requirements
    - Better optimisation of hydrodynamic shape and function
    - Use of adaptive structure
    - Non-compressible buoyancy
    - Condition monitoring

- **End of life.** Research should explore the potential of new materials to reduce the "end of life" embracing:
    - Energy and material recycling
    - The impact to the environment and associated cost
    - The impact on Health and Safety of decommissioning, dismantling and disposal

v. Complex Design Risk Reduction

- **Exploitation of Available/Emerging Computational Power.** Vital to make "smarter" use of available and emerging computational power. Use to link:
  - Manufacturing processes
  - Material performance, failure algorithms, etc
  - Design tools
  - Virtual manufacturing to react to late changes and risk reduction
  - Computational experimentation
  - Knowledge management in design practices

- **Risk Based Processes.** Urgent need to move to risk based design processes to facilitate exploitation of disruptive technologies taking into account benefits and consequences.

- **Regulatory and Statutory Considerations.** Vital that regularity and statutory bodies are in step with developing designs and technologies and do not form a major hindrance through traditional excessive conservatism. Involvement of regulatory bodies in innovative R&D is thus of high priority.

3.2 Final Plenary Session

3.2.1 The principal issues that emerged from the plenary session, while not technical in nature, included:

- Identifying and continuing to make greater use of collaboration. A significant number were discussed including: a) international collaboration (e.g new "EUROPA"s), Framework VII, etc, and b) national collaboration via Dti's Technology Programme and the forthcoming MoD research competitions.

3.2.2 Roadmaps were discussed as a possible aid to co-ordinating R&D efforts and where R&D strands could be linked, etc. The NCN tentatively offered to fund such an activity if felt beneficial to the participants.

3.2.3 Cross sector working and lessons learnt from others sectors should continue to be enhanced. Many technologies are not unique to a particular sector and common areas of R&D should be identified and capitalised on. It was noted that the Dti's technology programme and the NCN expressly desired cross sector involvement.

4 Recommendations for way forward

4.1 The following recommendations are provided to progress the recommendations arising from the workshop reported herein:

a) The recommendations should be reported to the MOD's Research Acquisition Organisation and its capability and technology advisers to assist in formulating future MOD naval Materials and Structures R&D thrust areas

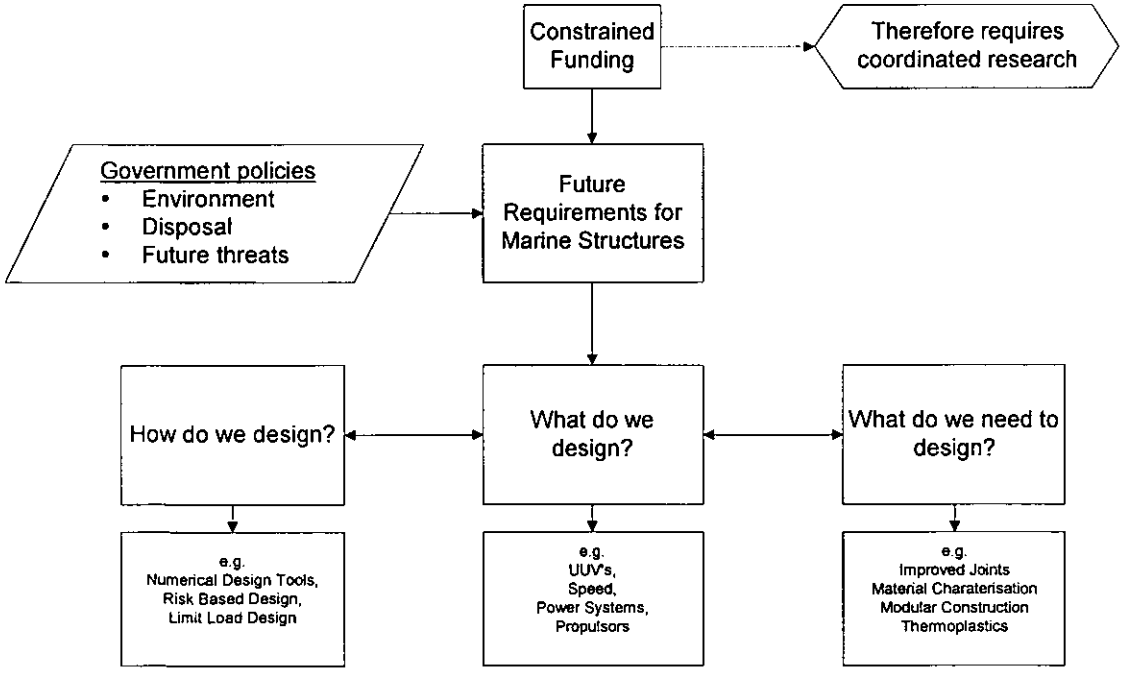
b) The recommendations should also be presented to the Marine IGT, Materials and Structures Technology Programme Managers in the Dti and the Materials and Structures NAC.

c) Findings should be reported to the Research Councils to encourage highly innovative research calls from academia.

d) Opportunities for collaboration should continue to be explored using available funding, both nationally and internationally. Collaboration should embrace partnerships of academia, research organisations, manufacturing industry and regulatory societies. Such consortia facilitate technology transfer and accelerate insertion of new technologies in the maritime environment.

e) Cross sector working should be encouraged wherever practical.

4.2 One mechanism for the manner of collaborative working is shown in the figure below.



4.3 The approach shown above is predicated on the assumption that funding is likely to be constrained and that progress will be best made through collaborative endeavours involving the pertinent government, industrial and research organisations. The main driver for this research is the set of government policies deemed to be essential for future maritime based platform requirements.

4.4 The research programme is to be targeted to answer three types of questions:

- How do we design (or what tools do we use in design)?
- What (systems) do we design?
- What (detailed aspects within the systems) do we need to design?

5 Acknowledgements

The authors of the report acknowledge the support of the following for the successful running of the marine vision workshop:

- The Research Acquisition Organisation of UK MOD, the UK's Department of Trade and Industry through the National Composites Network, the US Office of Naval Research, Dstl and the University of Southampton.

- Time, expertise and commitment from all attendees.

6. Nomenclature

Dti	Department of Trade and Industry
Dstl	Defence Science Technology Laboratories
EPSRC	Engineering and Physical Sciences Research Council
Maine IGT	Marine Innovation Growth Team
MOD	Ministry of Defence
NAC	National Advisory Committee
NCN	National Composites Network
NSWC	Naval Surface Warfare Centre
ONR	Office of Naval Research
RAO	Research Acquisition Organisation
UUV	Unmanned Underwater Vessel

7. Distribution – Electronic Distribution

1. All workshop attendees

2. Ministry of Defence
   - Professor J van Griethuysen – Sea Technology Group
   - Mr C Leach – RD WPE Research Acquisition Organisation
   - Mr I Burch – WPE Research Acquisition Organisation
   - Professor R L Jones & Dr Neil Lindsay – Chief Scientists Dstl
   - Mr C Broadbent, Capability Advisor, Dstl Portsdown West
   - Professor P Curtis, Capability Advisor, Dstl Porton Down

3. Dti
   - Dr R Quarshie – Materials Manager, Dti Technology Programme
   - Dr S Manimaaran – Design and Simulation Manager, Dti Technology Programme
   - Mr N Hayes – Marine Innovation and Growth Team
   - Mr R Pitman - Assistant Director, Platform Technologies

4. National Composites Network
   - Dr D Pullen – TWI

5. US Office of Naval Research
   - Professor C Calvano, ONR European Office, London
   - Dr Y Rajapakse , ONR, Washington, USA
   - Dr R Barsoum, ONR, Washington, USA

6. US Naval Surface Warfare Centre
   - Dr Jeffrey Beach – Operations Director, NSWC, Carderock

7. National Advisoy Committee.
   - Dr S Garwood – Rolls Royce Plc
   - Dr M Robb – Bae Marine

8. UK Research Councils
   - Dr. Alicia Greated – EPSRC
   - Dr N Davies - EPSRC

9. European Union Framework VII
   - Dr F Roland - CMT, Germany

Annexes

Annex A – Workshop Format

School of Engineering Sciences [dstl]

International Experts Workshop
In Marine Structures – A 30 Year Vision

Southampton, 16-18 November 2005

Programme of 16th November [dstl]

09:00 - 09:30	Welcome: Professor Ajit Shenoi (University of Southampton) and Dr. Alan Groves (Dstl)
09:30 - 10:00	Keynote 1 from UK Perspective: Professor John van Griethuysen (MoD)
10:00 - 10:30	Keynote 2 from US Perspective: Dr. Jeff Beach (NSWC)
10:30 - 11:00	Coffee
11:00 - 11:20	Forecasting future requirements from a 30-year hindcast perspective: Dr. Paul Frieze (PAFA Consultants)
11:20 – 12:00	Challenges from societal, safety and environmental perspectives: Professor Brian Hayman (DNV and University of Oslo)
12:00 – 12:30	Possible lessons from an aerospace perspective: Professor Mark Spearing (University of Southampton)

Programme of 16th Nov. (contd.) [dstl]

→12:30 – 13:45	Lunch
→13:45 – 14:00	Plenary
→14:00 – 15:30	Workshop 1: Modelling and Simulation
→15:30 – 16:00	Tea
→16:00 – 17:30	Workshop 2: Materials and Structures
→1900	Reception and Dinner

Programme of 17th November [dstl]

→08:45 – 09:00	Plenary
→09:00 – 10:30	Workshop 3: Above-water Environment
→10:30 – 11:00	Coffee
→11:00 – 12:30	Workshop 4: Underwater Environment
→12:30 – 14:00	Lunch
→14:00 – 15:30	Workshop 5: Unchemed/Open Agenda
→15:30 – 16:00	Tea
→16:00 – 17:00	Plenary Session: Summing-up and the future
→1700	Finish of formal proceedings

Breakout Workshops [dstl]

→Format	
→5 minutes	Briefing by Facilitator
→5 minutes	Personal thought time and recording thoughts on form
→5 minutes	Recording thoughts on flip charts
→30 minutes	Open discussion
→5 minutes	Personal thoughts' summing up and recording thoughts on form
→10 minutes	Group Rapporteur to prepare OHP slide for plenary

Plenary after Breakouts [dstl]

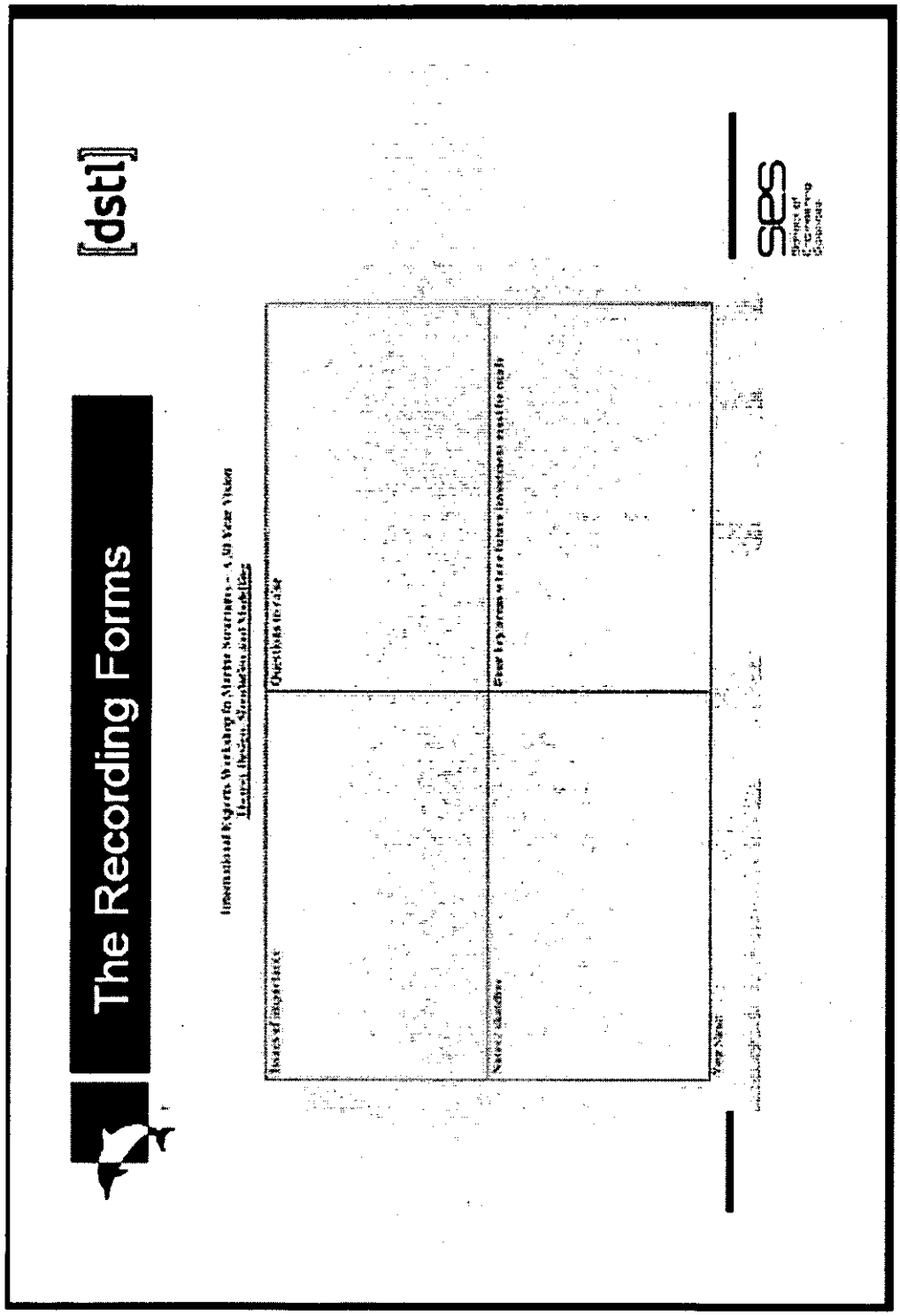
→Format	
→5 minutes	Presentation by each group through its Rapporteur, summing up the significant points emerging from the discussion. Note that there is no format for this except that each group will have just one A4 slide to present its thoughts and only 5 minutes to make the presentation.

Breakout Workshop 'Rules' [dstl]

→No wrong answers
→No point scoring
→Feed off stimuli from one another
→Explore implications
→Be 'adventurous'
→Please feel free to 'dream'

The Recording Forms [dstl]

Annex B Delegates Record Sheet



ANNEX C

Record of Principal Comments arising from the Modelling and Simulation Workshop Sessions

- Need to progressively integrate validated models at ship system level with sanity checking
- Model arbitrary hull forms with appendages
- Prediction tools to model fabrication effects over time – process modelling
- Move to multi-physics approach, i.e., CFD/motions/structural analysis/material models/human factors, etc
- Urgent need for improved load prediction:
  - Accuracy
  - Different levels of complexity
  - Extreme loads
- Improved modelling for damage assessment and consequences thereof:
  - Different types of event
  - Collision/blast/etc
  - Damage growth after event
- Appropriate design methods to deal with:
  - Complex vs simple
  - Information overload vs lost information
  - Feedback from practical experience
  - Innovation vs prescribed rules
  - Supplementing class rules with 1st principles design
  - Class rules prescriptive – alternative approach to demonstrate acceptability without excessive effort
- Improved calibration of CFD/FEA
- Machinery/structure interaction
- Improved modelling capabilities, from material modelling through to structural performance
- Manufacturing process modelling – leading to low cost/low defect/low deformation, etc

ANNEX D

Record of Principal Comments arising from the Materials and Structures Workshop Sessions

- Optimised materials and structural component performance for normal and abnormal use- basic properties, performance in fire etc. Signatures (stealth)

- Reduce life cycle cost – capital platform costs, maintenance, manufacturing
    - Does industry understand the full material/structure life cycle cost?
    - Corrosion, fatigue, self diagnostics, low maintenance

- Multifunctional and adaptable structures
    - Sandwich materials
    - Layered structures
    - Functional coatings
    - Hybrid materials

- Environmentally friendly materials consistent with current and anticipated legislation

- A systems approach - materials, structures and other aspects need to be considered as an entire system.

- Joints and interfaces:
    - FE does not effectively model mechanical fastening, welding etc.
    - Reducing number of joints
    - Control monitoring and repair

- Means of accelerating insertion of new technologies included in design. One possibility is to streamline shipyards and classification society's interactions.

- Thermoplastic technologies need greater assessment for improved damage tolerance, low cost, etc.

- Failure of joints remains poorly defined.

- Greater understanding of material properties, for example: failure, ageing, extremes of temperature etc. Frequently the understanding of commonly used materials is shallow! Hence adoption of large safety factors.

- Continue to look to ease of production, standardising interfaces, system integration

- Multi-functionality – re-configurability, adaptability, fire properties

ANNEX E

Record of Principal Comments arising from the Above Water Environment Workshop Sessions

- Use of secondary structure to contribute to hull girder strength or functionality e.g. integrated pipework in structure

- Increase unmanned capability as reduced manning can result in greater survivability e.g. fire situation, whereby minimal crew would permit use of halon fire suppression in uninhabited areas

- Manned vs unmanned issues:
  - Health and safety issues radically change
  - Greatly influence choice of material options
  - Motions become unimportant.... as do other human factors
  - Could remove defence systems as there are no people to defend
  - Reducing manning reduces ship husbandry
  - Personnel required in naval theatre for weapon deployment /peacekeeping
  - Smaller crew requires greater automation
  - High volume low cost ships will lend themselves to unmanned disposable solutions
  - High cost low volume be-spoke manned solutions need to be highly adaptable
  - Reduction of manning levels to zero elevates the requirement for designed survivability
  - Protection of unmanned nuclear powered vessels – what are the solutions?

- High speed - low weight platforms/vehicles
  - Further exploit existing materials via geometric features
  - Environmental issues
  - Fire resistance/structural performance

- Systems approach to achieving high speed – Requirement, technology etc.

- Modular vessel
  - Flexibility and ease of change-out
  - Use of jettisonable crew modules for improved crew safety

- Sensor systems
  - Inside ship – health monitoring
  - Outside ship – Terrorist detection
  - High-resolution – combined signals – smart sensors – smart use

- Propulsion
  - Fuel consumption reduction
  - Alternative fuels – must be reliable
  - Risk of fuel change - hydrogen, nuclear, coal (?)
  - Electrification
  - Wind power
  - Wave power

- Structure
  - Membrane structures
  - RF signature
  - Terrorist attack
  - Fuel storage, high pressure – low temperature – vulnerability

- Human Behaviour
  - Uninhabited ships allow for alternative materials
  - Habited ships are becoming larger therefore evacuation systems/strategies need improvements

- Design Tools
  - Wide ranging
  - Performance and failure mechanisms

- Novel Hull Concepts
  - Increased deck area and speed
  - Structural challenges e.g. fatigue
  - Hydrodynamics

- Stealth
  - Chameleon ("spoof rather than invisible" radar signal)

ANNEX F

Record of Principal Comments arising from the Under Water Environment Workshop Sessions

- Life extension and maintenance of current classes

- Modification of current vessels to face new threat/roles
  - Use of tubes
  - Towed
  - Bolt-on

- Propulsion and position systems and maintenance of stealth

- UUV's
  - Method of deployment and recovery
  - Materials of construction
  - Structural requirement
  - Non-compressible buoyancy
  - Oceanographic vs. military needs
  - Integration of hull & systems

- Unmanned systems
  - Deployment ad recovery
  - Modular system
  - Power system

- Lightweight corrosion resistant materials
  - Fairing, appendages, propulsors, maintenance

- Ocean floor exploitation
  - Mineral harvesting processes
  - Oil and gas exploration and maintenance
  - Habitat

- Military applications
  - Future weapons
  - Survivability – Signatures, stealth, asymmetric attack, integration of functionality into hull

- Mother vessels – UUVs
  - Underwater communications
  - Launch and recovery

- UNDEX

- Manufacturing
  - Design/manufacture for reduced maintenance
  - Better use of materials
  - Skills and capability

- Propulsion
  - Speed – role dependent
  - Nuclear, fuel cells, alternatives
  - Nuclear – alternative required for steam plant

- Condition Monitoring
  - Fire management, reduce costs etc.

- Pressure hull optimisation
  - Layered materials with embedded outward pre-stresses
  - Composite filament winding

- Composite structures
  - Appendages – skegs, propellers etc.
  - Multi-functionality included – SMART, signature reduction

ANNEX G

Record of Principal Comments arising from the Complex Design Risk Reduction Workshop Sessions

- Systems Engineering Approach Required
  - Design – iterative application of engineering analysis
  - Domain knowledge is vital
  - Education

- Quantify Probability of Risk and Consequences
  - Articulate!
  - Calibrate
  - Define

- Underpinning Tools/Knowledge
  - Modelling
  - Physical verification

- Establish Robustness and Adaptability

- Conduct Research into the Evaluation of Designs
  - Comparison of designs
  - Verify correctness of design

- Identify skills needed to provide solutions to our requirements

- Limit State Design Philosophy
  - Loads/demands on structure and its response

- Apply Computing Power More Widely
  - Manufacturing processes
  - Material properties
  - Design tools

- The Process of Improvement
  - Collaboration, e.g. offshore example
  - Shared benchmark

- Think Simpler
  - Too complicated won't happen
  - Simpler processes

- Risk Management
  - New designs need some risk
  - Balanced with benefit
  - Common terminology for risk
  - Human vs. technical

- Regulation
  - Class rules
  - In step with developing designs?
  - Very conservative (cost driver)

- Versatility
  - Changing threats
  - Unexpected events

- Product Development
  - Modelling
  - Scale models

- Centres of Excellence
  - Urgent need to retain breadth and depth

ANNEX H

Record of Principal Comments Arising from Plenary Session

- Coordination of research. Urgent considerations include:
  - Sharing with others globally to create a database of properties (materials) and applied loads and maintained
  - Project for collection of data for better design – what is the mechanism for this
  - What do we do with the database once its been collected? Who owns and updates?
  - Can classification societies contribute to collaborative R&D
  - Communication is ultimately important to avoid overlapping projects but in reality unavoidable say between Europe and USA
  - Where is the interesting research being done, how do we share the idea and results – this is a research co-ordinators job.

- How to best move forward?
  - Some funding to collect a similar group as per this event to discuss collaboration
  - Dstl will talk to EDA for moving forward marine collaborative research
  - International community involved in any follow-up workshops need to be asked to identify areas for future research prior to the event.
  - But what are the key issues and areas? Reason for workshops

- Management of change
  - Manage moving forward as technologies change – strategies
  - Get the naval architecture community working together more efficiently

- Dstl expressed desire for more national and international collaboration

- ONR – money well spent and well organised and good exchange of ideas
  - Incorporation of system engineering in research
  - There are opportunities for research collaboration with ONR

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School of Engineering Sciences

Ship Science

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