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AN EXPLORATORY STUDY OF ALTERNATIVE STRUCTURAL MATERIALS FOR SMALL SWATH CRAFT

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CONTENTS

1. INTRODUCTION

1.1 Current State of the Small SWATH World Fleet

The SWATH Fleet of 500 tonnes and below, consists of one CFRP/GRP craft, four all aluminium alloy, two hybrid (steel catamaran hulls, aluminium alloy deck structure) and one steel with alloy deck house.

These craft together with "paper" designs taken from references 1 to 5 are shown on Figure 1.

Three regimes may be identified:

1. Predominantly all aluminium alloy,
2. Predominantly all steel
3. No clear predominance.

High speed, high payload designs require the use of aluminium alloy. However as the size of vessel increases both requirements can be met with steel construction, since hull weight fraction is inversely proportional to displacement.

For the same speed, payload and range, the designer has the option of a bigger craft constructed of steel or a smaller craft constructed of a lighter, though more expensive material (see Figure 2, taken from reference 46).

Other constraints such as limiting draft may exclude the bigger craft option.

If the world SWATH Fleet is to grow significantly, it is believed that this is most likely to occur in two distinct areas, viz;

- Large SWATH ships of 3000t and above, engaged primarily in naval roles.
- Small pleasure or work boats, with the occasional highly specialised research craft.

This report is concerned with the latter type where steel will be a viable option only for low speed, low payload designs.

As lightweight construction is going to be necessary one might question why FRP has not been more extensively employed. Many small boat builders offer the same design in aluminium alloy and GRP which suggests the two materials are fairly competitive. This project seeks to investigate the application of FRP to small SWATH craft.

1.2 FRP as a Structural Material

The hull of a SWATH craft is commonly circular in cross section. As hull diameter decreases, quality control of welds may become more difficult especially for 'low-tech' boatyards. GRP sandwich construction would appear, at least superficially, to offer fabrication advantages in this area.

A simple male mould could be laid over with a foam core and laminated in the normal way. The mould could be lengthened by the insertion of parallel middle body and could thereby be used for a range of craft sizes.

The bridging structure (or box) resembles a conventional ships double bottom. This may be more difficult to produce in GRP. An 'open cell' structure may be a better solution or alternatively a GRP (hull and strut)/Aluminium alloy (box) hybrid design could be considered.

Problems associated with all GRP or GRP-hybrid SWATH craft concern the provision of adequate strength connections between the various components especially the haunch-box connection.

There are clearly a number of questions to be answered before GRP SWATH craft can be built routinely in 'low-tech' boatyards. An extensive research programme would be required which would need to result in the development of computer aided structural design tools. This would be particularly true if expensive advanced composites were found to be necessary.

However before such a structural research programme can be justified it is necessary to establish the relative merits of GRP, aluminium alloy and mild steel. This report describes the results of such a preliminary investigation.

1.3 Method of Investigation

This investigation consists of three phases:

- Definition of scope of investigation
- Structural design phase
- Evaluation phase

An extensive study involving many types of SWATH craft and structural arrangement is felt to be unnecessary at this stage. The objective is not to attempt to optimise in any way. This must come later, after the development of reliable design aids. The objective here is to obtain a 'feel' for the relative merits of different materials. This can be achieved by limiting the number of variables. These limitations are described in the next three chapters.

The structural design and evaluation phases are accomplished by three computer programs written for the Hewlett Packard 86B desk top computer. The relationship between these programs is outlined in Figure 3. The background to their development is described in the next three Chapters.

2. LOAD PREDICTION PROGRAM 'LOADS'

2.1 Load Types

The six generalised force components are:

1. F_z (Vertical force)

Composed of vertical slam induced loads on the underside of the bridge structure and wave induced forces transmitted through the struts.

2. F_y (Horizontal force, athwartships)

Transverse force arising principally from the diffraction of the waves. Waveslap forces not considered.

3. F_x (Longitudinal force)

This is neglected owing to the small cross section of the SWATH craft particularly at the water level.

4. M_x (Moment about longitudinal axis)

Comprises the transverse bending moment at the box–strut intersection (which is almost entirely due to F_y) plus the torque which is thought to be largely due to the vertical separation of F_y values, port and starboard.

5. M_y (Moment about transverse axis)

Comprises the conventional longitudinal bending moment plus a torque induced by longitudinal variations of F_z between the two hulls.

6. M_z (Moment about vertical axis)

Induced by longitudinal variations in F_y.

Vertical forces other than bridge slam forces are likely to be small since they will be largely dependent on waterplane area. Lee (6) has demonstrated that vertical shear forces are an order of magnitude smaller than horizontal (or side) forces.

Longitudinal bending is also likely to be unimportant owing to the short hull length and large modulus associated with SWATH craft.

The principal loads are illustrated in Figure 4.

For detailed structural design, it would be necessary to formulate a DESIGN LOAD SET of the type:

$$Q_D = (\Phi_1 . P_{m1}, \quad \Phi_2 . P_{m2} \; ..... \;) \tag{1}$$

where P_{mi} = The maximum value of load type i obtained for the SWATH poised in the most disadvantageous position with respect to the predominant wave direction FOR THAT PARTICULAR LOAD TYPE.

Φ_i = A load combination factor, less than or equal to one.

For preliminary structural design, a simplified approach is adopted, namely:

i) Use of the peak value of slam pressure for design of panels of plating and stiffeners in the wet deck and haunch region.

ii) Use of the peak value of transverse moment for box and strut design.

iii) Use of the peak side force for design of shear area of strut and haunch.

iv) Use of hydrostatic pressures for design of panels of plating and stiffeners where this is more appropriate than slam pressure.

v) Torsional moments are not included at the preliminary design level.

Although 'LOADS' will provide initial estimates of all load types shown in Figure 4, when used as input to 'STRUDES', only the peak side force and panel design pressure are estimated. The transverse bending moment is calculated by 'STRUDES'.

It has been demonstrated (6) that an RAO curve for transverse moment may be estimated from the side force RAO at the same frequency by multiplying side force by the lever arm from the half draft to the neutral axis of the box structure. Since this distance (Z_{NA}) is a constant, the peak transverse moment is obtained from;

$$M_x = F_{y(side)} \cdot Z_{NA} \qquad (2)$$

2.2 Load Prediction Method Options

In developing a preliminary load prediction method it is essential to ensure that the data requirements are consistent with the level of detail implied by the term preliminary.

Of most use to the designer are simple formulae, based primarily on the principal dimensions and form coefficients, of the type found in Classification Society Rules. Such formulae are often an amalgam of simple theory and past experience. With limited data on SWATH craft available, it was necessary to use a more theoretical method.

Two other constraints are imposed:

i) Since scantlings are as yet unknown, a hydro-elastic based method is not possible. Loads are therefore to be determined by rigid-body theory and are to be applied as static loads in 'STRUDES'.

ii) Many design formulae include a 'design wave' (e.g. effective wave height in WBM predictions). The value used may not be obvious. For coastal operations, reduction factors are often employed. For small craft, this is considered to be unacceptable. It is most important that the designer should be able to design to a limiting sea state and thus he must be able to specify this parameter.

In the light of these constraints, peak values of slam pressure and side force are obtained from their respective response spectra which are developed from response amplitude operators (RAO), a designer specified sea state and the principle of superposition.

Two procedures are available for determining design loads from response spectra (7):

i) Lifetime weighted sea method

ii) Design sea method (8).

The first method requires a series of short term response spectra which represent the entire lifetime of the craft. These discrete responses are weighted according to their relative exposure time as a fraction of the ships life. The method requires considerable computation and is therefore considered unsuitable for preliminary design. In addition, the method considers sea states which are most unlikely to give rise to critical stresses.

The second method uses wave statistics to estimate the probable extreme value of significant waveheight. A response analysis is then performed for this waveheight plus one or two similar values.

2.3 Design Sea Method

The Design sea method has been selected since it is compatible with available design data. However both methods give similar predictions (7). The method has been slightly modified in that only one value of significant waveheight is used, this value being the maximum sea state in which the vessel is intended to operate. The margin over nominal operational sea states is left to the designer as he has control over this parameter.

The design load is then obtained from:

$$P_i = \sqrt{2\, m_{oi}\, \ln\left\{\frac{1800}{\pi\,\alpha}\, T \sqrt{\frac{m_{2i}}{m_{oi}}}\right\}} \qquad (3)$$

where P_i = design load type i

m_{oi} = area under response curve of load type i

m_{2i} = 2nd moment of area of response curve for load type i

T = Time (hours) in sea state

α = Risk parameter

If $\alpha = 1$ then equation (3) gives the largest single value of P_i. If $\alpha = 0.01$ the P_i corresponds to the largest single value which would be experienced by 100 ships operating in this sea state. Both α and T are supplied by the designer.

The sea spectra used in calculating m_{oi} is a two parameter, nine member family of the Bretschneider type;

viz;

$$S(\omega) = \frac{5}{16}(\omega_m/\omega)^4 \;.\; H^2_{s/\omega}\; e^{-1.25(\omega_m/\omega)^4} \tag{4}$$

where ω_m = modal wave frequency
H_s = significant waveheight

For each of the nine members a weighting factor is available which reflects the probability of occurrence. The exposure time T used in equation (3) is multiplied by this factor to reflect the likely exposure time to that member. Note; the 9 factors sum to one.

Hence nine values of P_i are calculated, the largest of these being taken as the design value.

2.4 Validity of Superposition

From the foregoing it is apparent that the load prediction method relies heavily on conventional short term prediction theory. It is therefore appropriate to consider the validity of linear theory.

The most important limitation in applying the method to small craft is on waveheight:length ratio. For small craft in high sea states, small amplitude RAO's will not reflect the correct response. For example, many failures of yacht hulls can be attributed to the craft being left 'airborne' by a large wave leading to subsequent heavy slamming. For SWATH craft it is known that rigid body motions are likely to be small and therefore providing sensible waveheights are used, no major problems are anticipated. Waveheights of 16m on a frigate of length 100m have been used with linear theory (9). This corresponds to 3.7m on a 23m SWATH craft.

In view of the wall-sidedness and small motions associated with SWATH craft non-linearity arising from hull shape and flare induced slamming should be negligible. Damping effects are known to be non-linear (6) and may well give problems.

A possible solution may be:

i) To use RAO's derived from high waveheight:ship length experiments.

ii) To attempt the use of correlation factors derived from full scale tests.

This is however pure speculation. It is felt that a non-linear treatment is inappropriate at the initial stage. Even if such treatment were required, insufficient data is available to proceed at the present time.

2.5 Peak Side Force

This aspect of the loads imposed on twin hull ships has received the most research interest. Early work (10) on catamarans attempted to estimate the side loads from consideration of differential hydrostatic loading for beam seas. As the width of each hull tends to zero so this force tends to zero. One might expect that side loads on SWATH craft would be very small. However it has been shown (6) that undisturbed incident waves account for only a small portion of the total force imposed. It would appear from theoretical analysis that the diffraction of the incident wave caused by the presence of the ship accounts for most of the force and is certainly responsible for producing a sharp peak in the RAO curve.

The method of Lee & Curphey (6) considers the beam sea condition and zero forward speed. The SWATH ship is represented by uniform twin cylinders having a cross sectional shape which is usually similar to the midship section. The approach of treating the SWATH ship as prismatic which presumably means a reduced length, will of course mean care must be taken in the treatment of added mass and damping coefficients in order to reflect the 3-D flow. However the authors have been able to demonstrate good agreement with experiment and the present author has no hesitation in utilising predictions which are available from this work.

Some discussion is required on the subject of zero speed. From the considerable work of DWTNSRDC there appears little doubt that side forces reduce with increasing speed. While acknowledging this, Sikora (11) neglected the effect en route to developing a method for lifetime side force prediction. For small SWATH craft, it could be argued that the craft is most vulnerable after suffering a complete power failure such that not only is the craft at rest but all active stabilising systems are dead. Accepting this argument, means zero speed RAO values are the ones that should be used anyway. In this case, the designer would be advised to use the anticipated recovery time in lieu of the sea state duration (assuming the former to be the smaller of the two).

There are two modes in which 'LOADS' operates:

i) User defined RAO data (USER)
ii) Default data (DEFAULT)

In the USER mode, RAO may be supplied either as Force/wave amplitude versus frequency OR non-dimensional force coefficient versus wavelength/hull separation.

viz:
$$f_y = \frac{F_{y(side)}}{\rho\ g\ A_p \cdot \zeta_o} \qquad (5)$$

A_p = Projected side area
f_y = Side force coefficient
ζ_o = Wave amplitude

If the user has access to model tests or analytical results or can find published RAO data for a SWATH which closely resembles the intended design, then it is considered that 'LOADS' will give as accurate an initial estimate of side force as any other procedure currently available.

At the outset of this part of the project it had been hoped that the currently available data could be analysed such that force coefficients could be made to collapse into a single (or nearly so) curve. Unfortunately, with only some 10 sets of curves available it was felt that little confidence could be placed in any such analysis. Consequently, it was decided to use a single default curve in 'LOADS'. (See Figure 5 which represents an upper limit of all published data). This fact should be borne in mind when selecting a value for the risk parameter α.

Sikora (11) developed an equation for the lifetime side force (F_{max}) viz:

$$F_{max} = (1.5399\ T/U.(1.55-0.75\ \tanh(\Delta/110)(-.725+2.989\ \tanh(Le/24))\Delta\ (MN) \quad (6)$$

where Δ = Displacement (MN)

U = Moulded volume 0.333 (metres)

T = Draft (metres)

Le = 3.271/U(Length of struts + 1/2 (Hull length − strut length) (metres)

This equation is applicable to SWATH ships operating in North Atlantic conditions where waveheights in excess of 10 metres account for about 2% of a lifetimes total. It would appear that equation (6) should not be applied to small craft operating in coastal waters. However 'LOADS' calculates $F_{y(side)}$ according to equation (6) in addition to that obtained from equation (3). It is anticipated that equation (6) may serve as an indication of the upper limit on $F_{y(side)}$ although this may not always be the case if the default f_y curve turns out to be unduly pessimistic.

It is not possible at present to indicate the limits of accuracy of side force predictions. For small SWATH craft secondary hydrostatic and slam loads are expected to be critical (4).

In addition Kennell (12) has shown that the structural weight of SWATH ships in the size range 2000–5000 tonnes is virtually independent of the magnitude of the side load for side loads in the range 0–2 times the weight of the ship.

2.6 Peak Slam Pressure

Peak slam induced pressures are very sensitive to the loaded area. A brief study of the literature shows a wide variation in recorded pressure peaks. What is more important than peak pressure is maximum force imparted to the structure during the slam. This force can then be applied as a point load (one extreme) or as a patch load where the patch area is taken as the largest loaded area during the slam (other extreme).

The very high pressures corresponding to the first few milliseconds of impact are applied to a very small area. The load is usually small. In addition, structural inertial resistance is significant. This means that such pressures are of no use for structural DESIGN purposes. Instead it is convenient to determine the pressure corresponding to a 'reference' area of structure.

The reference area used in 'LOADS' for input to 'STRUDES' is taken as the typical lateral area of a panel of plating obtained from user supplied input.

The impact pressure obtained from 'LOADS' is to be applied as a quasi-static load. The impulse function will generally be triangular in shape. Providing the impulse duration exceeds the natural period of the structure, this approach is acceptable (13).

'LOADS' calculates panel design pressures by two independent methods.

1. Sellars Method (14)

Sellars method allows for the effect of structural elasticity on impact pressure via a structural impedance factor, C (high C implies a rigid structure).

The panel pressure is obtained from:

$$P = 0.1013 \left[0.5\left\{(1+C.V_o/V_1-C/\delta_v) + \sqrt{(1+C.V_o/V_1-C/\delta_v)^2+4C/\delta_v}\right\} - 1\right] \text{ MN/m}^2 \qquad (7)$$

where V_o = Relative impact velocity

V_1 = $P_1/\rho_o.C_o$

P_1 = Atmospheric pressure

ρ_o, C_o = Mass density and speed of sound for pure liquid

δ_v = Liquid-air mixture volumetric impedance ratio

and

$$C = C_1/C_L \left[\frac{\rho_1.C_L}{\rho_o.C_o}\right] \frac{1}{\alpha} \qquad (8)$$

where C_L = Speed of sound in solid

C_l = Bending wave speed

ρ_1 = Mass density of structure

α = Impact area factor

and,

$$\alpha = \frac{1}{2t} \sqrt{\frac{l \times b}{\pi}} \qquad (9)$$

where b = panel width

t = Panel thickness

and,

$$C_l/C_L = \frac{\pi t}{\sqrt{12}\, b} \left(1 + (b/l)^2\right) \qquad (10)$$

where l = Panel length

2. Allen & Jones Method (15)

$$P = N_z \,.\, K_D \,.\, \Delta/(A_R \times 0.09) \qquad (11)$$

where N_z = Maximum amplitude of vertical acceleration at the centre of gravity due to impact forces, i.e. not buoyancy forces.

Gross loaded area, obtained from:

$$A_R = 0.479\, \nabla^{0.667} \qquad (12)$$

where ∇ = Volume of displacement

Equation (12) assumes a pitch radius of gyration of 25% of the box length.

K_D = Pressure reduction coefficient

From equation (7) and (11) it can be seen that the major difficulty in calculating pressures lies in estimating impact velocity and acceleration. Given that an approximate solution only is being sought, 'LOADS' estimates V_o and N_z on the basis that the SWATH craft behaves as a single degree of freedom rigid body, heaving in beam seas.

Impact velocity

$$V_o = \dot{z}_{max} + 1/2\, H_s \,.\, \omega \qquad (13)$$

where $\dot{z}_{max}$ = Peak heave velocity obtained from equation (3)

ω = $\sqrt{m_{2i}/m_{oi}}$ for the spectrum corresponding to z_{max}

Impact acceleration

$$\ddot{z}_t = \ddot{z}_b + \ddot{z}_i \qquad (14)$$

where suffices are; t = total, b = due to buoyancy forces and i = due to impact forces.

or

$$\ddot{z}_t = \ddot{z}_b + k.\ddot{z}_t \qquad (15)$$

or

$$\ddot{z}_t = \frac{\ddot{z}_b}{(1-k)}$$

or

$$\ddot{z}_i = \frac{k\ \ddot{z}_b}{(1-k)} \qquad (16)$$

where k = Impact acceleration:total acceleration ratio

$\ddot{z}_b$ will be the acceleration derived from the same single degree of freedom model used to find $\dot{z}_{max}$.

Allen & Jones (15) indicate k to be in the region of 0.3 to 0.5. 'LOADS' assumes k = 1/3.

The peak velocity and acceleration are obtained from the nine family spectra analysis in the same way as side force. For both methods of predicting impact pressure it is necessary to have heave RAOs. 'LOADS' accepts user defined RAOs. In the default mode, the single degree of freedom model determines RAOs from:

$$RAO(\omega) = \frac{F_H(t)}{(\rho g A_w - M_H\ .\ \omega^2)^2 + B_H\ \omega^2)^{1/2}} \qquad (17)$$

where A_w = Waterplane area

M_H = Virtual mass in heave (Craft mass plus added mass)

B_H = Damping coefficient in heave

$F_H(t)$ = Heave exciting force

RAOs are calculated for frequencies in the range 0.05 to 2 rads per sec. at 0.05 intervals. At 2 rads/sec, the energy content of the wave spectrum is a negligible proportion of the peak, even for the maximum modal frequency used for the nine family members.

In the default mode, the heave natural frequency is estimated from:

$$\omega_H = (\rho g \; A_w/M_H)^{1/2} \tag{18}$$

As the added mass component of M_H (m_H) is a function of frequency, 'LOADS' repeats equation (18) until ω_H agrees with the frequency assumed for calculating m_H.

The forcing function is determined along similar lines to the methods of Penney and Riiser (16) and Oo and Miller (17). It is composed of a Froude-Krylov force and an inertia force due to the acceleration of the added mass of the body. Diffraction effects are neglected. This may be acceptable for semi-submersibles but is expected to lead to errors in SWATH forms and the neglect of diffraction may need to be reconsidered at a later date.

The forcing function is calculated separately for the hull and the strut as follows:

HULL

$$F_H^h(t) = -\rho g \; \zeta_o \; e^{-KZ_1} KV(1 + AMF) \cos(Ky) \tag{19}$$

where V = Hull volume

Z_1 = Vertical distance of hull centre below still waterline

AMF = Added mass factor

y = Distance from SWATH centreline to hull centreline

k = Wave number

STRUT

$$F_H{}^s(t) = \zeta_o \, . \, e^{-KZ_2}(\rho g \; A_w - m_H^s \; \omega^2) \cos (Ky) \tag{20}$$

where A_w = Waterplane of strut (p & s)

m_H^s = Added mass of strut (p & s)

Z_2 = Vertical distance from underside of strut to still waterline

i.e. $$F_H = F_H{}^h + F_H{}^s$$

'LOADS' relies on data obtained from published literature as follows:

Strut added mass data (for use with equation (20))

Added mass coefficient (added mass/ρt_s^2) versus frequency coefficient ($\omega(T/g)^{1/2}$) for t_s/T of zero (thin ship approximation). This maximises the added mass (t_s = strut thickness, T = Z_2). Source: Newman (18).

Hull added mass data (for use with equation (19))

Added mass coefficient (added mass/$1/2\rho\pi D_H^2$) versus frequency coefficient ($\omega^2 D_H/g$) for a submerged cylinder having a draft (Z_l):D_H ratio of 0.66 to 5.0. The data is stored in the form of polynomial coefficients as a function of Z_l/D_H. (D_H = hull diameter). Source: Kim & Chou (19).

Bulbous hull data (for use with equation (17))

Added mass coefficients (added mass/$1/2\rho\pi D_H^2$) versus frequency coefficient ($\omega^2 D_H/g$) as a function of t_s/D_H (0.0 to 1.0). The data is stored in the form of polynomial coefficients as a function of t_s/D_H. The added mass coefficients are also a function of draft:D_H ratio (1.35 to 2.0). Source: Kim & Chou (19), Frank (20) and Maeda (21).

Damping data (damping force/$1/2\omega\rho\pi D_H^2$) versus frequency coefficient with t_s/D_H as above for draft/D_H = 2.0 only. Source: Kim & Chou (19), Frank (20).

All data applies to 2-D sections. In the absence of J values for correcting for 3-D flow it has been assumed somewhat arbitrarily that;

$$J_{strut} = C_w \quad \text{and} \quad J_{hull} = C_p.$$

This is equivalent to maintaining the relationship that

$$\frac{\text{added mass (2-D section)}}{\text{immersed area}} = \frac{\text{added mass (3-D section)}}{\text{immersed volume}}$$

It is known that the forcing function will be fairly sensitive to the accuracy of the added mass data particularly at high frequencies. Theoretical predictions for heave exciting force (21) are compared with the simple prediction from 'LOADS' (Figure

6). From this it is concluded that although the 'LOADS' prediction follows the correct trend, notably as far as cancellation frequencies are concerned, the absolute comparison is somewhat poor. Whether this is due entirely to errors in added mass is questionable. The neglect of wave diffraction seems a possible partial explanation.

Further work may show the simplified approach adopted for slam pressure prediction to be unreliable or simply too inaccurate for incorporation in any design procedure. However, for the present the accuracy of impact velocity and acceleration predicted by 'LOADS' is believed to be comparable with the general level being sought from the other default options.

2.7 Evaluation of 'LOADS'

The major problem faced by structural designers is the need to use extreme values of load which are very difficult to substantiate. This is true of all programs whatever their level of sophistication.

Correlation is best done by analysis of actual structural failures using limit state theorems in order to estimate the failure load for comparison with extreme load predictions. For novel concepts this is not possible.

However, loads are only of interest in that they affect the structural weight of a SWATH craft. This is discussed in Chapter 5.

3. STRUCTURAL DESIGN PROGRAM 'STRUDES'

3.1 Structural Arrangement Employed in 'STRUDES'

Numerous structural arrangements have been proposed for SWATH craft (see Figure 7). A logical arrangement would be to transversely frame the box to resist the side force and transverse bending moment. For the haunch, strut and hull in steel or aluminium alloy, longitudinal framing with deep transverse web frames should produce a lightweight structure capable of resisting the dominant secondary loads as well as facilitating fabrication (see Figure 8).

For GRP, sandwich construction would be suitable for the haunch, strut, hull and deckhouse. Transverse frames of top hat form would also be employed (see Figure 9). For the box, single skin construction is preferred to sandwich construction. Top hat stiffeners over non-structural cores would be used in preference to an angle for torsional stability reasons. This is likely to lead to a heavier structure than would be possible with sandwich construction. For sandwich panels under inplane loading, it is most important to produce a high quality bond between skin and core. As the box is such a critical part of the structure, this writer is not prepared to recommend sandwich construction until a detailed research program has been completed.

The haunch-box connection may be one of two types:

1. "Full width wet deck" (Figure 7I and 7II).
2. "Partial width wet deck" (Figure 7III).

The first type is preferred for the following reasons:

i) Fracture of the weld between the haunch and the wet deck is less likely to lead to fracture of the weld between the wet deck and the internal girder giving a 'clean break'. In the event of the loss of one hull and strut, the box is more likely to remain watertight. There are however alignment problems associated with this arrangement.

ii) The mixed framing system and hybrid construction could both be more easily accommodated.

The structural arrangement employed in "STRUDES" is not an optimum one.

Rather it is one realistic arrangement among many others.

It may be possible to consider the optimum arrangement as a result of a detailed research program. However, as this is not the purpose of this preliminary study no further reference will be made to this aspect.

3.2 'STRUDES' Data Requirements

The data required consists of:

i) Principal dimensions of hull, strut, haunch, box (except depth) and deckhouse.

ii) Material properties for steel, aluminium alloy, GRP and core, including design stress. (Default values available).

iii) Side force and slam pressure from 'LOADS'.

3.3 Determination of Initial Scantlings

With the exception of the deckhouse, initial scantlings are obtained as follows:

Steel or aluminium alloy plate thickness

Small deflection theory may be modified by use of a 'large deflection stress reduction coefficient' (22). This approach has been adopted by 'STRUDES' which gives plate thickness, rounded up to the next 1/4mm, given plate dimensions, design pressure and design stress (see 3.8).

Steel or Aluminium alloy stiffener scantlings

The required section modulus of plate-stiffener combinations (PSC) are obtained by treating the PSC as a built in beam subject to a uniformly distributed load. The effective width of the plate flange is determined from (23):

$$\frac{be}{b} = \frac{1.1 \times 0.85}{1 + 2(b \times .85/0.583L)^2} \qquad (21)$$

b = stiffener spacing, L = stiffener span.

The factor 0.85 is intended to allow for out of plane distortion (7). The actual scantlings of the stiffener are obtained by incrementing the web thickness (t_w) in 1/4mm steps. The web depth is obtained by:

$$d_w = K_1 \cdot t_w \tag{22}$$

where K_1 = 18 (steel) or 15 (alloy) for flat bars

or K_1 = 30 (steel) or 25 (alloy) for angle bars

d_w is rounded to the nearest centimetre.

The stiffener is initially assumed to be a flat bar. If the depth required to satisfy the modulus requirement exceeds 120mm, an angle bar is substituted and the whole calculation repeated until a satisfactory angle is identified.

The flange thickness (t_f) is taken as equal to the web thickness and the flange width is taken as 12 t_f (rounded to the nearest centimetre).

Glass reinforced plastic single skin

Thickness is taken directly from ABS GRP rules (25).

$$t = 0.051 \ s \ \sqrt[3]{kh} \quad mm \tag{23}$$

where k = an aspect ratio factor (= 0.028 for long plates)

h = design head (m)

s = span of shorter side (mm)

It is a simple matter to show that this equation is based on a limiting span–deflection ratio (apparently ≃ 100) and therefore design stress does not feature.

The panel stress is approximately given by

$$\sigma = 21 \ h^{1/3} \quad MN/m^2 \tag{24}$$

where h = design head (metres).

Glass reinforced plastic sandwich panel

ABS rules (25) require:

i) A minimum core depth of

$$d_c = 0.0015 \, k_2 \, h \, s \, / \, u \quad \text{mm} \tag{25}$$

where k_2 = core depth–skin thickness related coefficient
u = shear strength of core (MN/m^2)

ii) Equivalent flexural stiffness to that given by equation (23).

Two further requirements are included in 'STRUDES':

iii) The maximum stress in the GRP is not to exceed the design stress.

iv) The skin thickness is not to be less than 65% of that given by equation (23), where s = 300 + 5L mm (L = scantling length in metres). The requirement is imposed in order to improve the impact resistance of the sandwich (45).

The core depth is obtained from requirement i) and is kept constant while any other strength deficiencies (i.e. requirements ii) and iii) are corrected by increasing the skin thickness in $^1/_2$mm intervals from a minimum of 3mm. A final check is then made with regard to requirement iv) and the skin thickness is increased as necessary.

The weight of GRP sandwich panels was found to be fairly sensitive to requirement iv. While the scantlings obtained from 'STRUDES' using iv) show reasonable agreement with current practice (see Appendix A), this area is in need of considerable further study in order to substantiate the results of Section 5.

Minimum weight solutions in GRP sandwich construction would tend towards the minimum skin thickness of 3mm and the minimum core depth to satisfy i, ii) and iii) since S.G.(core) << S.G.(skin).

Questions of general robustness and core–skin bond strength would need further consideration before opting for this minimum weight solution. For the present, 'STRUDES' GRP sandwich panel routine may be regarded as slightly conservative.

Glass reinforced plastic – top hat stiffeners

Required section modulus and 2nd moment of area values are obtained from ABS rules. The stiffener proportions are those specified by ABS. The procedure for determining scantlings is similar to that employed for metal sections. A non-structural core is assumed.

3.4 Bridging Structure (Box) Scantlings

Wet deck scantlings are based on the slam pressure from 'LOADS'. Dry deck scantlings use a design head taken from ABS rules.

The side force is assumed to be uniformly distributed between each plate frame. An initial minimum box depth of 650mm is specified. Using scantlings from 3.3, the primary box stress is found from:

$$\sigma_1 = \frac{F_{y(side)}}{NPF} \cdot \frac{Z_{NA}}{SM} \left[\frac{\sigma_{cr}}{\sigma_{cr} - \sigma}\right] + \sigma \qquad (26)$$

where NPF = Number of plate frames

σ = $(F_{y(side)}/NPF) / A$

A = CSA of one plate frame space

SM = Section modulus of one plate frame together with wet and dry deck flanges of effective width equal to 60% of plate frame spacing (26)

σ_{cr} = elastic buckling stress of one plate frame

Note: If $\sigma < 0$, $\sigma_{cr}/(\sigma_{cr} - \sigma) = 1$ (compression +ve)

If the primary stress exceeds the design stress, the depth of the box is increased in increments of 1cm. 'STRUDES' then determines peak values of secondary and tertiary stress, viz:

Stiffener stress

$$\sigma_{ST} = \sigma_2 \left[\frac{\sigma_{cr}'}{\sigma_{cr}' - \sigma_1}\right] + \sigma_1 \qquad (27)$$

Panel stress

$$\sigma_{PL} = \sigma_3 \left[\frac{\sigma_{CR}''}{\sigma_{CR}''-\sigma_1}\right] + \sigma_1 \qquad (28)$$

where σ_2 (σ_3) = bending stress under design head on stiffener (plate)

$\sigma_{cr}'(\sigma_{cr}'')$ = elastic buckling stress of stiffener (plate).

The maximum combined stress corresponds to σ_1, σ_2 and σ_3 compressive.

Equation 28 overestimates the panel stress as secondary stress is neglected, secondary stress being tensile at the plate flange of the stiffener at the built in end.

The magnification factor is an approximate way of allowing for beam-column effects. For good accuracy the lateral deformation must be in sympathy with the lowest model of buckling. It is considered to be good enough for preliminary design. It is most important to employ such a factor when comparing materials having different moduli of elasticity if a biased comparison is to be avoided.

The stresses from equations 27 and 28 are compared with the maximum allowable defined as the limit stress (yield, proof or ultimate) divided by a safety factor (set at 1.1 for metal and 3 for GRP). This approach is considered reasonable since the combined load of peak side force (and moment) and peak slam pressure is a severe one.

If the maximum stress exceeds the allowable, plate or stiffener scantlings are incremented and the calculation repeated. The box depth is not altered during this process of local scantling correction and therefore the structural arrangement is not as efficient as it might be. This approach was adopted as a result of the excessive computation required when the box depth was included. Structural weight variations were found to be small between the two approaches.

Although torsion is not formally included in the design process, peak stresses are determined in the worst lift or docking condition on the basis that the hull-strut-haunch is rigid compared to the box. The peak stresses are highly localised and therefore this loading is considered inappropriate for global design purposes. Stress predictions are for information only.

3.5 Haunch and Strut Scantlings

The initial scantlings are obtained as described in 3.3 with the exception of the inclusion of a stress concentration factor for the transverse web frame. This factor is intended to allow for the discontinuity at the haunch–box junction and at the haunch–strut junction. In the absence of better data these factors are taken as 2 for the haunch and 1.2 for the strut.

Haunch scantlings are based on the slam pressure. Strut plate thickness and longitudinals are based on a hydrostatic head measured from 1m above the dry deck to a point one third of the strut depth above the top of the hull. Hydrostatic loading is used for the vertical web frames.

A check is carried out on the shear area of the web frames under the action of the side force. Primary bending stresses are also evaluated. If either stress exceeds the design stress, the web thickness (excessive shear stress) or shell thickness (excessive bending stress) are increased accordingly.

3.6 Hull Scantlings

Hull scantlings are based on a hydrostatic head measured from 1m above the dry deck to the hull centre. Hull shell and longitudinals (where appropriate) are based on the flat plate/beam routines described in 3.3

The web frame scantlings are determined as follows:

i) Stress on a perfect cylinder

A long cylinder subjected to a significant hydrostatic pressure gradient (i.e. immersion is less than about ten times the cylinder diameter) will experience significant bending stresses.

The moments and forces may be analysed by applying Castigliano's (least work) theorem to a width of curved plating. Maximum value of bending moment is given by:

$$M_o = 0.75 \rho g \, s \, R^3 \qquad (29)$$

where R = cylinder radius, s = width of plating.

The shear and thrust forces at the position of maximum moment are given by:

$$SF_o = \frac{\pi}{2} \rho g s R^2 \qquad (30)$$

$$T_o = \rho g s R.h \qquad (31)$$

where h = Head to axis of cylinder

The foregoing equations have been checked using an 'ANSYS' F.E. model. Direct and shear stresses are calculated in the normal way.

ii) Stress on an imperfect cylinder

A deviation from circularity of 1/2% of the radius is assumed (27).

The bending stress is obtained from (27, 28):

$$\sigma_F = 3 \frac{E\,ec}{R^2} \left[\frac{\sigma_y}{\sigma_y - \sigma}\right] \qquad (32)$$

where e = 0.005 R

c = Distance between frame N.A. and extreme fibre

E = Modulus of elasticity

σ = Compressive stress (= T_o/frame C.S.A.)

σ_y = Failure stress

Note, the factor $[\sigma_y/\sigma_y - \sigma]$ is an approximation to the true magnification factor.

iii) Equivalent stress (σ_e)

The stress in the frame is obtained from the von Mises criterion;

$$\sigma_e = \sqrt{(\sigma_T^2 + 3\tau^2)} \qquad (33)$$

where τ is the shear stress (= SF_o/Web Area)

σ_T is the total direct stress (= $\sigma_F + \sigma + M_o/SM$)

(SM = section modulus of frame)

The scantlings of the web frame are adjusted until the equivalent stress is less than or equal to the design stress.

In the calculations, the effective breadth of the shell is given by (27):

$$b_e = 1.56 \sqrt{Rt} \qquad (34)$$

t = shell thickness

3.8 Design Stress

A SWATH ship has been described as a natural fatigue machine (41). Since fatigue cannot be taken into account explicity, it is necessary to minimise the possibility of fatigue failure by making the design stress equal to the fatigue limit. This criterion is relaxed for combined loads (see 3.4).

3.9 Deckhouse Scantlings

These are taken directly from LR small craft rules (steel and aluminium alloy) or ABS GRP rules. No modifications were thought necessary to make the rules applicable to SWATH craft.

3.10 Evaluation of 'STRUDES'

Typical output of 'STRUDES' is included in Appendix A. The program has been run in the default mode for material properties. The data has been based on references 25, 29, 30 and 31.

Full correlation was not possible. Requests for information from SWATH ship builders were largely unsuccessful.

Two sets of SWATH craft scantlings were available and comparisons with 'STRUDES' are shown in Table A1. Correlation with GRP SWATH craft was not possible. However predictions from 'STRUDES' seem consistent with typical small craft values. See Appendix A.

4. SMALL SWATH CRAFT EVALUATION PROGRAM 'EVAL'

4.1 Craft Particulars

Comparisons of weight and an economic measure of merit have been made for a family of SWATH craft in the displacement range of 30–250 tonnes. All members of the family are geosims of each other. The principal ratios are:

Hull;	Length	–	diameter ratio	=	12
Strut;	Length	–	thickness ratio	=	28
Box;	Length	–	breadth ratio	=	2.1
	Draft	–	diameter ratio	=	1.5

The design has been based on an analysis of existing SWATH craft. Two operational roles were selected for consideration.

1. Ferry/Excursion boat
2. Workboat (payload carrier).

Each boat has a deckhouse of height 2.2m, width equal to 80% of the overall beam and length equal to 75% of the overall length with a small wheelhouse mounted over.

For the ferry/excursion role, the number of passengers is based on a requirement that they shall be accommodated within the deckhouse at a space rate of not less than 0.8 m^2 per passenger, subject to adequate passenger payload being available.

i.e. maximum No. of passengers = 0.75 [LOA x BOA] (65)

A study of existing craft suggested that the space rate lay in the range of 0.8 – 1.6 m^2 per passenger. No overnight accommodation is provided for passengers or crew.

The workboat accommodates the crew in single or twin berth cabins.

The crew requirement is given by:

$$\text{Complement} = k \ \Delta^{2/3} \qquad (36)$$

An analysis of SWATH craft (1,2,5) revealed k to be in the range 0.33 - 1.55 with a mean of 0.69. This compared with a figure of 0.7 for large Naval SWATH Ships (32). A figure of 0.5 is employed in 'EVAL' which reflects the tendency for fewer crew but higher standard of accommodation found in merchant ships.

Speed and range must be selected independent of the craft size. A requirement for the larger vessel to have increased range and/or speed would mean that like was not being compared with like and would unfairly penalise the larger craft. It was therefore necessary to select values which are obtainable by the smaller craft. The larger craft will probably have the capability for extended range and this constitutes a useful, though unquantifiable, bonus. Identical speed requirements throughout the displacement range mean that number of round trips per annum is a constant and can be eliminated from comparative studies.

Values selected:

	Ferry/Excursion Boat	Workboat
Maximum Speed	24 knots	20 knots
Cruise Speed	18 knots	15 knots
Range	400 nm	800 nm

3.2 SWATH Craft Evaluation

The net payload is defined as:

$$\text{Net payload} = \text{Displacement} - \text{fuel} - \text{ballast} - \text{outfit} - \text{machinery} - \text{personnel} - \text{structure} \qquad (37)$$

Although minimum structural weight is clearly important, it is not a sufficient criterion in itself for evaluating the performance of a craft.

The operator is concerned with maximising net income. The choice between craft size and structural material should be based on a lifetime Net Present Value calculation. Such a calculation would consider variations in maintenance and repair costs for different materials and variations in fuel bill between different size craft, as well as variations in initial capital costs.

Insufficient data was available for such an NPV approach and hence a more limited 'measure of merit' was required. For small commercial SWATH craft with a high structural weight fraction, total production cost of the hull structure is indicative of the total capital cost. The number of passengers or net payload is indicative of earning capacity. In addition to the MINIMUM STRUCTURAL WEIGHT CRITERION an economic criterion has been adopted which has the form:

For ferry/excursion boat:

$$EC1 = \frac{\text{Total production cost of structure}}{\text{No of passengers}} \quad \text{£/person} \qquad (38)$$

For workboat:

$$EC2 = \frac{\text{Total production cost of structure}}{\text{Net payload}} \quad \text{£/tonne} \qquad (39)$$

Designs with the lowest 'EC' value are sought.

The production cost is estimated by:

$$\text{Production cost} = \text{Structural weight} \times \text{wastage factor} \left[\frac{\text{basic material price}}{\text{tonne}} + \frac{\text{manhours}}{\text{gross tonne}} \times \text{wage rate} \times \text{overhead factor} \right] \qquad (40)$$

where the term in square brackets represents an overall estimating figure of the sort used in preliminary cost estimating rather than for specific phases of the construction process.

4.3 Program 'EVAL'

The program organisation is shown in Figure 10. The remainder of this Chapter summaries the principal features and background of program 'EVAL'.

4.4 Subroutine 'POWER'

In order to estimate machinery and fuel weights, powering estimates are necessary for maximum and cruise speeds. Although it is possible to calculate wave making resistance theoretically (35), a very simple approach has been adopted here. This involves the use of a single curve of wave making resistance (Figure 11) which has been taken from the open literature and applies to a SWATH craft having a very similar form to that of the family members.

The wetted surface area is estimated from (36):

$$S = \nabla^{2/3} . [13.6 - 0.31 (20 - L_H/D_H)] \qquad (41)$$

where $L_H(D_H)$ = Length (diameter) of the hull
∇ = Volume of displacement

Other Data Used

Form factor = 1.15 (37)
Appendage coefficient = 10% of frictional resistance
Wind and rough weather allowance = 25%
QPC = 0.68 (32)
Transmission efficiency = 94%

Despite its simplicity, the method seems capable of producing acceptable predictions of engine size (see Table 1).

4.5 Fuel and Ballast Requirement

Fuel weight is estimated using a specific fuel consumption of 0.225 kg/kW.hr together with a reserve requirement of 10%.

There is adequate volume for water ballast. The question is whether any ballast will be carried at the same time as the full fuel load, thereby detracting from the available payload. Some ballast may be required for operational reasons. It was decided, somewhat arbitrarily, that sufficient ballast should be carried to allow the load draft to be changed by ±5%. The transference of this ballast from the forward tank to the aft tank produces a trim of some 8–9% of the craft length. This was felt to give a reasonable degree of operational flexibility.

4.6 Machinery and Outfit Calculations

Defining the non-structural weight (NSW) as the combined machinery and outfit weight, two forms have been proposed;

For Naval SWATH ships (32):

$$NSW = 0.14\ \Delta + 0.04\ kW + 0.8\ N + 0.0084\ P_s \text{ tonnes} \qquad (42)$$

where kW = Installed electrical power (kW)

Δ = Mass displacement (tonnes)

N = Complement

P_s = Installed propulsive power (kW)

For Merchant ships (38):

$$NSW = C_o\ .\ L.B + 12 \left[\frac{MCR}{RPM}\right]^{0.84} + C_1\ .\ MCR^{0.7} \text{ tonnes} \qquad (43)$$

Where C_o, C_1 are coefficients

MCR = Maximum continuous Rating of main engine (kW)

RPM = Engine speed

L = Length of ship (metres)

B = Breadth of ship (metres)

Although neither equation is directly applicable, a similar level of simplicity was felt appropriate for use in 'EVAL'. Both the ferry/excursion boat and the workboat employ high speed marine diesels. Following the lead given by equation 43, an analysis of 74 marine diesels covering a number of European Manufacturers was carried out (see Figure 12).

The resulting weight equation was found to be:

$$\text{Weight of one diesel} = 7 \left[\frac{MCR}{RPM}\right]^{0.95} \text{ tonnes} \qquad (44)$$

Outfit and remainder machinery weight estimates were made for three SWATH craft of 58t, 125t and 340t displacement. This was done using a combination of manufacturers catalogues and data gathered as a result of time served at a small shipyard.

The non-structural weight items are grouped according to the parameter upon which they are assumed to depend.

These groups are:

Installed electric power (kW):	Generators, alternators, harbour set, fittings, wiring, switchboards, cable trays.
Installed propulsive power (MCR):	Engine cooler, oily water seperators, steering gear (speed dependent), gearbox, start-up equipment.
Crew or passengers (N):	Lifesaving, accommodation, w.c. & wash, galley services.
Linear related items (LOA): (Length overall)	Bilge and ballast, railings, wheelhouse, ladders, ventilation trunking, fendering.
Area related items (LOA^2):	Rudder, gratings, deckhouse linings, canard and stabilisers, paint.
Displacement related items (Δ):	Propeller, sterngear, deck machinery, mooring equipment.

The combined outfit and machinery is estimated from:

$$NSW = 0.114\ LOA + 0.011\ LOA^2 + 0.089\Delta + 0.037\ kW + 0.03\ MCR^{0.7} + 14 \times \left[\frac{MCR}{RPM}\right]^{0.95} + k.N \text{ tonnes} \qquad (45)$$

where k = 0.034 for the ferry/excursion boat
k = 0.610 for the workboat

Summaries of the weight groups are shown in Table 2. The variation in coefficients is considered to be acceptable. However it must be stressed that these coefficients are only valid for the arrangement assumed.

Equation 45 has been plotted for the work boat role on Figure 13, which also shows data for existing similar twin hull craft. The spread of data points is obviously due to differing speeds and roles. However as these data points represent the normal range, had equation 45 lain outside this range, doubt would be cast on its validity. One SWATH craft which closely fits the excursion role is a Halcyon variant (39) having a non-structural weight of 24.4t. Equation 45 predicts 23.1t.

In the absence of anything better, equation 45 is thought capable of giving plausible estimates of machinery and outfit weights.

It is hoped that the coefficients can be re-evaluated as part of a subsequent and far more elaborate study.

4.7 Production Costs

Manhours per gross tonne have recently fallen into disfavour as a method of estimating production costs. They nevertheless continue to be used for preliminary cost estimates in small shipyards and are considered appropriate for an investigation of this level. However great care is required in selecting values appropriate to the type of construction undertaken, as manhours per tonne for predominantly manually produced small craft can be a factor of 10 times greater than those for highly automated big ship construction.

Smith and Monks (40) suggested the following figures for construction of hydrofoils or fast patrol boats:

Steel	:	620 manhours per gross tonne
Aluminium Alloy	:	1400 manhours per gross tonne
GRP (single skin)	:	1400 manhours per gross tonne
GRP (sandwich)	:	1120 manhours per gross tonne.

A survey of some 15 U.K. small ship and boat builders was conducted. This produced few useful replies. The manhours per tonne were found to lie in the range

Mild Steel	–	110 (fabricated units) – 800
Aluminium Alloy	–	1000 – 1700
GRP	–	Unsufficient applicable data

Other shipyard data suggested the following manhour per tonne ratios:

Alloy : Steel 3.2:1 (2:1)*

GRP : Steel 3:1 (1:1)*

* The data in brackets is taken from reference 42.

Other GRP data (42):

Single skin with frames (pleasure boats)	; 112
Single skin with frames (military boats)	; 187
Sandwich construction (pleasure boats)	; 224
Sandwich construction (military boats)	; 373.

It is noted here that sandwich manhours are twice single-skin manhours. This is due to the considerable extra work required to lay-up the core material for only about a 20% increase in the weight of a square metre of panel. However for more complicated GRP single skin hulls, involving many intersections of longitudinal stringers and web frames, the use of sandwich construction may lead to a reduction in manhours. A 20% reduction was assumed in reference 40.

As a result of this study it became apparent that only a detailed work study would yield reliable values. As this was not appropriate for an exploratory investigation, the following tentative figures have been selected;

Steel	400 manhours/tonne
Alloy	800 manhours/tonne
GRP (single)	750 manhours/tonne
GRP (sand)	600 manhours/tonne

Wage rate and overhead factor;

Data from several shipyards produced an overall figure (including overheads) of about £12.75/hr. Alternative data for 1982 (40) gives an equivalent 1987 figure of £11.60/hr (assuming wage escalation at 7% p.a.).

No distinction is made between wage rates for different materials, although an $8^1/_2$% increase for aluminium alloy over steel and GRP has been suggested (42).

GRP tooling costs could vary between about 70% (40) and 400% (42) of the cost of a single hull. These figures apply to monohull forms. SWATH ships are quite unlike monohulls in that they consist of large areas of flat or single curvature plating. There is reason to suspect that tooling costs for SWATH ships may be far less significant that for conventional ships. In the absence of reliable information this aspect is not considered further here but must be borne in mind when comparing production costs in Section 5.

Material costs;
Data from manufacturers catalogues and shipbuilders indicated the following values;

Steel	;	£420 per tonne (35% sections) (3-5mm plate)
Alum.	;	£2400 per tonne (35% sections) (N8)
GRP	;	£1750 per tonne (35% CSM/WR-65% polyester fire retardant resin)
GRP (sandwich)		£2400 per tonne (end grain balsa, 20% by weight)

A wastage allowance of 30% was assumed.

The cost per net tonne is given by:

$$1.30\ [\text{cost per tonne} + 12.75 \times \text{manhour per tonne}]$$

Tentative figures used in this study are;

Steel	£7200/tonne
Alloy	£16400/tonne
GRP (single)	£14700/tonne
GRP (sand)	£13000/tonne

5. RESULTS

5.1 Design Loads

The values of design load used for the craft in this study are shown in Figure 14. Assumed limiting significant wave heights are also shown. A risk factor of 1 was used in all cases. The variation in slam pressure between the two methods included in 'LOADS' is considered to be acceptable.

The effect of significant waveheight and risk factor on design loads is illustrated in Figure 15.

Fortunately, and somewhat surprisingly, total structural weight is not very sensitive to load. Variations of ±50% in side force or slam pressure give rise to changes in structural weight of about ±4% and ±6% respectively (Figure 16).

An earlier study (26) indicated variations in structural weight of −4.3% and +5.2% due to a 50% change in side force for a large SWATH ship of about 1600 tonnes (steelweight). The same study indicated that changing the slam pressure from zero to 0.7 MN/m^2 increased the structural weight by only 6%. The same result would not apply in this study to the same extent as the slam pressure is used to design larger areas of structure (hence slam pressures which are an order of magnitude smaller than that used in Ref. 26). In addition, 'STRUDES' uses elastic design exclusively whereas in reference 26, plating was allowed to undergo permanent deformation.

5.2 Modulus of Elasticity

The use of the fatigue limit for initial scantling determination makes the GRP a strength rather than deflection limited design. However, the beam-column effect which affects box scantlings is dependent on the modulus of elasticity.

The effect of variations in modulus of elasticity is shown in Figure 17. The range of E values selected reflects that which can be obtained using various lay-ups of E-Glass (WR, CSM etc). The effect is significant but not dramatic. Advanced composites may be necessary if greater weight savings are required.

5.3 Weight Comparisons

Weight comparisons for homogeneous construction and hybrid construction are illustrated in Figures 18 and 19.

The mild steel configuration is fitted with an alloy deckhouse. The alloy, GRP and GRP-alloy hybrid configurations are about 65% of the weight of steel. The semi-heavy hybrids (i.e. those with some steel) are about 81% of the steel version.

5.4 Production Cost Comparisons

Production cost comparisons are shown in Figures 20 and 21. Aluminium alloy is the most expensive being about 30% greater than the steel and about 10% greater than GRP or GRP hybrids.

The 10% cost advantage of GRP would probably be lost due to mould amortisation. Nevertheless, GRP appears to be reasonably competitive with aluminium alloy.

5.5 EC1 Comparisons

EC1 comparisons are shown in Figures 22 and 23. The uncompetitive nature of steel is clearly demonstrated as is the superiority of the semi-heavy hybrids at displacements greater than about 150t. At this displacement the number of passengers becomes limited by space rather than weight and hence the extra weight gained by using light materials (at an increased cost) cannot be gainfully employed.

5.6 EC2 Comparisons

EC2 comparisons are shown in Figures 24 and 25. Once again steel is shown to be uncompetitive for small high speed craft.

The semi-heavy hybrids, while converging, do not supersede the light materials. This is not to say that light materials should always be adopted. As SWATH ship size increases, the required payload may be obtainable with a semi-heavy configuration.

The EC2 comparison was based on the available payload rather than a designer specified payload. Had the latter been the case, then Figure 25 would resemble Figure 23 if a sufficient range of SWATH size were to be considered and only a moderate payload was specified.

6. CONCLUSIONS

1. Structural weight is fairly insensitive to variations in side force. Consequently a very elaborate load prediction method is not justified at the initial design stage.

2. GRP structural weight is not highly sensitive to the variations in modulus of elasticity which can be achieved without resorting to advanced fibres. As such fibres have impact strength and cost related difficulties, it is recommended that attention should be directed at stabilising conventional GRP by improved design.

3. All aluminium alloy, all GRP and GRP-alloy hybrid configurations exhibit similar total weight trends being about 65% of the steel version.

4. Aluminium alloy is some 10% more expensive than GRP or GRP hybrids. Even allowing for mould amortisation, GRP does not appear to have any severe cost penalty compared with aluminium alloy.

5. For small (<150t), high speed SWATH craft, GRP and GRP-alloy hybrid configurations offer much the same return as aluminium alloy in either ferry or workboat roles.

6. It is often said to be quite difficult to produce cost/weight competitive GRP designs, aluminium alloy being the preferred material for ships greater than 30m (discussion of Ref. 40). While it would be wrong to suggest any great advantage in using GRP, this study indicates that GRP is certainly worthy of further research.

7. This study is of an exploratory nature, requiring many simplifying assumptions to be made. It has served to suggest the competitive nature of GRP and the likely range of craft size where it could be usefully employed. However, a significant improvement in performance may be possible if the optimum structural arrangement is sought for each material rather than using the same basic arrangement (Figures 8 and 9). Work study methods may reveal a significant variation in manhours ratios from that used in this study. The problem of ensuring adequate joint strength between hull components needs further consideration in order to demonstrate the viability of GRP and GRP - alloy hybrid configurations. The next stage therefore, must be a more

detailed investigation of GRP and aluminium alloy as structural materials for small SWATH craft. Such an investigation may need to consider novel structural arrangements as shown in Figure 26.

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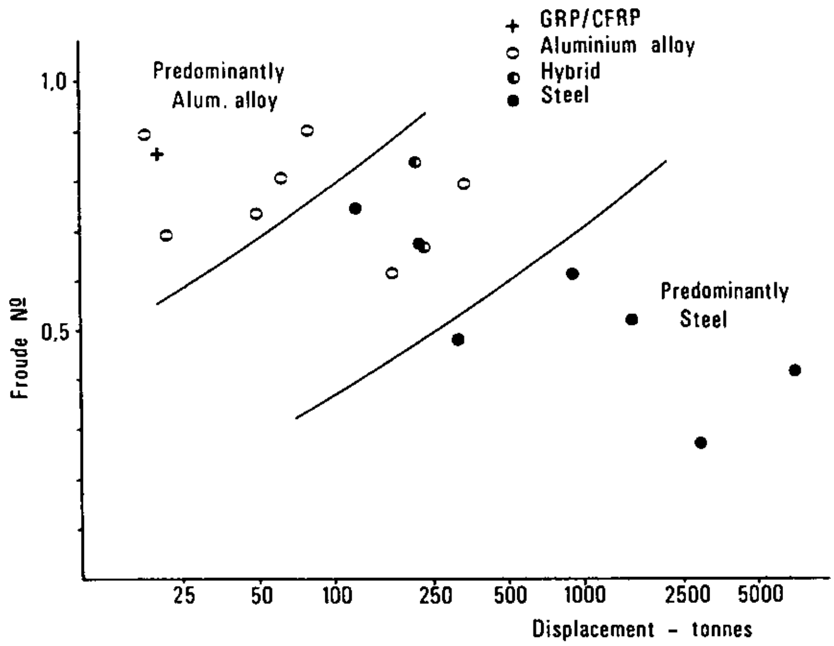


Figure 1: SWATH hull materials versus speed and displacement

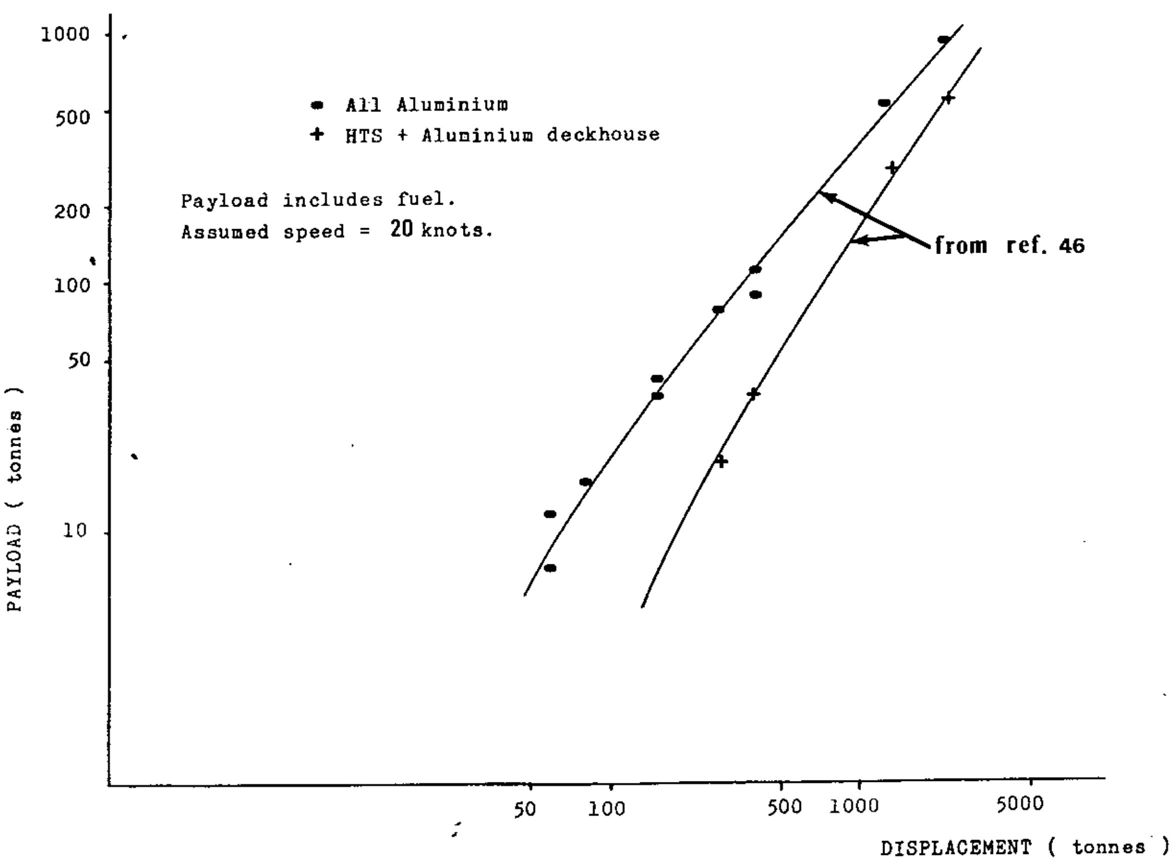


Figure 2: Payload versus hull material and displacement

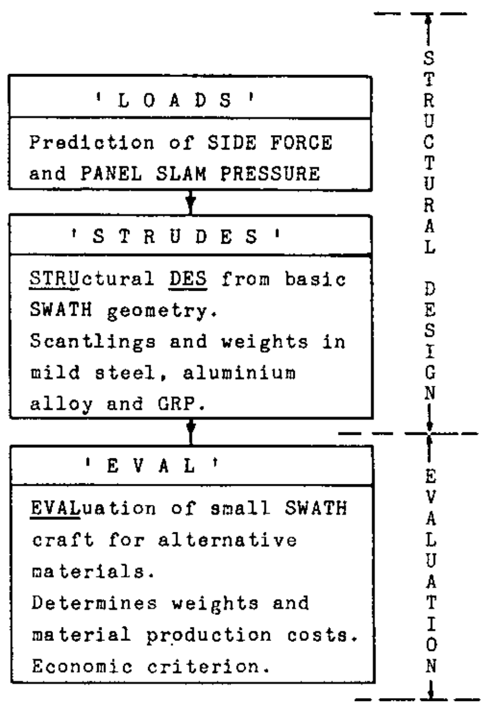
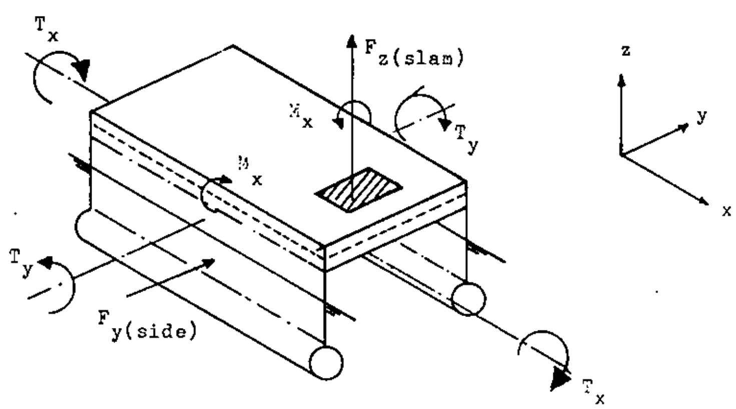


Figure 3: Structural design and evaluation procedure



where $F_{y(side)}$ = Peak side force

M_x = Peak transverse moment applied to the box-strut intersection.

$F_{z(slam)}$ = Peak vertical force caused by water impact with the underside of the bridge structure.

T_x = Torsional moment about the x axis

T_y = Torsional moment about the y axis

Figure 4: Principal design loads

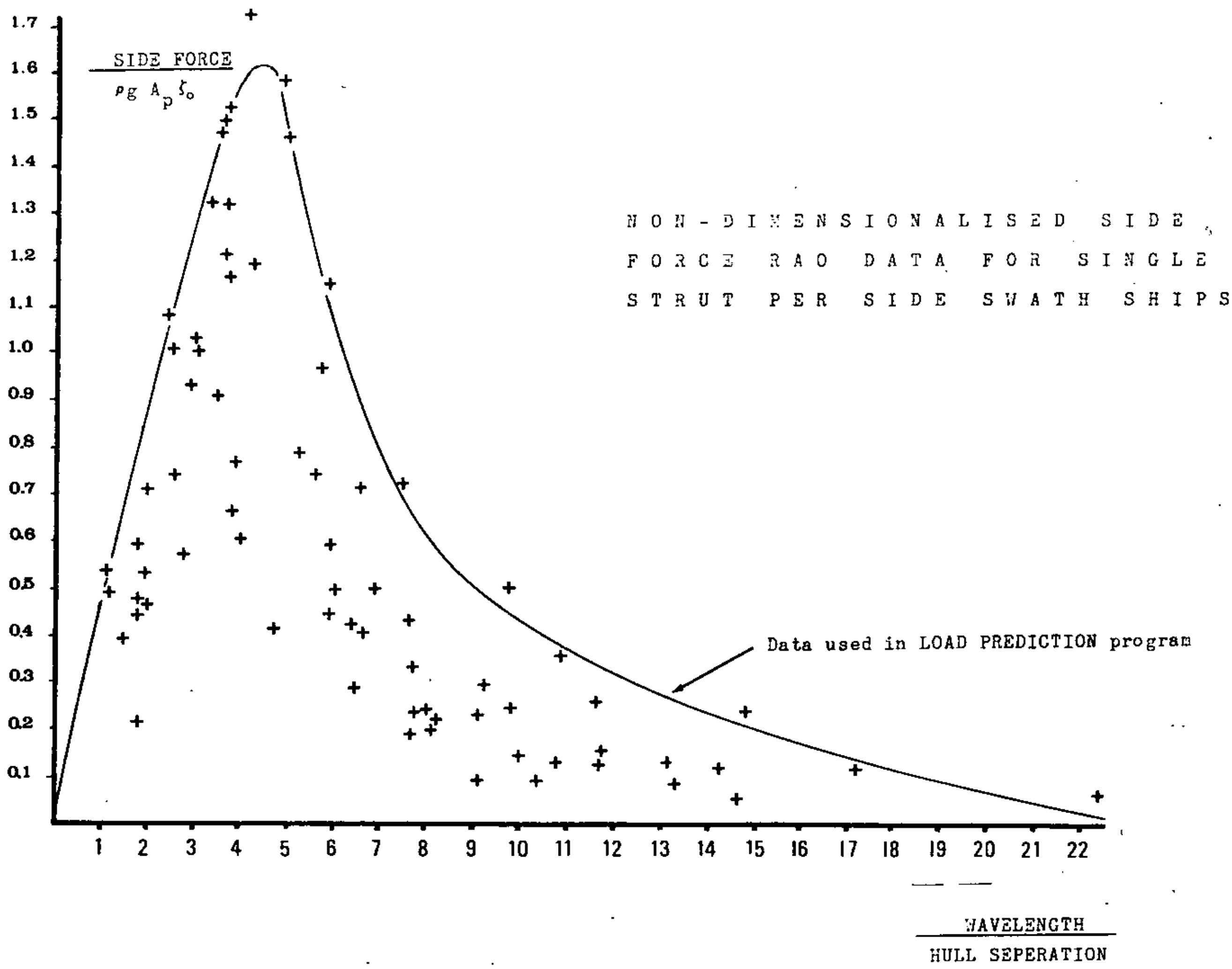


Figure 5: Side force RAO data (6,11)

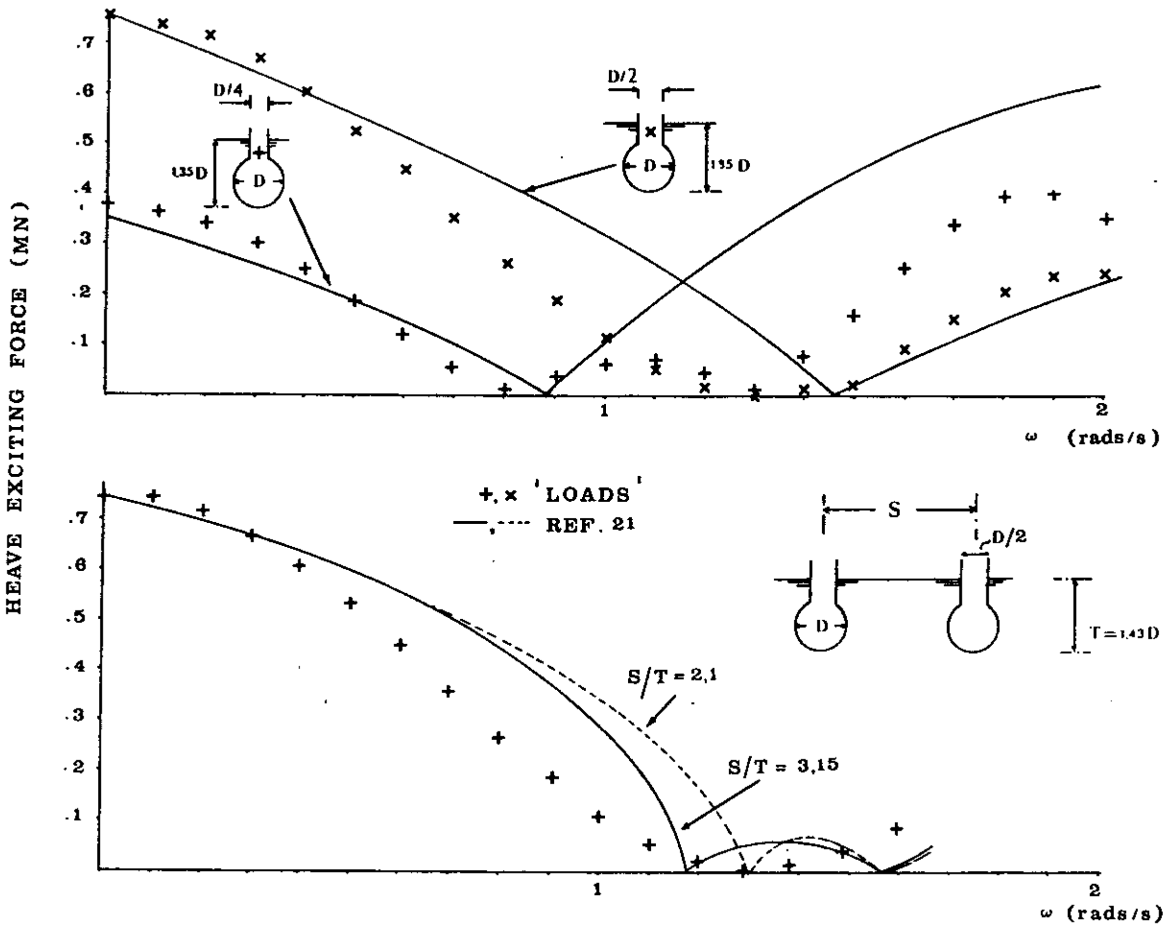


Figure 6: Heave exciting force comparison

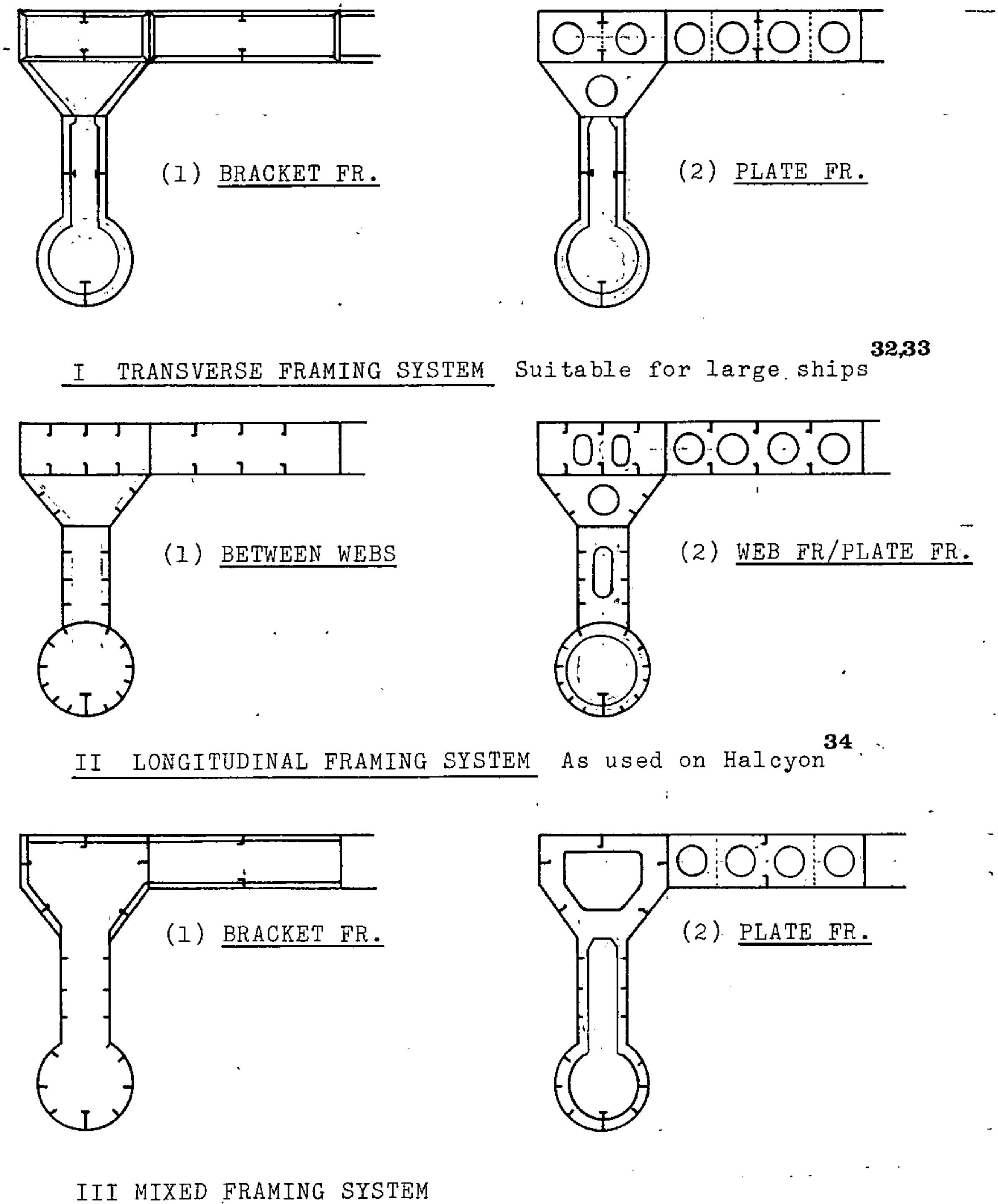


Figure 7: Structural arrangement options

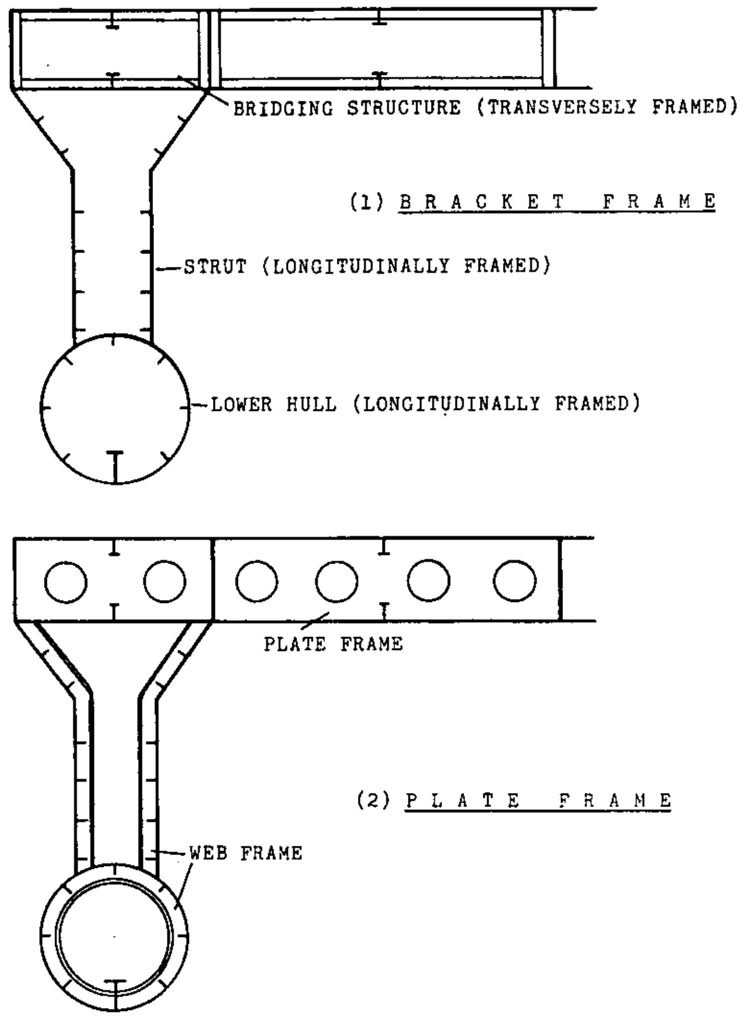


Figure 8: 'STRUDES' arrangement (steel or aluminium alloy)

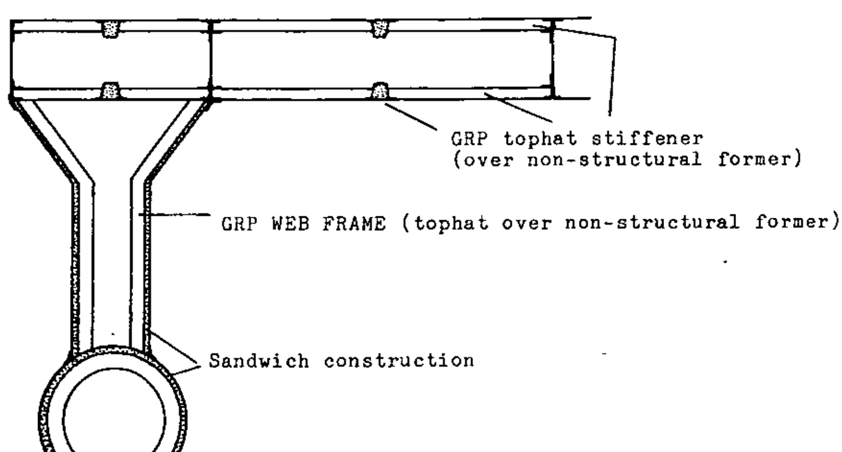
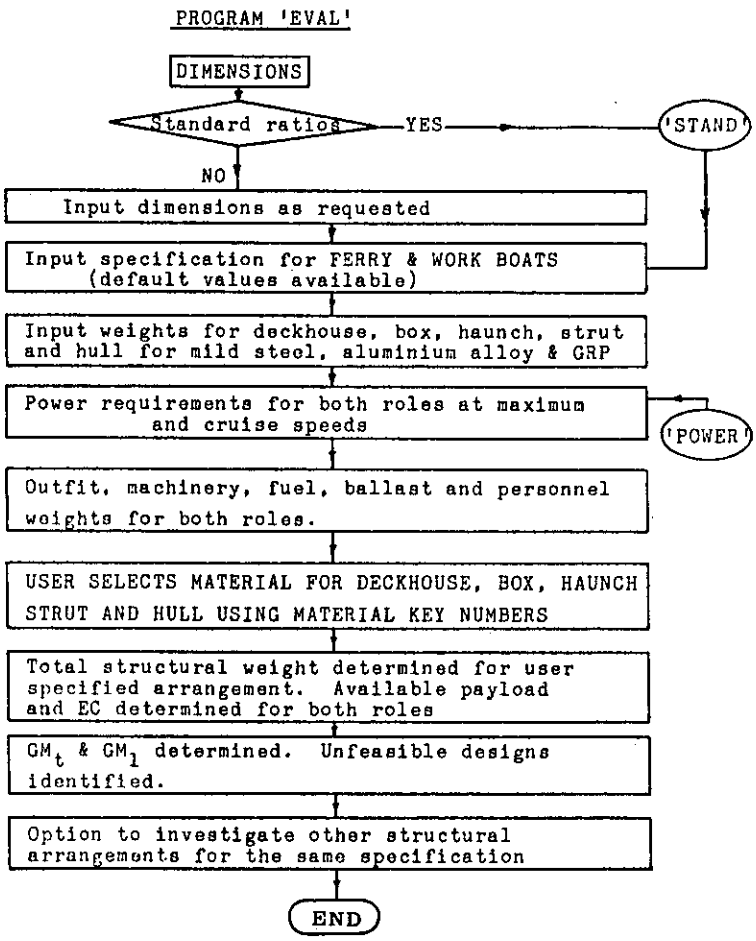


Figure 9: 'STRUDES' arrangement (GRP)



'STAND' Develops all the required dimensions from a USER DEFINED length overall.

'POWER' Produces estimates of Maximum Continuous Rating (MCR) according to the method outlined in section 4.4

Figure 10: Program 'EVAL'

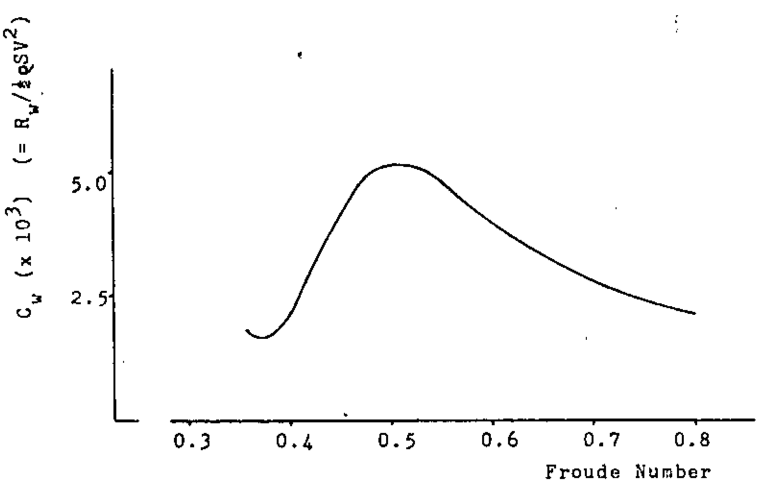


Figure 11: Wave making coefficient adopted in 'EVAL'

SWATH	MAIN ENGINE SIZE (kW)	
	FITTED	PREDICTED BY 'POWER'
'Seagull'	2 x 3022	2 x 3600
'Kotozaki'	2 x 1417	2 x 1450
'Kaiyo'	2 x 1380	2 x 1250
'Halcyon'	2 x 380	2 x 450
Fairey Mar.	2 x 850	2 x 900

Table 1: MCR predictions by subroutine 'POWER'

GROUP	DISPLACEMENT 58 t			DISPLACEMENT 125 t			DISPLACEMENT 340 t			USED
	WEIGHT	PARAMETER	COEFFICIENT	WEIGHT	PARAMETER	COEFFICIENT	WEIGHT	PARAMETER	COEFFICIENT	
MCR	2.014	380 kW	0.0315	3.730	850 kW	0.0332	8.090	3020 kW	0.0296	0.030
kW	2.230	50 kW	0.0446	2.784	58 kW	0.0480	6.518	330 kW	0.0198	0.037
Passenger	2.931	83	0.0353	4.476	128	0.0350	9.612	306	0.0314	0.034
Crew	4.590	7	0.656	7.203	12	0.600	13.806	24	0.575	0.610
LOA	2.333	18.29m	0.128	2.541	23.1 m	0.110	3.761	35.9 m	0.105	0.114
LOA^2	4.098	$334.5 m^2$	0.0123	6.077	$533.6 m^2$	0.0114	12.721	$1289 m^2$	0.0099	0.011
Δ	2.698	58 t	0.0465	4.508	125 t	0.0360	11.392	340 t	0.0335	0.039*

* Errors & omissions taken as 5% of displacement. Weights are in tonnes.

Table 2: Non-structural weight groups

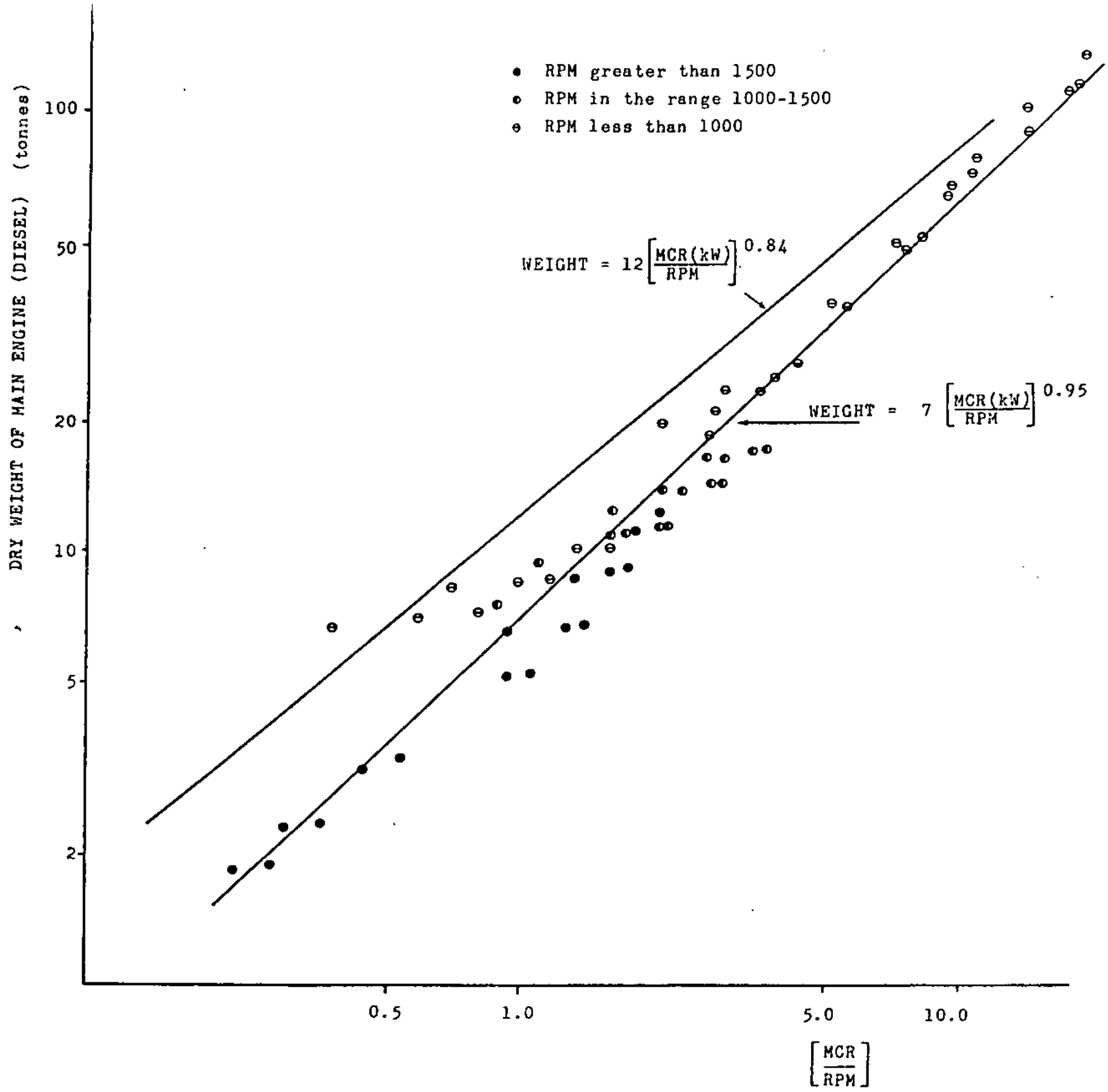


Figure 12: Weight analysis of marine diesels

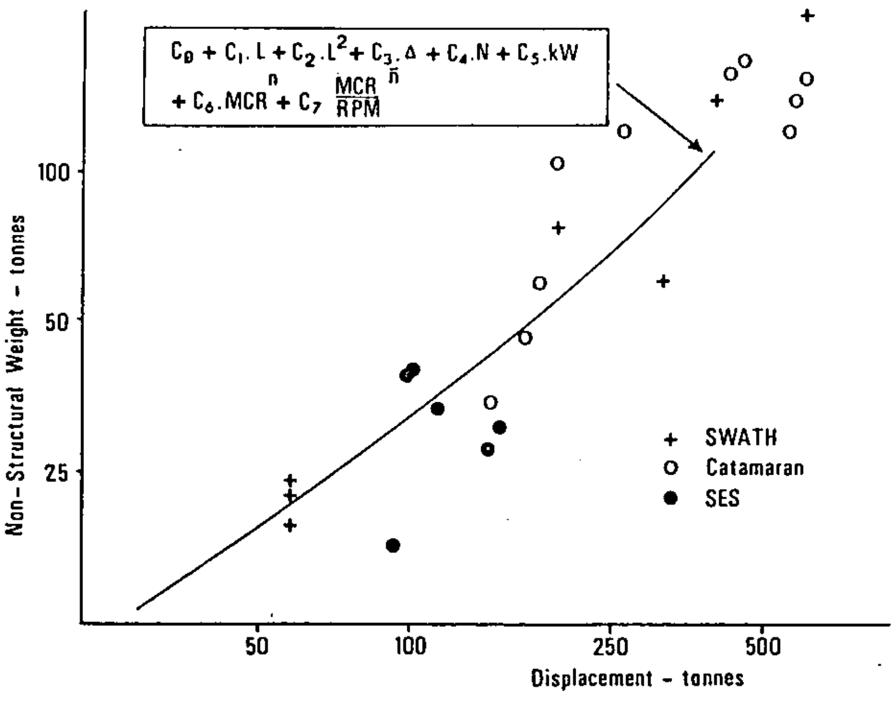


Figure 13: Non-structural weight comparison

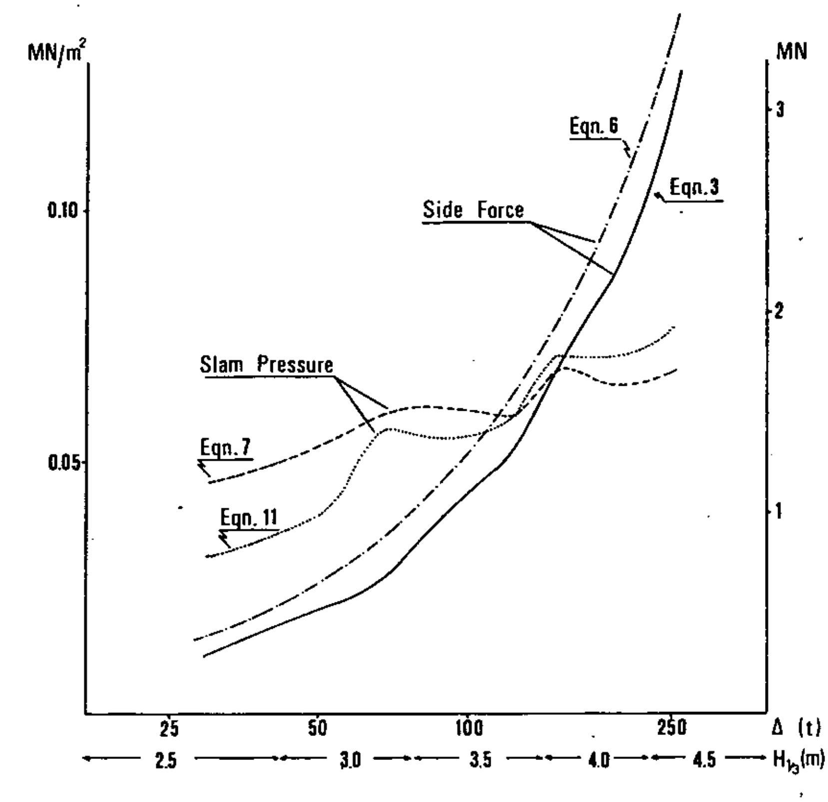


Figure 14: Design loads used in weight studies

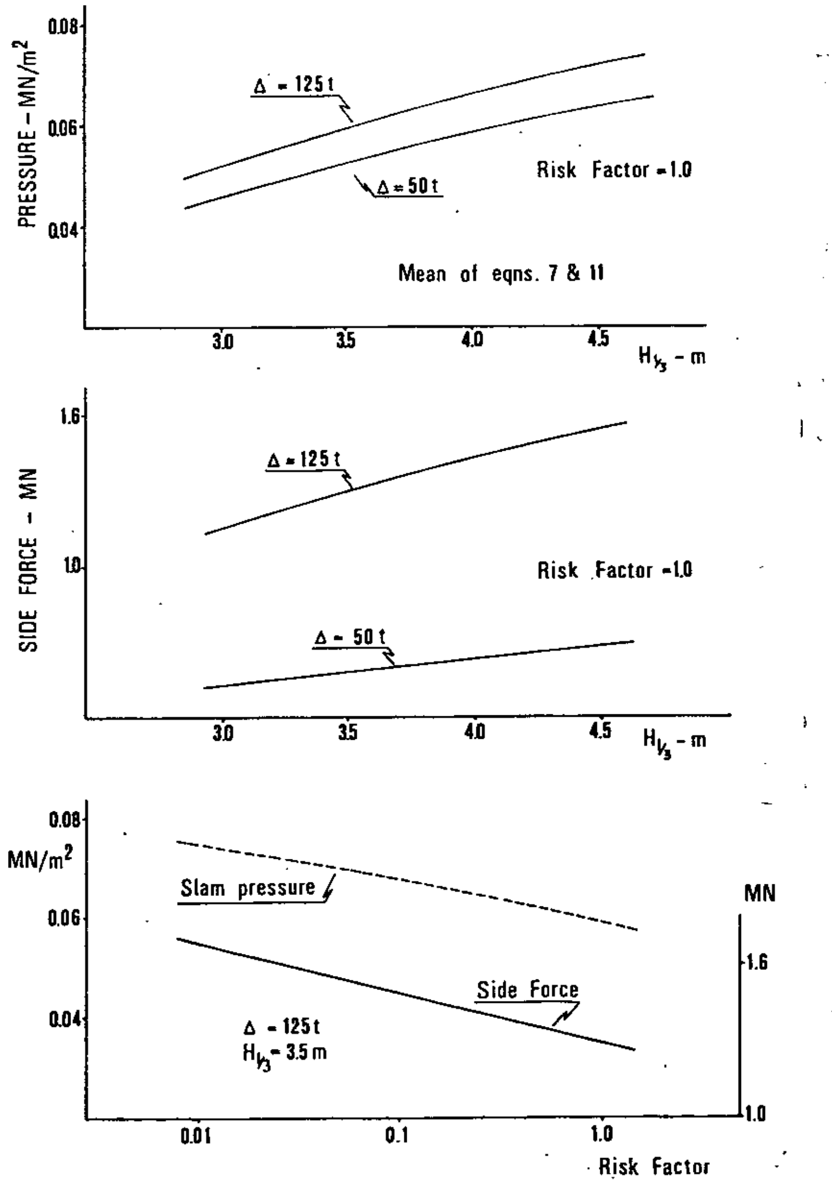
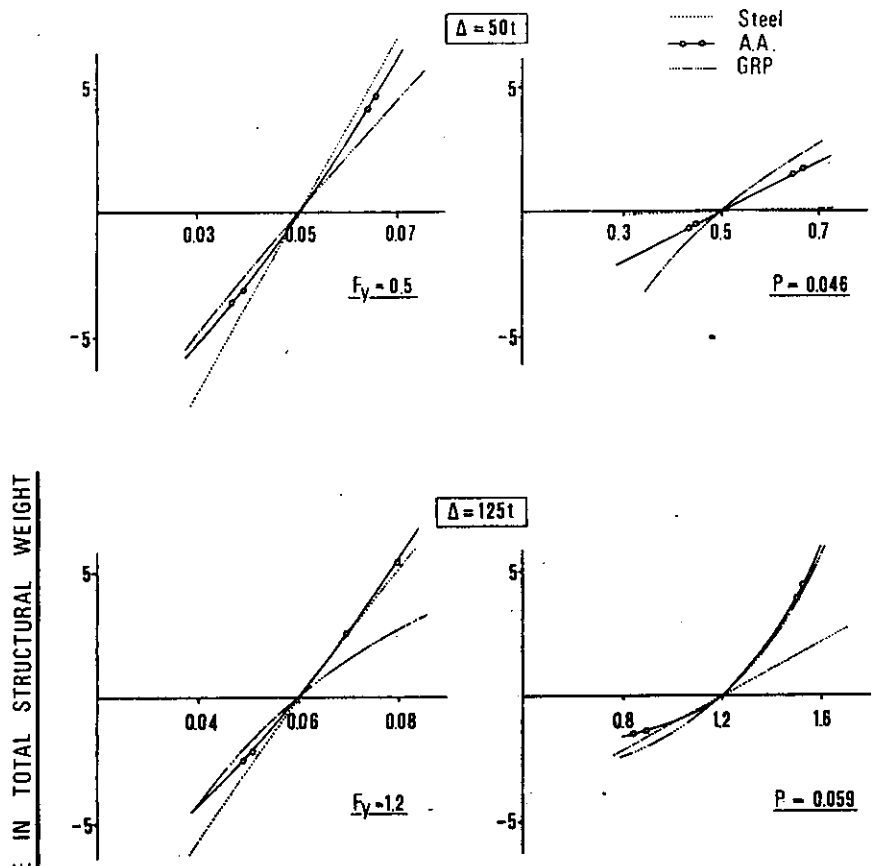


Figure 15: Load sensitivity studies



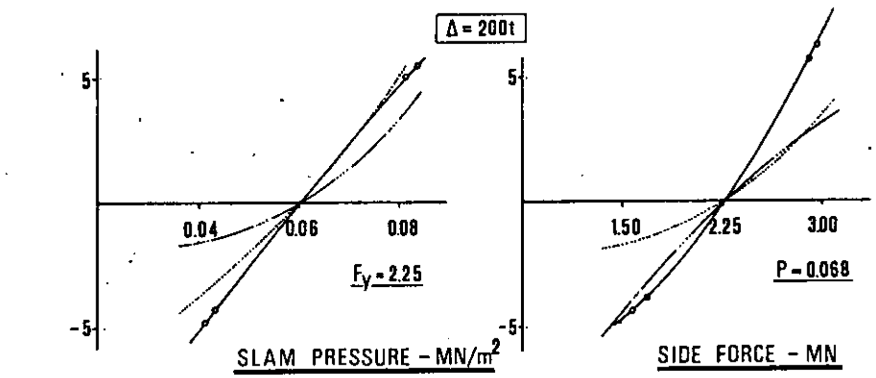


Figure 16: Effect of load variations on structural weight

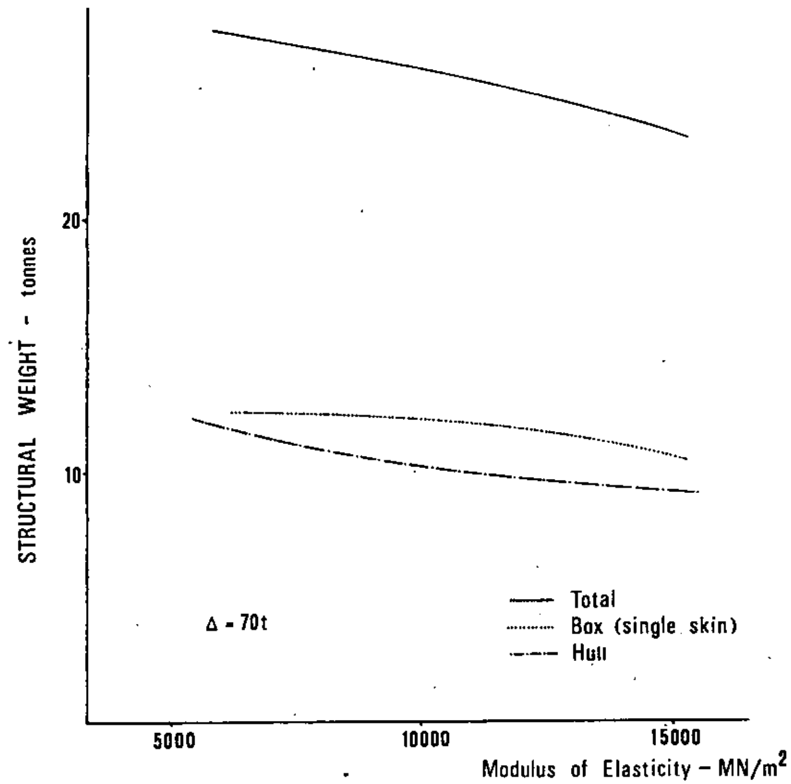


Figure 17: Effect of modulus of elasticity on GRP structural weight

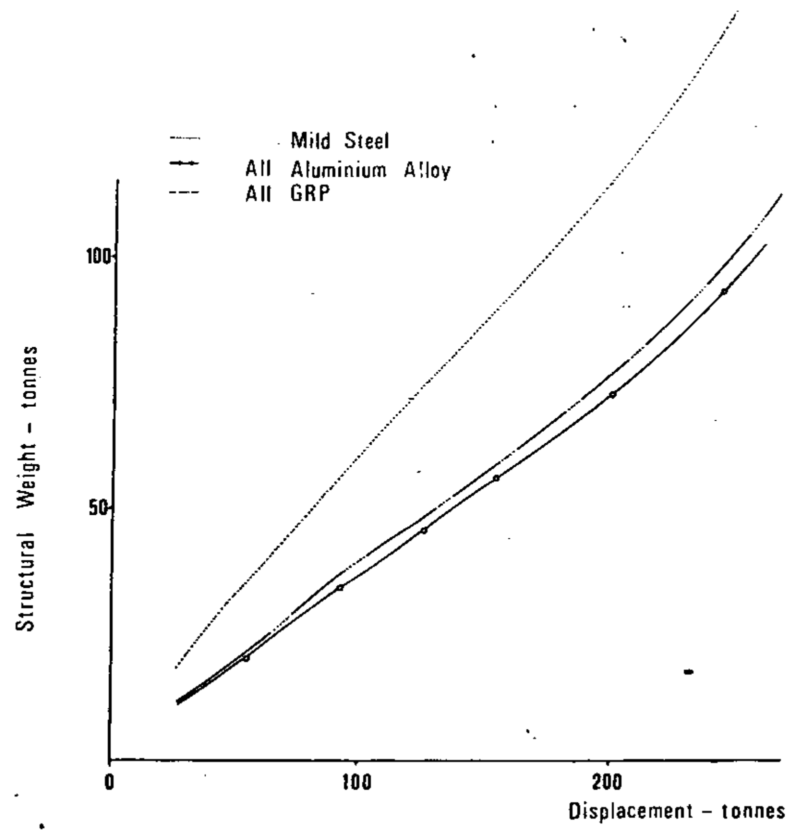


Figure 18: Structural weight for homogeneous construction

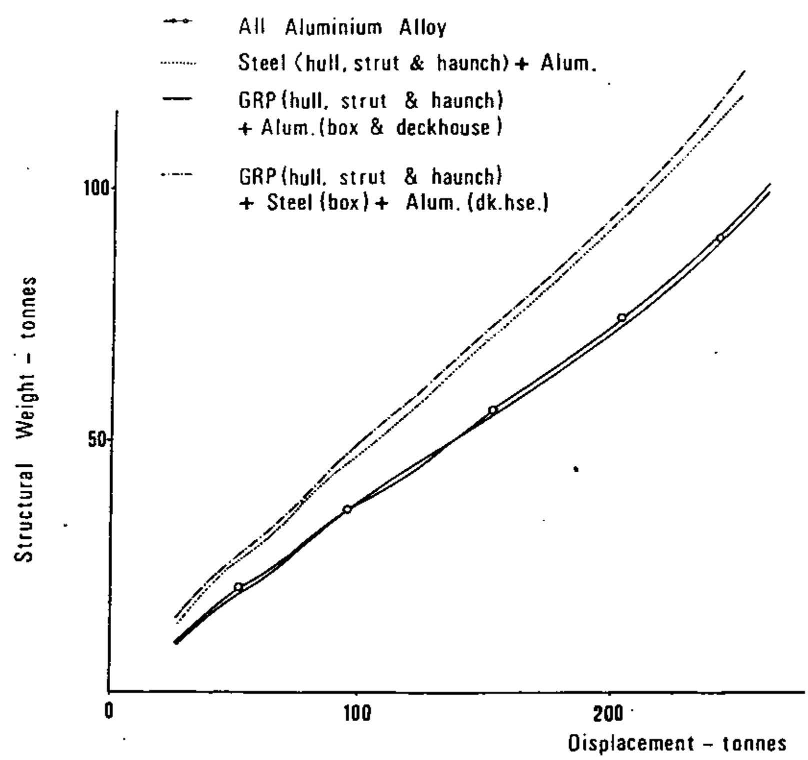


Figure 19: Structural weight for hybrid construction

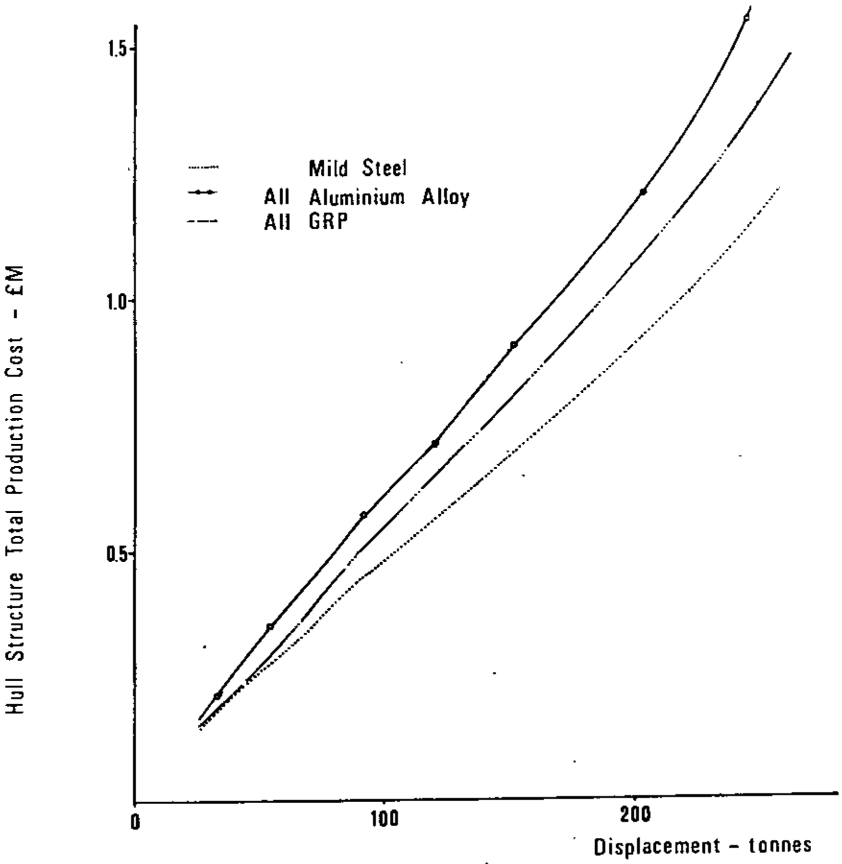


Figure 20: Production cost for homogeneous construction

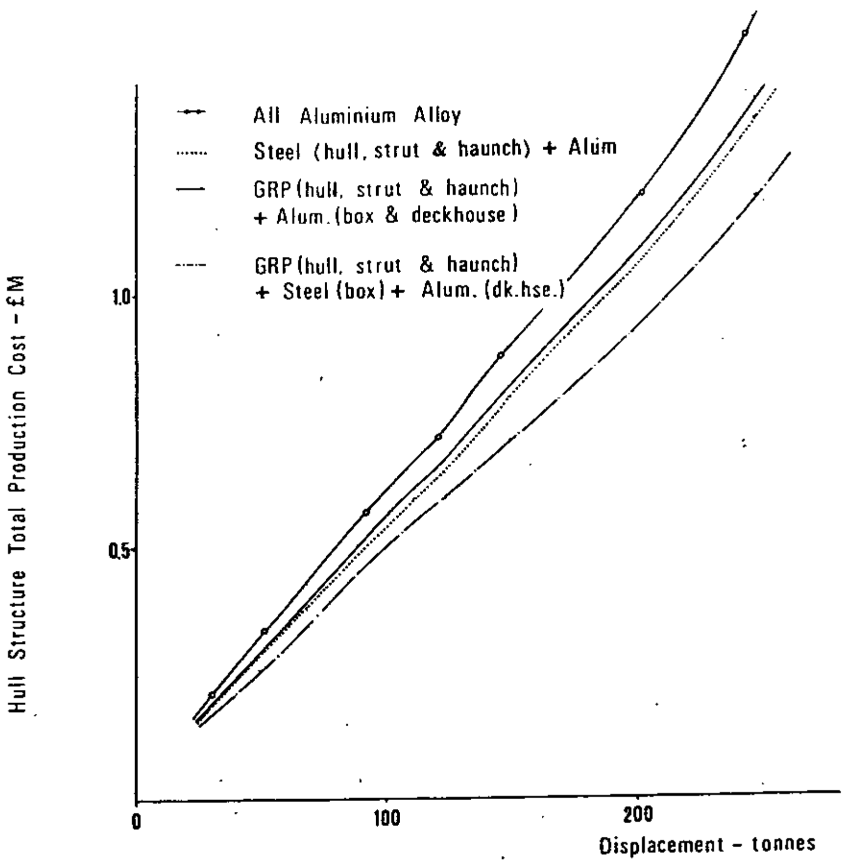


Figure 21: Production cost for hybrid construction

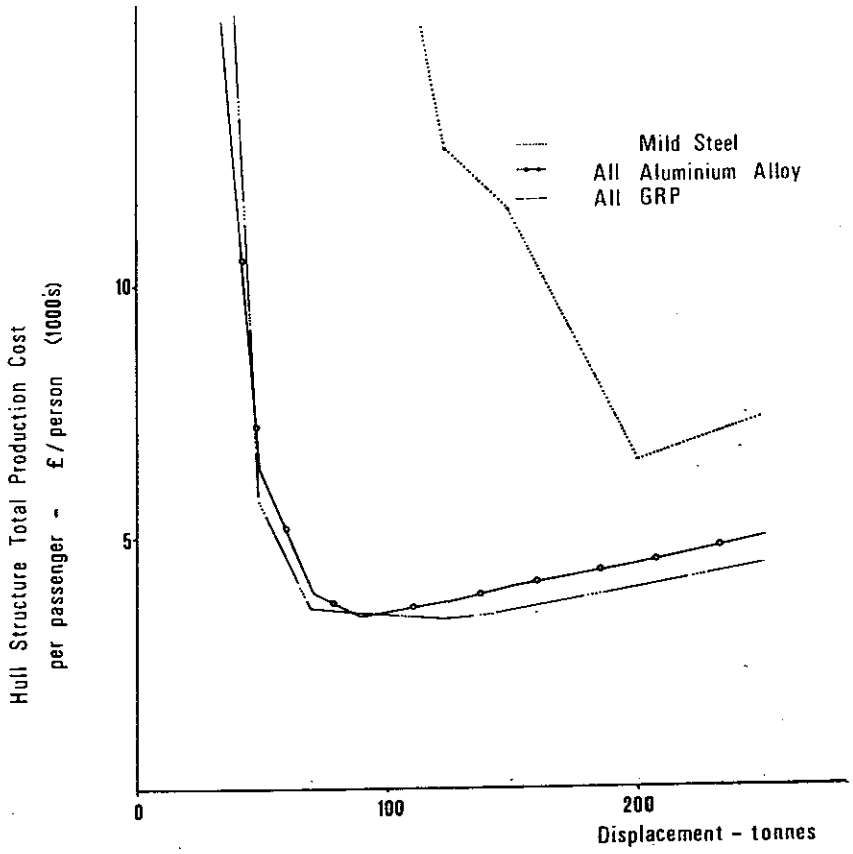


Figure 22: EC1 factor for homogeneous construction

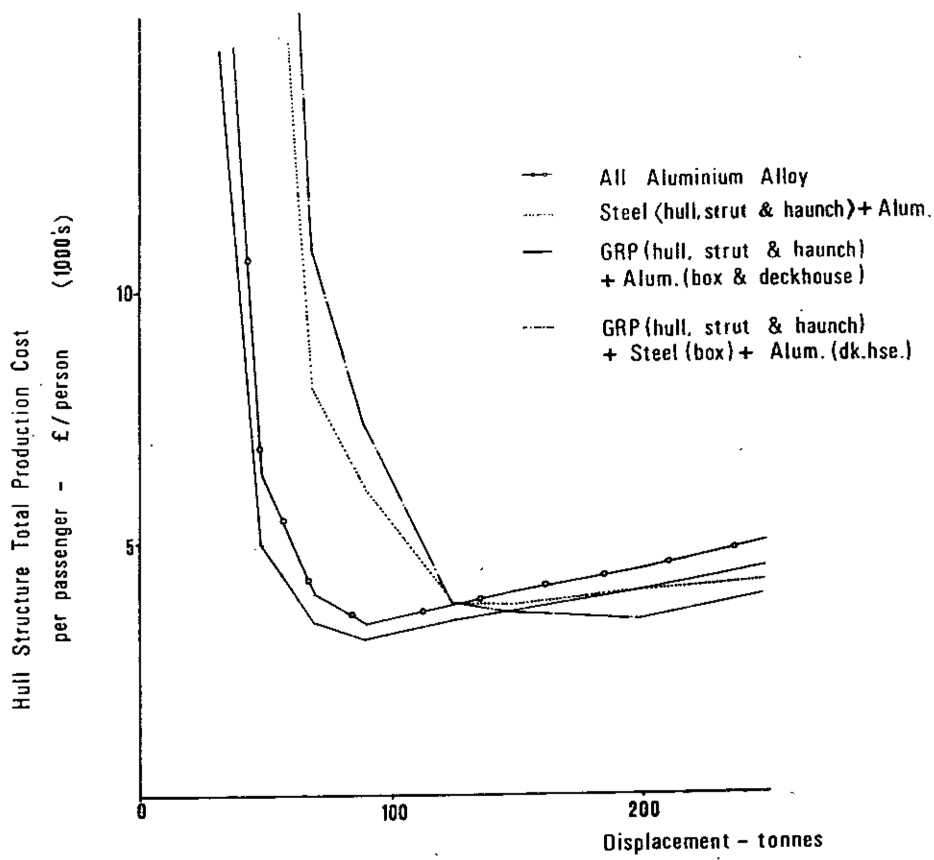


Figure 23: EC1 factor for hybrid construction

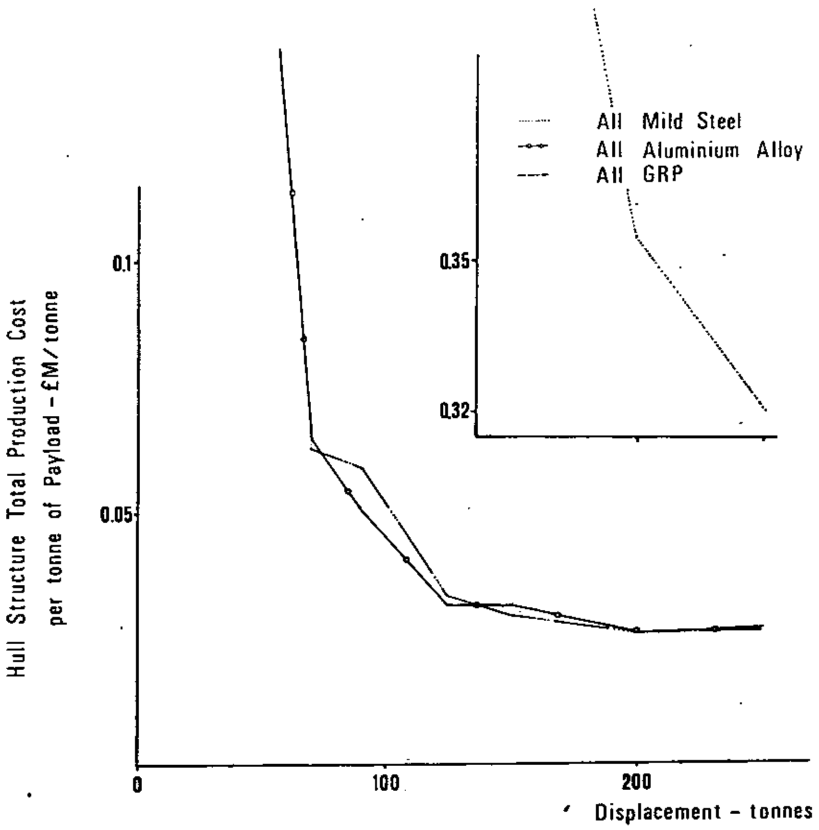


Figure 24: EC2 factor for homogeneous construction

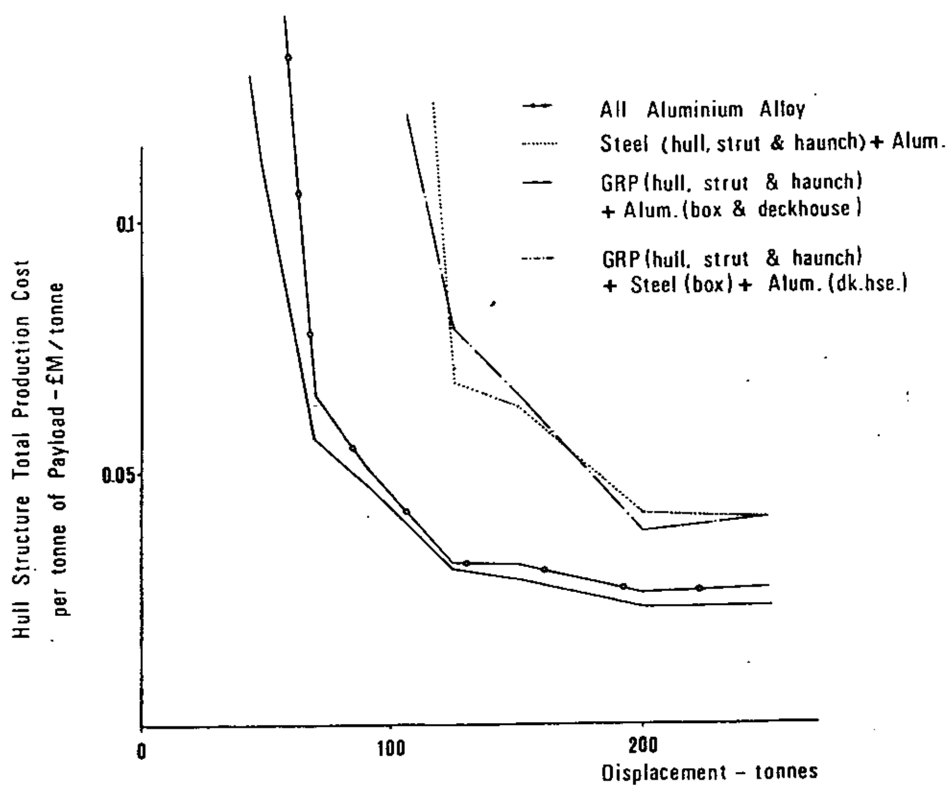


Figure 25: EC2 factor for hybrid construction

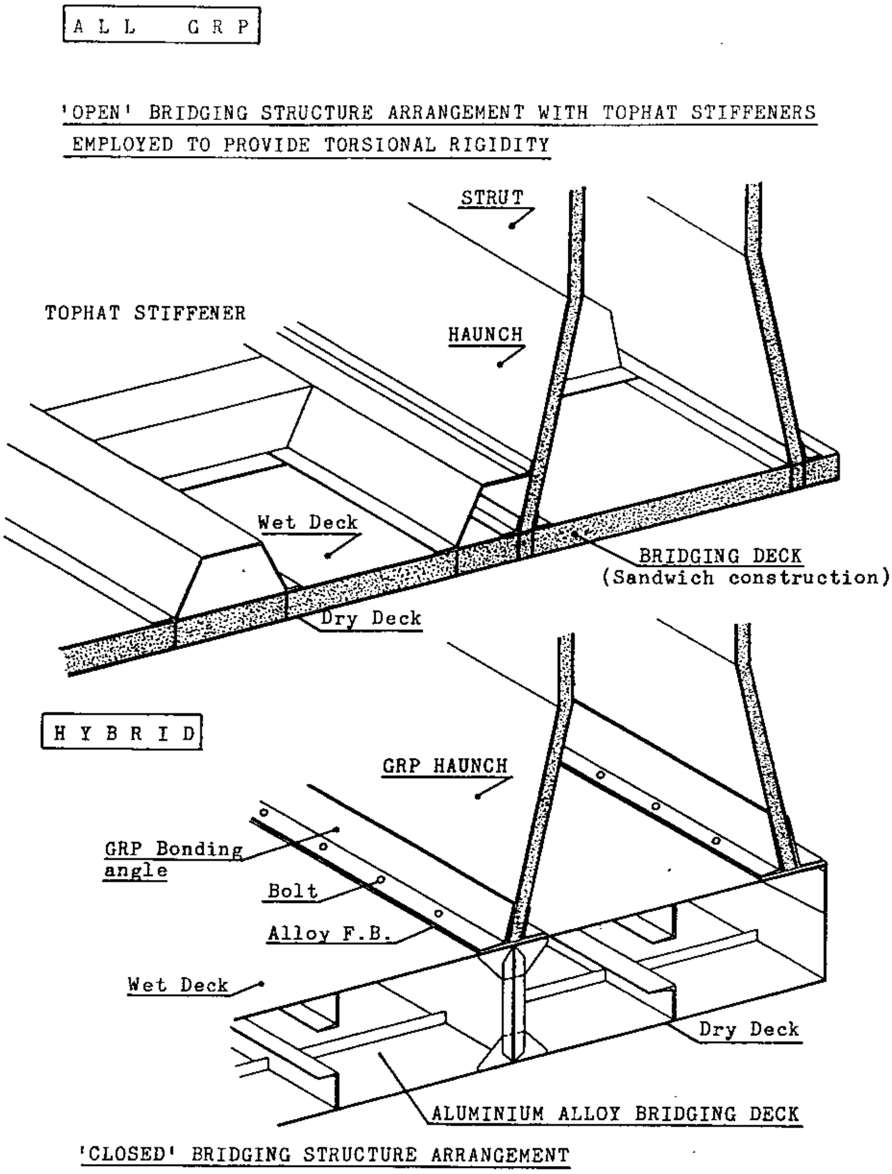


Figure 26: Novel structural arrangements for further study

APPENDIX A: EVALUATION OF PROGRAM 'STRUDES'

Test Case 1

A detailed 'paper' design for a mild steel SWATH ship of mixed framing type (Figure 7) is compared with the 'STRUDES' arrangement (Figure 8). The scantlings are generally in agreement (Table A1) although it would appear that different philosophies have been used to design the wet deck.

The two arrangements are not identical although similar overall weights are to be expected. The designer considered the use of alloy bridging structure and comparison with 'STRUDES' is included in Table A1. Scantlings were not available for the alloy box.

Test Case 2

One of the few SWATH craft built to date is the Halcyon (34). Only a weight comparison is made in Table A1 as scantling data was insufficiently precise.

Test Case 3

Attempts to obtain data for the only FRP SWATH craft built to date were unsuccessful. No 'paper' designs for GRP SWATH craft were identified during a literature survey. 'STRUDES' predictions could therefore only be validated against non-SWATH data. Wet deck plate thickness (single skin) and lower hull sandwich properties are compared with bottom shell scantlings for a variety of yacht and boat forms in Figure A1.

Test Case 4

Bottom shell and side shell structural area densities are available for an 18m LOA boat designed to Lloyd's Rules (43).

An estimate of the hull weight of a similarly sized (70t) SWATH craft has been developed on the assumption that wet deck, haunch and lower hull weights can be based on the bottom shell density, dry deck and strut can be based on the side shell density and internal plate frames and girders can be based on unstiffened side shell values.

A comparison with 'STRUDES' is made in Table A2. GRP sandwich data was not available, but applying single skin data to the box gave a value of 13.4 tonne compared with 12.2 tonnes from 'STRUDES'.

Test Case 5

In an effort to evaluate 'STRUDES' at the extreme range of displacement, predictions were made for 250t and 765t for comparison with data from reference 4. The 765 ship is beyond the intended limits of application of 'STRUDES' being designed with a full height box. This will produce a larger surface area of plating than is assumed by 'STRUDES' but very much thinner plating owing to the greater depth of the section (see Figure A2).

Test Case 6

Aluminium alloy structural volume densities for hydrofoils (44) are compared with 'STRUDES' predictions in Figure A3.

VALUES FOR A 125t MILD STEEL DETAILED DESIGN STUDY		
SCANTLING ITEM	ACTUAL VALUE	'STRUDES'VALUE
Wet deck (mm)	4.00	5.25
Dry deck (mm)	4.00	4.00
Deck beam depth (mm)	100	85-120
Deck girder depth (mm)	110	90-120
Haunch plating (mm)	5.00	5.00
Strut plating (mm)	5.00	4.75
Web fr. depth (strut) (mm	180	140
Long. depth (strut) mm	100	90
Lower hull plating (mm)	5.00	5.25
Long. depth (hull) mm	100	100
Web fr. depth (hull) mm	180	150

COMPARISON OF WEIGHT ESTIMATES (TONNES) (Δ = 125t)		
STRUCTURAL MATERIALS (ALLOY DK.HSE. FOR BOTH)	DESIGNER'S ESTIMATE	'STRUDES' ESTIMATE
MILD STEEL HULL	59.0	63.9
ALLOY BOX, REMAIN. M.S.	45.2	49.6

58 tonne ALL ALUMINIUM ALLOY SWATH SD-60 'HALCYON'		
TOTAL WEIGHT (tonnes)	BUILDER'S VALUE	'STRUDES' ESTIMATE
	24.9	25.2

Table A1: SWATH craft scantling and weight comparisons

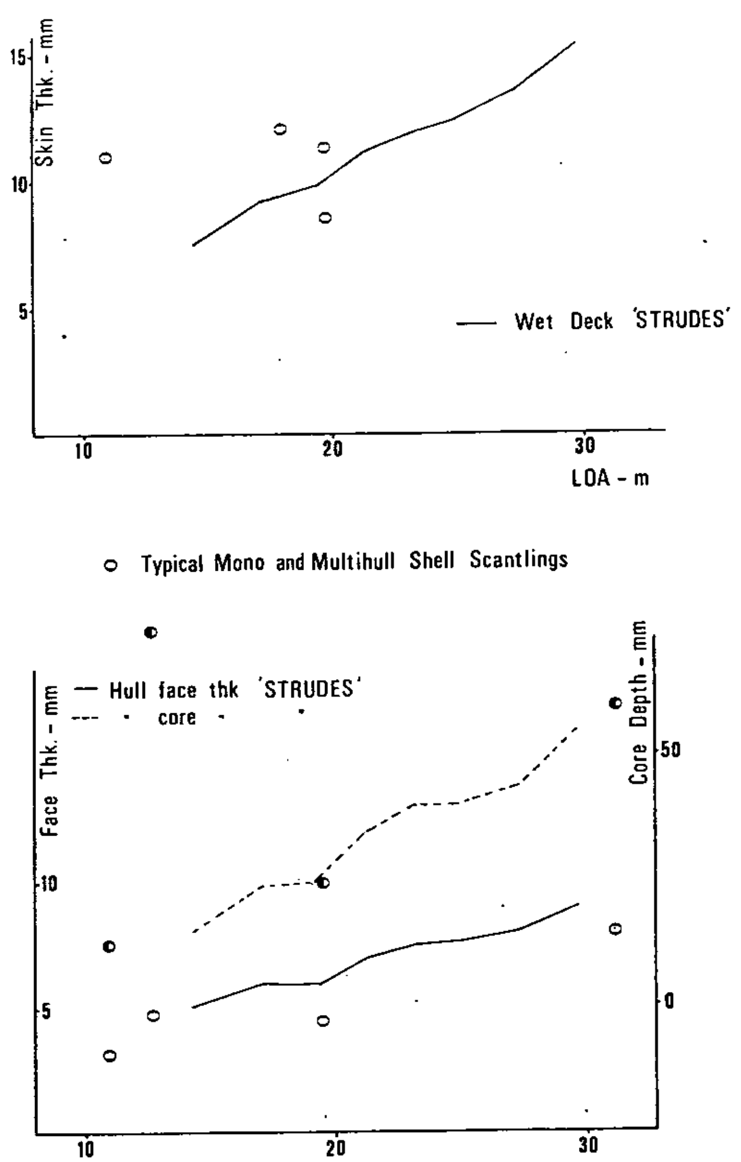


Figure A1: Typical scantlings for GRP craft

M I L D S T E E L		
AREA STRUCTURAL DENSITIES FROM LR RULES' FOR 18m BOAT APPLIED TO A 70t SWATH		
ITEM	AREA DENSITY	'STRUDES'
Bridging Deck	27.0	20.3
Haunch	2.4	2.3
Strut	2.5	2.1
Lower Hull	5.7	4.8

A L U M I N I U M A L L O Y '		
AREA STRUCTURAL DENSITIES FROM LR RULES FOR 18m BOAT APPLIED TO A 70t SWATH		
ITEM	AREA DENSITY	'STRUDES'
Bridging Deck	12.6	11.2
Haunch	1.1	1.4
Strut	1.2	1.3
Lower Hull	2.8	2.8

Table A2: Comparisons of weight with area-density

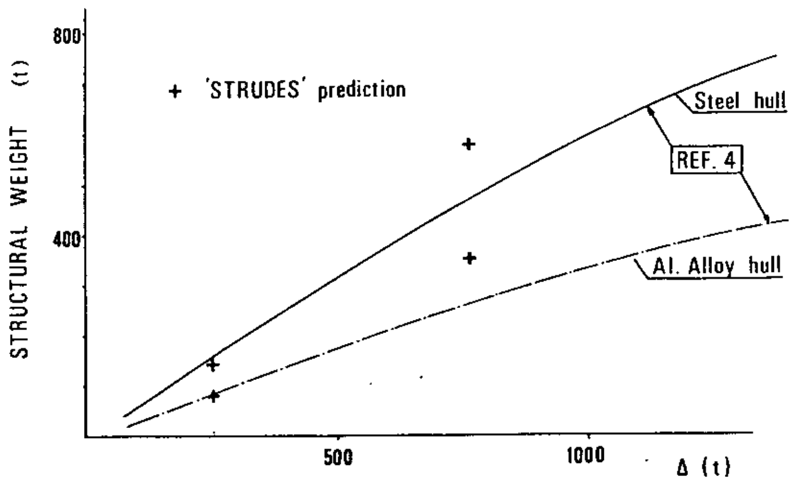


Figure A2 : Structural weight of large OPV ships

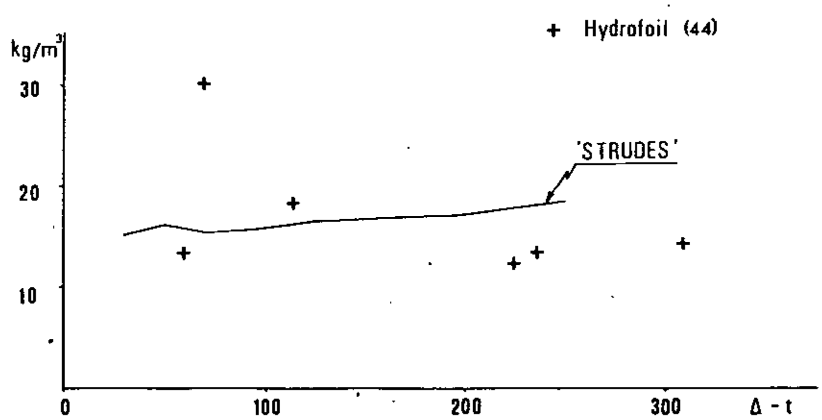


Figure A3: Deckhouse volume density

APPENDIX B: TYPICAL PROGRAM OUTPUT

For 70 tonne displacement SWATH craft.

1. Output from 'LOADS'

2. Output from 'STRUDES'

3. Output from 'EVAL'.

'LOADS'

```
***********************************************************
* P R E L I M I N A R Y   S T R U C T U R A L   D E S I G N *
* O F   S M A L L   W A T E R P L A N E   A R E A   S H I P S *
*                                                         *
*        L O A D     P R E D I C T I O N                  *
*        ---------   ----------------------------         *
***********************************************************
```

PROJECT TITLE

SHIP SCIENCE REPORT
WAVEHEIGHT = 3 METRES

SWATH TITLE
----
70 tonne DISPLACEMENT DESIGN

```
**********************
D E S I G N   L O A D S
**********************

************************************************
* REDUCED VERSION FOR USE WITH PROGRAM 'STRUDES' *
************************************************
```

SIDE FORCE

```
BEAM SEA SIDE FORCE  (MN)  :    .697
Force/displacement         :   1.016
Force/displacement         :   1.319
(Sikora et al equation)
BOW SEA SIDE FORCE   (MN)  :    .593
```

TRANSVERSE BENDING MOMENT

```
MAX. TRANSVERSE MOMENT (MN.m):   1.962
```

SLAM LOADING

```
PANEL PRESSURE BASED ON AN AREA OF       .525 SQ.M
--------------------------------------------------
PRESSURE  - Seller's method (MN/sq.m):    .061
PRESSURE  - Allen's  method (MN/sq.m):    .057
```

```
********** E N D   O F   L O A D   P R E D I C T I O N  *********
```

D E S I G N   D E F I N I T I O N
```
*********************************
```

HULL DEFINITION

```
Length  =  17.900 m, Diameter =   1.500 m, Cp =  .850
```

STRUT DEFINITION

```
Length  =  18.500 m, Width    =    .600 m, Depth =   2.100 m
Cw      =  .900
```

BOX DEFINITION

```
Length  =  19.500 m, Width    =   9.200 m, Depth =    .650 m
```

MASS DETAILS

```
Mass    =   70.0 tonnes, Draft =   2.223 m
Hull volume/displaced volume =  .789
```

SEA STATE DETAILS

```
H(1/3) =  3.000 m, Exposure = 24.00 hours
Risk factor employed =  1.000

Natural frequency in heave  1.346 rads/sec
```

```
*******************************************************
*        STRUCTURAL DESIGN OF SMALL SWATH CRAFT       *
*   PROGRAM 3; Preliminary scantlings and structural  *
*              weight estimation.                     *
*                                                     *
*   FOR EVALUATION OF ALTERNATIVE STRUCTURAL MATERIALS *
* Mild steel, Aluminium Alloy & Glass Reinforced Plastic *
*******************************************************
```

'STRUDES'

P R O J E C T   T I T L E
*************   *********

70 tonne SWATH SHIP (SHIP SCIENCE REPORT EXAMPLE)

METHODOLOGY
----

1. D E C K H O U S E

Lloyd's Registers Small Craft Rules are employed for steel and aluminium alloy.
ABS Rules are used for GRP.

2. B R I D G I N G   D E C K (ALSO CALLED 'BOX')

Plate and beam theory are employed together with results from 'LOADS'.
The miniumum acceptable deck depth is obtained from transverse bending moment considerations.
Peak stresses in the deck plating and the plate frame resulting from the worst possible torsional loads (i.e. lifting/docking condition) are obtainable as an option. These stresses are for information only and do not exercise any influence over scantlings.
This is due to the highly localised nature of the stresses.
Reference is also made to ABS Rules for GRP.

3. H A U N C H & S T R U T

Plate and beam theory as per bridging deck. Slam pressure is employed for the haunch and maximum hydrostatic pressure for the strut. Reference is also made to ABS GRP RULES.
Shell thickness and shear area of web frames are checked against the effect of transverse moment and side force

4. L O W E R   H U L L

Plate, beam and curved beam theory are employed.
Reference is also made to ABS Rules for GRP.

NOTES
*****

A. Design stresses are based on fatigue limit values.
B. GRP sandwich construction is employed for the lower hull, strut, haunch and deckhouse, with single skin for the bridging deck.

P R E L I M I N A R Y   S C A N T L I N G S

****
*   MILD STEEL   *
****

1. D E C K H O U S E   S C A N T L I N G S

COACHROOF
****

Plating thickness (mm)   3.00

COACHROOF STIFFENERS
Web Depth   (mm) ; 60 - Web Thickness   (mm) ; 3.50
- Coachroof stiffeners run athwartships, supported by three deck girders.

TRANSVERSES (Every third stiffener)
Web Depth   (mm) ; 90 - Web Thickness   (mm) ; 3.25
Flange Width (mm) ; 30 - Flange Thickness (mm) ; 3.25

GIRDERS (three fitted)
Web Depth   (mm) ; 90 - Web Thickness   (mm) ; 3.25
Flange Width (mm) ; 30 - Flange Thickness (mm) ; 3.25

DECKHOUSE SIDES AND AFT BULKHEAD
****

Plating thickness (mm)   3.00

VERTICAL STIFFENERS
Web Depth   (mm) ; 60 - Web Thickness   (mm) ; 3.50

TRANSVERSES (Every third stiffener)
Web Depth   (mm) ; 90 - Web Thickness   (mm) ; 3.25
Flange Width (mm) ; 30 - Flange Thickness (mm) ; 3.25

FRONT BULKHEAD
****

Plating thickness (mm)   3.75

VERTICAL STIFFENERS
Web Depth   (mm) ; 60 - Web Thickness   (mm) ; 3.50

TRANSVERSES (Every third stiffener)
Web Depth   (mm) ; 90 - Web Thickness   (mm) ; 3.25
Flange Width (mm) ; 30 - Flange Thickness (mm) ; 3.25

2. B R I D G I N G   D E C K   S C A N T L I N G S

Wet Deck
*** ****
Plating thickness (mm)   5.00

DECK BEAMS (Running athwartships)
Web Depth   (mm) ; 120 - Web Thickness   (mm) ; 6.75

DECK LONGITUDINAL GIRDERS
Web Depth   (mm) ; 110 - Web Thickness   (mm) ; 3.75
Flange Width (mm) ; 40 - Flange Thickness (mm) ; 3.75
(Based on four girders per deck)

Dry Deck
*** ****
Plating thickness (mm)   3.00

DECK BEAMS (Running athwartships)
Web Depth   (mm) ; 70 - Web Thickness   (mm) ; 4.00

DECK LONGITUDINAL GIRDERS
Web Depth   (mm) ; 90 - Web Thickness   (mm) ; 3.25
Flange Width (mm) ; 30 - Flange Thickness (mm) ; 3.25
(Based on four girders per deck)

Depth of Bridging Deck (mm) ; 650
Plate Frame thickness (mm) ; 3.00

3. H A U N C H   S C A N T L I N G S

SHELL PLATING
Plating thickness (mm)   5.00

SHELL LONGITUDINALS
Web Depth   (mm) ; 90 - Web Thickness   (mm) ; 5.50

WEB FRAMES
Web Depth   (mm) ; 150 - Web Thickness   (mm) ; 5.00
Flange Width (mm) ; 60 - Flange Thickness (mm) ; 5.00

4. S T R U T   S C A N T L I N G S

SHELL PLATING
Plating thickness (mm)   3.50

SHELL LONGITUDINALS (spaced 325 mm apart)
Web Depth   (mm) ; 80 - Web Thickness   (mm) ; 4.50

WEB FRAMES
Web Depth   (mm) ; 110 - Web Thickness   (mm) ; 3.75
Flange Width (mm) ; 40 - Flange Thickness (mm) ; 3.75

5. L O W E R H U L L

SHELL PLATING
Plating thickness (mm)   4.25

HULL STRINGERS (spaced 337 mm apart)
Web Depth (mm) ; 90 - Web Thickness (mm) ; 5.00

RING FRAME TRANSVERSE
Web Depth (mm) ; 120 - Web Thickness (mm) ; 4.25
Flange Width (mm) ; 60 - Flange Thickness (mm) ; 5.25

DOCKING GIRDER
Web Depth (mm) ; 240 - Web Thickness (mm) ; 5.50
Flange Width (mm) ; 80 - Flange Thickness (mm) ; 6.50

****
*   ALUMINIUM ALLOY   *
****

1. D E C K H O U S E   S C A N T L I N G S

COACHROOF
****

Plating thickness (mm)   3.75

COACHROOF STIFFENERS
Web Depth (mm) ; 70 - Web Thickness (mm) ; 4.75
- Coachroof stiffeners run athwartships, supported by three deck girders.

TRANSVERSES (Every third stiffener)
Web Depth (mm) ; 80 - Web Thickness (mm) ; 3.50
Flange Width (mm) ; 40 - Flange Thickness (mm) ; 3.50

GIRDERS (three fitted)
Web Depth (mm) ; 80 - Web Thickness (mm) ; 3.25
Flange Width (mm) ; 30 - Flange Thickness (mm) ; 3.25

DECKHOUSE SIDES AND AFT BULKHEAD
****

Plating thickness (mm)   3.75

VERTICAL STIFFENERS
Web Depth (mm) ; 70 - Web Thickness (mm) ; 4.75

TRANSVERSES (Every third stiffener)
Web Depth (mm) ; 80 - Web Thickness (mm) ; 3.50
Flange Width (mm) ; 40 - Flange Thickness (mm) ; 3.50

FRONT BULKHEAD
****

Plating thickness (mm)   4.75

VERTICAL STIFFENERS
Web Depth (mm) ; 70 - Web Thickness (mm) ; 4.75

TRANSVERSES (Every third stiffener)
Web Depth (mm) ; 90 - Web Thickness (mm) ; 3.75
Flange Width (mm) ; 40 - Flange Thickness (mm) ; 3.75

2. B R I D G I N G   D E C K   S C A N T L I N G S

Wet Deck
*** ****
Plating thickness (mm)   8.25

DECK BEAMS (Running athwartships)
Web Depth (mm) ; 130 - Web Thickness (mm) ; 5.50
Flange Width (mm) ; 60 - Flange Thickness (mm) ; 5.50

DECK LONGITUDINAL GIRDERS
Web Depth (mm) ; 140 - Web Thickness (mm) ; 5.75
Flange Width (mm) ; 60 - Flange Thickness (mm) ; 5.75
(Based on four girders per deck)

Dry Deck
*** ****
Plating thickness (mm)   4.25

DECK BEAMS (Running athwartships)
Web Depth (mm) ; 80 - Web Thickness (mm) ; 3.50
Flange Width (mm) ; 40 - Flange Thickness (mm) ; 3.50

DECK LONGITUDINAL GIRDERS
Web Depth (mm) ; 80 - Web Thickness (mm) ; 3.50
Flange Width (mm) ; 40 - Flange Thickness (mm) ; 3.50
(Based on four girders per deck)

Depth of Bridging Deck (mm) ; 650
Plate Frame thickness (mm) ; 4.25

3. H A U N C H   S C A N T L I N G S

SHELL PLATING
Plating thickness (mm)   8.25

SHELL LONGITUDINALS
Web Depth (mm) ; 120 - Web Thickness (mm) ; 8.25

WEB FRAMES
Web Depth (mm) ; 180 - Web Thickness (mm) ; 7.50
Flange Width (mm) ; 90 - Flange Thickness (mm) ; 7.50

4. STRUT SCANTLINGS

SHELL PLATING
Plating thickness (mm) 5.75

SHELL LONGITUDINALS (spaced 325 mm apart)
Web Depth (mm) ; 100 - Web Thickness (mm) ; 6.75

WEB FRAMES
Web Depth (mm) ; 140 - Web Thickness (mm) ; 5.75
Flange Width (mm) ; 60 - Flange Thickness (mm) ; 5.75

5. LOWER HULL

SHELL PLATING
Plating thickness (mm) 7.00

HULL STRINGERS (spaced 337 mm apart)
Web Depth (mm) ; 110 - Web Thickness (mm) ; 7.50

RING FRAME TRANSVERSE
Web Depth (mm) ; 190 - Web Thickness (mm) ; 6.50
Flange Width (mm) ; 90 - Flange Thickness (mm) ; 7.50

DOCKING GIRDER
Web Depth (mm) ; 240 - Web Thickness (mm) ; 5.50
Flange Width (mm) ; 80 - Flange Thickness (mm) ; 6.50

****
*   GLASS REINFORCED PLASTIC   *
****

1. DECKHOUSE SCANTLINGS

COACHROOF
****

Skin thickness (mm) 3.00 Core depth (mm) 12.5

DECK BEAMS
Top-hat stiffener details

Web depth (mm)	90	Web thickness (mm)	3.00
Crown width (mm)	80	Crown thickness (mm)	4.00
Lap width (mm)	50	Lap thickness (mm)	3.00

GIRDERS (three fitted)

Web depth (mm)	90	Web thickness (mm)	3.00
Crown width (mm)	80	Crown thickness (mm)	4.00
Lap width (mm)	50	Lap thickness (mm)	3.00

DECKHOUSE SIDES AND AFT BULKHEAD
****

Skin thickness (mm) 3.00 Core depth (mm) 12.5

VERTICAL WEB FRAMES

Web depth (mm)	120	Web thickness (mm)	4.00
Crown width (mm)	100	Crown thickness (mm)	5.00
Lap width (mm)	50	Lap thickness (mm)	4.00

FRONT BULKHEAD
****

Skin thickness (mm) 3.50 Core depth (mm) 12.5

VERTICAL WEB FRAMES
Top-hat stiffener details

Web depth (mm)	120	Web thickness (mm)	4.00
Crown width (mm)	100	Crown thickness (mm)	5.00
Lap width (mm)	50	Lap thickness (mm)	4.00

2. B R I D G I N G   D E C K   S C A N T L I N G S

Wet Deck
*** ****

Plating thickness (mm) 10.00

DECK BEAMS (Running athwartships)
Top-hat stiffener details

Web depth	(mm)	110	Web thickness	(mm)	6.00
Crown width	(mm)	80	Crown thickness	(mm)	7.00
Lap width	(mm)	50	Lap thickness	(mm)	6.00

DECK LONGITUDINAL GIRDERS

Web depth	(mm)	120	Web thickness	(mm)	4.00
Crown width	(mm)	100	Crown thickness	(mm)	5.00
Lap width	(mm)	50	Lap thickness	(mm)	4.00

Dry Deck
*** ****

Plating thickness (mm) 7.00

DECK BEAMS (Running athwartships)
Top-hat stiffener details

Web depth	(mm)	95	Web thickness	(mm)	3.50
Crown width	(mm)	80	Crown thickness	(mm)	4.50
Lap width	(mm)	50	Lap thickness	(mm)	3.50

DECK LONGITUDINAL GIRDERS

Web depth	(mm)	90	Web thickness	(mm)	3.00
Crown width	(mm)	80	Crown thickness	(mm)	4.00
Lap width	(mm)	50	Lap thickness	(mm)	3.00

Depth of Bridging Deck (mm) ; 650
Plate Frame thickness (mm) ; 7.00

3. H A U N C H   S C A N T L I N G S

Skin thickness (mm) 6.50 Core depth (mm) 30.0

TRANSVERSE WEB FRAMES
Top-hat stiffener details

Web depth	(mm)	180	Web thickness	(mm)	6.00
Crown width	(mm)	140	Crown thickness	(mm)	7.00
Lap width	(mm)	50	Lap thickness	(mm)	6.00

4. S T R U T   S C A N T L I N G S

Skin thickness (mm) 5.50 Core depth (mm) 20.0

TRANSVERSE WEB FRAMES
Top-hat stiffener details

Web depth	(mm)	90	Web thickness	(mm)	3.00
Crown width	(mm)	80	Crown thickness	(mm)	4.00
Lap width	(mm)	50	Lap thickness	(mm)	3.00

5. L O W E R   H U L L

Skin thickness (mm) 6.00 Core depth (mm) 25.0

RING FRAME TRANSVERSE

Web depth	(mm)	150	Web thickness	(mm)	5.00
Crown width	(mm)	70	Crown thickness	(mm)	6.00
Lap width	(mm)	50	Lap thickness	(mm)	5.00

DOCKING GIRDER

Web depth	(mm)	120	Web thickness	(mm)	4.00
Crown width	(mm)	100	Crown thickness	(mm)	5.00
Lap width	(mm)	50	Lap thickness	(mm)	4.00

STRUCTURAL WEIGHT

ITEM	STEEL	AL.ALLOY	GRP
Deckhouse	7.9	3.7	3.7
Bridge Deck	20.3	11.2	12.2
Haunch	2.3	1.5	1.4
Strut	2.1	1.3	1.3
Lower Hull	4.8	2.9	2.8
TOTAL (P & S)	46.7	26.2	26.8

MATERIAL	STRESS LIMIT (MN.sq.mm)	STRESS DESIGN (MN.sq.mm)	MODULUS YOUNG'S (MN.sq.mm)	MODULUS SHEAR (MN.sq.mm)	DENSITY (kg/cub.m)	POISSONS RATIO
Steel	235.0	150.0	208000	80000	7.800	.30
Al.Alloy	125.0	55.0	70000	27340	2.760	.28
GRP Lam.	170.0	37.0	7550	3090	1.700	.13
Core	1.8	1.8	200	100	.128	.10

PRINCIPAL DIMENSIONS

BRIDGING STRUCTURE

Length 19.50 Breadth 9.20 Depth .65

STRUT

Length 18.50 Breadth .60 Depth 1.30

HULL

Length 17.90 Diameter 1.50 Cp .85

HAUNCH

Width 1.60 Depth .80

DECKHOUSE

Length 14.60 Breadth 7.30 Depth 2.20

DESIGN LOADS

Side force (MN) .697
Slam pressure (MN/sq.m) .059
Frame spacing (mm) 350
Web frame spacing (mm) 1050

STRUCTURAL WEIGHTS USING ROUGH AREA DENSITIES

ITEM	STEEL	ALUMINIUM
Deckhouse	10.2	4.9
Bridge Deck	27.0	12.6
Haunch	2.4	1.1
Strut	2.5	1.2
Lower Hull	5.7	2.8
TOTAL	58.3	27.7

GRP SINGLE SKIN BRIDGE DECK

Bridge Deck ONLY 13.4 tonnes

END OF PROGRAM
Version as of April 1987 (C)PRL

DESIGN EVALUATION FOR A SMALL SWATH CRAFT

##
70 tonne DISPLACEMENT SWATH SHIP
##

PRINCIPAL DIMENSIONS & FORM COEFFICIENTS

Hull	; Length =	17.90	Diameter =	1.50		
Strut	; Length =	18.50	Depth =	1.30	Width =	.60
Haunch	; Width =	1.60	Depth =	.80		
Box	; Length =	19.50	Depth =	.65	Width =	9.20
Deckhouse	; Length =	14.60	Depth =	2.20	Width =	7.30
OVERALL	; Depth =	4.25	Draft =	2.20	'Clear'=	1.40

'Clear' refers to wet deck clearance in calm water
All dimensions are in metres

FORM COEFFICIENTS
Hull prismatic coefficient .850
Waterplane area coefficient .900

FERRY/EXCURSION BOAT SPECIFICATION

Number of passengers is dependent on the material configuration
Max. Speed (knots) ; 24.00
Cruise Speed (knots) ; 18.00 Range (n.m.) ; 400

WORKBOAT SPECIFICATION

Complement (berthed) ; 8
Max. Speed (knots) ; 20.00
Cruise Speed (knots) ; 15.00 Range (n.m.) ; 800

##

MATERIAL CONFIGURATION NO. 1

DESIGN EVALUATION

WEIGHT BREAKDOWN

STRUCTURAL WEIGHT

ITEM	WEIGHT(tonnes)	MATERIAL
Deckhouse	3.7	Al.Alloy
Box	20.3	Mild Steel
Haunch	4.6	Mild Steel
Strut	4.2	Mild Steel
Hull	9.6	Mild Steel
TOTAL	42.4	

FERRY/EXCURSION BOAT
****

BREAKDOWN OF DISPLACEMENT

ITEM	WEIGHT(tonnes)
Structure	42.4
Outfit & Mach.	22.8
Fuel	5.0
Water Ballast	2.3
Passengers	-2.6
Net Payload	.1
DISPLACEMENT	69.9

WARNING Negative payload means that the SWATH craft
******* is not viable with this material configuration and in this role.

STRUCTURAL MATERIAL COSTS (Pounds sterling)

Total production cost of structure 339320
Production cost per passenger meaningless, DESIGN INVALID

WORKBOAT
****

BREAKDOWN OF DISPLACEMENT

ITEM	WEIGHT(tonnes)
Structure	42.4
Outfit & Mach.	25.0
Fuel	9.2
Water Ballast	2.3
Crew	.6
Net Payload	-9.6
DISPLACEMENT	69.9

WARNING Negative payload means that the SWATH craft
******* is not viable with this material configuration and in this role.

STRUCTURAL MATERIAL COSTS (Pounds sterling)

Total production cost of structure 339320
Production cost per tonne payload meaningless, DESIGN INVALID

****

MATERIAL CONFIGURATION NO. 2

DESIGN EVALUATION

WEIGHT BREAKDOWN

STRUCTURAL WEIGHT

ITEM	WEIGHT(tonnes)	MATERIAL
Deckhouse	3.7	Al.Alloy
Box	11.2	Al.Alloy
Haunch	3.0	Al.Alloy
Strut	2.6	Al.Alloy
Hull	5.8	Al.Alloy
TOTAL	26.3	

FERRY/EXCURSION BOAT
****

BREAKDOWN OF DISPLACEMENT

ITEM	WEIGHT(tonnes)
Structure	26.3
Outfit & Mach.	27.7
Fuel	5.0
Water Ballast	2.3
Passengers	8.7
Net Payload	.0
DISPLACEMENT	69.9

WARNING Negative payload means that the SWATH craft
******* is not viable with this material configuration and in this role.

STRUCTURAL MATERIAL COSTS (Pounds sterling)

Total production cost of structure 431320
Production Cost per Passenger 3957
Total Number of Passengers 109
Covered Floor Area per Passenger .99 sq.m
(Suggested minimum ; 0.8 sq.m per passenger)

DESIGN CHARACTERISTICS

Stability; Transverse GM 1.57 Longitudinal GM 4.85
Ballasting operation
Maximum change in draft (% draft) 5.0
Maximum change in trim (% LWL) 8.6
Installed Powers
2 x 950 kW diesels running at 2100 rpm
Power required at cruise speed (kW) 900
Generator capacity 30 kW

WORKBOAT
****

BREAKDOWN OF DISPLACEMENT

ITEM	WEIGHT(tonnes)
Structure	26.3
Outfit & Mach.	25.0
Fuel	9.2
Water Ballast	2.3
Crew	.6
Net Payload	6.5
DISPLACEMENT	69.9

WARNING Negative payload means that the SWATH craft
******* is not viable with this material configuration and in this role.

STRUCTURAL MATERIAL COSTS (Pounds sterling)

Total production cost of structure 431320
Production Cost per tonne of payload 66730

DESIGN CHARACTERISTICS

Stability; Transverse GM 3.09 Longitudinal GM 6.37
Ballasting operation
Maximum change in draft (% draft) 5.0
Maximum change in trim (% LWL) 6.5
Installed Powers
2 x 550 kW diesels running at 2100 rpm
Power required at cruise speed (kW) 700
Generator capacity 30 kW

****

MATERIAL CONFIGURATION NO. 3

DESIGN EVALUATION

WEIGHT BREAKDOWN

STRUCTURAL WEIGHT

ITEM	WEIGHT(tonnes)	MATERIAL
Deckhouse	3.7	GRP
Box	12.2	GRP
Haunch	2.8	GRP
Strut	2.6	GRP
Hull	5.6	GRP
TOTAL	26.9	

FERRY/EXCURSION BOAT
****

BREAKDOWN OF DISPLACEMENT

ITEM	WEIGHT(tonnes)
Structure	26.9
Outfit & Mach.	27.5
Fuel	5.0
Water Ballast	2.3
Passengers	8.2
Net Payload	.1
DISPLACEMENT	69.9

WARNING Negative payload means that the SWATH craft
******* is not viable with this material configuration and in this role.

STRUCTURAL MATERIAL COSTS (Pounds sterling)

Total production cost of structure 370440
Production Cost per Passenger 3597
Total Number of Passengers 103
Covered Floor Area per Passenger 1.05 sq.m
(Suggested minimum ; 0.8 sq.m per passenger)

DESIGN CHARACTERISTICS

Stability; Transverse GM 1.57 Longitudinal GM 4.85
Ballasting operation
Maximum change in draft (% draft) 5.0
Maximum change in trim (% LWL) 8.6
Installed Powers
2 x 950 kW diesels running at 2100 rpm
Power required at cruise speed (kW) 900
Generator capacity 30 kW

WORKBOAT
****

BREAKDOWN OF DISPLACEMENT

ITEM	WEIGHT(tonnes)
Structure	26.9
Outfit & Mach.	25.0
Fuel	9.2
Water Ballast	2.3
Crew	.6
Net Payload	5.9
DISPLACEMENT	69.9

WARNING Negative payload means that the SWATH craft
******* is not viable with this material configuration and in this role.

STRUCTURAL MATERIAL COSTS (Pounds sterling)

Total production cost of Structure 370440
Production Cost per tonne of payload 63176

DESIGN CHARACTERISTICS

Stability; Transverse GM 3.14 Longitudinal GM 6.42
Ballasting operation
Maximum change in draft (% draft) 5.0
Maximum change in trim (% LWL) 6.5
Installed Powers
2 x 550 kW diesels running at 2100 rpm
Power required at cruise speed (kW) 700
Generator capacity 30 kW

****

MATERIAL CONFIGURATION NO. 4

DESIGN EVALUATION

WEIGHT BREAKDOWN

STRUCTURAL WEIGHT

ITEM	WEIGHT(tonnes)	MATERIAL
Deckhouse	3.7	Al.Alloy
Box	11.2	Al.Alloy
Haunch	2.8	GRP
Strut	2.6	GRP
Hull	5.6	GRP
TOTAL	25.9	

FERRY/EXCURSION BOAT
****

BREAKDOWN OF DISPLACEMENT

ITEM	WEIGHT(tonnes)
Structure	25.9
Outfit & Mach.	27.8
Fuel	5.0
Water Ballast	2.3
Passengers	9.0
Net Payload	.1
DISPLACEMENT	69.9

WARNING Negative payload means that the SWATH craft
******* is not viable with this material configuration and in this role.

STRUCTURAL MATERIAL COSTS (Pounds sterling)

Total production cost of structure 387360
Production Cost per Passenger 3459
Total Number of Passengers 112
Covered Floor Area per Passenger .96 sq.m
(Suggested minimum ; 0.8 sq.m per passenger)

DESIGN CHARACTERISTICS

Stability; Transverse GM 1.56 Longitudinal GM 4.84
Ballasting operation
Maximum change in draft (% draft) 5.0
Maximum change in trim (% LWL) 8.6
Installed Powers
2 x 950 kW diesels running at 2100 rpm
Power required at cruise speed (kW) 900
Generator capacity 30 kW

WORKBOAT
****

BREAKDOWN OF DISPLACEMENT

ITEM	WEIGHT(tonnes)
Structure	25.9
Outfit & Mach.	25.0
Fuel	9.2
Water Ballast	2.3
Crew	.6
Net Payload	6.9
DISPLACEMENT	69.9

WARNING Negative payload means that the SWATH craft
******* is not viable with this material configuration and in this role.

STRUCTURAL MATERIAL COSTS (Pounds sterling)

Total production cost of structure 387360
Production Cost per tonne of payload 56437

DESIGN CHARACTERISTICS

Stability; Transverse GM 3.06 Longitudinal GM 6.34
Ballasting operation
Maximum change in draft (% draft) 5.0
Maximum change in trim (% LWL) 6.6
Installed Powers
2 x 550 kW diesels running at 2100 rpm
Power required at cruise speed (kW) 700
Generator capacity 30 kW

****

MATERIAL CONFIGURATION NO. 5

DESIGN EVALUATION

WEIGHT BREAKDOWN

STRUCTURAL WEIGHT

ITEM	WEIGHT(tonnes)	MATERIAL
Deckhouse	3.7	Al.Alloy
Box	20.3	Mild Steel
Haunch	2.8	GRP
Strut	2.6	GRP
Hull	5.6	GRP
TOTAL	35.0	

FERRY/EXCURSION BOAT
****

BREAKDOWN OF DISPLACEMENT

ITEM	WEIGHT(tonnes)
Structure	35.0
Outfit & Mach.	25.1
Fuel	5.0
Water Ballast	2.3
Passengers	2.6
Net Payload	.1
DISPLACEMENT	69.9

WARNING Negative payload means that the SWATH craft
******* is not viable with this material configuration
and in this role.

STRUCTURAL MATERIAL COSTS (Pounds sterling)

Total production cost of structure 349840
Production Cost per Passenger 10933
Total Number of Passengers 32
Covered Floor Area per Passenger 3.36 sq.m
(Suggested minimum ; 0.8 sq.m per passenger)

DESIGN CHARACTERISTICS

Stability; Transverse GM 1.68 Longitudinal GM 4.96
Ballasting operation
Maximum change in draft (% draft) 5.0
Maximum change in trim (% LWL) 8.4
Installed Powers
2 x 950 kW diesels running at 2100 rpm
Power required at cruise speed (kW) 900
Generator capacity 30 kW

WORKBOAT
****

BREAKDOWN OF DISPLACEMENT

ITEM	WEIGHT(tonnes)
Structure	35.0
Outfit & Mach.	25.0
Fuel	9.2
Water Ballast	2.3
Crew	.6
Net Payload	-2.2
DISPLACEMENT	69.9

WARNING Negative payload means that the SWATH craft
******* is not viable with this material configuration
and in this role.

STRUCTURAL MATERIAL COSTS (Pounds sterling)

Total production cost of structure 349840
Production cost per tonne payload meaningless, DESIGN INVALID

DESIGN CHARACTERISTICS

Stability; Transverse GM 3.78 Longitudinal GM 7.06
Ballasting operation
Maximum change in draft (% draft) 5.0
Maximum change in trim (% LWL) 5.9
Installed Powers
2 x 550 kW diesels running at 2100 rpm
Power required at cruise speed (kW) 700
Generator capacity 30 kW

****

MATERIAL CONFIGURATION NO. 6

DESIGN EVALUATION

WEIGHT BREAKDOWN

STRUCTURAL WEIGHT

ITEM	WEIGHT(tonnes)	MATERIAL
Deckhouse	3.7	Al.Alloy
Box	11.2	Al.Alloy
Haunch	4.6	Mild Steel
Strut	4.2	Mild Steel
Hull	9.6	Mild Steel
TOTAL	33.3	

FERRY/EXCURSION BOAT
****

BREAKDOWN OF DISPLACEMENT

ITEM	WEIGHT(tonnes)
Structure	33.3
Outfit & Mach.	25.6
Fuel	5.0
Water Ballast	2.3
Passengers	3.8
Net Payload	.1
DISPLACEMENT	69.9

WARNING Negative payload means that the SWATH craft
******* is not viable with this material configuration
and in this role.

STRUCTURAL MATERIAL COSTS (Pounds sterling)

Total production cost of structure 376840
Production Cost per Passenger 8018
Total Number of Passengers 47
Covered Floor Area per Passenger 2.29 sq.m
(Suggested minimum ; 0.8 sq.m per passenger)

DESIGN CHARACTERISTICS

Stability; Transverse GM 1.91 Longitudinal GM 5.19
Ballasting operation
Maximum change in draft (% draft) 5.0
Maximum change in trim (% LWL) 8.0
Installed Powers
2 x 950 kW diesels running at 2100 rpm
Power required at cruise speed (kW) 900
Generator capacity 30 kW

WORKBOAT
****

BREAKDOWN OF DISPLACEMENT

ITEM	WEIGHT(tonnes)
Structure	33.3
Outfit & Mach.	25.0
Fuel	9.2
Water Ballast	2.3
Crew	.6
Net Payload	-.5
DISPLACEMENT	69.9

WARNING Negative payload means that the SWATH craft
******* is not viable with this material configuration
and in this role.

STRUCTURAL MATERIAL COSTS (Pounds sterling)

Total production cost of structure 376840
Production cost per tonne payload meaningless,
DESIGN INVALID

****
* END OF PROGRAM (C) PRL FEB.87 *
****