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DAVID W. TAYLOR NAVAL SHIP RESEARCH AND DEVELOPMENT CENTER

Bethesda, Md. 20084

ADVANCED NAVAL VEHICLES CONCEPTS EVALUATION

PLANING VEHICLE TECHNICAL ASSESSMENT (U)

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August 1976

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DEPARTMENT OF THE NAVY
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From: Project Officer, Advanced Naval Vehicles Concepts Evaluation
To: Distribution List

Subj: Advanced Naval Vehicles Concepts Evaluation (ANVCE) State-of-the-Art Technology Assessment for Planing Craft

Ref: (a) OPNAV memo ser/59694 of 25 July 1975; subj: Directive for Advanced Naval Vehicle Concepts Evaluation

Encl: (1) State-of-the-Art Technology Assessment for Planing Craft ; forwarding of

1. Enclosure (1), prepared by the David Taylor Naval Ships Research and Development Center (DTNSRDC) under the aegis of the ANVCE project office is forwarded for review and consideration. The assessment was conducted under the direction of ANVCE and does not necessarily represent an opinion of the Chief of Naval Operations or the Chief of Naval Material.

2. Enclosure (1) is an assessment of Planing Craft state-of-the-art technology compiled in response to the requirements of reference (a). The objective of this assessment is to provide a concise summary of what is known about the theory, design, performance and technical potential of the Planing Craft concept. During the course of this assessment, the technological effort necessary to support the development of point designs has been defined and initiated. In addition, it has formed the technological basis from which to select appropriate Planing Craft concepts for development as point designs. Ultimately, the assessment will be utilized in evaluating the military worth and technical feasibility of the Planing Craft selected for analysis.

3. This document has been prepared solely for use within the context of the ANVCE project.

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ADVANCED NAVAL VEHICLES CONCEPTS EVALUATION

PLANING VEHICLE TECHNICAL ASSESSMENT (U)

Edited by J. L. Gore

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VII. **BIBLIOGRAPHY**

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LIST OF SYMBOLS AND COEFFICIENTS

A_p	Projected blade area of propeller
b	Effective width of plating, in (see p. 110)
b	chine beam, ft
b_x	Maximum chine beam, ft
bhp	Brake horsepower of engine
c	Net specific fuel rate (lb/hp-hr) (for Breguet formula)
C_v	Speed coefficient = $v/\sqrt{gb}$
C_L	Lift coefficient of planing surface = $L/0.5\rho v^2 b^2$
C_p	Center of pressure $Cp = lp/Lm$ = 0.75 - $1/(5.21C_v^2/\lambda^2)+2.39$
C_{L0}	Lift coefficient of planing surface with zero deadrise
$C_{L\beta}$	Lift coefficient of planing surface with deadrise
C_Δ	Load coefficient = Δ/wb_x^3 ; the measure of "Beam loading"
CG	Center of gravity
D	Drag = Resistance of vehicle (=R), lb
D	Propeller diameter, ft
E	Modulus of elasticity, lb/in^2
EAR	Expanded area ratio = Expanded blade area/$0.25\pi D^2$
ehp	Effective horsepower = $Tv/550$
F_N	Froude number = $v/\sqrt{gL} = 0.298V_K/\sqrt{L}$
$F_{N\nabla}$	Volume Froude Number = $v/\sqrt{g\nabla^{1/3}}$
g	Acceleration of gravity, 32.16 ft/sec^2
$H_{1/3}$	Significant wave height, ft. It is the average of the one-third highest waves.
$H_{1/10}$	Average of the 1/10 highest waves, ft
J_T	Advance coefficient of propeller based on thrust = $v(1-w_t)/nD$
K_T	Thrust coefficient = $T/\rho n^2 D^4$
L	Lift = A = total weight of vehicle, lb or tons
L	Length on waterline, ft
L/b_x	Length/beam ratio

L_c	Wetted length of chine at speed, ft
L_k	Wetted length of keel at speed, ft
L_m	Mean wetted length = $(L_k+L_c)/2$, ft
L_P	Length of planing bottom = chine length for Series 62 hulls, ft
LCG	Longitudinal position of the center of gravity
LOA	Length overall
ℓ	Unsupported span (of a beam)
ℓp	Location of center of pressure of planing surface, ft forward of transom
M	Maximum moment (bending)
NM	Nautical mile
n	Rotative speed of propeller, rev/sec
OPC	Overall propulsive coefficient = ehp/bhp
P	Required brake horsepower, ft lb/sec
P	Propeller pitch, ft
P_A	Atmospheric pressure, lb/ft^2
P_e	Total power actually used (for Breguet formula)
P_H	Hydrostatic pressure at center of propeller, lb/ft^2
P_V	Vapor pressure of water, lb/ft^2
P/D	Pitch/diameter ratio of propeller, also called Pitch ratio
P	Unit pressure, lb/in^2; Hydrodynamic loading on structure
Q	Propeller torque, ft lb
Q_C	Torque load coefficient = $Q/0.5\rho A_p D v_{0.7R}^2$
R	Resistance of vehicle = drag(=D), lb
R_{AW}	Added resistance due to waves (rough water), lb
R_r	Residuary resistance = total resistance less frictional resistance; approximately equal to wavemaking resistance
rpm	Rotative speed of propeller, revolutions per minute
T	Thrust of propeller, lb
t	Thickness of plating, in
t	tonnes (metric tons)

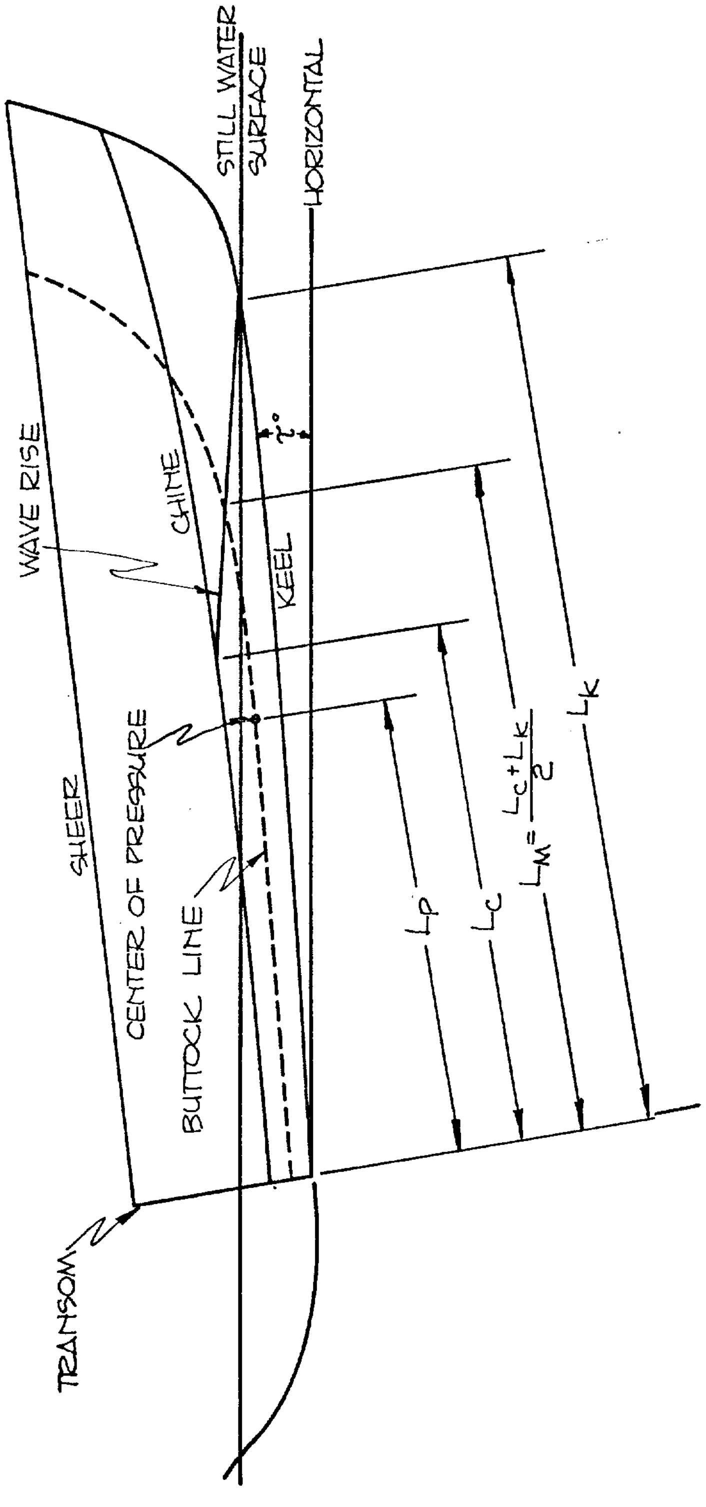
tn	long tons
V_k	Speed of vehicle, knots
$\overline{V}_k$	Average speed of vehicle, knots (for Breguet formula)
v	Speed of vehicle, ft/sec
W_f	Weight of vehicle fuel used, lb (for Breguet formula)
w	Weight density of water, lb/ft^3 (salt water=64.0; fresh water=62.4)
w_Q	Wake fraction based on torque
w_T	Wake fraction based on thrust
$L_p/\nabla^{1/3}$ =	Slenderness ratio
$\Delta/(.01\,L)^3$ =	Displacement length ratio
$V_k/\sqrt{L}$ =	Speed length ratio
β	Deadrise angle, degrees
Δ	Displacement = total weight of vehicle, lb or tn
$\overline{\Delta}$	Average weight of vehicle, lb or tn (for Breguet formula)
∇	Volume of displacement, $ft^3 = \Delta/w$, Δ in lb
η	Efficiency, general
η	Acceleration, vertical, due to rough water impact, g units
η_{bow}	Acceleration, vertical, at bow, g units
η_{CG}	Acceleration, vertical, at center of gravity, g units
η_D	Propulsive efficiency = Rv/P
η_o	Open water efficiency of propeller
η_R	Relative rotation efficiency of propeller
η_x	Total system transport efficiency = $\Delta v/P = \eta_D/(D/L)$
$\eta_{1/3}$	Average of 1/3 highest accelerations
$\eta_{1/10}$	Average of 1/10 highest accelerations
λ	Scale ratio, full scale to model
ρ	Mass density of fluid, $lb\text{-}sec^2/ft^4$
σ	Cavitation number based on forward velocity only = $P_A + P_H - P_V/0.5\rho v^2$
σ_y	Yield stress in material, lb/in^2
$\sigma_{0.7R}$	Cavitation number based on resultant water velocity at 0.7 radius of propeller = $\sigma[J_T^2/(J_T^2 + 4.84)]$
τ	Trim angle of planing surface, degrees
τ_c	Thrust load coefficient. See page 124a.

GLOSSARY

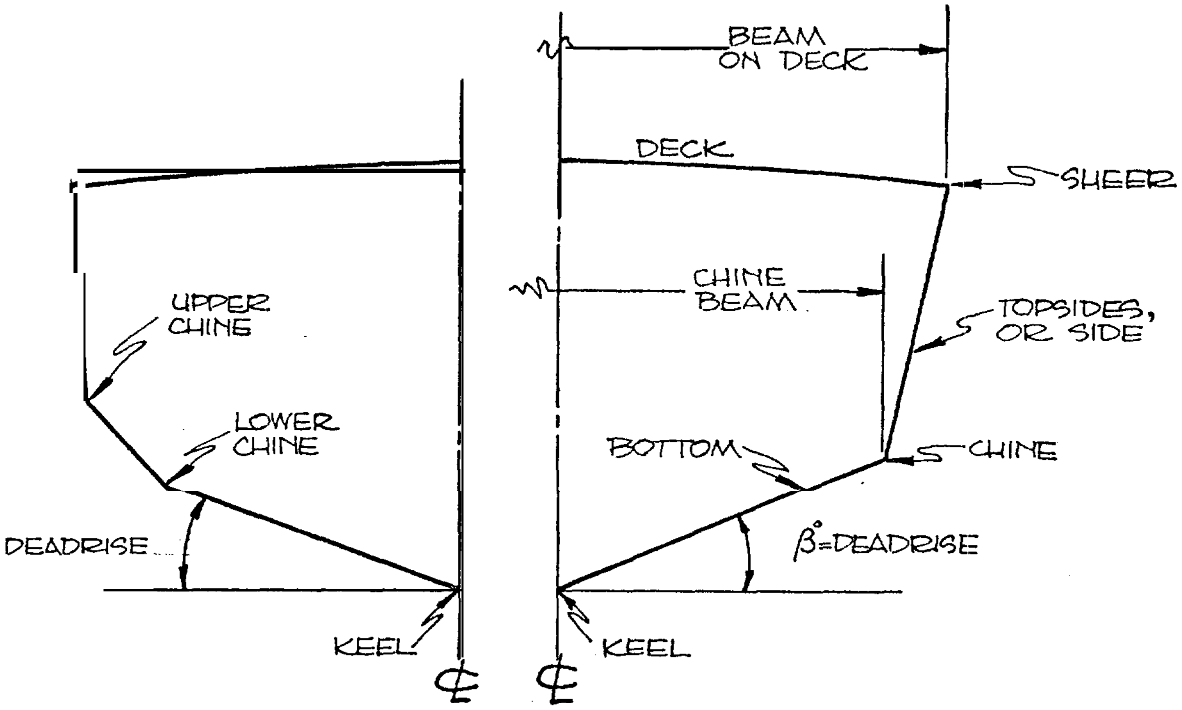
Planing surface	The bottom of a planing craft, sometimes used synonymously with planing craft when reference is to geometric or hydrodynamic considerations only.
Prismatic surface	A planing surface with constant chine beam and deadrise,
Scantlings	The dimensions (sizes) of structure members.
Standard of Subdivision	The degree of compartmentation, denoted by the number of compartments which can be flooded without submerging the margin line, an arbitrary line 3" below the deck at the ship's side.

For other terms see the List of Symbols and Coefficients, the accompanying sketches, and the following documents:

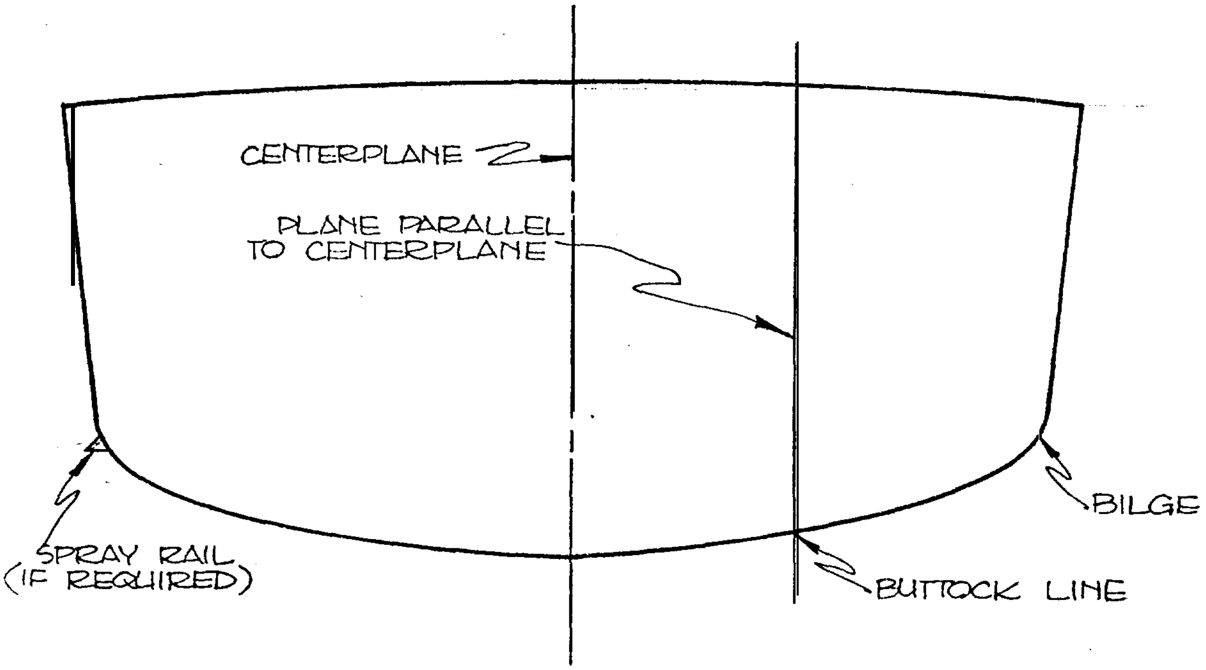
1. Standardization of Terminology for ANVCE ANVCE/PMJ: dtw, Memo No. 25-76, 9 April 1976, with enclosure ANVCE WP-002
2. Standardization of Terminology for ANVCE 6114PI/JKL, Ser 931, 18 March 1976, with Enclosures (1) and (2).



PLANING HULL, PROFILE



SECTION OF A HARD CHINE HULL



SECTION OF A ROUND BOTTOM HULL

ABSTRACT

(U) This report was prepared as part of Task II of the Advanced Naval Vehicles Concepts Evaluation (ANVCE).

(U) An Assessment is made of the design and construction of planing craft and ships, particularly combatants, indicating the current state-of-the-art and need for further development in each of the technological areas such as fluid mechanics, materials and structures, propulsion, human engineering, and weapons systems. It is seen that for many naval missions the most desirable vehicle is, quite naturally, the smallest one that will carry the mission equipment, and that such a vehicle requires relatively high speed. The usual resultants of these combinations of speed and size are generally outside the range of displacement ship hull types (hydrostatic support) and therefore require some form of dynamic support. The least expensive way to achieve this is to configure the hull so that, as its speed is increased, it lifts bodily from its static flotation draft and "planes" on the surface of the water. It needs no lift system. The limitations of the concept, particularly in regard to size, useful load fraction, speed and sea state, are discussed. Many naval missions fall within the practical planing vehicle regime and most fall within the speed range of planing hulls.

(U) The history of the planing hull concept is traced and it is seen that: 1) speed capability has slowly increased and seems likely to continue to do so; 2) great advances have recently been made in high-speed rough-water capability; 3) large increases in the size of planning vehicles are now possible. The 100-foot, 72 ton, CPIC-X is cited as an example of the current state-of-the art in all technological areas and is used to predict the performance of a 200-foot, 576 ton Open Ocean Planing Hull, and to indicate the feasibility of such concepts in sizes up to at least 1000 tons.

(U) In contrast to the image of the sterotyped planing boat, in which they are generally perceived as small "runabouts" capable of operation only in protected waters, the modern planing ship is, in fact, capable of carrying a very significant useful load over long distances in the open ocean, at relatively high speeds, and with relatively good crew comfort. Most importantly, the cost is relatively low compared to other types of dynamically supported vehicles.

(U) At the conclusion of the ANVCE project in FY77, there will be no ongoing Navy planing vehicle R and D effort in Advanced Development (Category 6.3).

ACKNOWLEDGEMENTS

This report represents the work of many participants in addition to the principal authors listed below. The authors wish to express their appreciation of the efforts and cooperation of all concerned in preparing the calculations, text, and figures. Particular acknowledgement is made of the overall editing support provided by Joseph G. Koelbel Jr., John M. Oseth, Rod Riddick, and other members of the staff of ASSET Incorporated.

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SECTION I - INTRODUCTION (U)

A. DESCRIPTION OF THE PLANING HULL CONCEPT (U)

1. (U) The planing hull is designed specifically to achieve relatively high speed on the surface of the water. Although it is not essential to the concept of planing, rough water operation is an important capability to have for most useful planing hulls and this aspect of their design will be discussed below. The general discussion of the features which enable a vessel to attain high speed will refer to smooth water operation only.

2. (U) Speed on the water surface is closely related to the size of the vessel. Length is the principal dimension used to define speed-size relationships at low speeds because the resistance of the hull to motion through the water is especially dependent upon the formation of surface waves which, of course, move at the speed of the hull. Surface waves have a fixed relation between their speed and their length. This is

sometimes expressed, in English units, as the wave speed in knots divided by the square root of the wave length in feet and this ratio is always equal to 1.34 (except in very shallow water). The speed/length ratio of a displacement vessel is similarly defined as its speed in knots divided by the square root of the water line length in feet, Therefore, when a vessel moves at a speed/length ratio $(V_k/\sqrt{L})$* of 1.34 it creates waves whose length is equal to the waterline length of the vessel. This critical speed is also stated in dimensionless form using the Froude Number, F_N,* where the equivalent value $F_N = 0.40$ marks the upper limit of true displacement operation and the beginning of "high speed displacement" operation. The reasons for this are given in the next two paragraphs.

3. (U) Below $F_N = 0.40$ the vessel spans two or more waves (of its own bow wave train), the changes in draft and trim are small, and power requirements are modest. In this speed range the hull is supported entirely by buoyant forces. Up to a Froude Number of 0.27 the drag is predominantly frictional. The hull is tapered at the stern and curved upward toward the waterline, to minimize flow separation which is another source of drag. This is typical of slow, heavy vessels as shown in Table 1. Above $F_N = 0.27$ the wavemaking drag becomes increasingly important. At about $F_N = 0.36$ it begins to increase at a very high rate and at about $F_N = 0.4$ wavemaking becomes a virtual barrier to further increases in speed for the true displacement hull form. This is because the increased local velocities caused by the rounded hull form result in low static pressures which allow the vessel to settle deeply, and to trim excessively by the stern. The ship is literally climbing the back of its own bow wave.

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* See List of Symbols

TABLE 1 - VESSELS TYPICAL OF VARIOUS FROUDE NUMBERS (U)

Length Froude Number F_N	Speed Length Ratio $V_K/\sqrt{L}$	Drag-Lift Ratio D/L	Lift-Drag Ratio L/D	Type of Vessel
0.15	0.5	0.001	1000	Slow Cargo Vessels
0.24	0.8	0.002	500	LST, Tankers
0.30	1.0	0.005	200	Amphibious Cargo Ships, Transports
0.33	1.1	0.008	125	Carriers
0.39	1.3	0.02	50	Light Cruisers, Ocean Escorts
0.45	1.5	0.03	33	Frigates
0.54	1.8	0.05	20	Destroyers, etc.
0.98	3.3	0.10	10	PG (Patrol Gunboat)
1.34	4.5	0.14	7	CPIC-X (Coastal Patrol and Interdiction Craft, Experimental)

These are approximate representative ratios for the general type of vessel shown.

Note: See Figure 1 on page 6 for graphical representation of the various speed regimes.

4. (U) At Froude Numbers above 0.4 it is therefore necessary to depart from the "canoe stern" or "counter stern" of the low speed types and to make the buttock lines flatter terminating in a transom stern. This hull form avoids the negative pressures that occur when a true displacement hull is overdriven, and causes the flow to separate cleanly at the stern thus keeping the separation drag to a minimum. As the design speed of the vessel is further increased even straighter buttock lines are required and the transom must be broader and more deeply immersed (but round bilge

sections may still be employed). This high speed displacement (or semi-planing) regime extends from F_N of about 0.4 to about 0.9. These speed regimes are depicted graphically in Figure 1.

5. (U) A systematic series of high speed displacement hulls (Series 64, [1]), the parent form of which is shown in Figure 2, was tested at Froude Numbers up to 1.8. In analyzing the results, the author of Ref. [1] makes the following statement regarding high speed displacement operation:

"The dropping off of residuary, i.e. wavemaking, resistance coefficients and the close spacing of R_r/Δ^* i.e. wavemaking resistance per ton of displacement (proportional to D/L), contours between the speed/length ratios of 2.0 (F_N = 0.6) and 3.0 (F_N = 0.9) mean that a small increase in horsepower will bring a higher return in speed in this speed range than in any other speed range, except at the very low speeds. The leveling off of the residuary resistance coefficients and their magnitudes after the speed/length ratio of 3.0 (F_N = 0.9) indicate that the wave resistance is no longer an important factor. The frictional resistance, however, remains the dominant factor, and its magnitude is about twice as large as the form drag... Therefore, for ships designed to operate at speed/length ratios over 3.0 (F_N = 0.9), it is highly desirable to keep the wetted surface to a minimum." It is precisely this factor that makes the planing type of hull desirable at higher speeds. The manner in which it generates lift (discussed below) causes it to rise bodily above its static flotation level and to trim up by the bow thereby reducing the wetted surface significantly.

6. (U) Since the formation of waves is less significant and not primarily influenced by hull length above semi-planing speeds, the

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* See List of Symbols

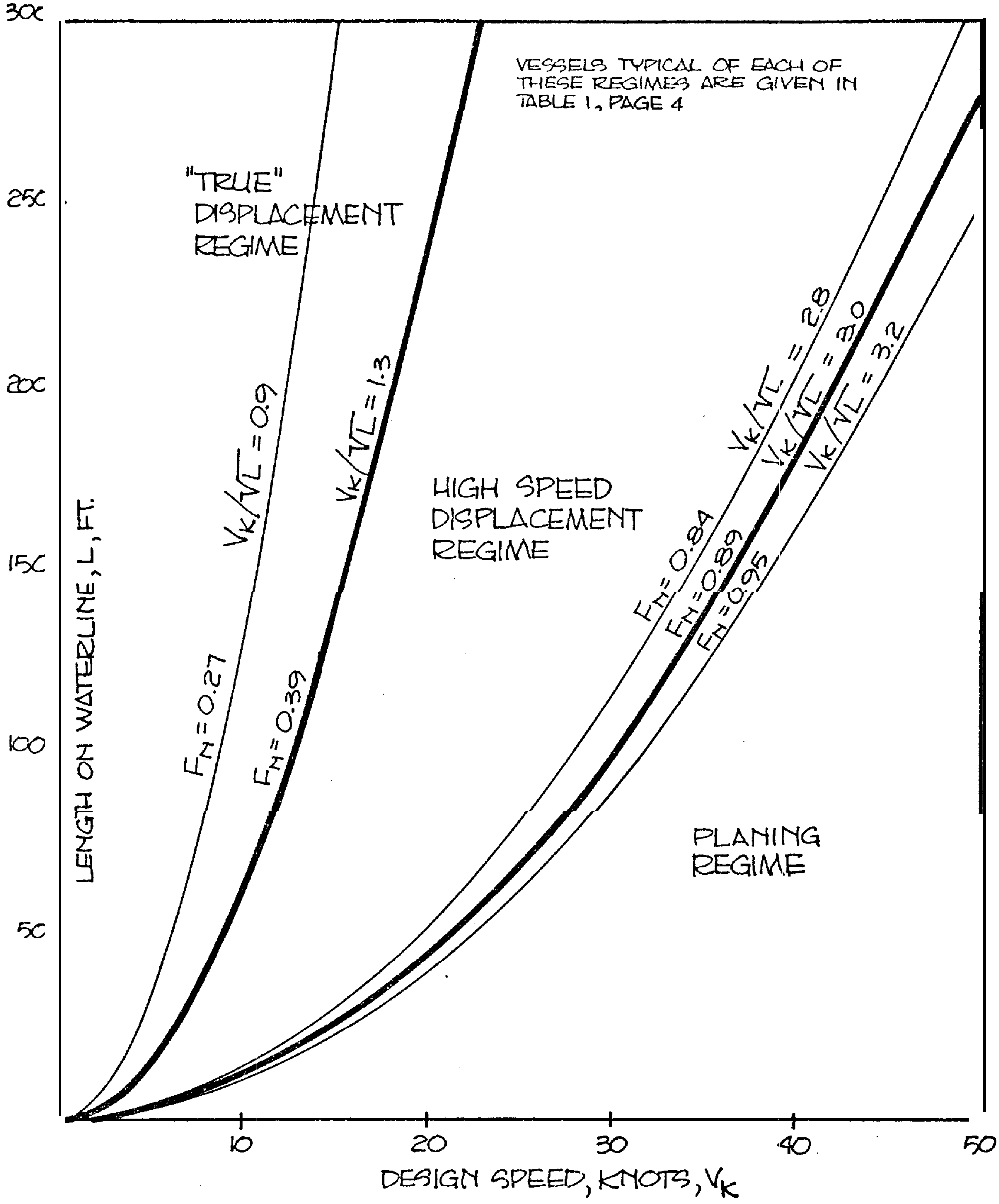
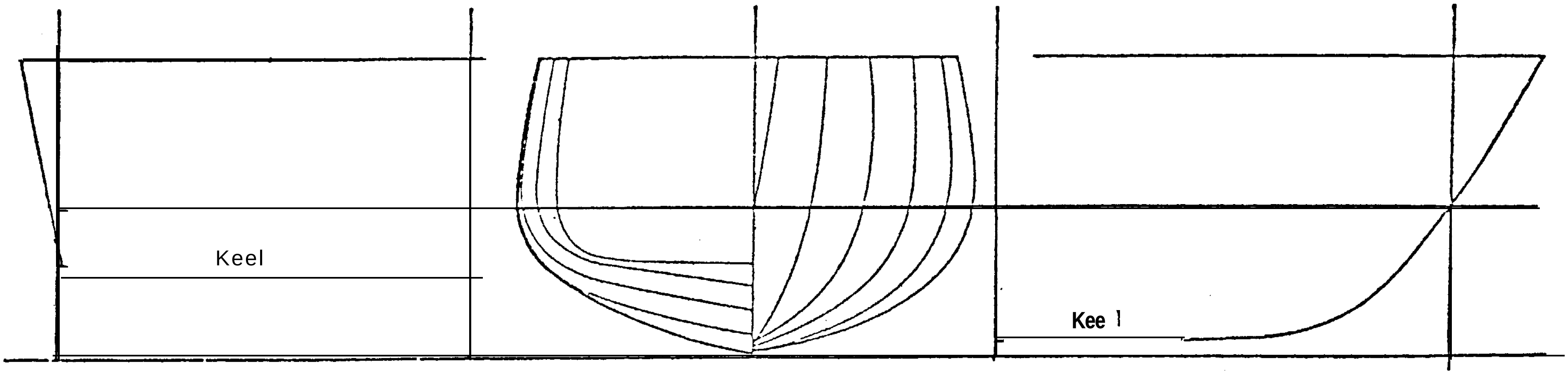
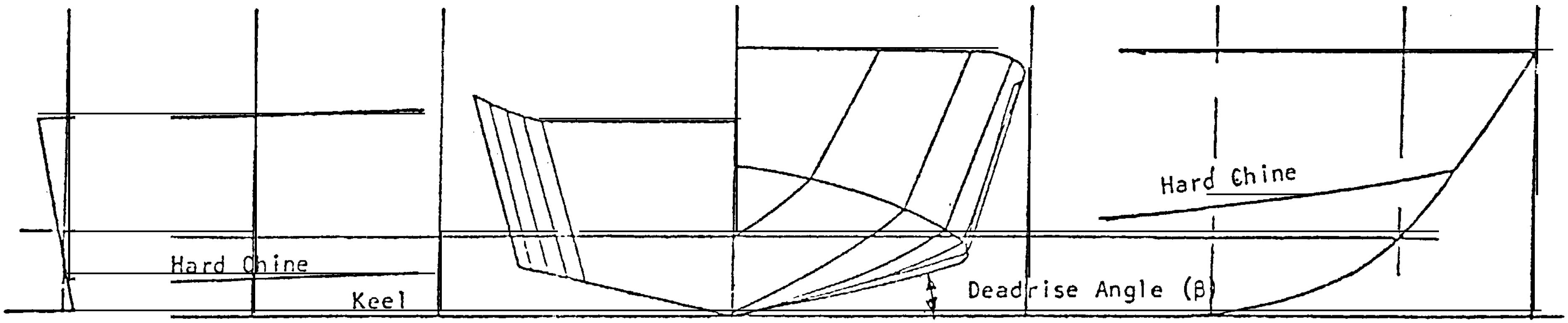


Figure 1 - Speed Regimes (U)

GEOMETRY OF TYPICAL
HIGH SPEED DISPLACEMENT HULL VS PLANING HULL



HIGH SPEED DISPLACEMENT HULL
(SERIES 64) [1]



HIGH SPEED PLANING HULL
(SERIES 62) [2]

Figure 2 - Typical Hull Geometry (U)

length Froude Number is no longer very useful as a measure of the speed-size relationship and the Volume (or Displacement) Froude Number $F_{N\nabla} = v/\sqrt{g\nabla^{1/3}}$ *is frequently used. Figure 3 shows a plot of drag/lift ratio against Froude Number for several slenderness ratios $(L_p/\nabla^{1/3})$.* The curves represent the state-of-the-art for efficient planing hulls at their design speeds, and do not represent any one hull throughout the speed range. It can be seen that the curves all cross in a small area around $F_{N\nabla} = 3.3$, indicating that the slenderness ratio, and hence the length, has little effect on the specific resistance at this Froude Number. At lower speeds longer hulls have a great advantage over shorter ones and (from other data) high speed displacement or semi-planing configurations have an advantage over full planing configurations, to be described below. At higher speeds, as noted above, the planing type of hull is required. These facts are illustrated dimensionally in Figure 4, where the line marked "Upper Bound Displacement Hulls!' represents $F_{N\nabla} = 3.3$, the limit of speed above which the high speed displacement type hull form may be more efficient depending on the length and weight (slenderness ratio) of the vessel. The shorter the hull, at constant weight (the lower the slenderness ratio), the lower the speed at which the planing type hull can be considered. This range of lower limits, shown in Figure 4 as the family of curves labeled "Lower Bound. Planing Hulls", corresponds to a range of length Froude Numbers from 0.84 to 0.95. This range is also shown in Figure 1, on p. 6.

7. (U) The chief characteristic of the planing hull is effective flow separation, not only at the transom as in the high speed displacement

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* See List of Symbols

This figure was developed from data reported in [18], a compilation of test results on Series 62 and Series 65.

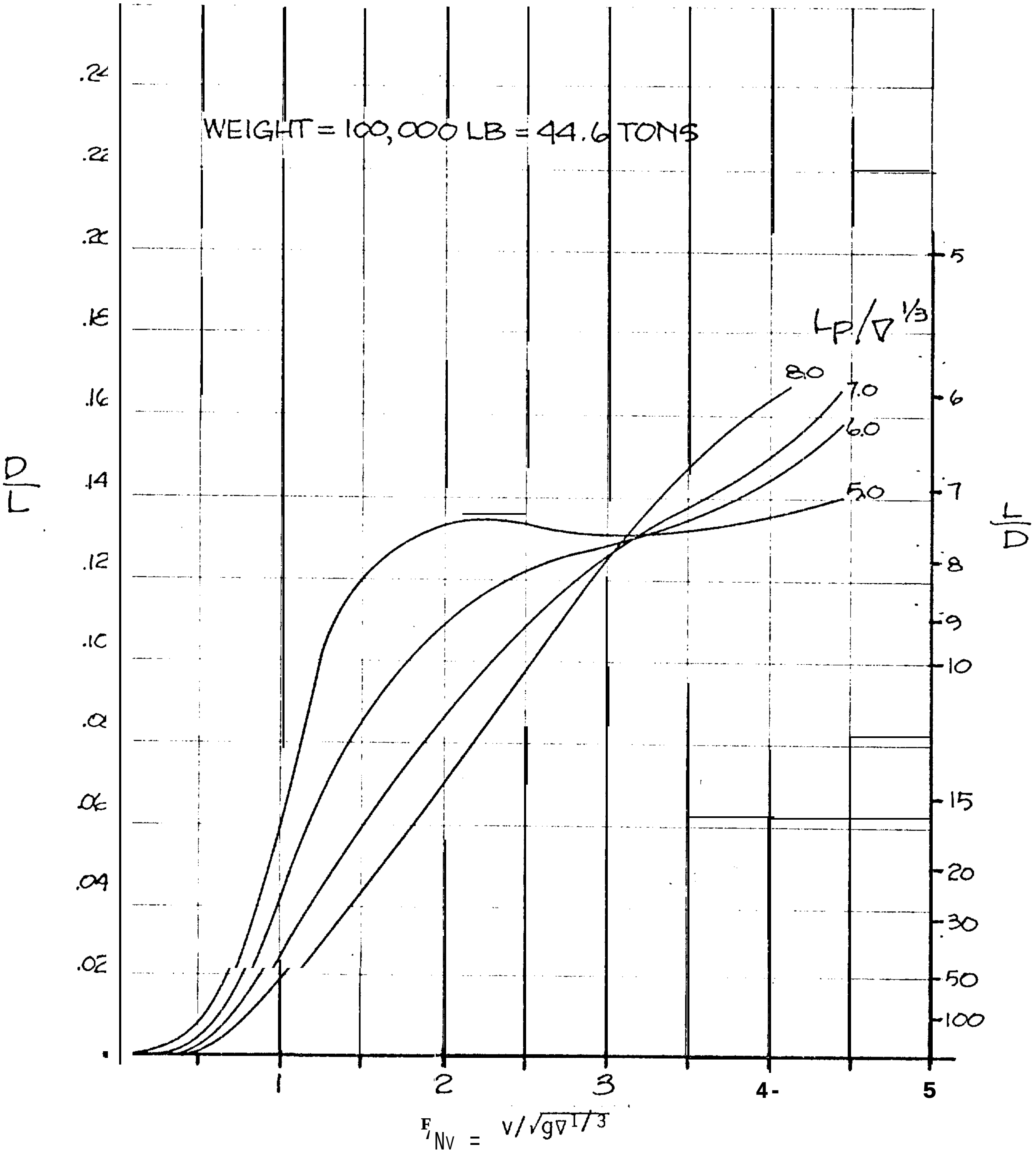

Figure 3 - Drag/Lift Contours for Efficient Planing Hulls as a Function of Volume Froude Number and Slenderness Ratio (U)

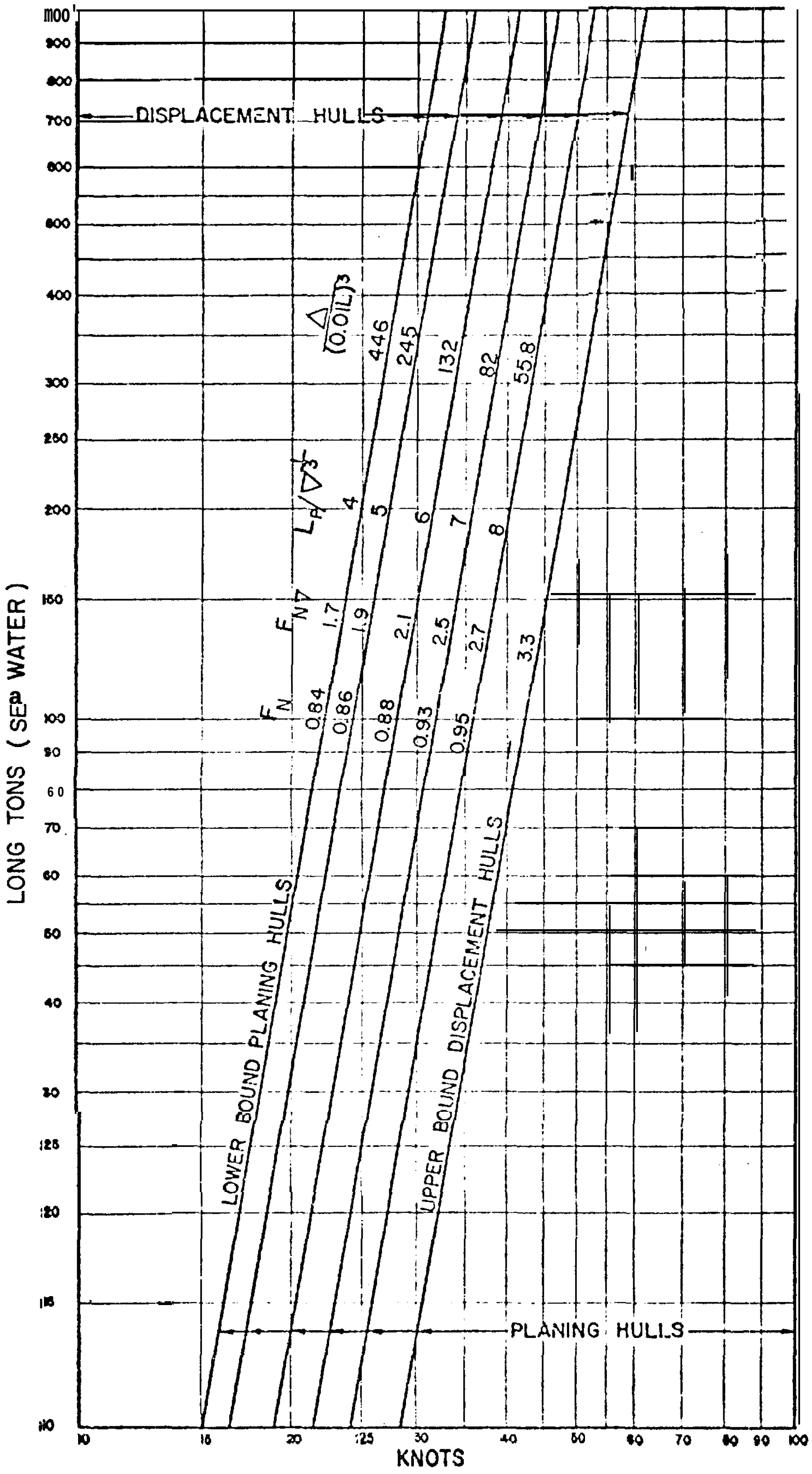

Figure 4 - Ranges of Application: Displacement - Planing (U)

ship, but also at the sides. Effective flow separation is necessary to prevent the formation of negative pressure areas on the bottom of the hull. This is usually accomplished with a hard chine configuration, one type of which (Series 62 [2]) is shown in Figure 2, p.7. Greater deadrise and/or more rounded transverse sections can be used if effective flow separation is achieved by proper placement of spray rails. The longitudinal shape (buttock lines) must have no convexity at least in the after part of the hull. When this type of hull is driven beyond the displacement speed range it trims down by the stern like the other types, but because it is a "lifting surface" it develops positive hydrodynamic pressures which provide a part of the support for the hull. As the hydrodynamic lift increases with increasing speed the amount of hydrostatic (buoyant) lift decreases. Figure 5 shows hydrostatic and hydrodynamic lift components versus Froude Numbers for a typical planing hull. At full planing speeds ($F_N>0.9$) the wavemaking resistance, which effectively becomes a speed barrier for a displacement ship, actually decreases as planing speed increases. This is because it is proportional to the trim angle which, at planing speeds, decreases with increasing speed.

8. (U) Although primarily adapted to high speed operation, useful planing hulls with few exceptions, must be able to operate successfully in the high speed displacement (semi-planing) and low speed (true displacement) regimes, and importantly in rough water as well. The hull form which best meets these requirements has a relatively high length-beam ratio (greater than 5) to reduce impact accelerations at high speed and to reduce trim and therefore resistance in the transition speed range.

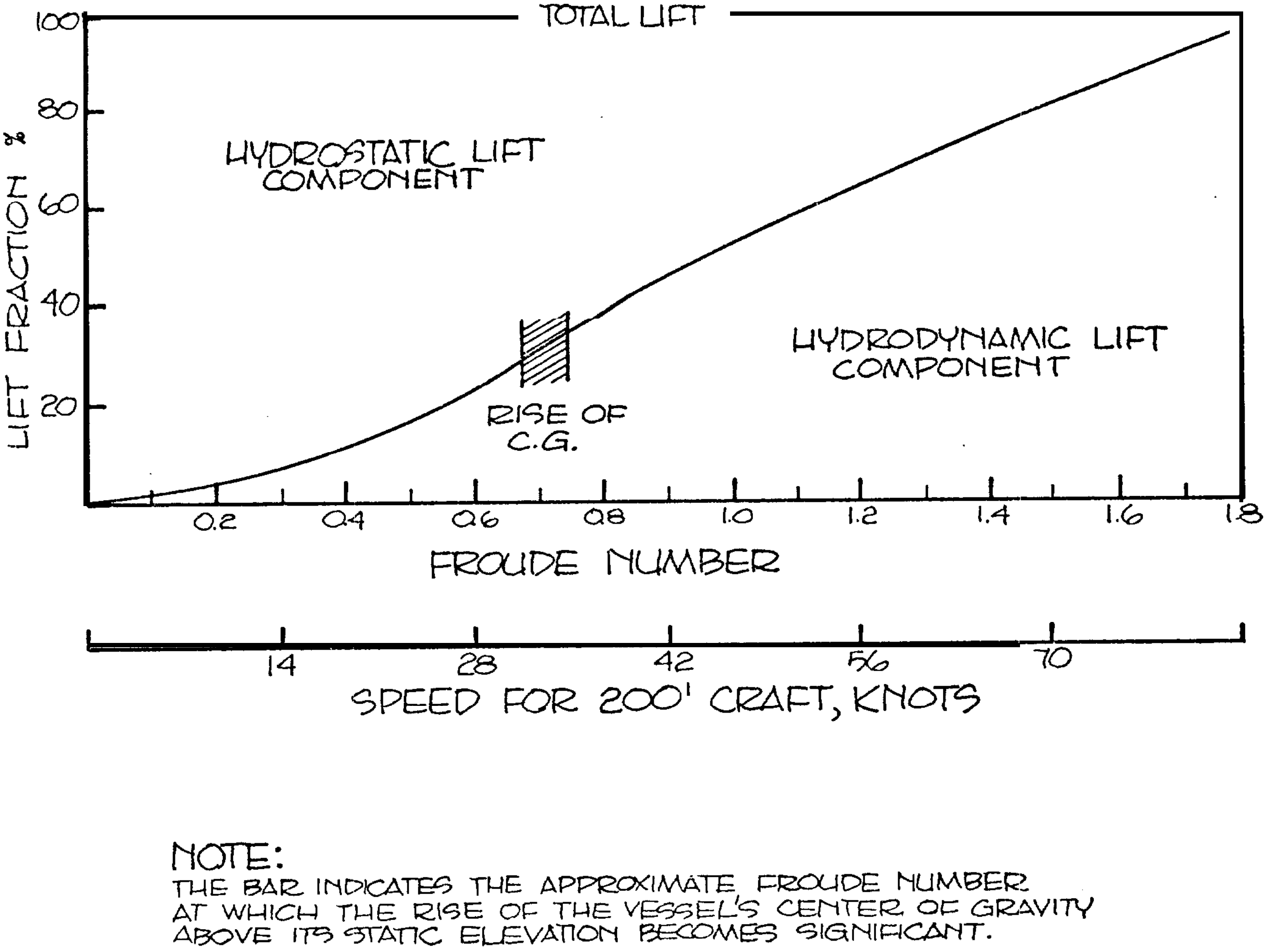

Figure 5 - Hydrostatic and Hydrodynamic Lift Components (U)

The high slenderness ratio associated with these proportions produces low resistence at low speeds. A good planing hull will also have moderate deadrise (about 15") aft increasing to high deadrise (about 45") forward combined with fine lines in the bow. These characteristics further reduce slamming at both high and low speeds, and minimize rough water resistance. The only disadvantage that must be accepted is a small increase in resistance at low displacement speeds and at full planing speeds compared to hulls optimized for either of these speeds. This is an acceptable penalty considering the all around good performance that is achieved, particularly the ability to run with good efficiency throughout the entire speed range.

9. (U)Thetheoretical and analytical considerations just described permit definitive model testing with dependable scaling, with high confidence in both the hull form selection and its full scale performance prediction. The way is then open to intelligent selection of hull material, construction techniques, and choices of scantlings and propulsion components.

10. (U) Hull construction can be of welded steel with light alloy superstructures (particularly for the larger sizes); of all-aluminum welded structures, of glass fiber reinforced plastic (particularly for the smaller sizes); or of wood.

11. (U) The vast majority of conventional planing hulls are powered by diesel engines driving fixed pitch propellers via reversible reduction gears. More recent high performance designs use gas turbine power-plants for high speed operation and separate diesel engines for slow speed/ maneuvering economy. Commercially available subcavitating propellers with high blade area ratio are used in the speed range up to approximately 35 knots (65 km/h). At higher speeds, special so-called "transcavitating" propellers are required. Transcavitating propellers combine features of both conventional and super-cavitating propellers, giving good efficiency over the entire speed range.

B. CAPABILITIES AND LIMITATIONS OF THE CONCEPT (U)

1. (U) The modern planing hull is a relatively inexpensive high speed platform capable of carrying potent military payloads. Development and eventual utilization of large sized planing ships can be achieved at a substantially reduced cost as compared to other types of advanced naval vehicle concepts.

2. (U) Principal Capabilities of a planing hull from the technological viewpoint are listed below. These features are discussed in depth in later sections of this report.

- The basic smooth and rough water hull hydrodynamic technology is sufficiently advanced to enable reliable preliminary performance predictions to be made.
- Model-prototype performance correlation is sufficiently well-documented to establish model-testing as a reliable design and evaluation procedure.
- Planing hulls generically do not have serious navigational draft limitations.
- The hard chine planing hull has more inherent roll damping, particularly underway,than a round-bilge hull, which effectively reduces roll motions in a seaway. Active roll fin stabilizers are easily added to the vessel and further reduce roll motions in the displacement speed range. This allows for comfortable long-term operation at these speeds.
- Planing vessels properly designed for seakeeping can retain a large portion of their calm water operational speed capability in moderate to severe sea conditions. For instance, at a speed of 37 knots (69 km/h), a 100 ft (31m) planing hull was able to perform its mission in waves of

$H_{1/3}$ = 5 ft (1.8m). See Section II.D.I, page 193, for extrapolations of seakeeping performance to larger size planing ships.

- Studies indicate a realistic growth potential for planing ships of up to approximately 1300 tons (1321 tonnes) with a concomitant open-ocean sea state capability of 50+ knots (92.6 km/h) in waves of $H_{1/3}$ = 13 ft (4m).
- Hull construction can follow normal shipyard practice and will not require aircraft-type fabrication techniques.
- Much of the required structural technology is in hand and no unresolvable structural design problems are envisioned.
- The large useful load fraction (40-50%) of a well-designed planing ship provides sufficient fuel for ocean transiting capabilities at low speed without refueling, and at medium speeds with refueling enroute.

3. Principal limitations of a planing hull from the technological viewpoint are listed below. These features are discussed in depth in later sections of this report.

- There is no precise limitation on planing vehicle size; it appears that above ≈ 1500 tons it may be difficult to achieve the very low weights and compactness of installed components and subsystems necessary to maintain the high useful load fraction required to accomodate both high performance and some degree of multi-mission capability in the combat suite with a suitable fuel fraction for independent ocean going operations. After completing the presently authorized 1000-plus ton ANVCE Task IV point design a more precise estimate will be made of a possible limitation on practical size.
- Seakeeping performance of large planing ships in high sea states will never be the equal of comparably sized hydrofoils or SWATH type vehicles.

ACV's and SES's in large sizes have been cited as being capable of providing a comfortable ride in high seas although they may require ride quality control systems to provide it. This question is still unresolved, however, and the efforts planned in the ANVCE Tasks underway are attempting to resolve the practical limits of ride quality for all advanced vehicle types, The limited data available for planing vehicles and the practical experience derived from crews indicate that properly designed planing vehicles may ride well enough to fall just below the threshold of malaise as discussed in Section III.E., p. 228, of this report. Such performance is of course not dependent on having the foils and cushions with their concomitant cost and complexity,

4. (U) Traditionally, planing hulls have been stigmatized as small boats with small payloads and little or no rough water capability. However, it must be recognized that very few, if any, of the prior hulls were optimized towards good seakeeping performance. In fact previous planing hulls were designed almost entirely for high speed in calm water, with low hull deadrise angles, and low beam loadings.* This produces an unacceptable ride quality in even moderate sea states. A good example of this type of hull is the British BRAVE class. Its estimated** behavior in a seaway is shown in Figure 6. Note, however, in Figure 6 that a reduction in acceleration of a factor of 2.0 can be made by designing a planing hull with higher hull deadrise and beam loading. CPIC-X is a good example of this type of hull, and represents the proper trend in modern military planing hull

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* Beam loading is measured by the Load Coefficient, $C = \Delta/wb^3$, i.e., the displacement of the boat in lb divided by the product of the beam cubed and the density of water.

** Estimated, in that for the BRAVE the average of the 1/10th highest acceleration values were derived from histograms; other points in Figure 6 are full scale experimental trial data.

[redacted] [redacted]

design. Planing hull technology has now advanced to the point where "planing ships" can be developed with reasonable risk to perform many missions at high speeds in the open ocean with large useful loads.

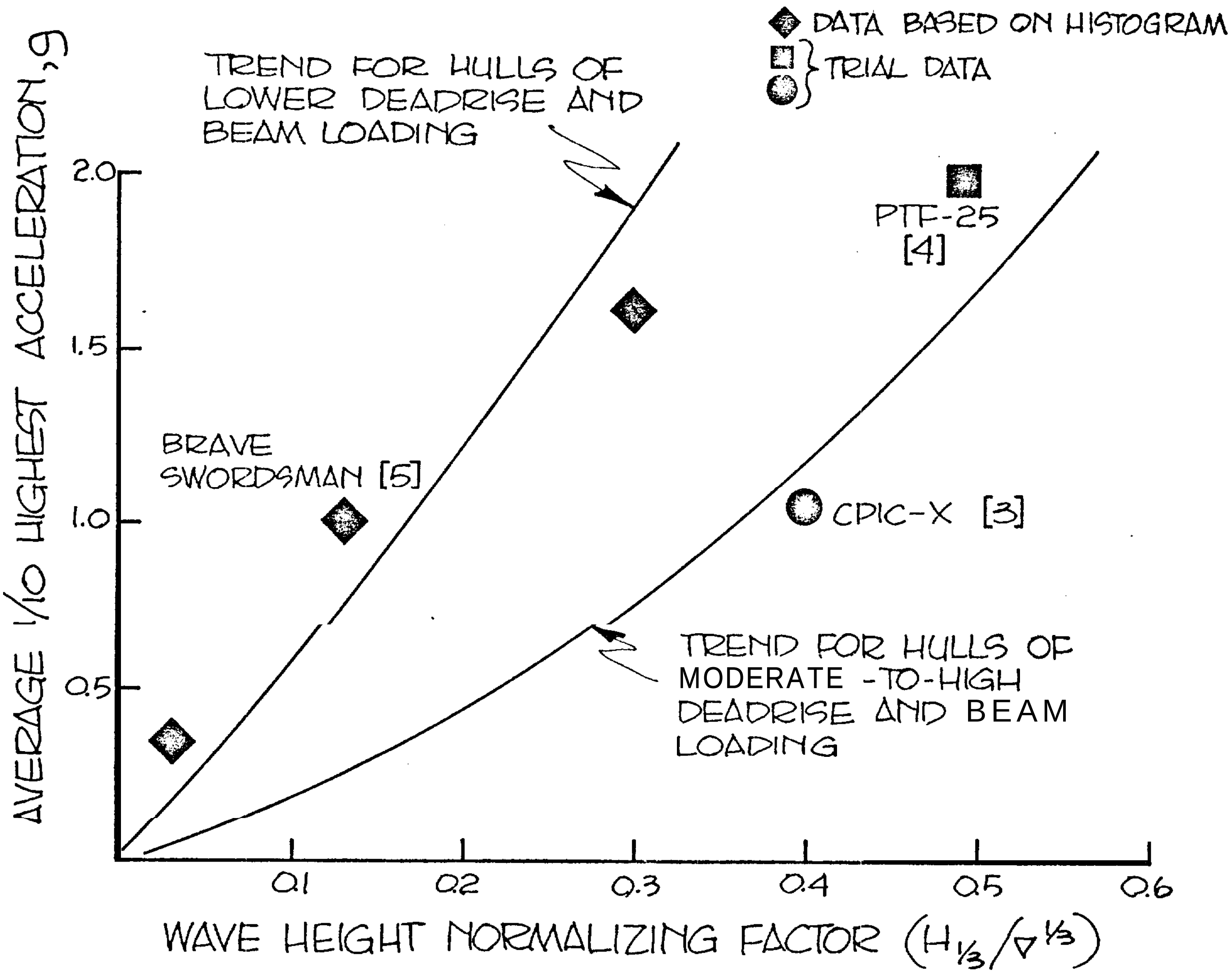

Figure 6 - CG Accelerations for Planing Hulls, $F_{N\nabla}\approx 3$ (U)

[redacted] [redacted]

C. HISTORY OF EFFORT (U)

1. (U) Fundamental research on the hydrodynamics of planing surfaces has been pursued in this country and abroad for over 50 years. The original impetus for this planing research was primarily by the hydrodynamic design requirements of water-based aircraft and, to a somewhat lesser extent, by the development of planing vessels. Planing technology is based principally upon experimental data obtained in model tests. Theoretical studies alone have not been altogether successful, mainly because the basic planing process is a most difficult non-linear, free-surface problem which still requires analytical research. This section will trace the major hull and propulsion developments, and the significant programs associated with planing hulls.

2. (U) Light displacement, high-speed, small combatant ships and ocean-capable patrol craft have been part of the world's navies since World War I. The Second World War brought substantial refinement and continued development which saw hard-chine hull forms evolving to equal status with the round-bilge forms so prevalent earlier. Great Britain, Germany, the United States and Russia, at this time, began to develop the early parentage of the planing hull forms as we know them today.

3. (U) To capitalize on the impressive German WWII E-Boat capabilities, two British prototypes called the BOLD Class were completed in 1948. BOLD (PATHFINDER) was produced in round bilge form, while its sister vessel used a planing hull with hard chines. PATHFINDER was the last British round-bilge planing boat built, all successors being hard-chine designs.

4. (U) A succession of follow-on efforts was undertaken, (see Figure 8 and Table 2) spurred by the outbreak of the Korean War. These included the GAY Class, a design not unlike the World War II Motor Torpedo Boats (MTB's), and the DARK Class, capable of 40 knots (74 km/h)and the first class of boats using the Napier 'Deltic' diesel engine. The early 1960's marked the real opening of the high-performance gas turbine propulsion era with the BRAVE Class which was targeted at a 50-knot (92.6 km/h) speed requirement, with a specific weapons payload identified. The BRAVE Class also used small gas turbines for generating electricity, no diesels being fitted at all.

-5. [redacted] When U. S. PT-Boat (Patrol Torpedo Boat) needs became obvious in the early 1940's, the British Navy's Packard-engined, Thorneycroft-designed MTB's served as parent vehicles from which the 80 ft (24.4m) ELCO and 79 ft (24.1m) Higgins PT-Boats evolved through the war years. The U. S. Navy's post-WW II program was late starting and consisted of developing a new class of PT's. Capitalizing on both foreign and U. S. World War II experience, this program spawned a family of four aluminum hull PT-Boats (hull numbers 809, 810, 811, and 812) which first saw service in the early 1950's. Each boat was different from the others, and all four were considerably larger than their wooden hull predecessors. Table 2 displays their important characteristics. As can be seen, speed capabilities of the three hard-chine vee-bottom boats were nearly identical, ranging from 44.3 knots to 47.7 knots (82 to 88.3km/h) [6]. The round-bilge 812 was slower at 38.2 knots (70.7 km/h) but more stable and easier riding in a seaway [7]. All three hard chine boats exhibited varying degrees of pounding and directional instability at various headings in waves of $H_{1/3}$ = 4.5 ft (1.4m) and higher [6].

SMALL COMBATANT FAMILY TREE

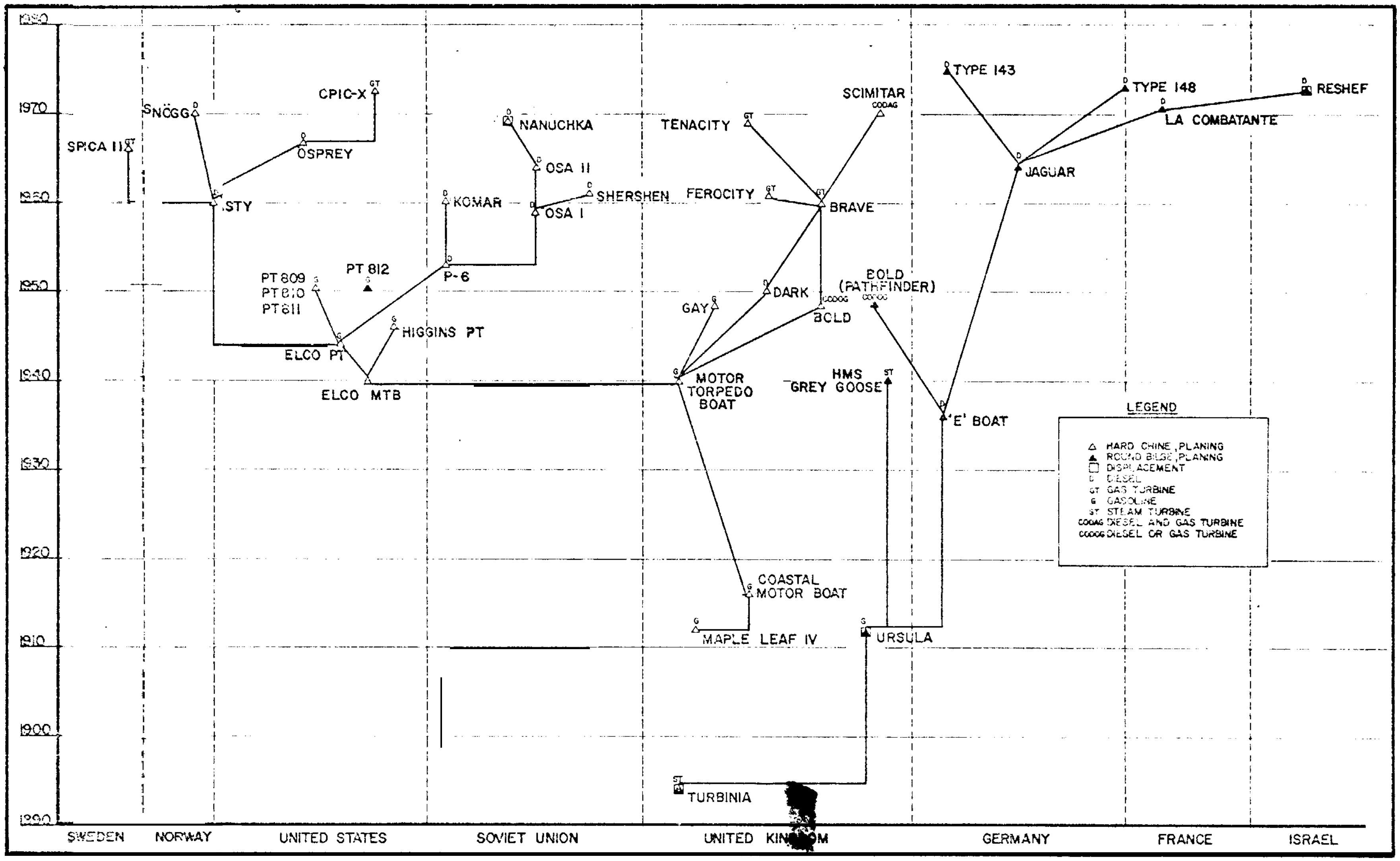

Figure 8 - Small Combatant Family Tree (U)

TABLE 2 - COMPARATIVE PLANING CRAFT CHARACTERISTICS (U)

Name/ Ident.	Country	Length ft (m)	Beam ft (m)	Displacement tons (tonnes)	Main Propulsion			Maximum Speed Knots	Hull Form	Year
					Type	No. of Units	Total Shp			
TURBINIA	U.K.	103 1/2 (31.5)	9 (2.7)	44.2 (44.9)	Steam Turbine	3	2000	35	Circ. Sect.	1894
URSULA	U.K.	49 (14.9)	6 1/2 (2.0)	5.2 (5.3)	Gasoline	1	760	35	Round	1912
MAPLE LEAF IV	U.K.	40 (12.2)	8 1/2 (2.6)	5.2 (5.3)	Gasoline	1	800	55	Convex Vee	1912
COASTAL MOTOR BOAT	U.K.	55 (16.8)	11 (3.4)	14.0 (14.2)	Gasoline	1	1200	46	Vee	1916
MTR TORPEDO BOAT	U.K.	117 (35.7)	21 1/2 (6.6)	92.8 (04.2)	Gasoline	2	4050	31	Round	1936
E BOAT	Germany	114 (34.8)	17 (5.1)	94.8 (96.3)	Diesel	3	7500	41	Round	1936
GREY GOOSE	U.K.	145 1/2 (44.4)	23 1/2 (7.1)	211.6 (214.9)	Steam Turbine	2	8000	35	Round	1940
PT (ELCO)	U.S.	80 1/2 (24.5)	23 (7.0)	52.5 (53.3)	Gasoline	3	4500	50	H C	1945
PT (HIGGINS)	U.S.	79 (24.0)	21 (6.4)	47.8 (48.5)	Gasoline	3	4050	40	H C	1946
"BOLD ("Gay" Proto.)	U.K.	122 (37.2)	20 (6.1)	127 (129)	Gasoline		8500	40	Round	1948

TABLE 2 - COMPARATIVE PLANING CRAFT CHARACTERISTICS (U) (CONTINUED)

Name/ Ident.	Country	Length ft (m)	Beam ft (m)	Displacement tons (tonnes)	Main Propulsion Type	No. of Units	Total Shp	Maximum Speed Knots	Hull Form	Year
"BOLD" ("DARK"Proto)	U.K.	122 (37.2)	20 (6.1)	127 (129)	Gasoline		8500	40	Vee H C	1948
"GAY"	U.K.	73 (22.2)			Gasoline		5000	40		1949
"DARK"		68 (20.7)			Deltic Diesel	2	5000	40	Vee H C	1950
PT 809		99 (30.2)	22 (6.7)	88.8 (90.2)	Gasoline	4	10,000	46.7	Vee H C	1950
PT 810		90 (27.4)		85 (86)	Gasoline	4	10,000	44.3	Vee H C	1950
PT 811		95 (29.0)		81 (82)	Gasoline	4	10,000	47.7	Vee H C	1950
PT 812		105 (32.0)		93.5 (95.0)	Gasoline	4	10,000	38.2	Round,	1950
BRAVE	U.K.	100 (30.4)	25 1/2 (7.8)	108.9 (110.7)	GT	3	12,750	55 1/2	HC	1960
FEROCITY	U.K.	88 (26.8)	23 (7.0)	75.0 (76.2)	GT	2	8500	52 1/2	HC	1961
NASTY	U.S.	80 1/2 (24.5)	24 1/2 (7.5)	85.5 (86.9)	Deltic Diesel	2	6200	44	HC	1962

TABLE 2 - COMPARATIVE PLANING CRAFT CHARACTERISTICS (U) (CONTINUED)

Name/ Ident.	Country	Length ft (m)	Beam ft (m)	Displacement tons (tonnes)	Main Propulsion			Maximum Speed Knots	Hull Form	Year
					Type	No. of Units	Total Shp			
SPICA II	Sweden	141 (43.0)	23 1/2 (7.1)	219.7 (223.3)	GT	3	12,720	40	HC	1966
OSPREY	U.S.	94 1/2 (28.9)	23 (7.1)	109.6 (111.4)	Deltic Diesel	2	6200	35	HC	1967
TENACITY	U.K.	144 1/2 (44.0)	26 1/2 (8.1)	210.2 (213.6)	GT	3	12,750	40	HC	1969
PG 92	U.S.	164 1/2 (50.1)	24 (7.3)	245 (249)	GT Diesel	1 2	12,500 1640	37	Displ.	1969
SNOGG	Norway	120 (36.6)	20 1/2 (6.2)	119.4 (121.3)	Deltic Diesel	3	7200	32	HC	1970
SCIMITAR	U.K.	100 (30.5)	26 1/2 (8.1)	97.4 (99.0)	CODAG	2	-	35	HC	1970
LA COMBATTANT II	France	154 (47.0)	23 1/2 (7.1)	246.5 (250.4)	Diesel	4	14,000	40	Round	1971
TYPE 148	W.Ger.	154 (47.0)	23 (7.0)	253.2 (257.2)	Diesel	4	12,000	38	Round	1972
CPIC-X	U.S.	100 (30.4)	18 1/2 (5.6)	71.9 (73.1)	GT Diesel	3 2	6000 440	43 1/2	OBl.C Vee	1973
RESHEF	Israel	190 1/2 (58.1)	25 (7.6)	396.5 (402.8)	Diesel	4	21,360	32	Round	1973

[redacted]

TABLE 2 - COMPARATIVE PLANING CRAFT CHARACTERISTICS (U) (CONTINUED)

Name/ Ident.	Country	Length ft (m)	Beam ft (m)	Displacement tons (tonnes)	Main Propulsion Type	No. of Units	Total Shp	Maximum Speed Knots	Hull Form	Year
TYPE 143	W.Ger.	200 (61.0)	24 1/2 (7.5)	793.3 (806.0)	Diesel	4	18,000	40	Round	1975
65' PBMK3	U.S.	65 (19.8)	18 (5.5)	36.8 (37.4)	Diesel	3	1950	30	Vee	1976

[redacted]

6. [redacted] No requirements were put forward leading to subsequent PT-Boat developments until the early 1960's when events in Southeast Asia created a need for fast coastal patrol craft. At this point, the U. S. Navy surveyed domestic and other free world patrol craft available for immediate acquisition and procured the Norwegian NASTY design. In addition to outright procurement of several craft from Norway, a U. S. construction program for six additional boats was initiated with John Trumpy and Sons, of Annapolis, Maryland. These craft could achieve a short-duration burst speed of approximately 44 knots (81.5 km/h); seakeeping was said to be slightly better than that of the PT 809-812 family (based largely on subjective operator opinion) but pounding at high speed in 4 l/Z-foot (1.4m) waves was severe. In an attempt to quickly acquire a more seakindly boat, the Sewart Seacraft Co. of Morgan City, LA, was approached to supply four craft of their own design which became the OSPREY Class in naval service.

7. (U) At this point (early to mid 1960's) both the British and U. S. Navies had achieved similar positions with respect to their high-performance patrol-craft configurations with one exception -- the British Navy had dropped the complex Napier Deltic diesel and was embracing the Rolls Royce Proteus gas turbine which had given the BRAVE "benchmark" status in performance for that era.

8. [redacted] During this post-WW II era, a similar evolution was occurring in Germany and in Russia. Their programs had produced the West German JAGUAR Class PTF, and the Russian OSA Class PTF(G) and NANUCHKA Class PGGP. The 139 ft JAGUAR, with a 23-foot beam and displacing 190 tons, is round-bilge forward but becomes hard chine in approximately the after one-third of the hull. Diesel propelled, this class achieved about 41 knots. A

[redacted]

number of other countries have purchased this boat. The OSA Class PTF (G) is a 127 ft hard chine, 240-ton boat with a 22-foot beam, 3-5 knots slower than the JAGUAR Class. This craft is quite widespread in Iron Curtain countries, armed in most cases with the STYX surface-to-surface missile (see para. 13 below). The NANUCHKA Class PGGP, at nearly 1000 tons with LOA of 198 ft and a 40 ft beam, is thought to be unique among the modern large high-performance craft in having a hard chine hull configuration. Top speed is in the vicinity of 33 knots. Both Russian craft are also diesel propelled.

9. (U) A "Small Combatant Family Tree" (Figure 8) provides some insight into the timing and chosen paths of planing hull technology pursued by selected nations as they relate to hard chine and round bilge hull forms, and to machinery selections. Principal characteristics of the craft discussed above, plus other small combatants, are displayed in Table 2.

10. (U) The completion of the U. S. Navy's experimental PT-Boat development effort in the early 1950's was followed by extensive laboratory research and experimentation. During this effort various modeling techniques were developed which involve several comprehensive hull series programs in which prismatic surfaces were optimized for smooth water, with little emphasis on seakeeping. In July, 1966, the Director of Defense Research and Engineering (DDR&E) directed the development of improved naval craft for use in the riverine environment (Southeast Asia). At this point the Navy rapidly initiated a series of engineering development programs, beginning with 38-05, then 38-08, and finally 38-16, which were geared to

[redacted]

the procurement of Armored Troop Carrier/Command Control Boat (ATC/CCB) and Assault Support Patrol Boat (ASPB) Mark 2 prototypes and a prototype of the unique Riverine Utility Craft. These prototypes were delivered in the March, 1968 to June,1969 period. They were thoroughly tested but never entered production. The need to continue the refinement of these engineering development prototypes diminished as the operational tempo began to slack off. The reason for this reduction in effort was the turnover to South Vietnam's Navy of hundreds of previously procured LCM-6 conversions and other hurriedly acquired Navy designs and commercial craft adaptations. Since these prototypes were lacking in much desired performance, and since changes in operational concepts had evolved which were impacting desired design characteristics, a follow-on Research,Development Test and Evaluation effort was initiated in lieu of any quantity production program for these new craft.

11. (U) In July 1970 a new advanced development program for Special Warfare Craft (38-20X) (now the Naval Inshore Warfare Craft Program [SSW-02]) was begun. It was intended to develop experimental prototypes of four generic craft types: the Coastal Patrol and Interdiction Craft (CPIC), the Coastal Patrol Craft (CPC), the Shallow Water Attack Medium (SWAM) Craft, and the Shallow Water Attack Light (SWAL) Craft. This advanced development program was the only planing hull research and development program sponsored by the Department of Defense, aimed at improving seakeeping while retaining as much speed as possible, and at improving the lift-drag ratio of the simple planing hull through (especially) the mid-speed region of the speed envelope. No other program existed to evaluate

and groom promising hybrid innovations for adaptation to the basic hull. Furthermore, this advanced development program was begun as a total weapons system effort from the outset, demonstrating that extensive development of both vehicle and weapons suites can be done rapidly and economically to satisfy the customer's requirement. Although the Experimental Coastal Patrol and Interdiction Craft (CPIC-X) was completed, the experimental CPC, SWAM and SWAL craft were never completely developed due to lack of funds. Congressional action has apparently terminated funding for the program at the end of Fiscal Year 1976.

12. (U) CPIC-X was designed, built and extensively tested as an advanced experimental prototype. It eventually was designated a pre-production prototype, to satisfy a need to assist in rebuilding the Republic of Korea (ROK) Navy. Currently, negotiations are underway between the U.S. and ROK Governments regarding the production of additional CPIC's for ROK Naval service. These negotiations, if successful, will mark the first time a U. S. Naval RDT&E combatant craft program has produced production vehicles.

13. (U) The concept of a relatively small, fast, inexpensive carrier of a potent weapon at sea is not new, but the operational proof of a new capability in this area caused its importance to jump several orders of magnitude on 21 October 1967. The event was the sinking of the Israeli EILAT by STYX missiles launched from an Egyptian KOMAR Class patrol boat at a range of about 12 NM (22 km). This was verified and reinforced by the success of the Indian OSA/STYX night attack in December 1971 and by the October 1973 Arab-Israeli war engagements involving Israeli Gabriel-equipped SAAR Class boats, in which five Syrian missile boats were put out of commission. The concept has become most attractive to many of the

[redacted] [redacted]

smaller and newly-independent nations who are acquiring fast, heavily armed small combatants from Great Britain, France, Germany, the Scandinavian countries, the United States, and Russia.

14. (U) Furthermore, modern technology is now available to incorporate seakeeping and endurance with the speed, maneuverability, low profile, and low relative cost, which are characteristic of these modern, very powerful vehicles. *In this era of confrontation at less than all-out war levels, a modest force of these relatively small combatants can effectively deny full freedom of the seas to the largest of navies in various maritime regions of the world.*

[redacted]

[redacted] [redacted]

D. PRESENT STATUS OF DEVELOPMENT (U)

1. (C) Within the last three years, the U. S. Navy has constructed and evaluated the prototype Experimental Coastal Patrol and Interdiction Craft (CPIC-X), an advanced 100 ft (31m) planing hull, capable of speeds in excess of 37 knots (68.5 km/h) in a seaway with significant wave heights ($H_{1/3}$) of 5 ft (1.5m). The hull characteristics were selected using technology generated in United States research programs over the past 10-15 years while the details of the hull form were based on design experience reported by Koelbel [8]. With an average acceleration at the center of gravity of 0.4g at design speed and sea conditions*, it was found to have excellent seakeeping ability and speed, a very low structural weight fraction, an excellent useful and military payload fraction, and excellent reliability. CPIC-X is of all-welded aluminum construction; it is powered by gas turbines for high speed operation, and by inboard-outdrive diesels for low speed cruise.

2. [redacted] The U. S. Navy is purchasing a number of in-house designed 65 ft MK3 (19.8m) hard chine planing patrol craft with a design speed of approximately 30 knots. Operational experience with the prototype in smooth water and in waves has confirmed the performance as predicted by model tests and analytical procedures. No new technology was introduced in connection with this design.

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* The measured vertical accelerations at the center of gravity were 0.4g, average; 0.8g, significant or 1/3 highest; and 1.1g, 1/10 highest. The 1/3 octave band RMS accelerations are shown in Figure 57, p. 163.

3. [redacted] An experimental planing version of an advanced Landing Vehicle Assault, LVA, is currently being developed for the U. S. Marine Corps, This nominal 28 ft (8.53m) prototype craft has a bottom loading nearly 100% greater than conventional planing hulls, and is expected to develop very high resistance at hump speed. The hump problem will be overcome by using adjustable trim flaps and retractable chine flaps. Model tests in head seas have shown acceptable seakeeping when running at 30 knots (55.6 km/h) in significant wave heights up to 2.2 ft (0.67m).

4. (U) Although the Naval Inshore Warfare Craft Program was never completed because of a lack of funding, a number of studies [9, 10, 11, 12] were carried out principally in connection with the development of the . Shallow Water Attack Medium Craft (SWAM). These reflect much innovative thinking which, if brought to completion, would have made a significant advance in the state-of-the-art of small combatant design.

5. [redacted] An interesting study currently underway is examining the feasibility of developing a large open-ocean planing ship. Using the 100 ft (31m) CPIC-X as a model, its measured smooth and rough water performance data have been extrapolated using a scaling factor of 2 to a planing ship which is 200 ft (61m) long, has a gross weight of 576 tons (585 tonnes) and a design speed of 61 knots (113 km/h) in smooth water. Section II. D.,3 on p. 193 describes this extrapolation. The analysis to date shows that the ship would be feasible, and could be developed quickly with available advanced hydrodynamic and structural design techniques and gear box technology. It would use available auxiliary machinery components, engines, propulsors, and construction techniques. This planing ship

would be expected to demonstrate an operational capability in [redacted]ificant wave heights ($H_{1/3}$) = 10 ft (3m), and have a useful load fraction approaching 50% of gross displacement.

6. (U) Projecting Navy experience with the CPIC-X to larger-sized planing ships, such as the 576-tonner mentioned above, does highlight these risk areas (also discussed in Section I. F, beginning on p. 51):

- lack of full-scale verification of design data for propellers at speeds greater than 45 knots (83 km/h), i.e., cavitation numbers less than about 0.4.
- as an alternative to high-speed propellers, further work is needed to determine the hydrodynamics of pump inlets for hydrojet propulsion systems and semisubmerged propellers for high-speed operation;
- the need for additional model and full-scale experimentation on the maneuvering and turning of rudder-controlled planing hulls so that reliable predictions can be made;
- the need for studies and experimentation relating to practical means for control of roll motions in a seaway and, to a lesser extent, the control of pitch and heave motions;
- a requirement for extending rational predictive techniques for bottom pressures on planing hulls to speeds and sea states where present techniques are unproven;
- a continuing research program to better understand and more accurately predict the motions, accelerations and added resistance of these high-speed planing hulls in waves, and the effect of the resultant ride quality on the crew;

- a need to investigate vehicle density requirements (vis-a-vis payload) to determine its relationship to beam loading as it may affect design proportions.

7. (U) At the present time, there is almost no research and development effort being expended in the U. S. Navy on the development of basic planing hull technology; furthermore, there are no funds allocated to the development of new advanced planing craft since Congressional action appears to have terminated the Naval Inshore Warfare Craft Program (SSW-02). The advances in planing hull technology have usually been derived as spin-offs from other advanced vehicle programs, oh were the result of specific studies undertaken in connection with an advanced oh engineering development of a particular planing craft. Thus, technological advances have resulted primarily from overcoming the problems of a particular concept and have not been broadly applicable. This is particularly unfortunate, and is not conducive to the development of the potential performance capabilities of the planing hull concept in either small craft or ship sizes.

E. DESCRIPTION OF EXISTING HARDWARE (U)

1. (U) In-service high performance hulls which represent today's U. S. Naval capability to patrol open waters in low to moderate sea states at 30 knots or more are:

- 100 ft (30.5m) CPIC-X - Experimental Coastal Patrol and Interdiction Craft
- 165 ft (50.3m) PG (92 Class) - Patrol Gunboat
- 95 ft (29m) PTF (OSPREY Class) - Patrol Craft (Fast)
- 80 ft (24.4m) PTF (NASTY Class) - Patrol Craft (Fast)
- 65 ft (19.8m) PB MK 3 - Patrol Boat

2. (U) Detailed plans and specifications for U. S. Navy planing craft are maintained at the Naval Ship Engineering Center, Norfolk Division (NAVSECNORDIV), Combatant Craft Engineering Department. A catalog of in-service boat and craft characteristics is currently available as a Naval Sea Systems Command (NAVSEA) confidential publication. [13].

3. (U) The NASTY Class PTF is now considered obsolete; and a program to re-engine the OSPREY Class PTF's with gas turbines (due to reliability, maintainability and availability (RMA) problems with the Napier Deltic diesels) is under consideration at NAVSEA. Upgrading the limited operational capabilities of the "92-Class" PG's would require major redesign and conversion to accomodate modern and reliable equipments; this class has therefore become candidate for lay-up.

4. (U) Data sheets and other information for these five craft are provided on the following pages.

100 ft (30.5m) CPIC-X - Experimental Coastal Patrol and Interdiction Craft [13] (U)

(U) CPIC-X is a high-speed, offensive weapons platform designed to locate, pursue, and destroy enemy surface craft under adverse sea conditions, day or night. The aluminum-hull craft derives its high speed from three gas turbine engines, each driving its own fixed-pitch propeller through an independent primary reduction gear box and a secondary V-drive reduction gear box. An auxiliary diesel propulsion system driving two outdrives provides a very economical cruising capability as well as a means to maneuver in confined areas. Habitability for the crew is enhanced by air conditioning and a hull design exhibiting extremely low slamming accelerations at speed in rough seas.

(U) Gyro-controlled fin stabilizers provide a stable weapons platform yielding a decided military advantage over enemy craft that CPIC-X may encounter*. The craft can be fitted with a variety of weapons ranging from basic pintle-mounted 7.62 mm machine guns to two fully automatic, twin, 30 mm gun mounts with large capacity, automatic feed, self-contained magazines. These mounts are controlled by stabilized optical sights (with day/night modes) and/or by a radar gun fire control system with a digital fire control computer. There is a limited AA capability. A 50 million candlepower searchlight can be provided and slaved to the forward remote optical sight. The craft was conceived with a view toward expansion to future multi-mission capabilities by the addition of modular systems, such as a surface-to-surface missile system. The craft, as designed, was required to fight and maneuver in 7 ft significant waves and survive in up to $H_{1/3}$ = 12 ft significant waves.

(U) The characteristics of CPIC-X are given in Table 3.

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* The stabilizers were deleted from the production boats because of hydraulic system design shortcomings.

[redacted]

EXISTING HARDWARE

TABLE 3 - CPIC-X CHARACTERISTICS [13] (U)

(U) CRAFT IDENTIFICATION DATA

NAVSH IPS Drawing No.	95-CPIC-845-4469408,9
Procurement Status	Operational FY75

PRINCIPAL CHARACTERISTICS

Length Overall	99'-10 1/2" (30.4 m)
Max Beam - Including Guard Rails	18'-6 3/8" (5.6 m)
Max Height - Exclusive of Masts, Antenna, Etc.	28'-0" (8.5 m)
Draft, Navigational	6' 6 1/2" (2.0m)
Full Load Displacement, Nominal	71.9 tn (73.1 t)
Light Load Displacement	49.6 tn (50.4 t)
Hoisting Weight - Light Load + Cradle	57.5 tn (58.4 t)
Hoisted by	Cradle
Total Fuel Capacity (incl. bow tank)	6300 gal (25740 liter) (95% full)
Total Potable Water Capacity	185 gal (700 liter)
Construction	Double Chine, Longitudinally Framed, Welded Aluminum, Vee-Bottom
Crew: Officers	1
Enlisted	10

(U) MACHINERY CHARACTERISTICS

Main Engines: High Speed

Three-if-CO-Lycoming,+| 5A marine gas turbines with integral Sier-Bath 2.34:1 reduction gears driving Precision V-Glide, V-drive gear boxes, model V81750, with 3.06:1 gear reduction; overall reduction: 7.16:1.

AVCO Lycoming rating: 2000 bhp @ 85°F. intake air, sea level.

U.S. Navy rating: 1800 cont. bhp @ 100°F. intake air, sea level.

Actual test output at this rating: 1707.2 shp (propeller hp), 14,700 rpm sfc = 0.7345 lb/hp-hr; fuel rate without gear losses: 0.6967 lb/hp-hr.

Secondary Engines: Low Speed

Two Volvo-Penta 6 cyl. Diesel engines model TAMD-70-B with Twin Disc hydraulic transmission (1:1 ratio) driving twin Volvo-Penta model 750 outdrives with 1.89:1 reduction ratio.

Each engine rated at 220 bhp (209 shp) @ 2200 rpm. (Engines derated to 185 cont. shp for CPIC-X only, due to propellers used).

Fuel rate: 0.40 lb/hp-hr.

Diesel Auxiliary Generators

Two General Motors 30 kw, 450v, 60 Hz A.C. three-phase units.

Propellers: High Speed

3-LH, 3 blade, 30" (76.2 cm) diameter x 36" (91.4 cm} pitch, Ni-Al-Br.

Propellers: Low Speed

2-LH, 3 blade, 23-1/2"(59.7cm) diameter x 23" (58.4cm) pitch, aluminum

[redacted]

TABLE 3 (Continued)

[redacted] **PERFORMANCE CHARACTERISTICS**

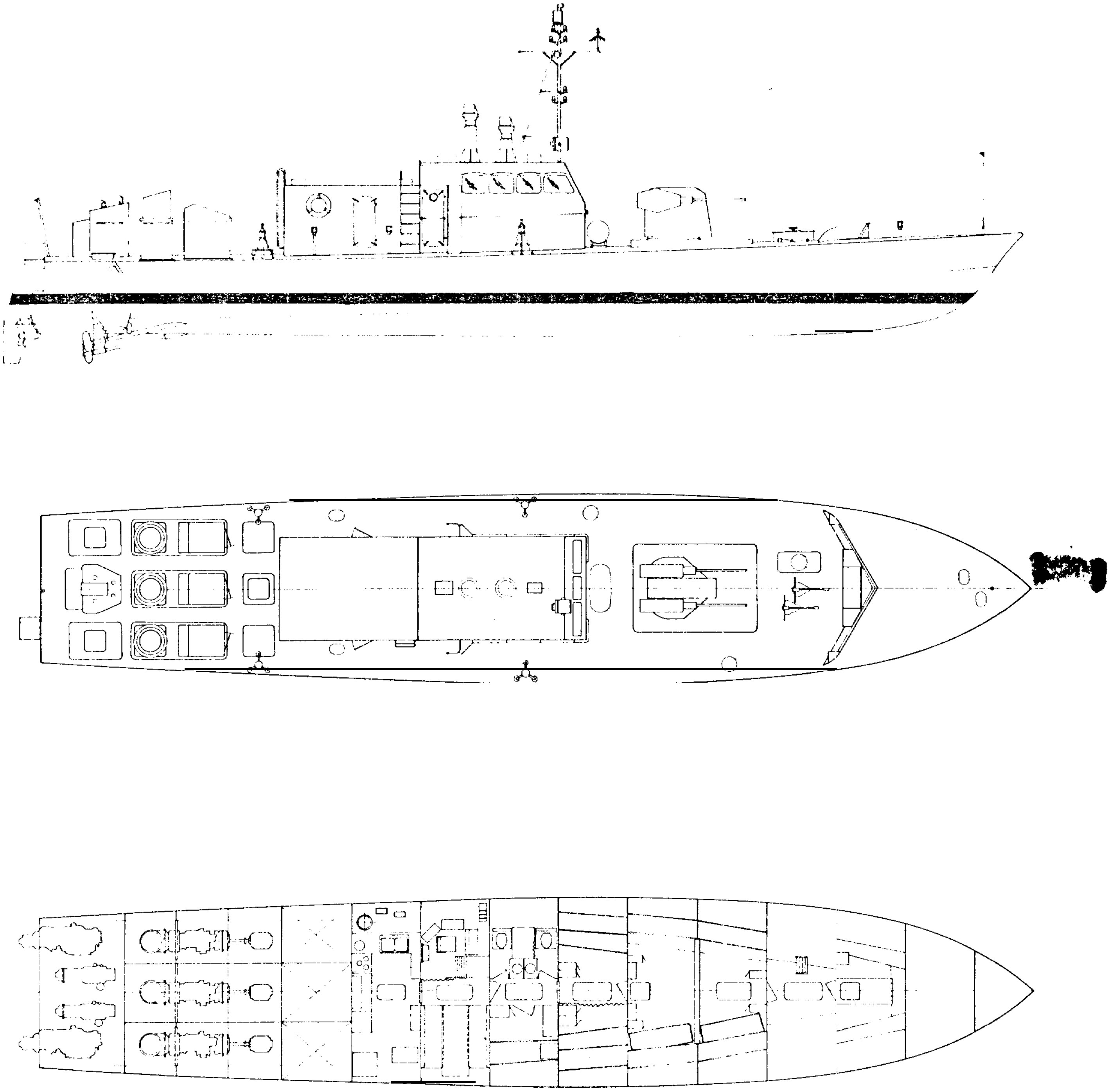
				References
Maximum Speed, Turbines	43.5	knots	(81 km/h)	[14]
Range at Maximum Speed	357	NM	(661 km)	[14]
Maximum Range, Turbines (3 main fuel tanks)	415	NM	(769 km)	[15]
Maximum Range, Turbines (all fuel tanks)	540	NM	(1000 km)	[15]
Speed for Maximum Range	36	knots	(67 km/h)	
Maximum Speed, Diesels	9	knots	(17 km/h)	[14]
Range at Maximum Speed (3 main fuel tanks)	1600	NM	(2963 km)	[14]
Maximum Range, Diesels (3 main fuel tanks)	7600	NM	(14075 km)	[14]
Maximum Range, Diesels (all fuel tanks; calculated from data in [11a])	10,400	NM	(19,261 km)	
Speed for Maximum Range	5.5	knots	(10 km/h)	[14]

[redacted] ARMAMENT

1 Twin 30 mm gun mount

2 Twin 7.62 mm M60 machine guns

2-40 mm grenade launches



[redacted]

Figure 9

PROFILE AND ARRANGEMENT (U)

100' CPIC-X

OPTIONAL AFTER MOUNT NOT SHOWN

165 ft PG (92 Class) - Patrol Gunboat [13]

(U) The versatility of the propulsion and fire power systems enable the 165 ft (50.3m) Patrol Gunboat to fulfill a variety of missions. These missions include interdiction of waterborne supply, support of amphibious operations, counter-insurgency, search, rescue, surveillance, blockade, and routine patrol. Continous cruising is accomplished by using twin Cummins Diesel engines driving controllable pitch propellers. A single General Electric gas turbine supplies power for tactical combat speeds, and the CODAG arrangement permits rapidly accelerating the ship to its maximum speed without deceleration while shifting modes. The aluminum hull and fiberglass superstructure design emphasize cruising, endurance and seaworthiness.

[redacted]

(U) CRAFT IDENTIFICATION DATA

NAVSHIPS Drawing No.	PG92-845-2533759
Latest Procurement	FY67

[redacted]RINCIPAL CHARACTERISTICS

Length Overall	164' 6" (50.15m)
Max Beam - Including Guard Rail	23' 10 3/4" (7.28m)
Max Height - Exclusive of Masts, Antenna, Etc	44' 0" (13.41m) [redacted]
[redacted]raft, Navigational	8' 10" (2.69m)
Full Load Displacement	245 tn (249 t)
Light Load Displacement	180 tn (183 t)
Total Potable Water Capacity	800 gal (3028 liter)
Construction	Aluminum Hull with Fiberglass Superstructure
Crew: Officers	4
CPO	4
Enlisted	21

(U) MACHINERY CHARACTERISTICS

Cruising Engines:
Two Cummins V12-875M diesel engines with direct drive.
Each engine develops 820 bhp @ 2300 rpm (725 shp @ 2100 rpm)

Combat Engine:
One General Electric LM-1500-PE102 gas turbine with 6:1 reduction gear.
Engine develops 12500 bhp @ 4200 rpm at primary reduction output

Diesel Auxilary Generator:
One GE/Cummins 100 kw, 450v, 60Hz, three phase unit

Propellers:
1-RH, 1-LH, 3 blade, 60" (152.4 cm) diameter x variable pitch,, stainless steel

[redacted] PERFORMANCE CHARACTERISTICS

Speed (Turbine)	37 knots	(68 km/h)
Range (Turbine) @ 35 knots (65 km/h)	325 NM	(600 km)
Speed (Diesel)	16 knots	(30 km/h)
Range (Diesel) @ 16 knots (30 km/h)	1700 NM	(3150 km)
Total Fuel Capacity	11900 gal	(45045 liter)

Note: Above data is based on full load displacement and is taken from test reports on tests conducted by DTNSRDC. Refer to DTNSRDC test report C-3539.

[redacted] ARMAMENT

1-3" 50 cal. rapid fire, single mount

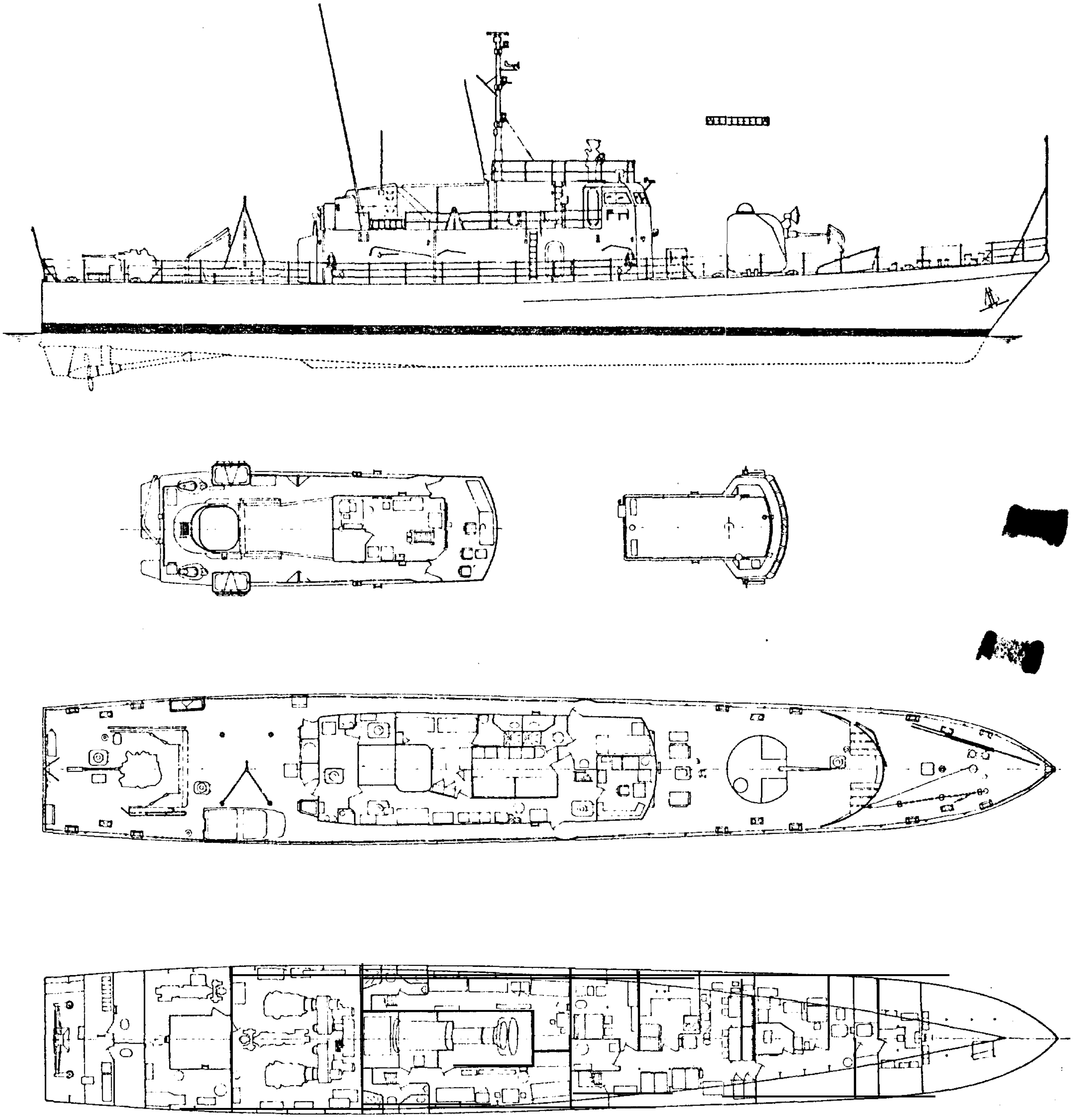
1-40 mm AA battery

2 twin mount .50 cal. machine guns

(Has been modified to handle standard missiles)

[redacted]

[redacted]



[redacted]

[redacted]

Figure 10

PROFILE AND ARRANGEMENT (U)
165' PG (92 CLASS)

[redacted]

[redacted]

[redacted]

95 ft PTF (OSPREY Class) - Patrol Boat (Fast) [13]

(U) The 95 ft PTF is an aluminum-hull patrol boat powered by twin Napier-Deltic diesel engines, and is considered very seaworthy and versatile. This craft differs from the NASTY in that the OSPREY is built of a different material, is longer, and has better habitability standards such as air conditioning. The OSPREY is designed to operate offensively as an escort or patrol craft in waters other than the high seas, but can also be configured as a minelayer or submarine chaser.

(U) CRAFT IDENTIFICATION DATA

NAVSHIPS Drawing No.	Sewart Seacraft Design
Latest Procurement	FY67

[redacted] PRINCIPAL CHARACTERISTICS

Length Overall	94' 8" (28.86 m)
Max Beam - Including Guard Rails	23' 2" (7.06 m)
Max Height - Exclusive of Masts, Antenna, etc.	22' 8 1/2" (6.92 m)
[redacted]aft, Navigational	7' 4 1/2" (2.25 m)
Full Load Displacement	109.6 tn (111.4 t)
Light Load Displacement	71.4 tn (72.5 t)
Hoisting Weight	78.1 tn (79.4 t)
Hoisted By	Slings
Total Potable Water Capacity	200 gal (757 liter)
Total Fuel Capacity	9450 gal (35771 liter)
Construction	Aluminum
Crew: Officers	1
Enlisted	18

(U) MACHINERY CHARACTERISTCS

Main Engines:

Two Napier-Deltic diesel engines 1.8:1 reduction gear, Mitchell thrust block.
Port and starboard engines: Type T18-37K
Each engine develops 3100 bhp @ 2100 rpm (2400 shp @ 1800 rpm)

[redacted]

Diesel Auxilary Generator:
Two 30 kw, 110/220v, 60 H-z A.C., single phase, General Motors unit Model 2150.

Propellers:
1-RH, 1-LH, 3 blade, 50" (127 cm) diameter x 50" (127 cm) pitch, bronze.

[redacted] PERFORMANCE CHARACTERISTICS

Speed	35 knots (65 km/h)
Range @ 30 knots (56 km/h)	1000 NM (1850 km)

Note: Above data is based on full load displacement, and is taken from DTNSRDC report C-3227 of December 1970.

[redacted] ARMAMENT

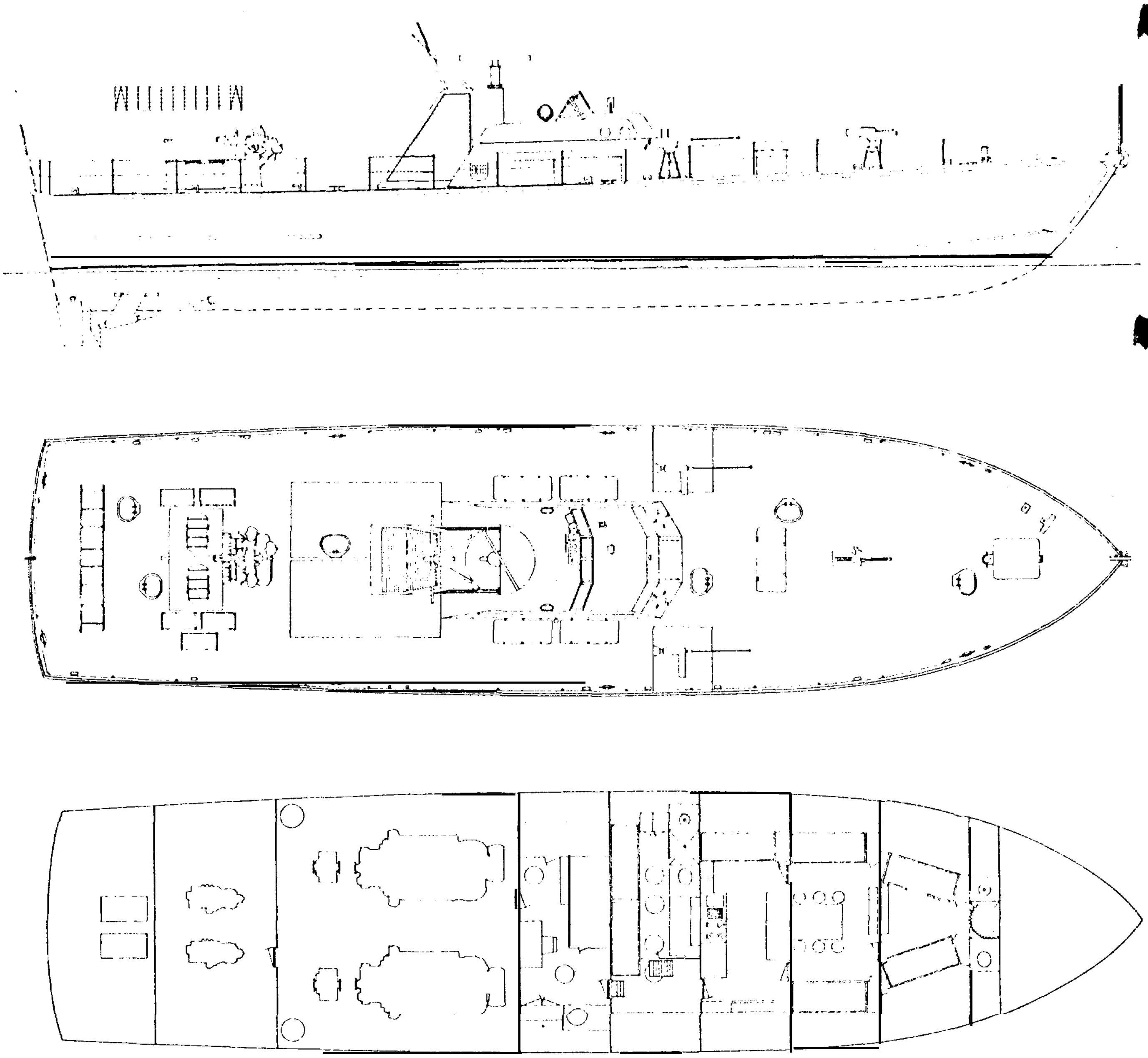
1-40mm AA battery

2-20mm machine guns

1-81mm mortar w/150 cal machine gun adapter

[redacted] [redacted]

[redacted]



[redacted]

Figure 11

PROFILE AND ARRANGEMENT (U)
95' PTF (OSPREY CLASS)

[redacted] [redacted]

80 ft PTF (NASTY Class) - Patrol Boat (Fast) [13]

(U) The 80 ft PTF's are of Norwegian design and were purchased originally from the Norwegian commercial designer and builder by the U.S. Navy. The later craft of this design, however, were built in the U.S. by John Trumpy of Annapolis, Maryland. These craft have a laminated wood hull, fiberglass superstructure, and powered by twin Napier-Deltic diesel engines. The NASTY Class boats are designed to operate offensively as escort or patrol in waters other than the high seas. They may be configured as a motor gunboat, motor torpedo boat, mine layer, submarine chaser, or a combination of these.

(U) CRAFT IDENTIFICATION DATA

NAVSHIPS Drawing No.	Norwegian Design
Latest Procurement	FY67

(C) PRINCIPAL CHARACTERISTICS

Length Overall	80' 4" (24.48 m)
Max Beam - Including Guard Rails	24' 7" (7.49 m)
Max Height - Exclusive of Masts, Antenna, etc.	24' 0" (7.32 m)
(C)Draft, Navigational	6' 9" (2.06 m)
Full Load Displacement	85.5 tn (86.9 t)
Light Load Displacement	59.6 tn (60.6 t)
Hoisting Weight = Full Load + Cradle	96.2 tn (97.7 t)
Hoisted By	Cradle
Total Fuel Capacity	5800 gal (21955 liter)
Total Potable Water Capacity	120 gal (454 liter)
Construction	Laminated Wood Hull, Fiberglass Superstructure, Vee-bottom
Crew: Officers	2
Enlisted	16

(U) MACHINERY CHARACTERISTICS

Main Engines
Two Napier-Deltic T18-37k diesel engines 1.8:1 reduction gear, V-drive
Each engine develops 3100 bhp @ 2100 rpm (2400 shp @ 1800 rpm)

Diesel Auxiliary Generator:
Two Onan 15-kw, 440v, 60Hz, A.C., single phase

Propeller:
1-RH, 1-LH, 3 blades, 47" (119.4 cm) diameter x 62" (157.5 cm) pitch, bronze

(C) PERFORMANCE CHARACTERISTICS

Speed	44 knots (81 km/h)
Range @ 38 knots (70 km/h)	450 NM (830 km)

Note : Above data is based on a 75tn (76 t) displacement, and is taken from NAVSHIPS publication 320-1048.

(C) ARMAMENT

1 40 mm AA battery

2 20 mm machine guns

1 81 mm mortar with .50 cal adapter

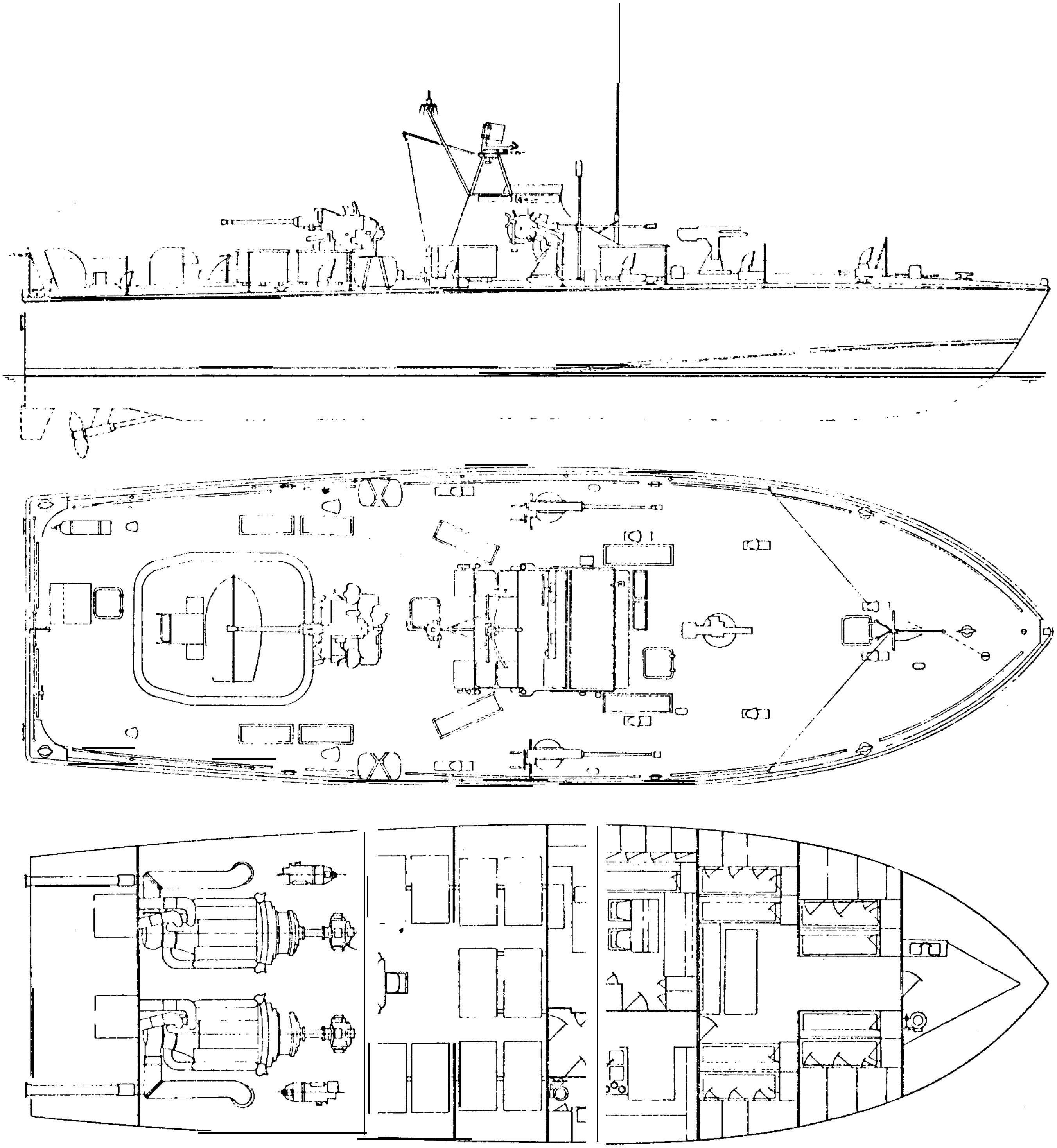


Figure 12
PROFILE AND ARRANGEMENT (U)
80' PTF (NASTY CLASS)

65 ft PB MK3-Patrol Boat [13]

(U) The 65 ft (19.8m) PB is the newest patrol boat in the USN inventory. It was designed as a high-speed weapons platform for the Naval Inshore Warfare forces and is capable of carrying a variety of U.S. or foreign weapons in a number of alternate locations. A modular payload concept is incorporated, allowing the craft to be adapted to a variety of missions in deep rivers, harbors, coastal or open sea environments. Missions envisioned include patrol, surveillance, interdiction, fire support against ashore and afloat targets and insertion/extraction of NIW units. The main deck of the craft is reinforced in vital areas so that future mission capabilities, dependent upon the development and/or availability of the necessary systems hardware, may include antisubmarine sonar or torpedoes, minelaying, mine detection and mine sweeping.

(U) The craft is powered by three high power, lightweight diesels providing speeds significantly higher than any other USN patrol boat of this size. Fuel and accommodations will permit unsupported missions of up to five days or 450 NM (2000 NM at reduced speeds). Multi-frequency communications, high resolution surface search radar and reasonable stability in moderately heavy seas will permit day/night, all-weather operations. The all-aluminum craft was designed with a low silhouette, low radar cross section and extremely low acoustic noise levels to preclude ready detection.

(U) CRAFT IDENTIFICATION DATA

NAVSHIPS Drawing No.	65PBMK3-145-4382143
Latest Procurement	FY77

[redacted] [redacted]

(C) PRINCIPAL CHARACTERISTICS

Length Overall	64' 10 3/4"	(19.78m)
Max Beam - Including Guard Rails	18' 0 3/4"	(5.50m)
Max Height - Exclusive of Masts, Antenna, etc.	18' 6 1/2"	(5.65m)
(C)Draft, Navigational	5' 6"	(1.68m)
Full Load Displacement	36.8 tn	(37.4 t)
Light Load Displacement	28.1 tn	(28.6 t)
Hoisting Weight - Full Load + Bands	37.0. tn	(37.6 t)
Hoisted By	Belly Bands	
Total Fuel Capacity	1800 gal	(6814 liter)
Total Potable Water Capacity	100 gal	(379 liter)
Construction	Longitudinally framed Aluminum Hull, Vee-Bottom	
Crew: Officers	1	
Enlisted	4	

(U) MACHINERY CHARACTERISTCS

Main Engines:
Detroit Diesel model 7082-7399, 8V71TI diesel engines with 2:1 reduction gear
Each engine develops 650 bhp @ 2300 rpm (600 shp @ 2300 rpm)

Diesel Auxilary Generator:
One Onan 15 KW, 120/208v, 60 cycle, A.C., three phase unit

Propellers:
3-RH, 3 Blade, 32" (81.3 cm) diameter, x 35" (88.9 cm) pitch (cupped), bronze

(U) PERFORMANCE CHARACTERISTICS

Speed	30 knots (56.6 km/h)	
Range @ max speed	500 KM	(925 km)

Note: Above data is based on full load displacement, and is taken from NAVSECNORDIV report 6660-C14.

(C) ARMAMENT

4 .50 cal machine gun stands, 2 guns issued

Main weapons platform is capable of supporting 1 tri-tube torpedo launcher, 1-40mm gun, 1-20mm gun, l-81mm mortar, or other similar weapon.
Fore and aft centerline gun foundations are capable of supporting l-40mm gun, 1-20mm gun, 1-81mm mortar, or other similar weapon.

[redacted]

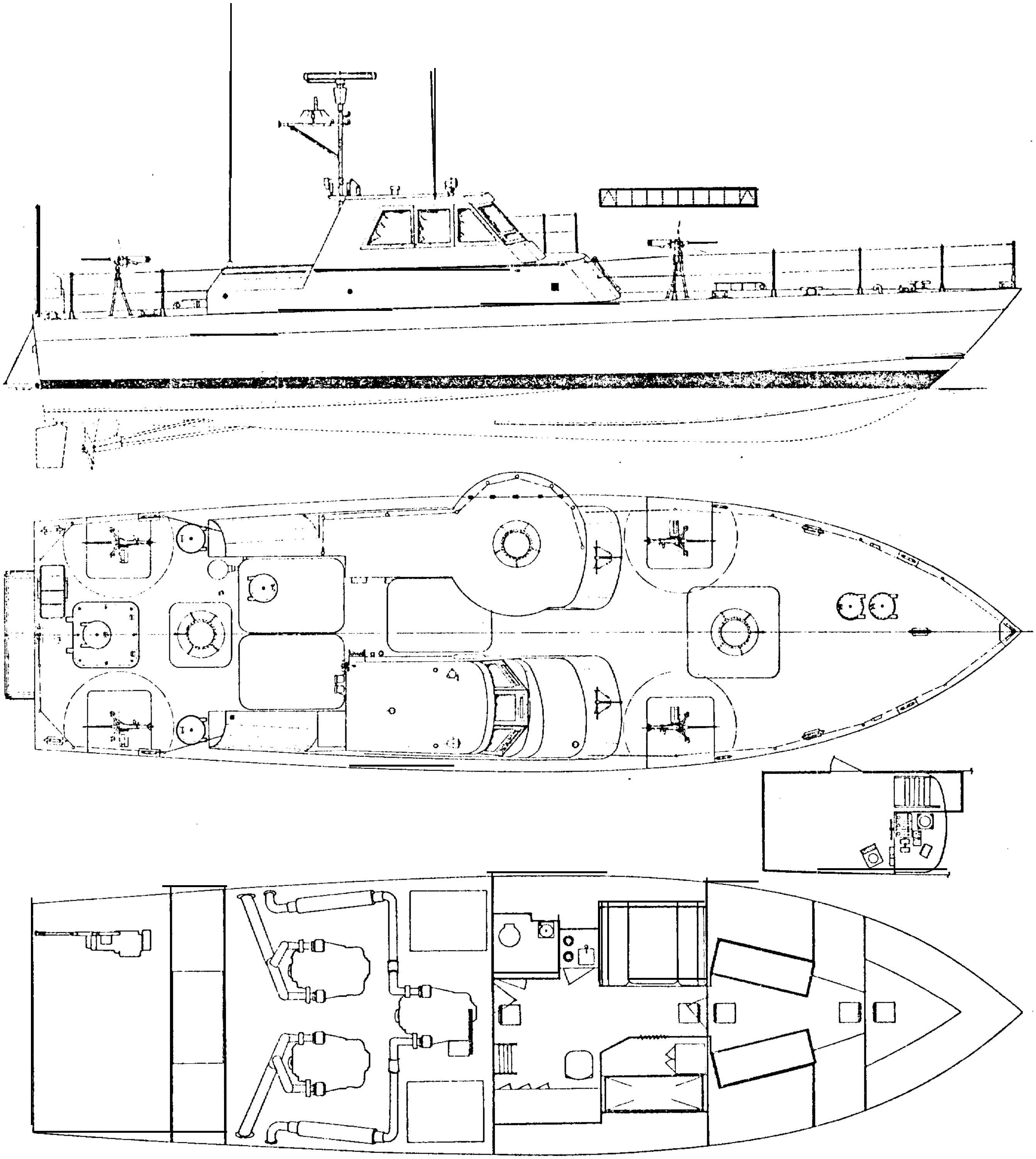


Figure 13

PROFILE AND ARRANGEMENT **(U)**

65' PB MK3

F. SUMMARY OF CURRENT PLANNING FOR FUTURE EFFORT (U)

1. (C) Funds for the Naval Inshore Warfare Craft Program, SSW-02, were terminated beyond FY76 by Congressional action. Alternative planning is underway which may lead to the initiation of a modest Engineering Development Program to design and build two state-of-the-art planing craft; a nominal 36 ft (11m) Special Warfare Craft (Light), SWC(L) and a nominal 85 ft (26m), Special Warfare Craft (Medium) SWC(M).

2. (C) The development of a planing version of an experimental Landing Vehicle Assault (LVA) for the U. S. Marines will continue. Further hydrodynamic studies are required to reduce the drag of the highly loaded LVA hull; to reduce the high speed impact loads and added resistance in a seaway; and to provide an efficient propulsor for the hump and high speed regimes.

3. (C) As mentioned in Section I.D.5, one consequence of the ANVCE study has been a brief effort to examine the feasibility of developing a large Open Ocean Planing Hull. The vessel characteristics for this purpose were derived by doubling the scale of CPIC-X for which there is a substantial amount of well-documented performance and design'data. This extrapolation procedure results in a planing ship having a length overall of 200 ft (61m), a beam of 36 ft (11m), a full load displacement of 576 tn (585 t), and a speed of 58 knots (107km/h) in $H_{1/3}$ = 9.2 ft (2.8m) significant waves. Propulsion power can be supplied by three GE LM 2500 turbines driving trans-cavitating propellers. A more complete discussion of the Open Ocean Planing Hull follows in Section II.A.1, beginning on p. 62. Planing hull ships which displace up to approximately 1000 tn are being recommended for examination in Task IV of the ANVCE Program.

[redacted]

4. Specific areas requiring further research and development, discussed in other appropriate places in this report, e.g. para. I.D.6 on p. 32 include the following:

a. Seakeeping Extended to Higher Speeds and Wave Heights
  - Motions
  - Impact Loads
  - Powering

b. Maneuvering and Control (Basics)
  - Control Surfaces (Size and Shape)
  - Dynamic Loads
  - Appendages

c. Propulsors
  - Transcavitating Props
  - Supercavitating Props
  - Hull/Appendage Propeller Interactions
  - Water-Jet Pumps and Inlets

d. Hydrodynamics
  - Pre-Planing Range
  - Overload Conditions

e. Design Synthesis Procedures
  - Parametric computer model extrapolation
  - Design trade-off inter-relationships

f. Machinery
  - Lighter weight, e.g. in gear boxes, diesel engines
  - Lower fuel consumption, e.g. in gas turbines

[redacted]

- Greater resistance to the marine environment, e.g. turbines to salt spray ingestion, outdrives to sea water, propulsors to debris and vegetation

g. Hardware and Equipment

- Lighter weight; almost all items
- Greater resistance to the marine environment, e.g. electrical components

h. Structures

- Hydroelastic effects in larger vessels
- Fire protection of aluminum
- Materials with greater strength to weight ratio

i. Vulnerability

- IR signature
- Silencing of engines and propulsors
- Armor protection

j. Weapons and Sensors

- Interfacing of weapons and sensors with fire control systems
- Development and qualification of suitable (lightweight) weapons systems for high performance marine vehicles.

SECTION II - STATUS OF VEHICLE TECHNOLOGY (U)

A. TECHNOLOGICAL PERFORMANCE FEATURES (U)

1. (U) Aerodynamics/Hydrodynamics

a. (U) Aerodynamics

The design and performance of planing craft are governed principally by hydrodynamic considerations. Aerodynamic effects are concerned mainly with the air drag of the superstructure and those portions of the hull which are above the water line. Empirically derived drag coefficients are used to estimate the air drag of all above water structures, which is a very small portion of the total drag at speeds below about 30 knots. Even at 60 knots, the aerodynamic drag of a typical planing hull is only about 6% to 7% of the total drag. Because of the relatively small magnitude of this air resistance, it does not require the same care in calculation as given to the resistance of underwater appendages and hull surface which will be discussed below under Hydrodynamics. Aerodynamics also affect the trajectories of hull-generated spray patterns which, because of wind effects, may result in uncomfortable deck wetness and deterioration of visibility. The problem is best solved by proper design and location of spray strips attached to the hull. Model tests in a towing tank are most useful in defining hull-generated spray patterns and evaluating means for suppressing the spray. There is good correlation between model and prototype spray patterns developed by planing hulls. [16]

b. (U) Hydrodynamics

Planing craft hydrodynamic technology is based primarily upon experimental data obtained from tests of prismatic planing surfaces such as those reported in Ref. [17] and results of hull series tests such as illustrated by Series 62 and 65 [18]. This technology has been synthesized into simplified empirical equations which a.re easily used in design.* The following discussion of the smooth and rough water characteristics of planing craft are based upon these tank results and full-scale data.

1) Lift

The lift on a planing surface is attributed to two separate effects depicted graphically in Figure 14. One is the positive dynamic reaction of the fluid against the moving planing bottom, and the second is the so-called buoyant contribution which is associated with the static pressures corresponding to a given draft and hull trim. At very low speeds, the buoyant lift predominates, while at high speed, the dynamic contribution to lift predominates. A plot of lift coefficient versus mean wetted length/beam ratio for a range of speed coefficients is given in Figure 15 [17] for a zero deadrise surface. The correction for deadrise is given in Figure 16 [17]. The important hydrodynamic characteristics demonstrated are:

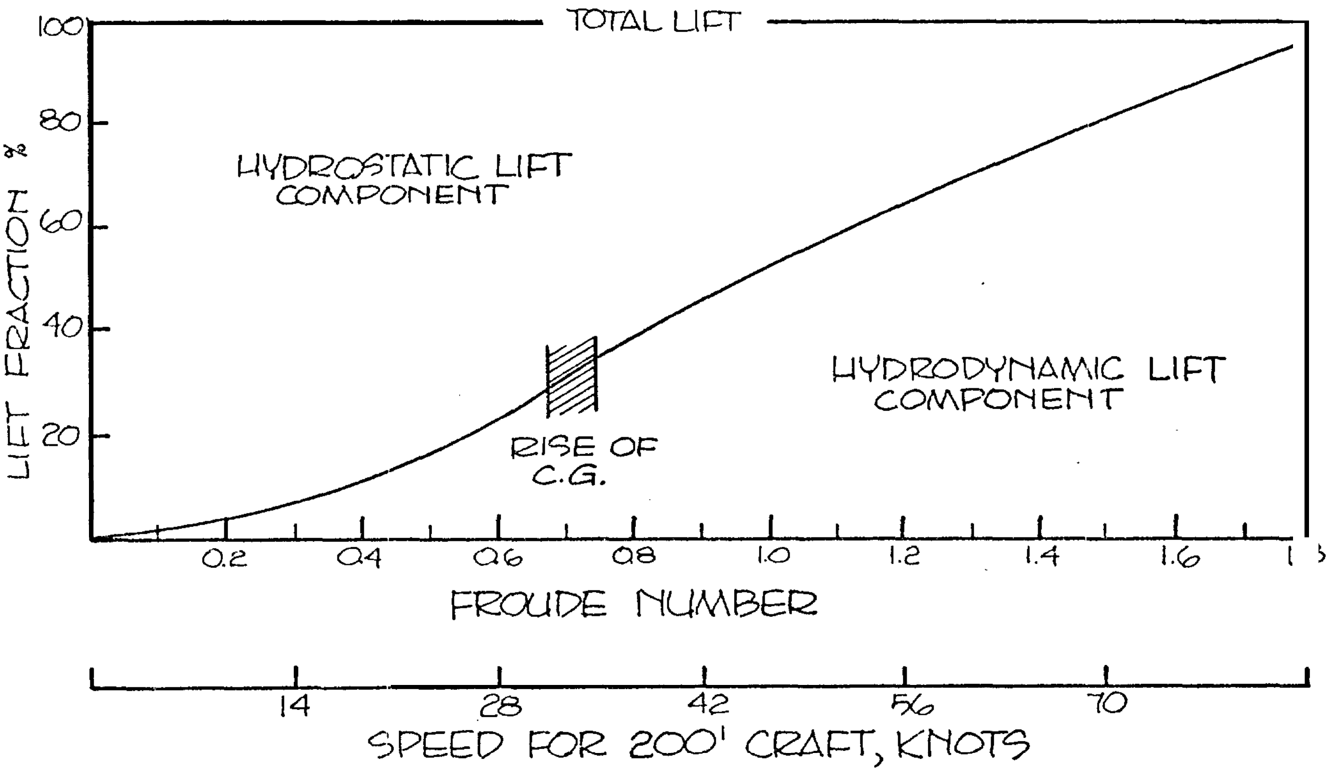
- The lift coefficient, C_L, increases as the exponential

---

* The shapes used, and the range of conditions, under which the data for these equations were obtained dictate the following approximate ranges of applicability for the various parameters:

Parameter	Approximate Range Of Applicability
τ	2" to 24"
λ	$\leqq 4$
C_V	0.6 to 25
$F_{N\nabla}$	$\geqq 1$
LCG/L_p	$\leqq 0.46$

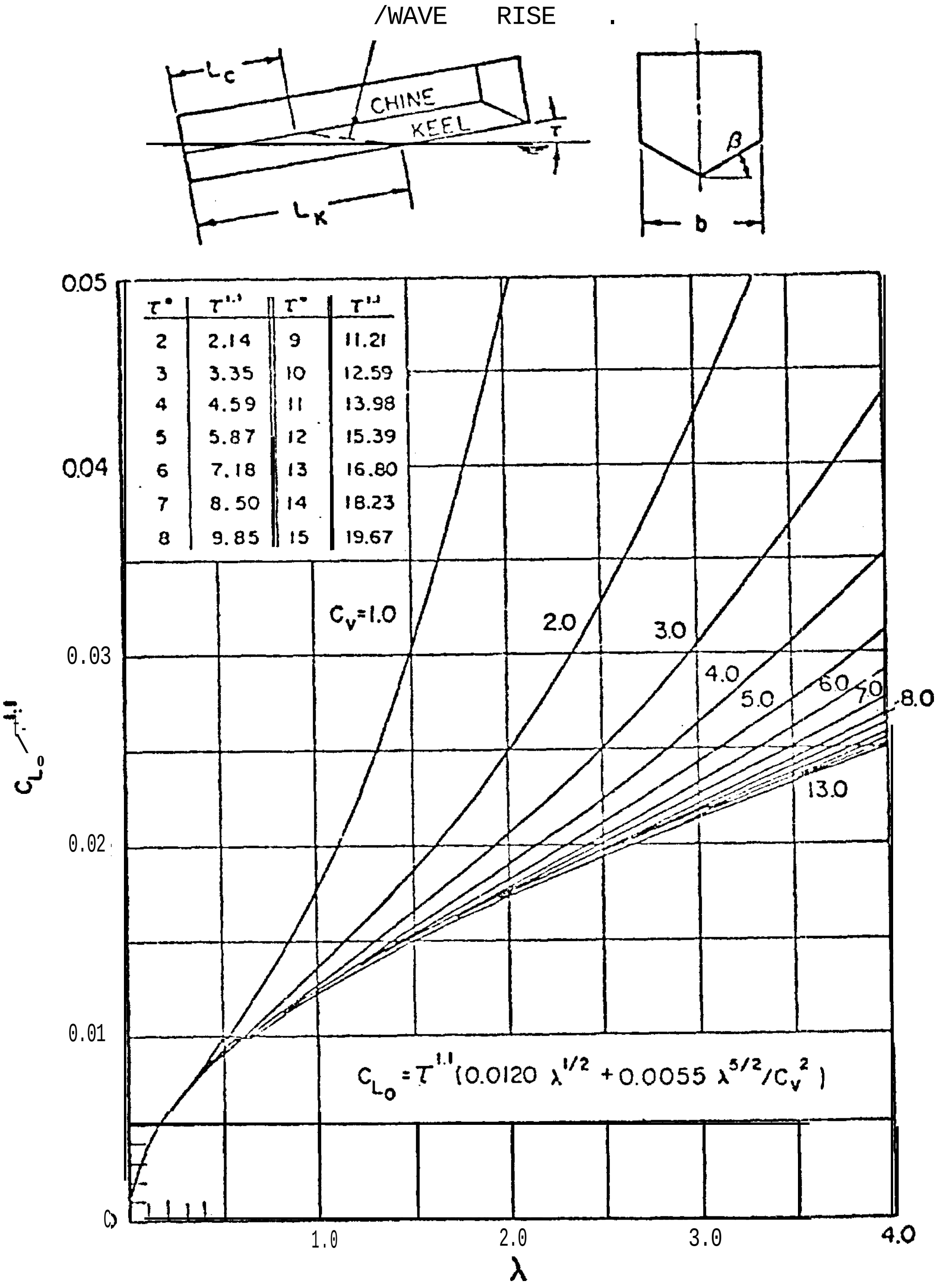
It is clear that care must be exercised in attempting to use these empirical equations by extrapolation beyond the stated ranges [19, 20)



NOTE:
THE BAR INDICATES THE APPROXIMATE FROUDE NUMBER AT WHICH THE RISE OF THE VESSEL'S CENTER OF GRAVITY ABOVE ITS STATIC ELEVATION BECOMES SIGNIFICANT.

Figure 14 - I-lydrosta-tic and Hydrodynamic Lift Components (U)

(Repeat of Fiqure 5)



$\tau°$	$\tau^{1.1}$	$\tau°$	$\tau^{1.1}$
2	2.14	9	11.21
3	3.35	10	12.59
4	4.59	11	13.98
5	5.87	12	15.39
6	7.18	13	16.80
7	8.50	14	18.23
8	9.85	15	19.67

Figure 15 - Lift coefficient of a flat planing surface; β = 0° [17] (U)

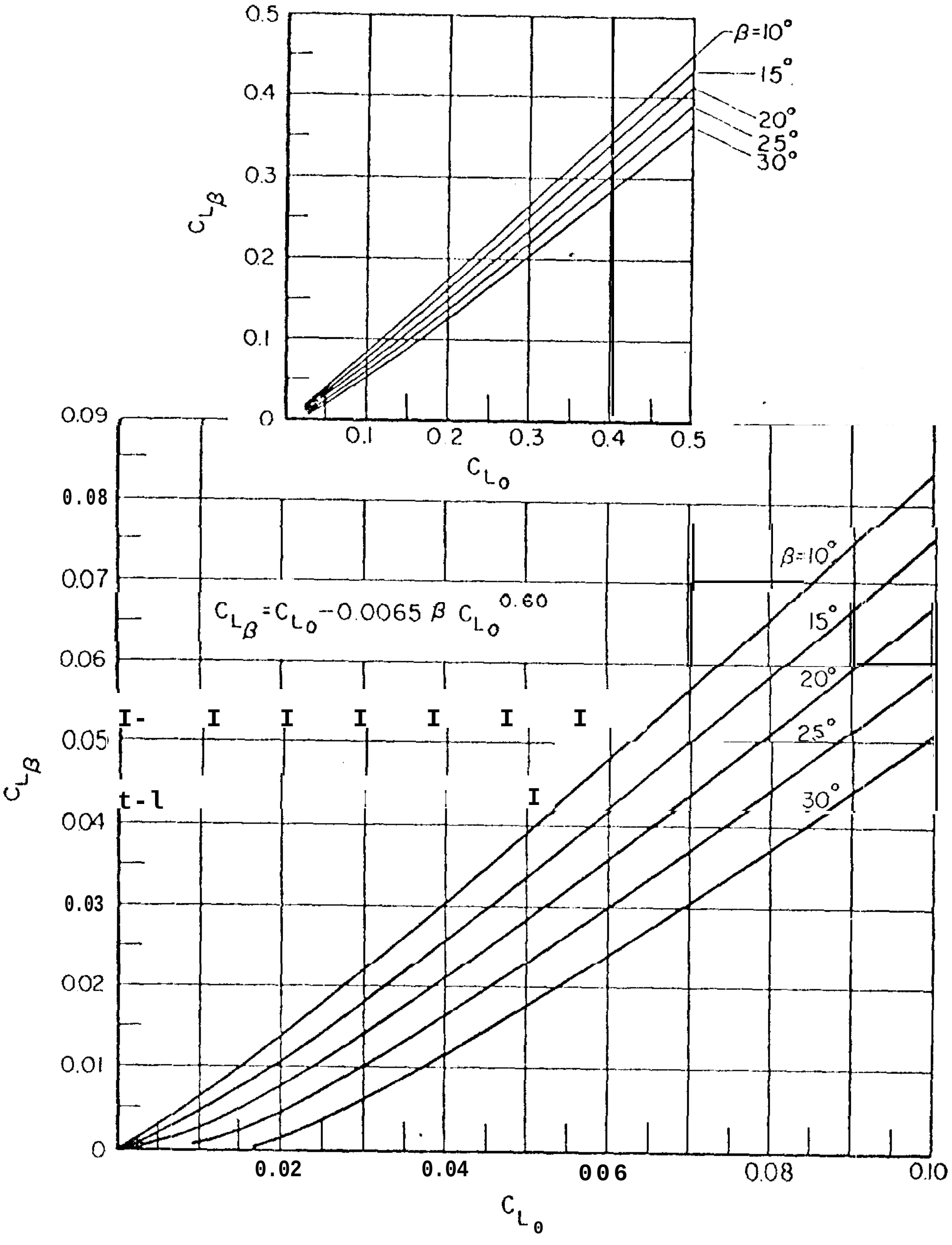


Figure 16 - Lift coefficient of a deadrise planing surface [17](U)

power of trim angle and as the square root of the mean wetted length/beam ratio, according to the following equation (for zero deadrise surface):

$$C_{L0} = \tau^{1.1}(0.0120\ \lambda^{1/2} + 0.0055\ \lambda^{5/2}/C_V^2)$$

where τ = trim angle, degrees

λ = mean wetted length beam ratio

C_V = speed coefficient = $V/\sqrt{gb}$

v = speed, ft/sec

b = beam of planing surface, ft

g = acceleration of gravity, ft/sec^2

- All other parameters being constant, the hydrodynamic lift varies as the square of the beam.
- The planing lift is predominately due to dynamic bottom pressures when the speed coefficient C_V, a Froude number defined above, is greater than 10.
- The effect of deadrise angle is to reduce the lift coefficient, all other factors being equal.

2) Drag

The hydrodynamic drag of the bare hull is composed of induced drag due to lift forces acting normal to the bottom, and to viscous drag acting tangential to the bottom in both the pressure area and in the spray area which is located immediately forward of the pressure area. These drag components, at full planing speed, are best illustrated in Figure 17 [17]. It has been found that these drag-lift ratios are only slightly dependent upon speed (except as speed influences trim) and mean wetted-length/beam ratio. These are the hydrodynamic characteristics illustrated:

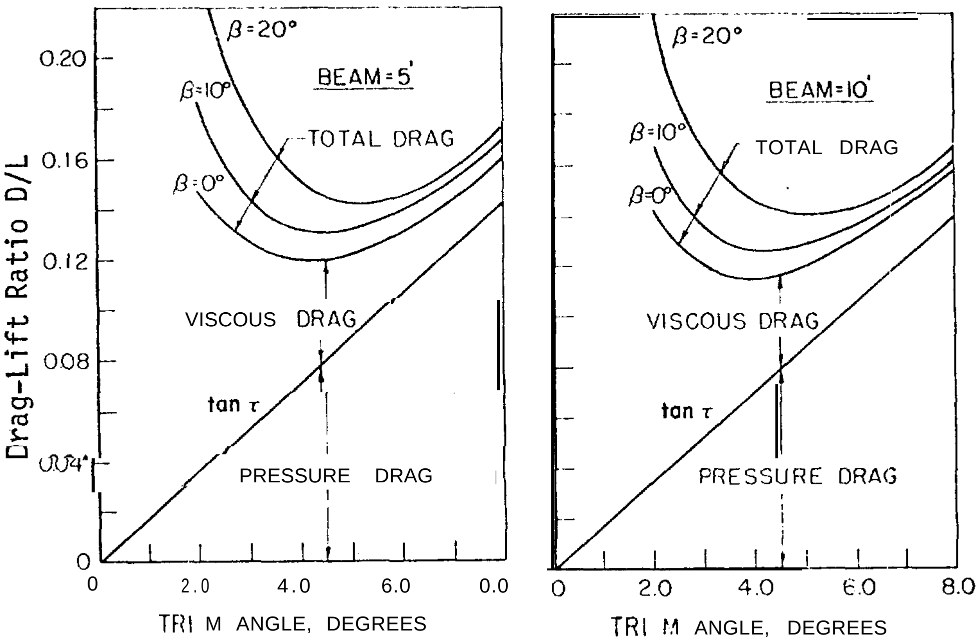


Figure 77 - Variation of drag-lift ratio for prismatic planing surfaces [17] (U)

- The drag/lift ratio is primarily dependent on trim angle, with the optimum trim at about 4°.
- At angles less than 4" the viscous drag due to bottom friction dominates while at larger trims pressure drag due to dynamic lift generation dominates.
- The drag/lift ratio increases significantly with increasing bottom deadrise.
- For a flat bottom surface the minimum drag/lift ratio is 0.12 which corresponds to a lift/drag ratio of approximately 8.3.
- For trim angles less than 4° the drag/lift ratio decreases with increasing trim angle; for trim angles greater than 4" the drag/lift ratio increases with trim angle. The significance of this feature to the performance of planing hulls, particularly when overloaded, is discussed in detail in Section II.C.6., page 185.

The results of systematic series tests (Series 62 and 65) have been synthesized into the results given in Figure 18 which show the drag/lift ratio for the most efficient planing hull as a function of speed for various slenderness or displacement length ratios. In this figure, the results are shown for a 45 tn hull. The curves show the characteristics high hump drag for the short hull and the advantage it has at high speeds. It can also be seen that the long hulls have little or no hump drag but have greater resistance at high speeds. These curves will be used in a subsequent section when comparing the performance of special hull designs to the conventional planing hull.

This figure was developed from data reported in [18], a compilation of test results on Series 62 and Series 65.

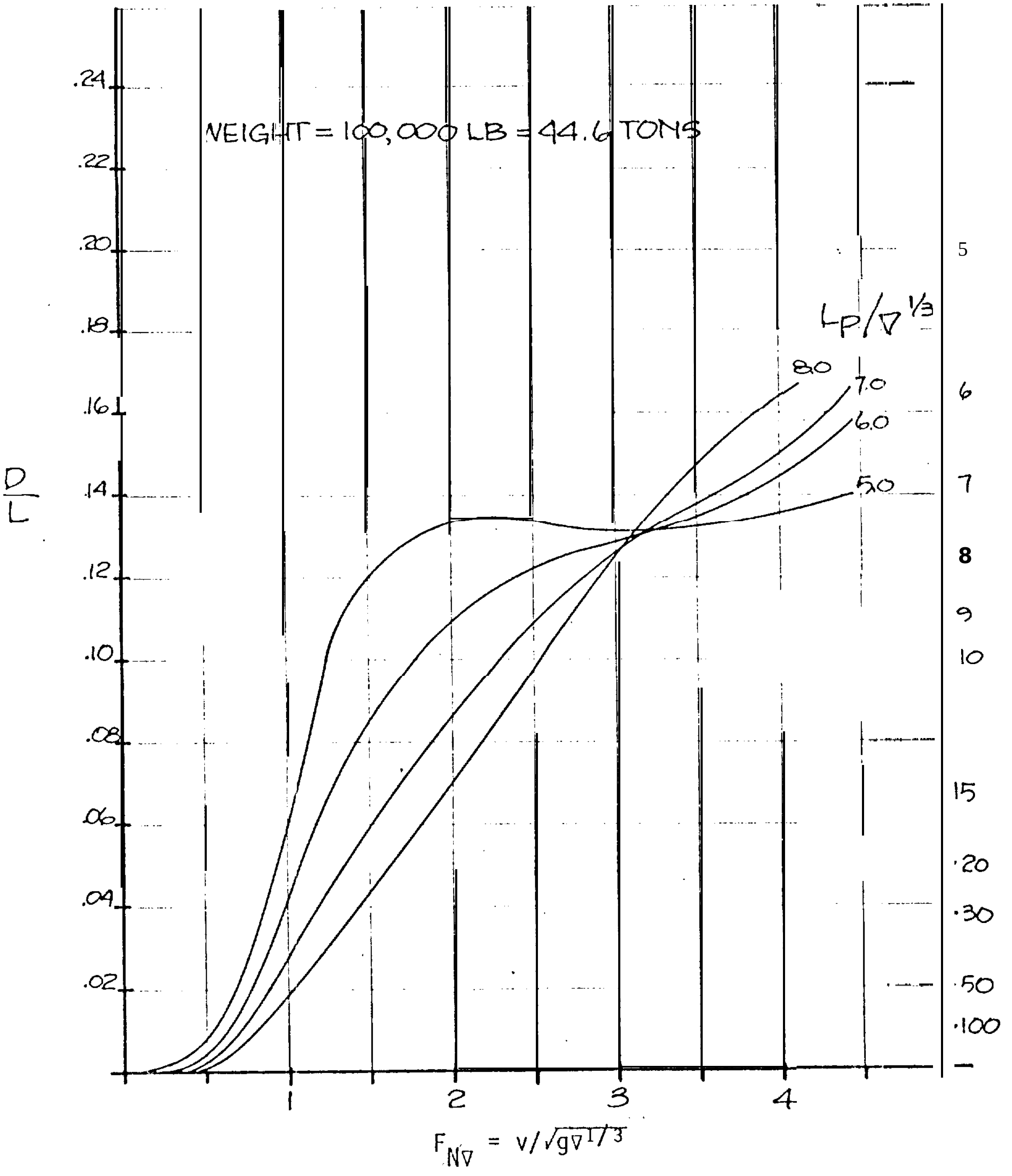


Figure 18 - Drag/Lift Contours for Efficient Planing Hulls as a Function of Volume Froude Number and Slenderness Ratio (U) (Repeat of Figure 3)

3) Center of Pressure and Trim

(a) Because trim angle is such a critical planing parameter, as discussed above under Lift and Drag, trim control devices such as transom flaps [21] or longitudinal transfer of fuel or ballast are used to achieve the desired running attitude. For example, low trim reduces impact accelerations at high speed in head seas, high trim is required for maximum speed in smooth water and for operating in following seas.

(b) The center-of-pressure of planing hulls is calculated by means of an empirical equation which approximates experimental model data. The equation, given in Figure 19, shows a variation in center of pressure from 33% of the mean wetted length forward of the transom at low speed to 75% forward at high speed. The figure shows how this variation takes place for several mean wetted length/beam ratios.

(c) For a planing hull having a specified length, beam, deadrise, displacement, center-of-gravity, and thrust line, there is a relation between running trim angle and speed at which the hull is in equilibrium. This equilibrium trim angle is easily computed using the basic hull technology just described and determines the drag-lift ratio of the boat as plotted in Figure 17 on page 60. Typical curves of trim and resistance versus speed for planing craft are demonstrated in Figure 20, (extracted from [2] with modified notation) for hulls of various length-beam ratios. It is seen that, as speed increases, the craft trim and resistance increase to a so-called "hump" value and then decrease as the speed is further increased. The hump trim and resistance decrease with increasing length/beam ratio and are barely noticeable at high length-beam ratios.

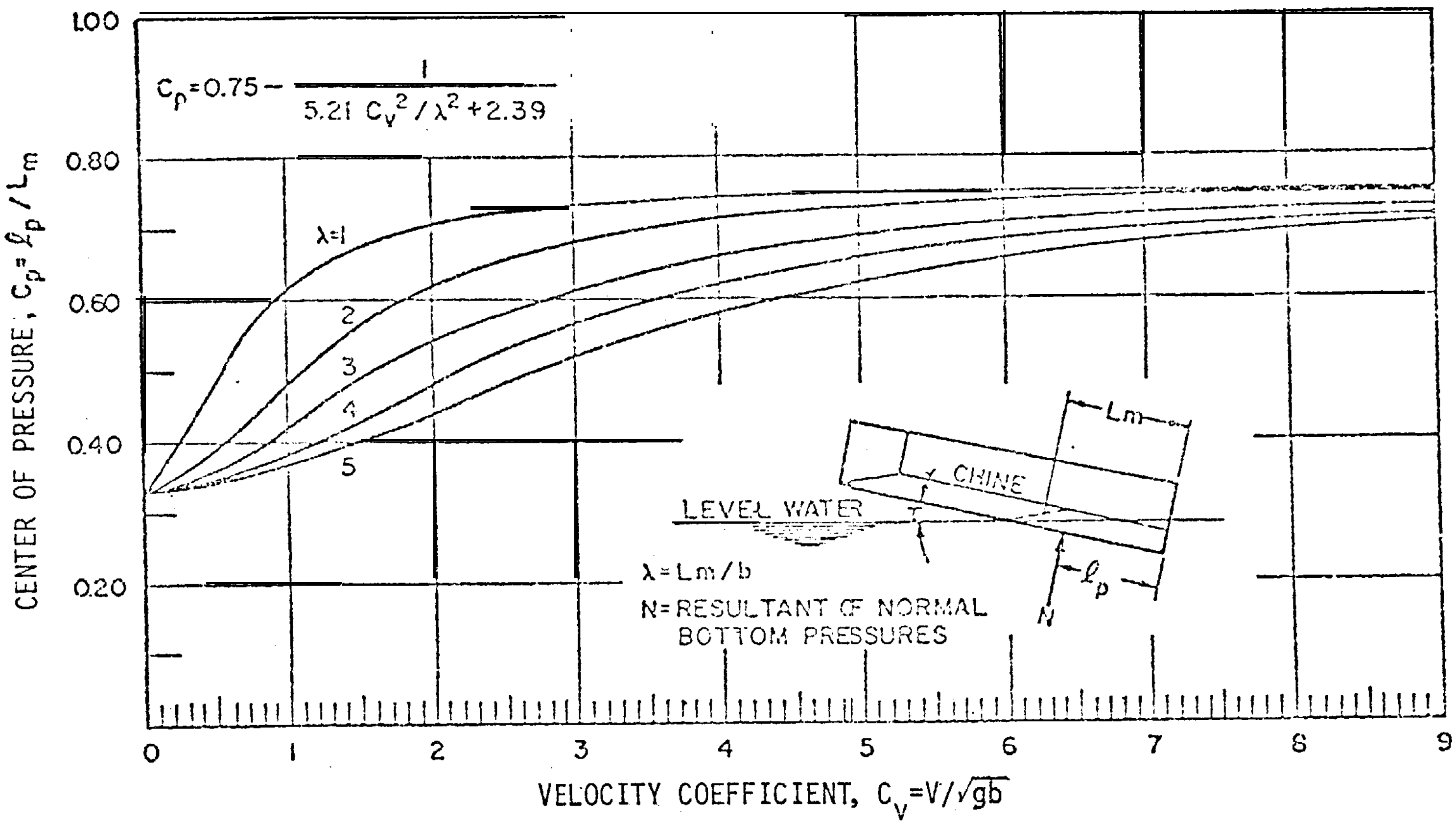


Figure 19 - Center of pressure of planing surfaces [12] (U)

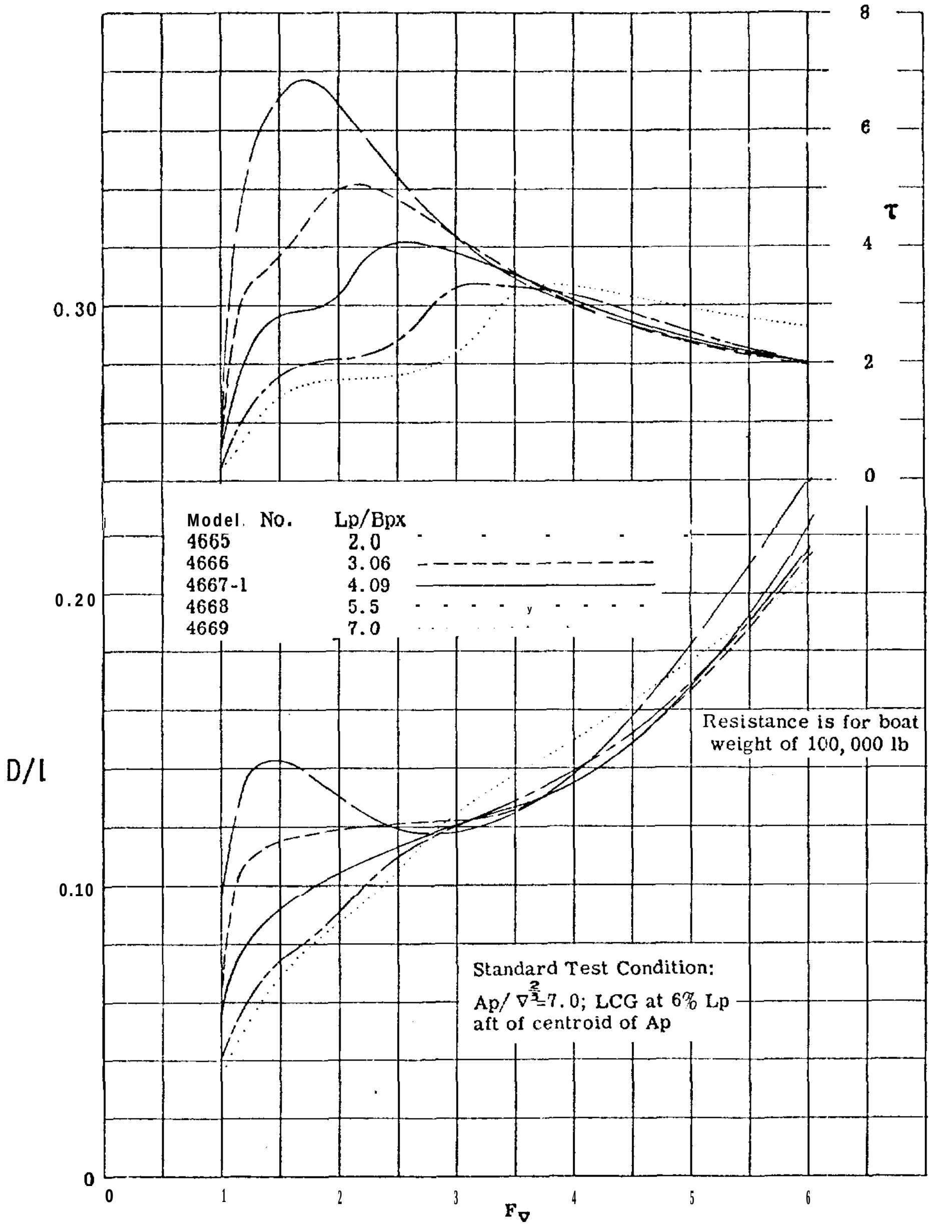


Figure 20 - Drag/Lift ratio and angle of attack versus Froude Number for five models of series 62 [2] (U)

c. (U) Total Resistance

The aerodynamic drag and the two components of bare hull drag have all been discussed above. To evaluate the total resistance for a planing hull, it is necessary to include also the hydrodynamic resistance of appendages such as skegs, propeller shafts, struts, rudders, strut palsm, appendage interference drag, etc. References [19, 22, 23] provide the means for evaluating the drag of each of these appendages. This work is summarized in [20]. For preliminary design purposes, it can be assumed that the appendage drag, which varies, has a value of approximately 5% of the hull drag at hump speed and nearly 15% at design speed [20].

d. (U) Powering Requirements

1) These are, of course, related to not only the total resistance of the craft but also the efficiency of the propulsion system, its interaction with the hull, and the sea state in which the vessel will operate. The propulsion system efficiency is determined by power losses due to engine air inlet and exhaust systems (including silencers and demisters), engine driven auxiliaries, gear boxes, bearings, shaft seals and propulsors. This last item, propulsion (including the effects of shaft angle and interactions), is treated in [19, 20, 24]. Reference [20] gives a usable calculation procedure and Reference [24] provides assistance in choosing the number of propellers, diameter and rpm for best efficiency for boats of a wide range of sizes, proportions and speeds.

2) The commonly used propulsors (propellers or waterjet) are described in Section II.A.6. Typical values of propulsor efficiency range from 30% to 65% depending largely on dimensional limitations of the propulsors which in turn limit the water flow rate and discharge velocity.

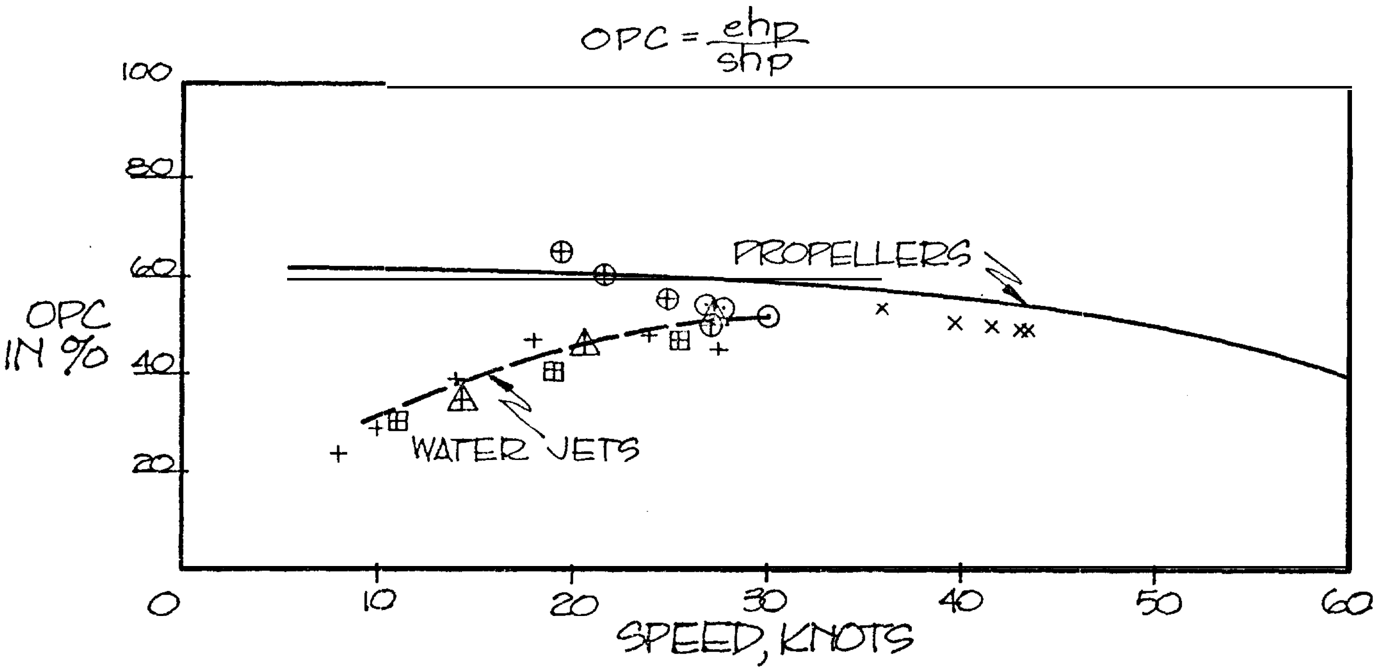
With a high flow rate and low discharge velocity less energy is lost as momentum in the slipstream. The lowest efficiencies are associated with waterjets at low craft speed.

3) Mechanical transmission systems are usually very efficient. Losses can most easily be reduced by reducing the number of components. Typical efficiency values range from near 100% for a "bob-tail" engine direct coupled to a waterjet, to approximately 95% for a V-drive, reduction gear, shaft arrangement. Propulsion systems are discussed further in Section II.B.2.

4) Figure 21 shows overall propulsive coefficient versus speed for the two propulsor types discussed above.

e. (U) Interdependency Between Speed and The Vehicle's Resistance and Gross Characteristics.

1) The gross characteristics of a vessel, principally its displacement and length, affect the resistance (drag) in the manner shown in Figure 18, p.62, where lift/drag ratio, L/D, is plotted versus Volume Froude Number, $F_{N\nabla}$, for several slenderness ratios, $L_p/\nabla^{1/3}$, through through a range of $F_{N\nabla}$ from zero to 4.5. The particular section here is only concerned with design speeds well within the planing range, that is, speeds represented by Volume Froude Numbers greater than 3.3. In this range of speeds and for the range of slenderness ratios under discussion (5 to 8) the longer the boat, for a given displacement (lift), the greater the resistance (drag). This figure shows that a lift to drag ratio (L/D) of 7 is attainable at planing speeds for a $L_p/\nabla^{1/3}$ of 5. The resistance is related to the required brake horsepower by the overall propulsive coefficient (OPC). Currently attainable values of OPC for both porpellers and waterjets, along with test data for six craft, are shown in Fiqure 21.



Symbol	Craft	Type Propulsion	Data Source Model	Full Scale
X	CPIC-X	**Propellers**	[25], [26]	[3]
⊙ W/TABS ⊕ W/O TABS	**65' PBMK 3**	**Propellers**	[27]	[28]
la	**Mini-ATC**	**Water** Jet	[29]	[30]
Δ	**ASPB MK2**	Water Jet	[411	[31]
+	PBR **MK2**	**Water** Jet	[32]	[33]

Figure 21 - Overall Propulsive Coefficient vs: Speed (U)

This figure also defines OPC. In the example to be given below a realistic value of OPC = 0.5 will be used at all speeds.

These relationships can be thought of in terms of the transport efficiency where, transport efficiency, $\Delta v/P$, in lb-ft-sec units, is equal to the product of the lift/drag ratio, L/U, and the overall propulsive coefficient, OPC. In the example below $\Delta v/P = (L/D)$ (UPC] = (7) (0.5) = 3.5 for all cases. As stated above, these values are attainable.

In some cases severe mission requirements may dictate the use of less than optimum hull or propulsion characteristics. In these cases a reduction in transport efficiency may have to be accepted. For example, if exceptionally good seakeeping characteristics are required at high speed it may be desirable to employ a long slender hull form (high slenderness ratio, $L/\nabla^{1/3}$) and accept a lower L/D.

As an illustration of the approximate relations between displacement, speed, and shaft horsepower, assume that a well designed planing hull with about 15" deadrise in the afterbody will have proportions which produce a running trim angle of approximately 3° at its design speed. This will give the above mentioned L/D of about 7. Also as stated above, assume an OPC of 0.5. This yields the following results:

	Shaft Horsepower @ Various Design Speeds OPC = 0.5		
Design Gross . Displacement Tons	V_K = 40 Knots	V_K = 50 Knots	V_K = 60 Knots
22	1,700 hp	2,200 hp	2,600 hp
45	3,400	4,300	5,100
67	5,200	6,500	7,800
134	10,400	13,000	15,600
223		21,500	25,500
563			65,000

The above tabulation is presented only for illustrative purposes in order to familiarize the reader with the approximate relations between displacement, speed and shaft horsepower. The shaft horsepower at each of the three speeds for a given displacement assumes a different design optimized for each speed, not a given design at several speeds. Length-beam ratio, bottom shape, and center of gravity position affect the required power as well as the slenderness ratio mentioned above. Any specific design must be separately evaluated either by the analytical procedures of [17] or by model tests.

f. (C) Interdependency of Endurance, Range and Operating Periods as a Function of Gross Characteristics

The trends for useful load fraction (as well as fractions for structure, and machinery and other fixed weights) for four existing military planing hulls are shown in Figure 22. These trends have been extrapolated to the projected sizes of ocean capable planing hulls. The general trend is for increasing useful load fraction with increasing size. Other information on useful load fraction may be found in Figure 23, and in Section II.C. p. 183, where Figure 23 is repeated as Figure 61. This figure shows the reduction in speed (expressed as Volume Froude Number, $F_{N\nabla}$) with increase in useful load fraction for 12 planing hulls. The data points shown are based on accurate measurements of speed during full scale trials, scale weighings of the boats, and accurate weight reports which permit identification of the useful load items.

Specific examples of payload and range dependencies require more detailes assumptions. An example of these interde-

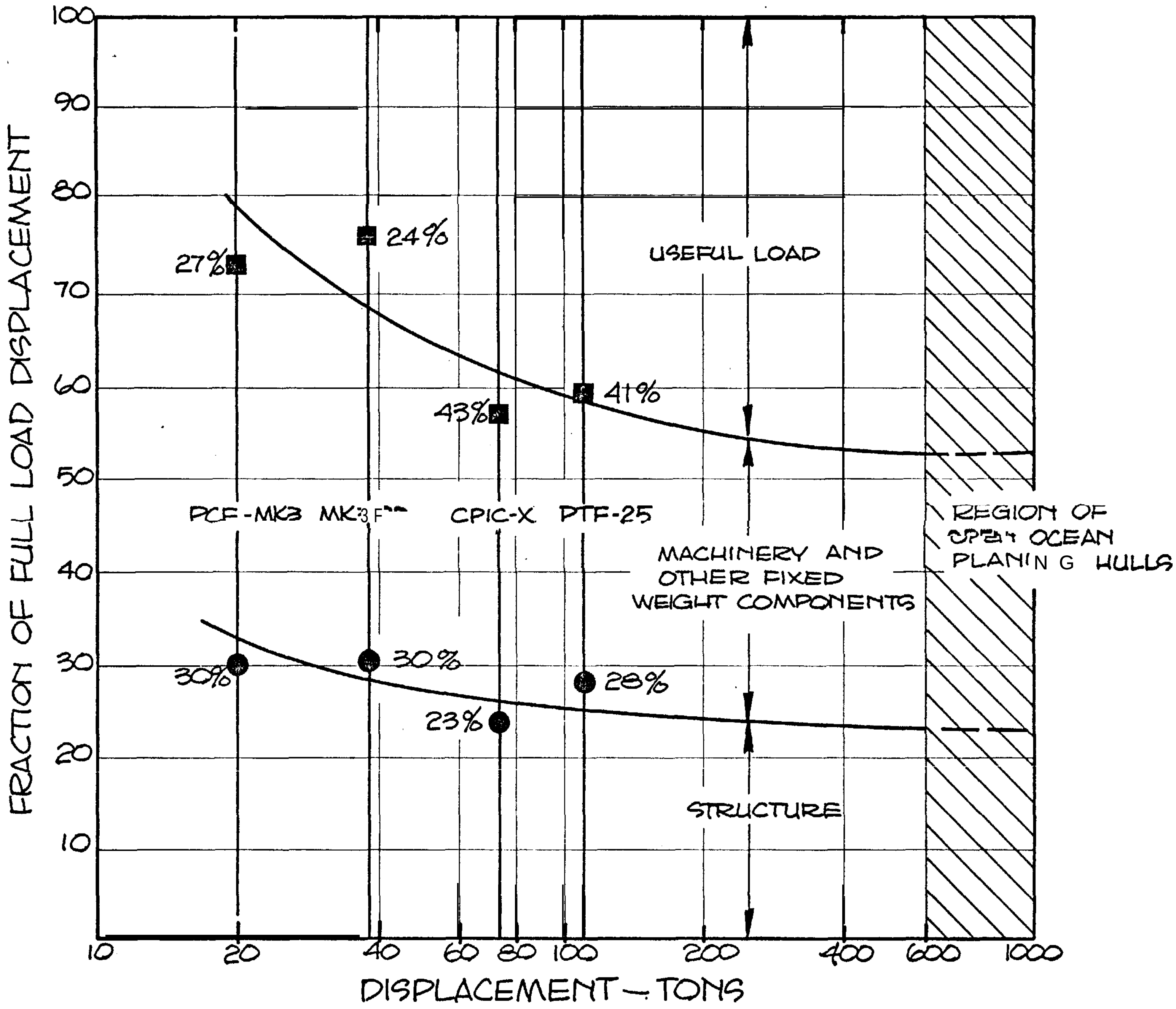
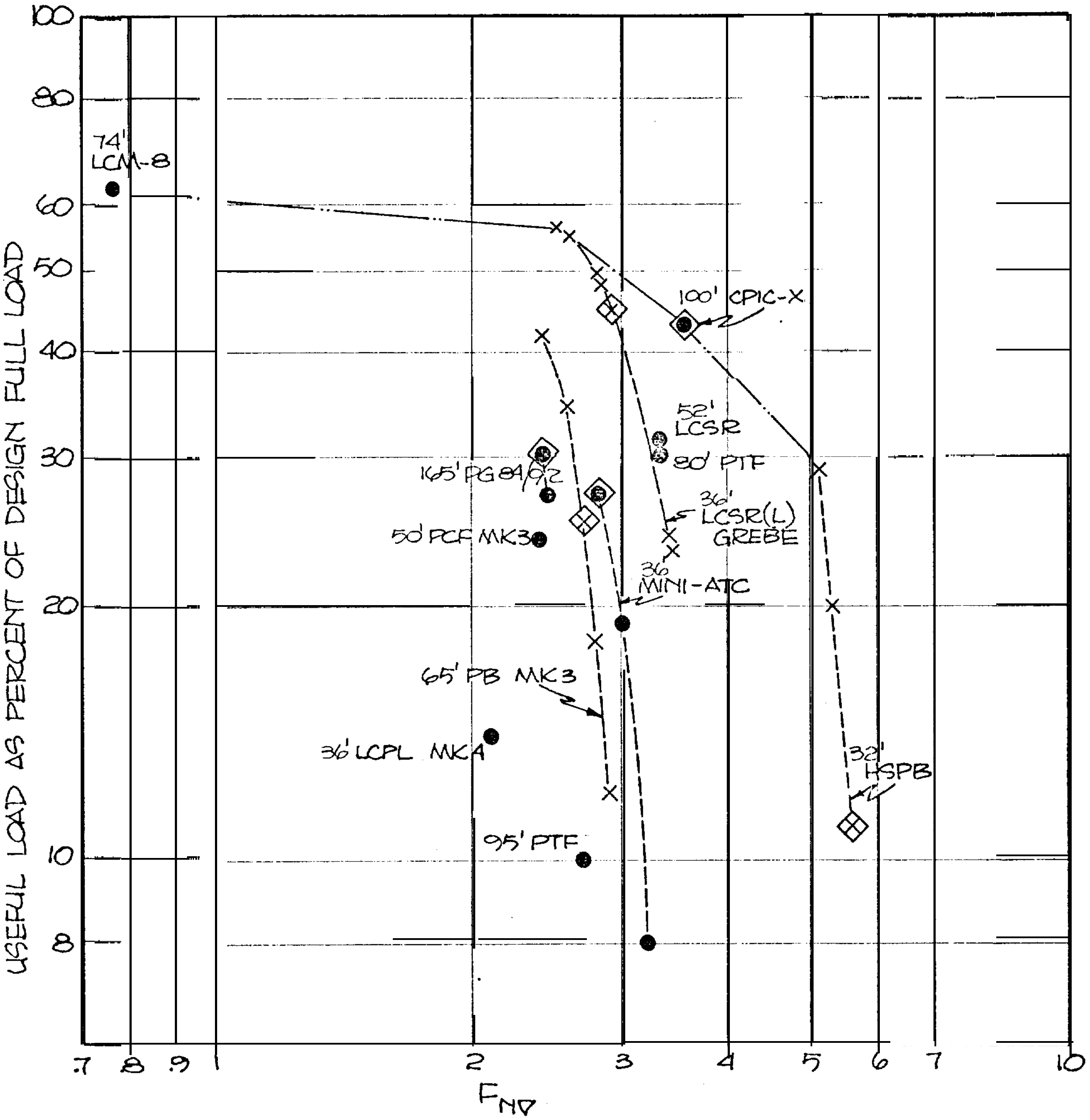


Figure 22 - Trends for various load fractions for four military planing hulls (U)



NOTE:
FOR CRAFT TESTED AT VARIOUS DISPLACEMENTS THE DESIGN CONDITIONS ARE NOTED BY: ◇

Figure 23 - Useful Load Fraction Upper Boundary (U)

pendencies, and of a way they can be scaled from the known CPIC-X data (see also Table 3 on pp. 36-37 for additional CPIC-X characteristics)to an extrapolated estimate of performance of a similar but larger craft, is given below. Summary results are given in subparagraphs 1) through 4) with details of the method used given in subparagraphs 5) and 6) which follow.

1) The useful load weight of CPIC-X is 42% of the gross weight. If the useful load is apportioned as 20% Military payload and 22% fuel * , the following relationship exists between range and speed:

Speed	Range ($H_{1/3}$ = 4.6 ft)
41 knots (76 km/h)	313 NM (580 km) (Turbines)
31 knots (56 km/h)	352 NM (652 km) (Turbines)
9 knots (16 km/h)	2492 NM (4675 km)(Diesels)

Further speed and range information may be found on p. 37. In addition, it is conventional and convenient to use a straight line variation of range with fuel capacity for most estimates. A somewhat more accurate approximation allowing for fuel burnoff can be made by use of the Breguet equation, and this was done for the ranges shown in Table 4 on p. 77.

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* This quantity of fuel (a nominal 5000 gal) equals 3 main tanks 95% full. See also Table 4, p. 77. for additional information.

[redacted]

2) The substantial increase in range at 9 knots is attributed to the low specific fuel consumption of the diesels compared to the turbines, and to the fact that the planing craft is operating as a high-speed displacement ship where its lift-drag ratio is much greater than it is at 41 knots. At 9 knots, the hull lift-drag ratio is approximately 20 while at 41 knots it is approximately 7.

3) These prototype data for CPIC-X have been extrapolated to a conceptual 200 ft (61m) 62 knot (114 km/h), 576 tn (585 t) Open Ocean Planing Hull, The range predictions for this ship are as follows:

Speed	Range $H_{1/3}$ = 9.2 ft
61 knots (112 km/h)	733 NM (1358 km)
46 knots (85 km/h)	826 NM (1530 km)
12 knots (22 km/h)	3643 NM (6747 km)

4) For this ship, the empty weight is only 51% of the total weight; it is powered by 3-GE LM2500 turbines with an SFC = 0.40 lb/hp-hr. Again, the useful load (49%) was taken to be approximately 19% military payload* and the remaining weight (30%) was fuel. At the 12 knot cruise speed, this planing ship operates as a high-speed displacement ship with a lift-drag ratio of approximately 26; at 61 knots L/D $\cong$ 7.5.

5) To carry out these calculations the CPIC-X test data were handled in the following manner: . The turbine shp measurements, which were taken at a point between the primary reduction gear and the secondary V-drive reduction gear, were corrected for the losses (3.43%)[34].

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* This military payload is used for illustrative purposes only. However, it is based on realistic military requirements as listed on p. 248, with a modest future growth margin which together equal 110 tons,. It was established prior to any Task I or NAVSEA 6212 weaponeering dialog.

[redacted]

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in the primary gear to give the turbine output bhp. Because the craft was tested at displacements less than full load, the bhp figures were multiplied by the ratio of the full load displacement to the pertinent trial displacement. These corrected bhp's are plotted against the measured speed in Figure 24. In addition, a rough water resistance increment for a significant wave height of 4.6 ft (15% per [3]) was added, and the resultant curve plotted. Speed loss in rough water is discussed further in subsection 8) below. For the diesel trials, no correction was applied to the horsepower ratings because the curve, in the region of interest, is so steep that the effect on speed is negligible. An addition of 15% [3 ,26] for rough water was added, however. Several standard engine ratings are shown in Figure 24 and the resulting speeds are listed in Table 4, along with the extrapolation to the 200 foot Open Ocean Planing Hull. Figure 25 shows a map of turbine performance, and defines the ratings for the TF25A.

6) Range calculations were made for each of the operating conditions listed and are included in Table 4. The calculations were made for rough water. The range in smooth water is only about 6% greater. In these calculations allowance has been made for fuel burn-off using the Breguet equation. The usable fuel is 16 tn (16.3 t)(22% A) for CPIC-X and 173 tn (176 t) (30% A) for the Open Ocean Planing Hull.

7) Additional discussion of scaling factors is given on p. 193.

8) The speed loss can be obtained from Figure 24 by reading across at constant power from the smooth water curve to the curve for rough water. See also the discussion in the next section (II. A.1.g.) for further details and data on speed loss.

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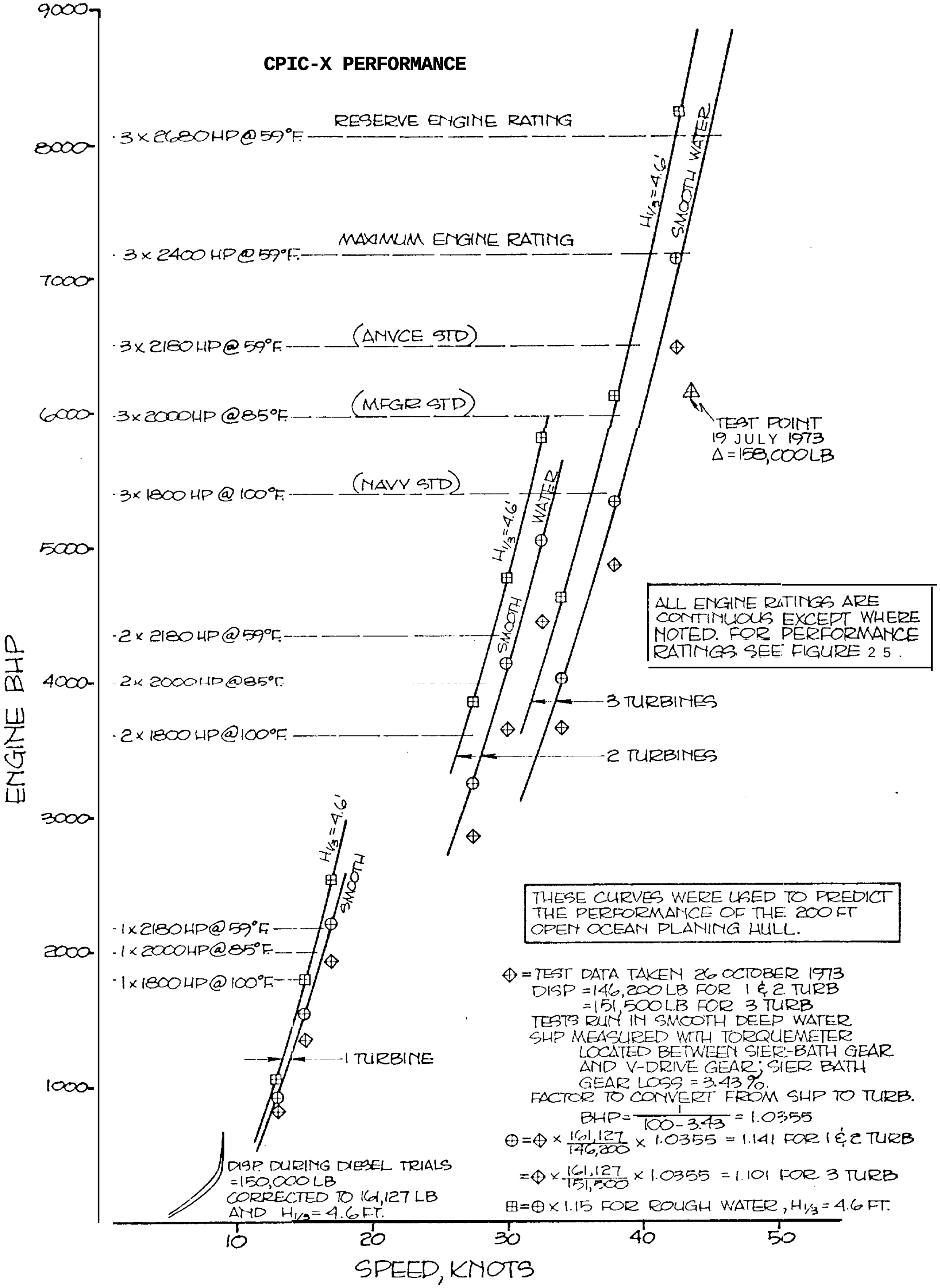

ALL ENGINE RATINGS ARE CONTINUOUS EXCEPT WHERE NOTED. FOR PERFORMANCE RATINGS SEE FIGURE 25.

THESE CURVES WERE USED TO PREDICT THE PERFORMANCE OF THE 200 FT OPEN OCEAN PLANING HULL.

◈ = TEST DATA TAKEN 26 OCTOBER 1973
DISP = 146,200 LB FOR 1 & 2 TURB
= 151,500 LB FOR 3 TURB
TESTS RUN IN SMOOTH DEEP WATER
SHP MEASURED WITH TORQUEMETER LOCATED BETWEEN SIER-BATH GEAR AND V-DRIVE GEAR; SIER BATH GEAR LOSS = 3.43%.
FACTOR TO CONVERT FROM SHP TO TURB.

$$BHP = \frac{1}{100 - 3.43} = 1.0355$$

$$⊕ = ◈ \times \frac{161,127}{146,200} \times 1.0355 = 1.141 \text{ FOR 1 \& 2 TURB}$$

$$= ◈ \times \frac{161,127}{151,500} \times 1.0355 = 1.101 \text{ FOR 3 TURB}$$

⊞ = ⊕ × 1.15 FOR ROUGH WATER, $H_{1/3}$ = 4.6 FT.

Figure 24 - **(C) CPIC-X Engine** BHP vs: Speed (U)

TABLE 4

(C) SPEED, ENDURANCE & RANGE FOR 100 Ft & 200 Ft PLANING SHIPS (U)

In-take Air Temp. °F	No. and Type of Engines	Continuous Engine Rating; Standard Fuel Load											
		00 Ft.; 72 tons (Fuel. 16 tons)						200 Ft.; 576 tons (Fuel. 173 tons)					
				$H_{1/3}$ = 0	$H_{1/3}$ = 4.6 ft.					$H_{1/3}$ = 0	$H_{1/3}$ = 9.2 ft.		
		TF 25A bhp (1)	En-durance Hrs.	Speed Knots F.F.(4)	Speed Knots F.F.(4)	Speed Knots Av (5)	Range NM (6)	I-M 2500 bhp (1)	En-durance Hrs.	Speed Knots F.F.(4)	Speed Knots F.F.(4)	Speed Knots (5)	Range NM (6)
59°	3 TURBINES		8.31	41.1	38.8	40.8	313	81750	12.88	61.7	58.3	61.0	733
85°		6000	8.71	39.7	37.6	39.4	330	75000	13.49	59.5	56.3	59.0	770
100°		5400	9.26	38.2	36.1	37.9	353	67500	14.35	57.1	54.0	56.6	821
59°	2 TURBINES	4360	12.47	30.7	28.9	30.5	352	54500	19.32	46.0	43.6	45.7	826
85°		4000	13.06	29.7	27.9	29.4	369	50000	20.24	44.5	42.1	44.3	867
100°		3600	13.89	28.4	26.6	28.2	394	45000	21.53	42.7	40.2	42.4	923
59°	1 TURBINE	2180	24.93	17.0	16.2	16.9	383	27250	38.64	25.3	24.0	25.3	909
85°		2000	26.12	16.4	15.7	16.3	410	25000	40.48	24.6	23.3	24.6	963
100°		1800	27.78	15.8	15.0	15.7	438	22500	43.06	23.6	22.5	23.6	1027
(5)	DIESELS	300(2)	292	8.3	8.0	8.5	2492	3225(3)	300	11.7	11.3	12.0	3643

		Continuous Engine Rating; With Reserve Fuel											
		100 Ft.; 77 tons (Fuel, 21.2 tons)						200 Ft : 601 tons (Fuel, 278 tons)					
59°	3 TURBINES	6540	8.31	40.1	37.8	40.2	472	81750	12.88	60.2	52.9	58.5	1139
59°	2 TURBINES	4360	12.47	29.6	28.2	30.0	421	54500	19.32	43.0	40.4	44.4	1297
59"	DIESEL	300	292	8.2	7.9	8.4	3360	3225	300	11.5	11.2	11.9	5530

TABLE 4 - Continued

NOTES:

(1) bhp - rated brake horsepower of turbine at stated temperature and standard conditions. See Figure 24 for map of TF25A performance.

(2) The horsepower shown for the 100 ft boat is well below the continuous power of the Volvo diesel engines. On trials CPIC-X has made 9 knots with the engines developing 538 hp. A lower speed (8.3 knots) is used here because of the better fuel economy. See pp. 36, 77, 78 and ' for further Volvo Diesel information.

(3) Continuous rating of the MTU 12V331TC at 100° F inlet air temp.

(4) Speed with full fuel, at beginning of run.

(5) Average speed over entire distance run.

(6) Range calculated with the Breguet equation; fuel load of 100 ft. hull is 16 tn (22 % A); fuel load of 200 ft hull is 173 tn (30% A).

Breguet Range (Nautical Miles) $= \frac{\overline{V}_K \, \overline{\Delta}}{C \, P_e} \, \ell n \, \frac{A}{A - W_F}$

where: $\overline{V}_K$ = average speed (knots) through range run

$\overline{\Delta}$ = average weight of craft (pounds) throughout range run

C = net specific fuel rate (lf/hp-hr) for total powering system

P_e = actual power used (not necessarily total installed power)

A = initial total weight of vehicle

W_F = weight of fuel used (pounds) for range run

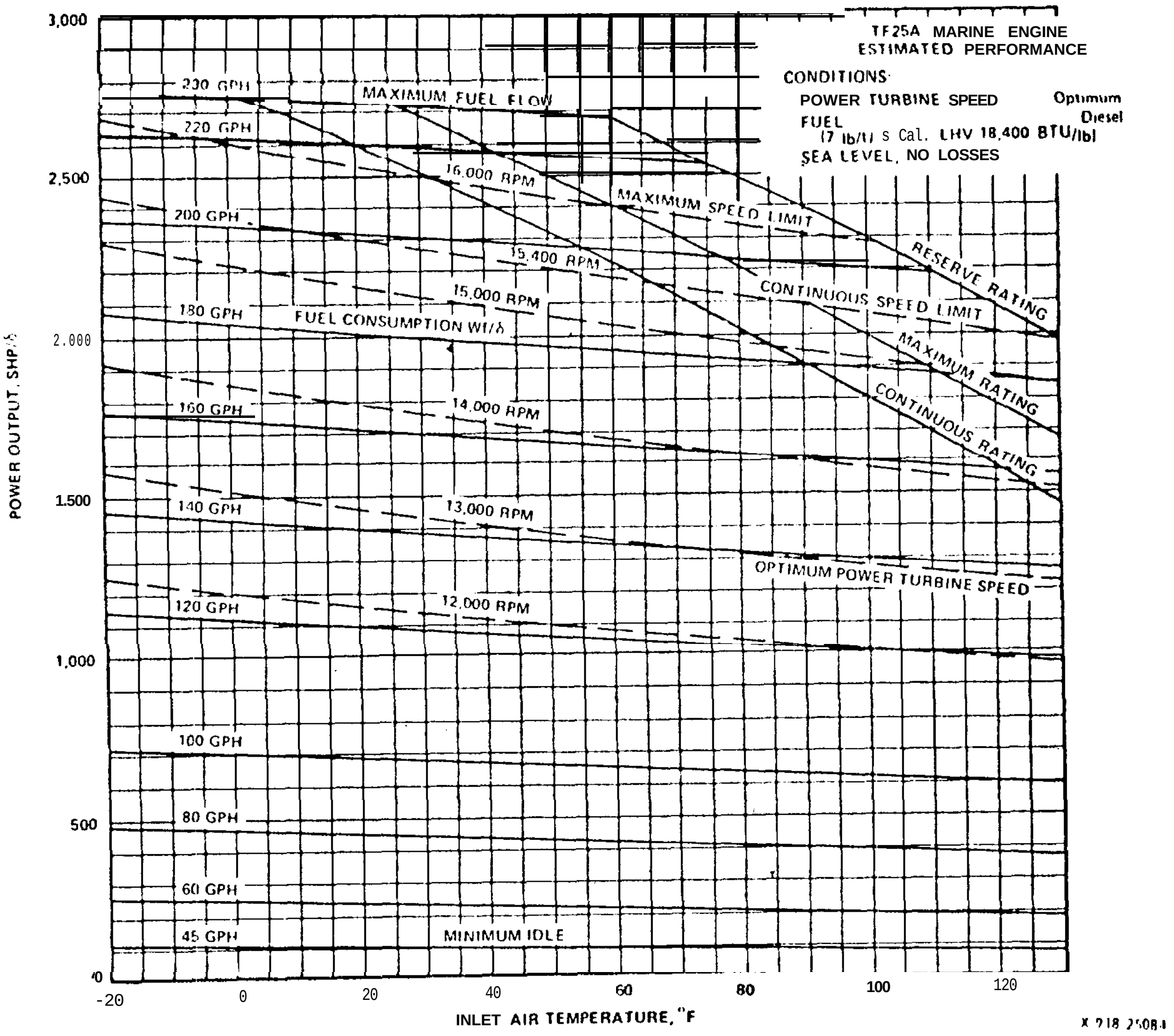

Figure 25 - Engine Performance Map, TF25A (U)

g. (U) Interdependency between environmental conditions and vehicle resistance and performance.

1) An essential requirement for combat-capable planing hulls is that they have an operational capability in a seaway. Fundamental experimental research [35] was carried out in 1970, to define the relationship between seakeeping and hull geometry, hull loading, speed and sea state. Some of the more pertinent results of this study are:

(a) With respect to both added resistance and impact:

- Model tests using constant speed or.constant thrust techniques yield essentially similar seakeeping results at the same test speed.

(b) With respect to added resistance:

- There is an added resistance in waves which increases with increasing Froude number and increasing sea state.
- The added resistance decreases with increasing trim and deadrise angle. As an example, at a length Froude number of 1.2, the added resistance in waves R_{AW} is given by the following approximate empirical formula based on model data:

$$\frac{R_{AW}}{a} = \frac{0.3\,\frac{H_{1/3}}{b}}{1+2\,\frac{H_{1/3}}{b}}\left(1.76 - \frac{\tau}{6} - 2\tan^{3}\beta\right)$$

where: $H_{1/3}$ = significant wave height, ft

τ = equilibrium trim angle, deg

β = deadrise angle, deg

b = beam, ft

- A typical curve of added resistance ratio versus significant wave height is shown in Figure 26. This is a mean line through model test points at 40 knots in various' wave heights. The model displacement was 150,000 lb [26]. Two full scale points from CPIC-X trials are included for comparison [3]. Additional CPIC-X full scale trial data is given in Figure 27 taken from [3]. The speed loss in $H_{1/3}$ = 4.6 ft (sea state 3) is only about 1 knot (an average of 3%) over most of the speed range tested. This corresponds to an average rough water trial resistance (or power) increment of about 8%. These tests represent the only measurements of full scale power in rough water trials that have ever been made on any planing or displacement vessel?

  However, the corresponding CPIC-X model results (from [26] are very conservative by comparison; they are presented in figure 28 as curves of full scale bare hull ehp** vs. speed in smooth and rough water ($H_{1/3}$ = 4.6 ft) for 4 displacements including an overload condition. These curves were used to prepare Figure 29 which shows the speed loss in waves of $H_{1/3}$ = 4.6 ft as a percentage of smooth water speed plotted against the smooth water speed. The model results average 10 1/2%

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[*] These pioneering efforts should be continued with further research into model full scale correlation of rough water powering.

[**] Full scale bare hull ehp = (model resistance without appendages, expanded to full scale, in lb) x (full scale speed in ft/sec)÷ (550 ft lb/sec/hp).

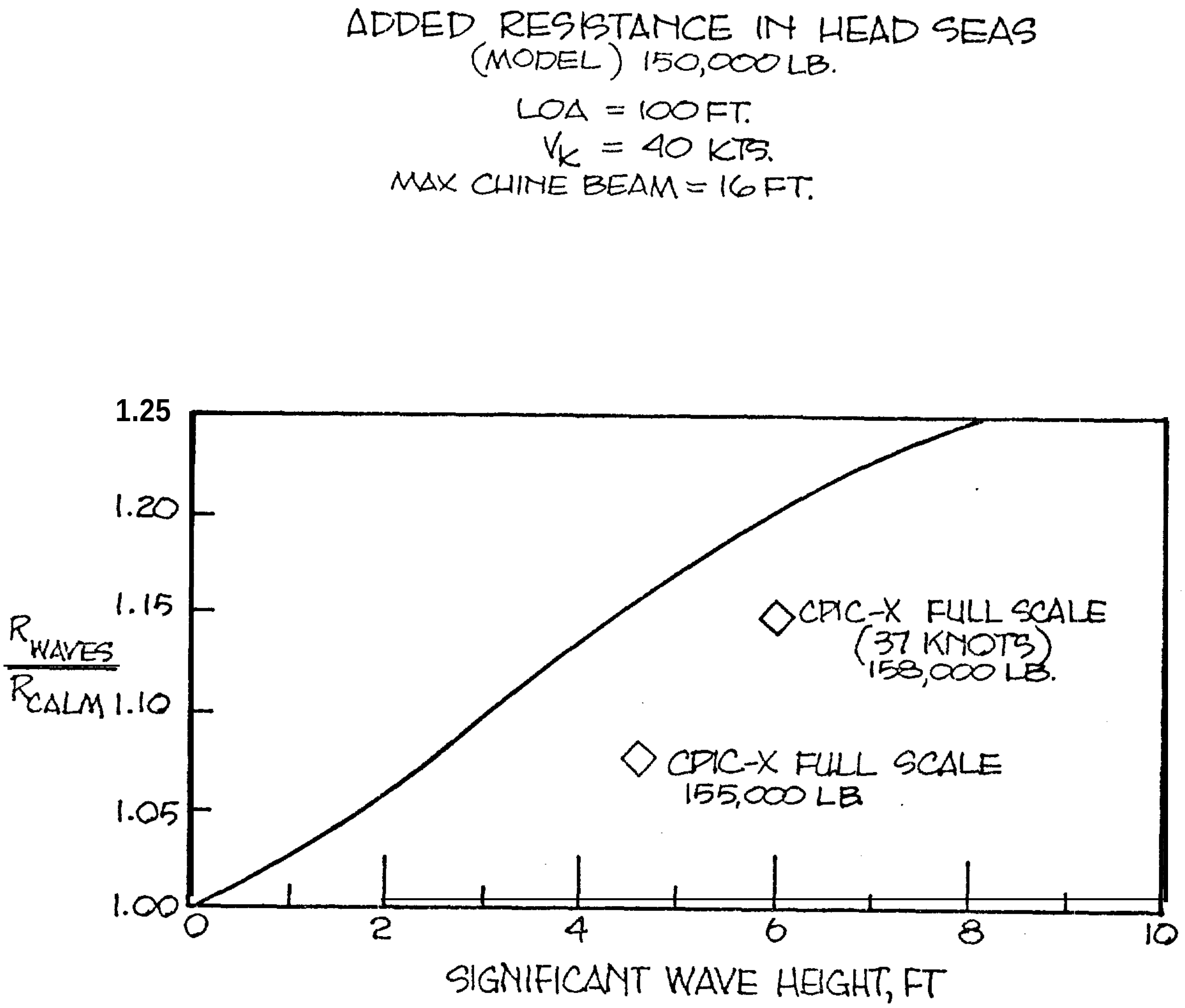

Figure 26 - (C) Added Resistance in Head Seas (U)

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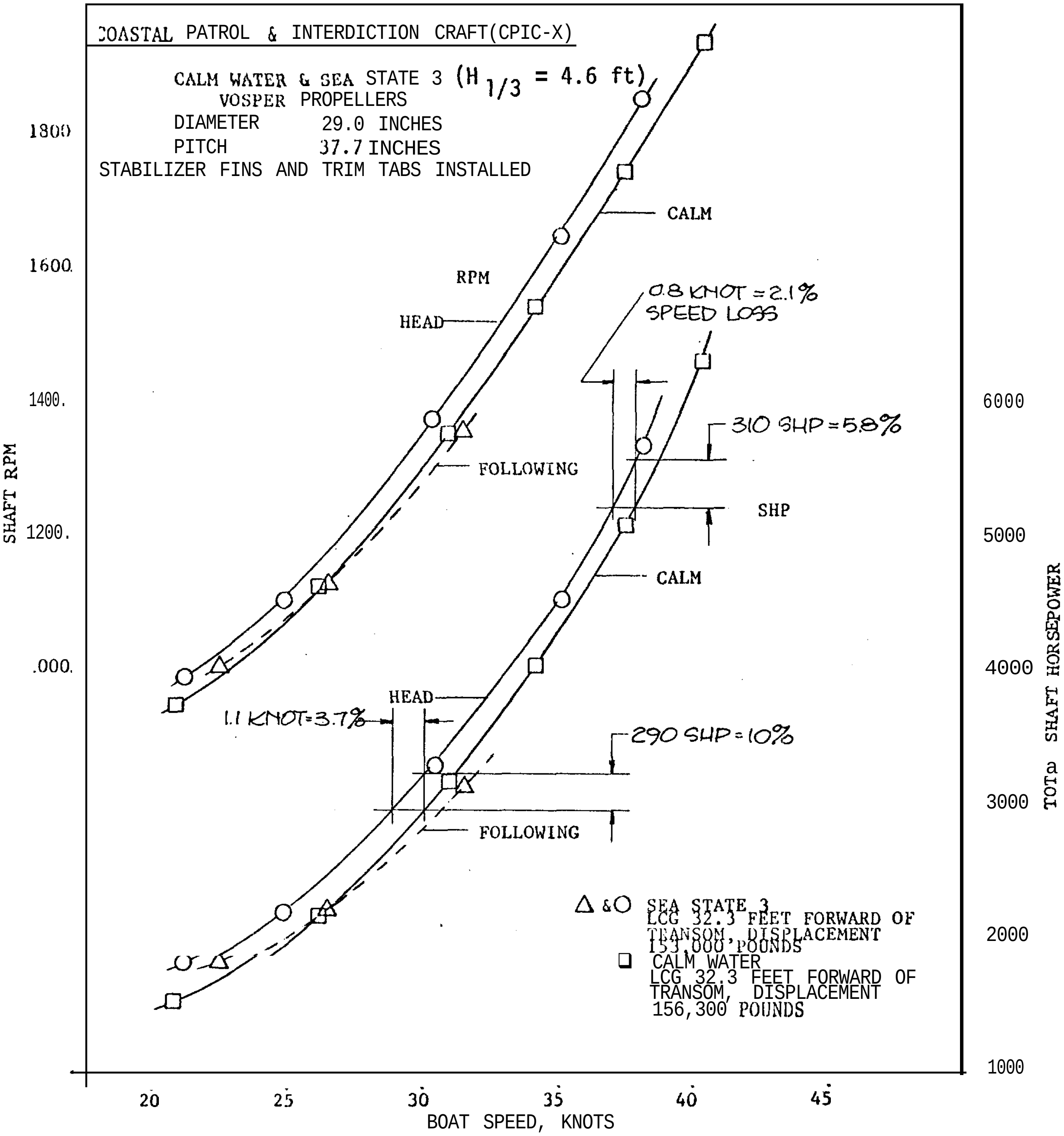

Figure 27 - (C) CPIC-X Speed-Power Rough Water [3] (U)

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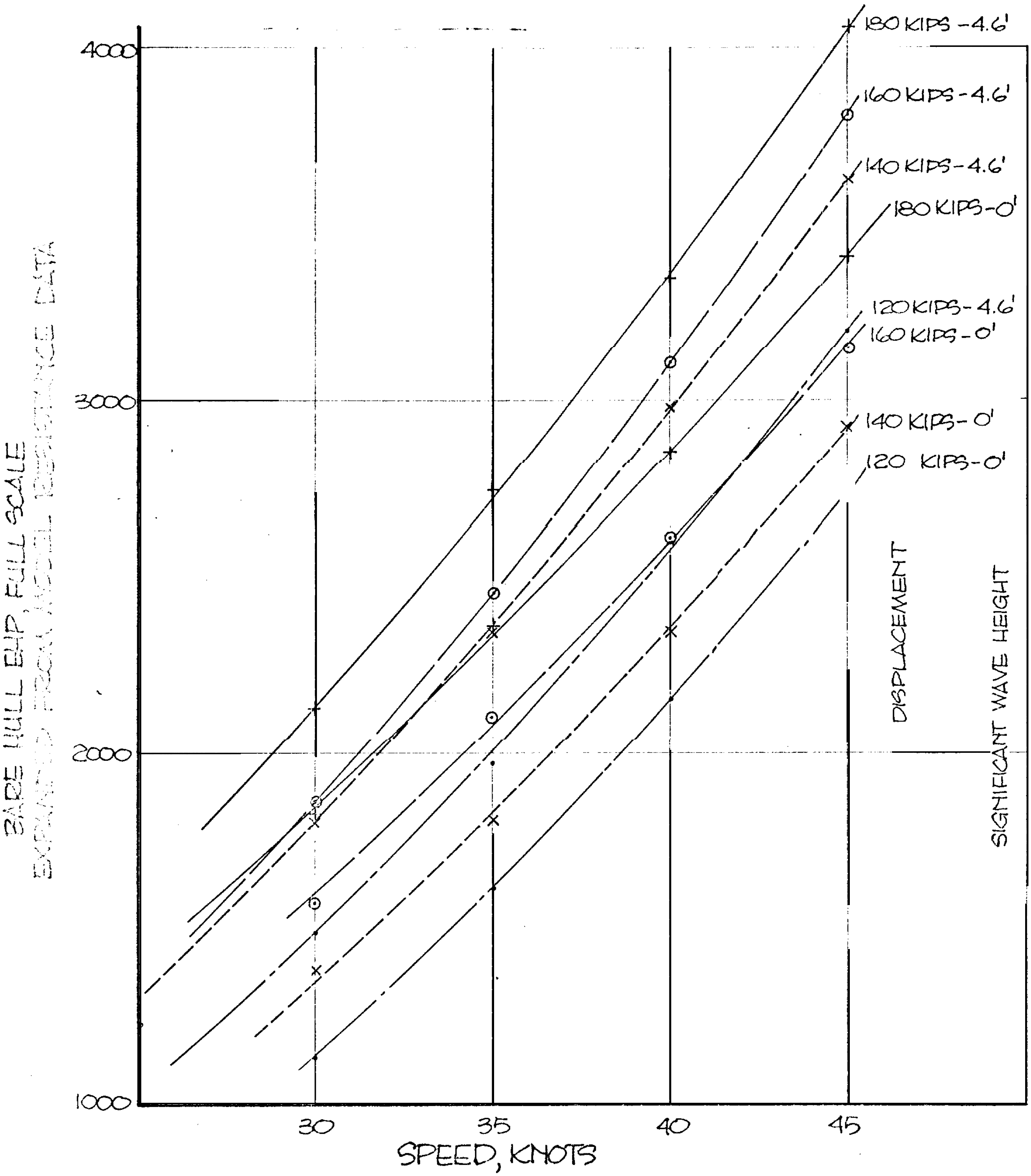

Figure 28 - (C) EHP for CPIC-X in Smooth and Rough Water [26] (U)

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THIS FIGURE DEVELOPED FROM FIGURE 28

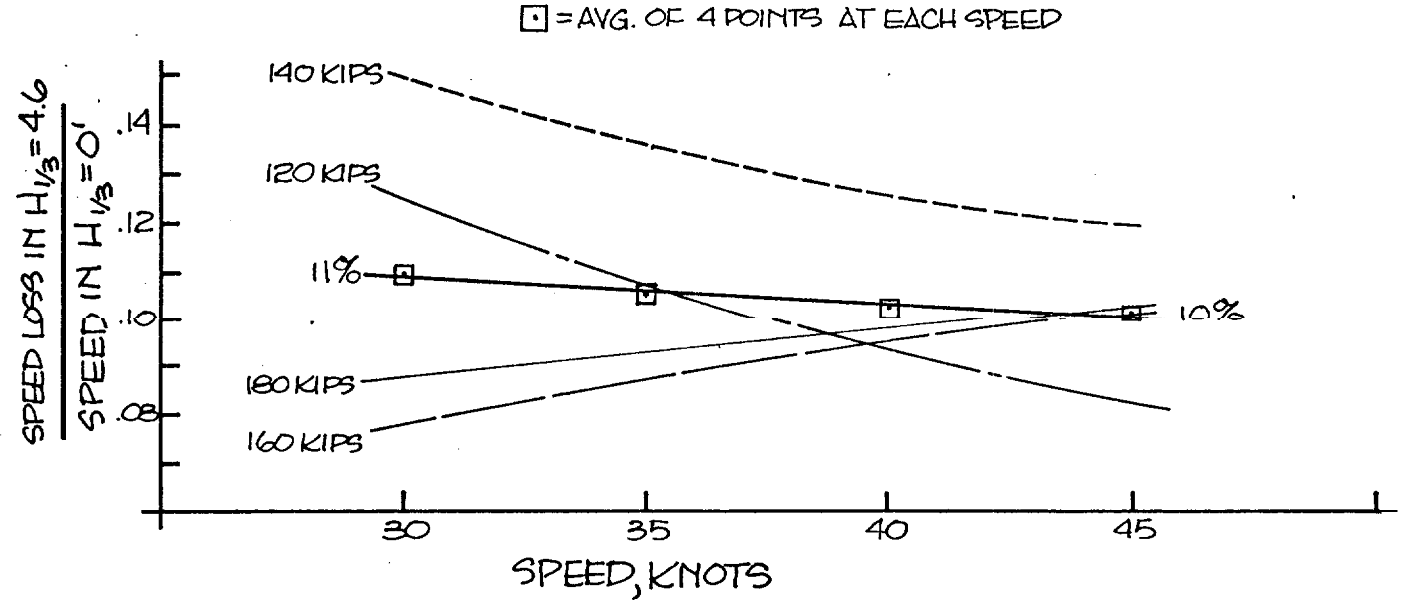


Figure 29 - (C) Speed Loss in Waves at Constant EHP, CPIC-X (U)

[redacted]

speed loss compared to about 3% from full scale results. Because these are the only full scale data, and because there has not yet been an opportunity to investigate the nature of any scale effects, the calculations of rough water shp in Figure 24, p. 76, and consequently the range calculations in Table 4, p.77 were based on the more conservative model data from which the RAW = 15% was derived. This contrasts with the above mentioned 8% from full scale trials.

One factor requires further explanation. The smooth and rough water full scale speed-power curves are only one knot apart. This indicates that at constant power there is one knot speed loss in rough water; however, the maximum speed actually attained in rough water is more than one knot below the maximum speed attained in smooth water. This is because the R_{AW} "loads" the propeller, thereby reducing both rpm and the power output of the engine. This causes the additional speed loss.

(c) With respect to impact:

- The impact accelerations in waves are not linearly dependent upon wave height. As a consequence, the linear superposition techniques developed for seakeeping analysis of displacement ships are not applicable to planing ships. Model tests must therefore be carried out in irregular seas.
- The impact accelerations in a seaway are simply expressed in terms of hull proportions, loading and speed as illustrated by the empirical data displayed in Figure 30 [36].

[redacted]

[redacted] [redacted]

EXAMPLE

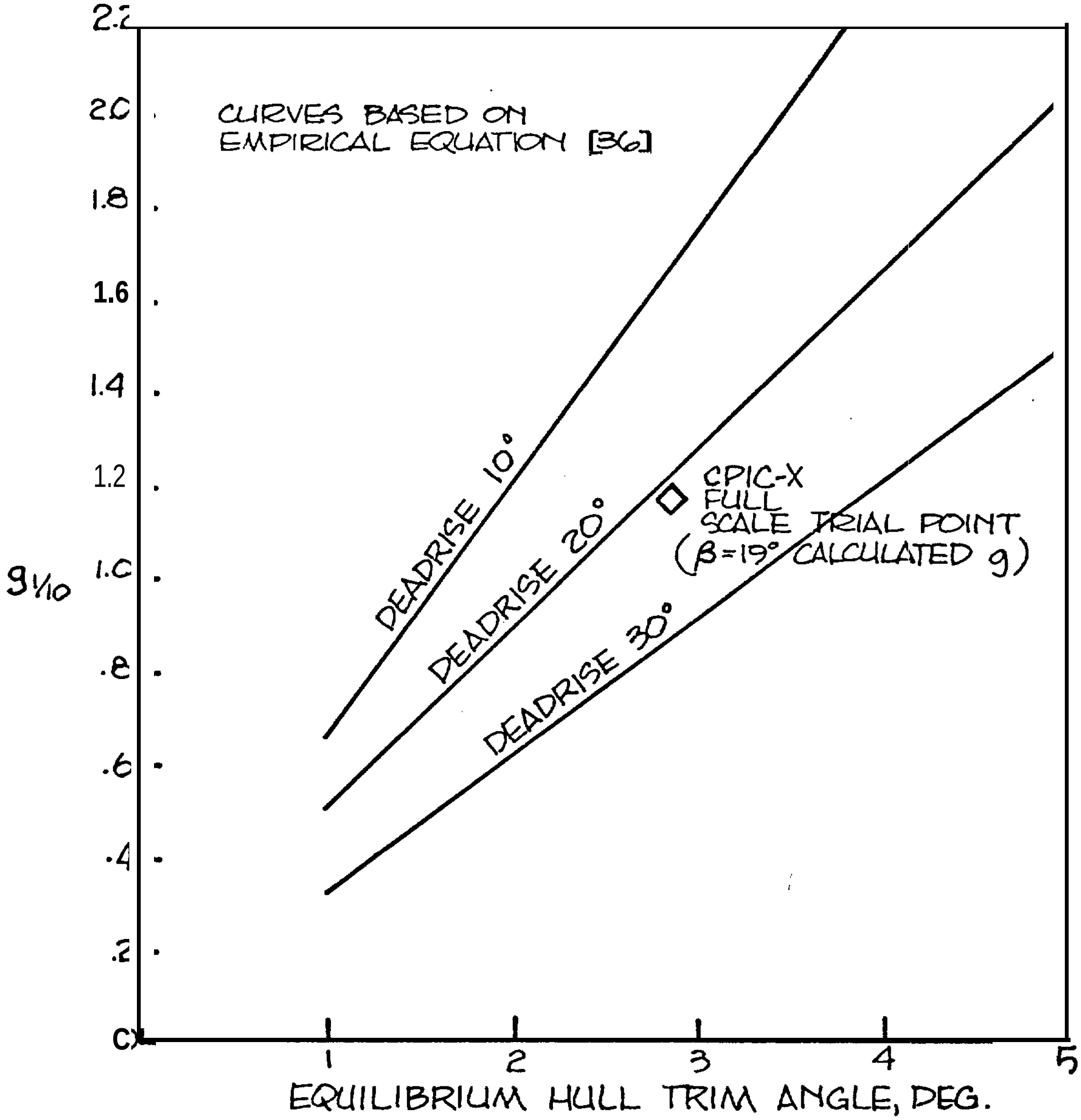
$LOA = 100$ FT

$b_x = 16$ FT.

$\Delta = 72$ TONS

$V_k = 37$ KTS.

$H_{1/3} = 4.6$ FT



EFFECT OF OTHER VARIABLES:

"g" INCREASES AS V_k^2

"g" INCREASES AS $H_{1/3}$

"g" INCREASES AS b_x^3

Figure 30 - (C) C. G. Impact **Acceleration**s **in Waves** [36] (U)

[redacted] [redacted]

[redacted]

for a high-speed planing hull. It is seen that impact accelerations at a given deadrise angle are linearly dependent upon equilibrium trim angle, so these loads may easily be reduced by a reduction in trim angle through the use of trim tabs or ballast transfer. The impact loads are also inversely proportional to deadrise angle.

- The impact loads vary as the cube of the beam. Thus, a 10% decrease in beam can reduce the "g" loading by nearly 30%.
- Impact loads are proportional to the significant wave height in an irregular sea and increase as the speed-length ratio squared.

2) Wave impact bottom pressures required for hull design have been formulated using empirical procedures developed from an analysis of full scale impact pressures and accelerations on a 95 ft planing hull (YP110) [37].

3) Refering to Figure30 it seems that, for a given speed and wave height, impact accelerations decrease linearly with decreasing equilibrium trim angle; decrease with increasing deadrise angle; and decrease with increasing beam loading. Thus, if reduction in impact acceleration were the only consideration, a planing hull would be designed with high deadrise; narrow beam to obtain a high beam loading; and with a longitudinal weight distribution such that the craft will run at a very low trim angle. Unfortunately, while this combination of design and operating parameters results in low impact accelerations, it also results in very large hydrodynamic resistance, especially in rough water (Fig. 17, p. 60, and p. 69), and also in reduced

[redacted]

internal volume. A "realistic" design procedure must therefore establish the best compromise among accelerations, resistance, and useful volume.

4) Another consideration in planing hull design is control of the spray pattern which affects both deck wetness and visibility. The problem is best solved by proper design and location of spray strips attached to the hull. The transverse shape of the hull near the spray strips is also an important consideration. Model tests in a towing tank are most useful in defining hull-generated spray patterns and evaluating means for suppressing the spray.

h. (U) <u>Vehicle motions in the fluid medium</u>

1) Sufficient technology is in hand to design a planing craft for a specified "g" loading. As discussed in the previous section, emphasis on very small "g" loadings results in a combination of small equilibrium trim angle, large deadrise angle and narrow beam. Unfortunately, such a narrow, high deadrise hull will have excessive resistance and limited hull volume. A design philosophy of effective hydrodynamic trade-off studies for powering and rough water operations is therefore essential. An example of one such philosophy is given in [38].

2) There are usually three factors which define the operational limits of planing hulls; (1) power available, (2) crew habitability, and (3) designated survival sea state; which of these governs the design most depends on the specific operational requirements. However, for a typical specific speed-wave height envelope (such as Figure 31), the portion B-C is the power limit, C-D is a habitability limit, and E-E is a survival limit. The line C-D will move downward as longer durations of time on station are required, i.e., the upper line might reflect a 1 hour limit of exposure, whereas line C'D' might reflect an 8 hour limit of exposure.

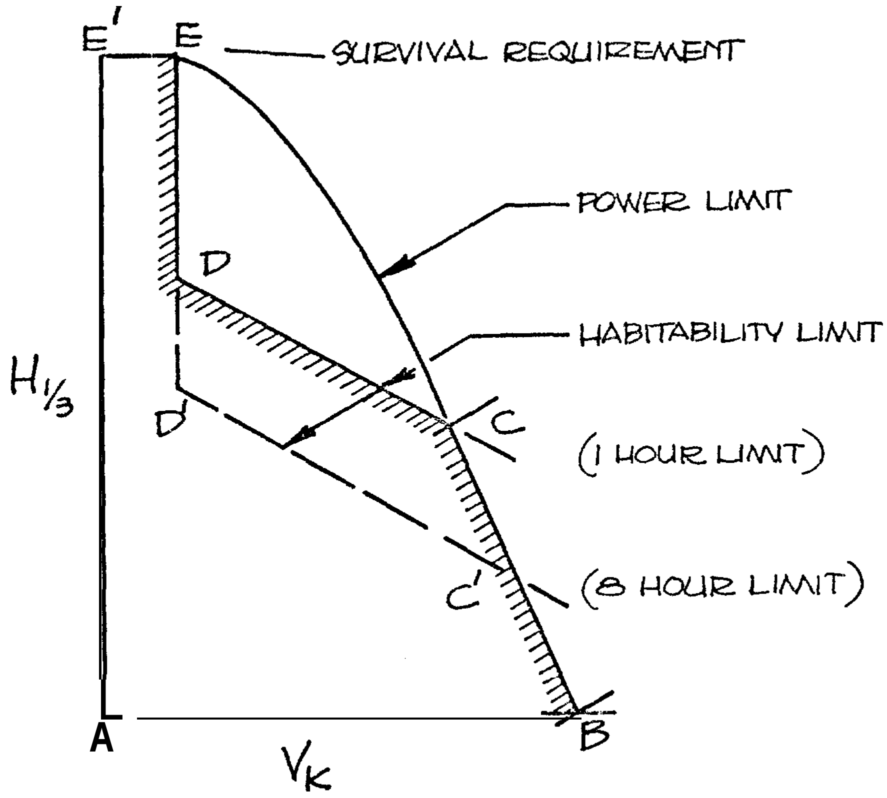


Figure 31 - Typical Speed/Wave Height Envelope (U)

3) The pitch and heave motions of a planing hull in a seaway are usually largest in the displacement mode of operation, particularly when the wave encounter period is equal to the natural pitch and/or heave period of the craft. At higher planing speeds, the craft's pitch and heave motions are approximately one-half the low speed motions.

4) Designers have recently been paying attention to reducing the rolling motions at low speeds in order to provide a more stable platform for weapons systems and to improve habitability. Various passive and active stabilization systems have been considered. It has been found that passive systems actually destabilize the craft in following seas. Active fin-stabilized systems have been used with good success at speeds greater than 10 knots when roll stabilization is required. On 65 ft torpedo retriever for example, the roll angle was reduced by a factor of 2 and weapon hit porbability was quadrupled when an active fin-stabilized system was installed. The fin area used was approximately 1% of the waterplane area [39 & 3 j. See also Sections II.A.2,d, p. 94, and II.B.6. p. 172 for further discussion of roll motions.

i. (U) Scaling relationships and accuracy.

1) Model tests of planing hulls in smooth and rough water are conducted on the basis of Froude Number scaling with proper corrections for Reynolds Number. This is identical to that used for displacement ships. Tests are usually made with an unpropelled hull model in smooth water and the propulsion system effects are accounted for separately. Propeller characterization is obtained from published series data or from tests in a variable pressure circulating water channel where cavitation effects can be simulated. Turning characteristics can be evaluated using test data obtained

from captive model tests in a rotating arm test facility [25]. Recent comparisons between model full scale powering and seakeeping for a 65 ft and a 95 ft planing craft have shown very good agreement. [74].

2) There is good correlation between model and prototype spray patterns developed by planing hulls [16].

3) Recently, new formulations for bottom pressure distribution have been developed using experimental data obtained from studies of bottom loads on water-based aircraft and full-scale planing craft [4, 57, 58]. This new procedure is based upon the observation that the pressure distribution for steady state planing and wave impact are identical when normalized on the basis of an "equivalent" planing velocity which accounts for the presence of a vertical velocity component in the impact case. Application of this procedure to CPIC-X has shown good agreement between computed and measured pressure distribution.

2. (U) Directional Stability/Maneuverability/Control

a. (U) Directional stability, maneuverability and control have received little research attention during the entire period of planing hull development, although there have been rotating arm tests on specific hulls to enable performance predictions to be made. Nevertheless, there is currently no published procedure for estimating the hydrodynamic derivatives required for a reliable prediction of coursekeeping stability, longitudinal stability and turning.

b. (U) 1) Directional instability has not been a serious problem. In the low speed range, the craft may be statically unstable on course because the bow has not yet trimmed up. However, with active rudder control, the craft can be made dynamically stable. In the planing speed range, when the' craft has positive trim, the boat usually has static and dynamic stability. If instability does exist at planing speeds, it is easily eliminated by increasing the skeg area at the expense of a minor increase in drag.

2) Directional control rudders are either mounted flush under the hull bottom, or stern-mounted in a surface-piercing position, are of such size and vertical location to develop adequate coupled yaw and roll moments to cause the boat to heel into the turn, and are located in the wake of the propellers whenever possible. High speed turning diameters are in the order of 10 times the boat length, and are mainly dependent on the rudder characteristics. In the displacement speed range, the turning diameters are considerably less -- especially for twin propeller installations where asymmetric thrust can be used to assist turning. An important hydrodynamic consideration in rudder design is to avoid cavitation and ventilation of these control surfaces if high speed tight turns are to be achieved. Chord-

wise fences on the stern mounted rudders can prevent ventilation; cavitation inception is delayed to higher speeds by the traditional means of reducing rudder thickness and lift coefficient.

3) Because of the usual roll-yaw coupling, a roll bias due to unbalanced engine torque on narrow beam planing hulls (e.g., when all propellers are of the same hand, as on CPIC-X) can require some rudder deflection in order to keep the boat on straight course. The addition of a fixed trailing edge tab on the outboard edge of the transom will provide a roll moment to counter this engine torque, avoiding the necessity for rudder deflection to maintain a straight course.

c. (U) Longitudinal instability (porpoising) has not been a serious problem. If it does occur, it can be corrected by means of trim flaps or forward movement of the center of gravity.

d. (U) Control of motions in a seaway is an area requiring further analysis. This is especially desirable in the case of roll motions where inherent hydrodynamic damping is low. The subject of roll motions is covered in detail in Section II.B.6 beginning on p. 202 which presents extensive full scale trial data taken from [3]. Brief excerpts follow: The roll fins which have been tested have a total planform area of approximately 1% of the waterplane area. This provides almost no damping at very low speeds, but is sufficient for very effective damping at speeds between 10 and 25 knots. Reference [39] documents the 4-fold increase in hit probability experienced on a 65 ft torpedo retriever when stabilized by active fins. Reference [3] documents the reductions in roll amplitude and rate achieved by use of the active fins on the 100 ft CPIC-X. In general, use of the fins reduces roll motions by 50%. Under some conditions the reductions are greater: e.g., in bow quartering seas at 23 knots the average 1/10 highest roll, double amplitude, was reduced from 20° to 5°. The improvement in crew habitability is obvious.

3. (U) Intact and Damaged Stability

a. (U) Floodable Length. (See also subparagraph b. on p. 183)

A "two compartment" standard of subdivision is an objective in hull design, although difficult to attain in smaller (under 100 ft) hulls. This "two compartment" capability allows for the simultaneous flooding of two adjacent compartments without submerging the margin line. The margin line is generally considered to be three inches below the sheer.

b. (U) Intact Stability.

Determination of intact stability adequacy is based on the following considerations and criteria:

1) Beam Winds Combined with Rolling. The wind heel calculations are based on a wind velocity of 60 knots for design considerations and 50 knots for vessels in service. (This criterion dictates that the craft be recalled to protected harbors in the event that winds in excess of 40 knots are anticipated.)

2) Lifting Heavy Off-center Weights. The heeling result of hoisting heavy loads over the side is a significant consideration in determining stability adequacy of such craft as torpedo retrievers, workboats and other craft with a lifting capability. Maximum allowable heel ± 15".

3) Crowding of Passengers to One Side. This consideration is applicable only to personnel boats, utility boats and other personnel carrying cr craft. Maximum allowable heel ± 15°.

4) Heeling Arms Produced in High Speed Turns. This consideration,

dictated by the centrifugal force exerted on the hull during a high speed turn, is applicable to all high speed planing hulls. The heel maxima allowed are 10" for design, 15" for service. (Note: A properly designed planing hull will bank inboard on a turn, obviating this requirement.)

5) Depending on the mission and operating environment of the craft, other considerations such as topside icing, are to be investigated and allowed for.

c. (U) Damaged Stability. Until now small combatant craft have rarely been designed with longitudinal subdivision and therefore unsymmetrical flooding is seldom a problem. Reserve buoyancy is the major consideration. For smaller personnel-carrying craft, polyurethane flotation foam is installed to maintain the hull upright and enable it to maintain a 30" range of stability in the damaged condition.

d. (U) The subject of intact and damaged stability is discussed in detail in [42].

4. (U) Materials

a. (U) Three groups of materials have been found to be practical for high performance planing hulls:

1) Marine Aluminums (primarily 5000 Series)

2) Glass Reinforced Plastics (GRP)

3) Mild Steel and High tensile Steel

The primary factors in selecting a specific aluminum alloy are usually yield strength and availability. Glass reinforced plastics (GRP) can be designed with widely varying properties but strength, deflection and cost are the primary factors in selecting a GRP laminate. Steel is selected when weight is not an overriding factor, since the cost advantage can be substantial.

b. (U) Other materials that find specialized uses are:

1) Stainless Steels

2) Bronzes

3) Monels

4) Advanced Composites (primarily Graphite Reinforced Plastic)

The principal uses of these materials are in secondary structure and/or in other craft systems. Table 5 shows the general area of application for the materials.

c. (U) Basic physical characteristics of these materials (with the exception of the reinforced plastics which depend on laminate design) are readily found in available literature. A good reference for aluminum properties is "Aluminum Afloat" [43]. More detailed information on aluminum, high strength steels and stainless steels including fatigue data, may be found in a report by Morton and Kelly [44]. Bedford and (Gross [45] deal with materials selection for propellers and give good guidance based on actual experience. Graul and Fry [46], treat the practical aspects of material selection and fabrication for metal planing hulls, including problems of galvanic corrosion.

d. (U) The most likely material for general use is weldable marine aluminum (5000 series). It is the only material that can produce a structural weight low enough to make very high performance designs feasible at reasonable cost. However, it does have disadvantages which can limit its use. Table 6 lists advantages and disadvantages of aluminum, GRP, and steel.

e. (U) Figures 32 and 33 also compare GRP, steel and aluminum. Figure 32 shows structural weight variation with ship overall length for the three materials. This was taken from the paper by Sharples [47]. Approximate

TABLE 5 - MATERIALS AND AREAS OF USE IN PLANING CRAFT (U)

MATERIAL	AREA OF APPLICATION								
	Hull-Plating & Decking	Bulkheads	Super-Structure	Foundations	Masts	Shafting	Propellers	Appendages	Fittings
Marine Aluminum	X	X	X	X	X			X	X
Glass Reinforced Plastic	X	X	X	X	X				
Medium and High Tensile Steels	X	X		X					
Stainless Steels						X	X	X	X
Bronzes							X		
Monel						X			
Advanced Composites					X				

TABLE 6 - CHARACTERISTICS OF CANDIDATE HULL MATERIALS (U)

MATERIAL	ADVANTAGES	DISADVANTAGES	COMMENTS
ALUMINUM ALLOYS	(1) High strength/weight ratio particularly for the newest alloys. (2) Easily formed. (3) Not subject to corrosion when proper galvanic protection is employed. (4) Fewer maintenance requirements. (5) May be left unpainted. (6) May be cut with wood working tools.	(1) Since the marine aluminums are work hardened to achieve their strength, welding significantly reduces their yield strength due to the annealed "heat affected zone". (2) Unprotected aluminum in sea water has no fatigue "endurance limit". (3) Has lower resistance to cracking than does steel. (4) Poor fire resistance (5) Has a high thermal conductivity (more insulation is required). (6) It is more costly. (7) Since highly skilled welders are required, the number of construction and repair facilities are limited, field repairs generally are more difficult.	Aluminum is presently considered the only practical material for fabrication of high speed planing craft in the 50-foot plus length range, until the larger tonnages (500-600 tons) where steel may become competitive.

Table 6 (Cont'd)
CHARACTERISTICS OF CANGIDATE HULL MATERIALS (U)

MATERIALS	ADVANTAGES	DISADVANTAGES	COMMENTS
MILD STEEL, HIGH TENSILE STEEL (HTS)	(1) Easily welded, flame cut, and formed. (2) Construction and repair capability widely available. (3) Good fatigue life. (4) Good fracture toughness. (5) Fire resistant. (6) Least costly of all	(1) While HTS has a similar strength/weight ratio to the typical marine aluminum alloys, this strength cannot be utilized in a small craft due to minimum gage constraints and therefore the hull is heavier. (2) Is subject to corrosion, which leads to significant maintenance requirements.	While high tensile steels offer improved strength/weight ratios, they can only be used efficiently in larger ships (500 tons), when high speed is also a requirement. Since minimum gage, not strength is governing for smaller ships (150-500 tons mild steel would be used almost exclusively.
GLASS REINFORCED PLASTIC (GRP)	(1) High strength/weight ratio. (2) Not subject to corrosion. (3) Least costly of all materials when built in large quantities, and the hull size is small. (4) Few maintenance requirements. (5) Easily repaired. (6) Good elastic impact resistance. (7) Low thermal conductivity. (8) Non-magnetic. (9) May be used in hybrid construction such as foam core sandwich at increased cost.	(1) Fatigue strength varies with laminate design and care in fabrication. (2) Material properties can vary with the skill of the laminators. (3) Generally lower toughness than metals. (4) Large local delaminations can extend under high stress. (5) Secondary bonds a problem area. (6) Poor fire resistance. (7) Low elastic modulus restricts use to smaller craft.	Glass reinforced plastic is currently considered to be the optimum material for the construction of high speed planing craft up to 50' in length.

[redacted] [redacted]

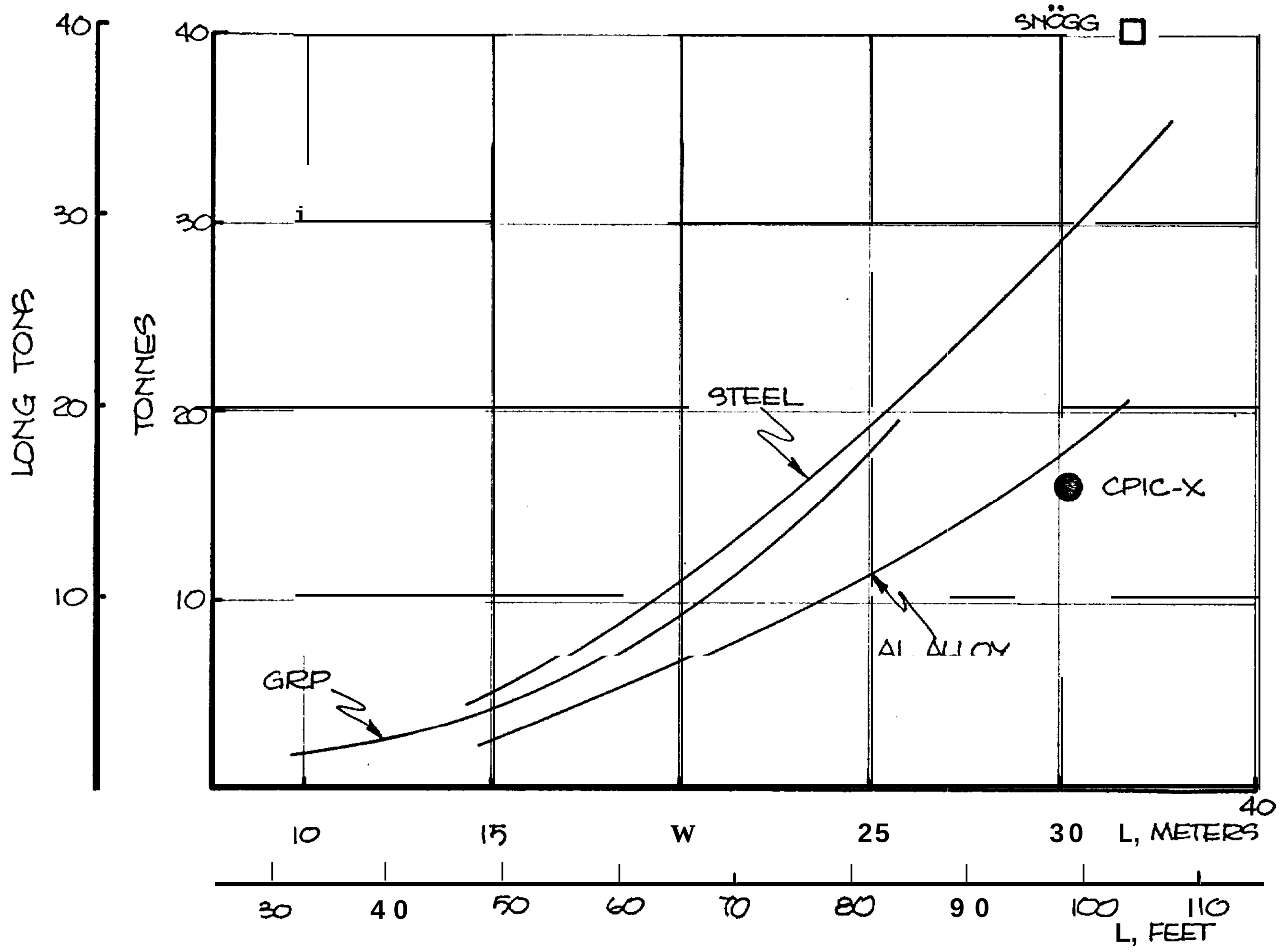


Figure 32 - Weight of Hull and Deck vs: Overall Length [32] (U)

[redacted] [redacted]

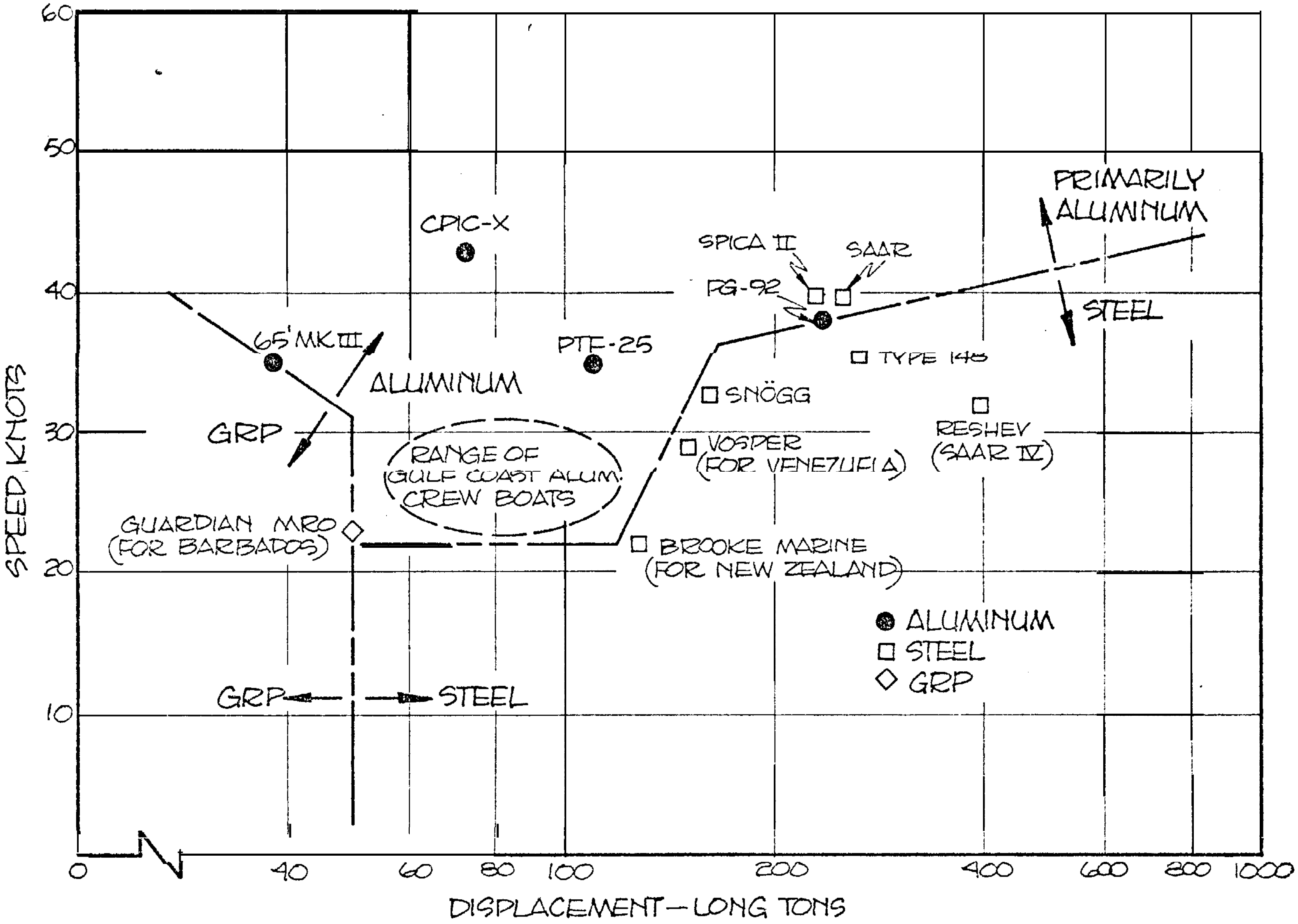


Figure 33 - Hull Materials Selected for Various Speed/Displacement Regimes U)

(See Table 2 for characteristics of vessels plotted above) data for the Norwegian "SNÖGG" class and the U.S. Navy developed Experimental Coastal Patrol and Interdiction Craft (CPIC-X) are shown for reference. It is noted that Sharples recommends that either steel or GRP be used, but not aluminum. His objection is primarily one of cost, with effects of fire also a consideration. Figure 33 shows various hull materials selected versus displacement and speed. The large foreign built hulls are exclusively steel, for which they pay a weight penalty. However, other considerations outweigh their need for weight savings. These steel hulls are also on the limits of steel fabrication with hull thicknesses often forced into the range of 3/16" to 1/4". These hulls use aluminum superstructure almost exclusively. See p. 131 for further discussion of aluminum vs. steel construction.

f. (U) While large, high speed aluminum ships have not been built, the state-of-the-art is such as to allow construction of experimental prototypes at reasonable risk. This risk is reasonable because of experience gained in the following ways:

- in-service performance of the PG's
- the extensive testing of the PTF-25 and Experimental CPIC-X
- on-going research programs such as the Advanced Surface Ship Structural Evaluation Program [48], in which an 85 ft aluminum model will be extensively fatigue tested.

5. (U) Structures

a. (U) The major reason for improving structural design for planing hulls can be directly or indirectly traced to one factor; the percentage of the full load displacement required for hull structure, i.e., hull weight. While this may seem to be an extreme position, it is nevertheless true. Structural weight interacts with several design factors as follows:

TECHNOLOGICAL PERFORMANCE FEATURES

- Speed/Wave Height Envelope

The first requirement is usually a set of speed/sea state conditions which determine the severity of loading experienced, and hence the strength (and weight) of the structure.

- Useful Load/Range

If structural weight is reduced more weight can be allocated to military payload and/or fuel.

- cost

If the structure must weigh less than a given limit to achieve platform feasibility, then greater cost can be tolerated, at least to the point where the entire concept becomes impractical. Conversely, if weight is not as important, cheaper methods of construction can be used.

- Reliability/Maintainability

The builder of commercial boats will design his structure as conservatively (a synonym would be heavy, in most cases) as the operator's requirements will allow, for he cannot afford a recall or expensive costs of upkeep. A military boat on the other hand can tolerate some damage and inconvenience, provided the payoff in performance made possible by the lighter structure justifies it. This does not mean that military craft are inherently unreliable,but the risk allowed to achieve performance is certainly higher.

- Survivability/Vulnerability

This is primarily a factor for military craft, but it (as well as cost) is probably the major reason why designers will accept a weight penalty to build a hull from steel rather than aluminum. In other cases, where the feasibility of the platform depends on low weight, safety and survivability must be traded off, or other subsystems must be devised to protect the ship. This of course adds some weight and substantial cost.

b. (U) Quantitative values are impossible to attach to these factors. Nevertheless Figure 34 attempts to qualitatively show the trends that are operative for three general types of craft. It shows a trend of rapidly increasing loadings with increased severity of operational requirements which add to the difficulty of producing an acceptable structure.

c. (U) Influence of Structural loads on Scantling Selection.

The single most influential factor affecting the ease of structural design is the loading the craft will experience. Figure 35 shows the general type of loadings that must be considered in the course of a structural design. Though there are many to be considered, in actuality only a few will heavily influence the structural design. These are noted by the numbered squares. The numbers indicate, in general, the priority of influence exerted on the design. Underwater explosion, wave impact and hydrostatic loads are the most critical induced loads. The second most critical structural loading, inertial, results from hull accelerations due to sea state. Cascading waves (e.g., green water falling on the bow) and weapon firing loads apply mostly to the topsides, deck, and superstructure.

d. (U) Predictive Methods.

1) Methods and data for predicting loadings on planing hulls are generally available and sufficiently accurate for use in new designs. Much of this information was developed through R & D efforts in the past 5-6 years. Although further effort is required to extend our knowledge to unexplored areas, it should be noted that the data base is well established.

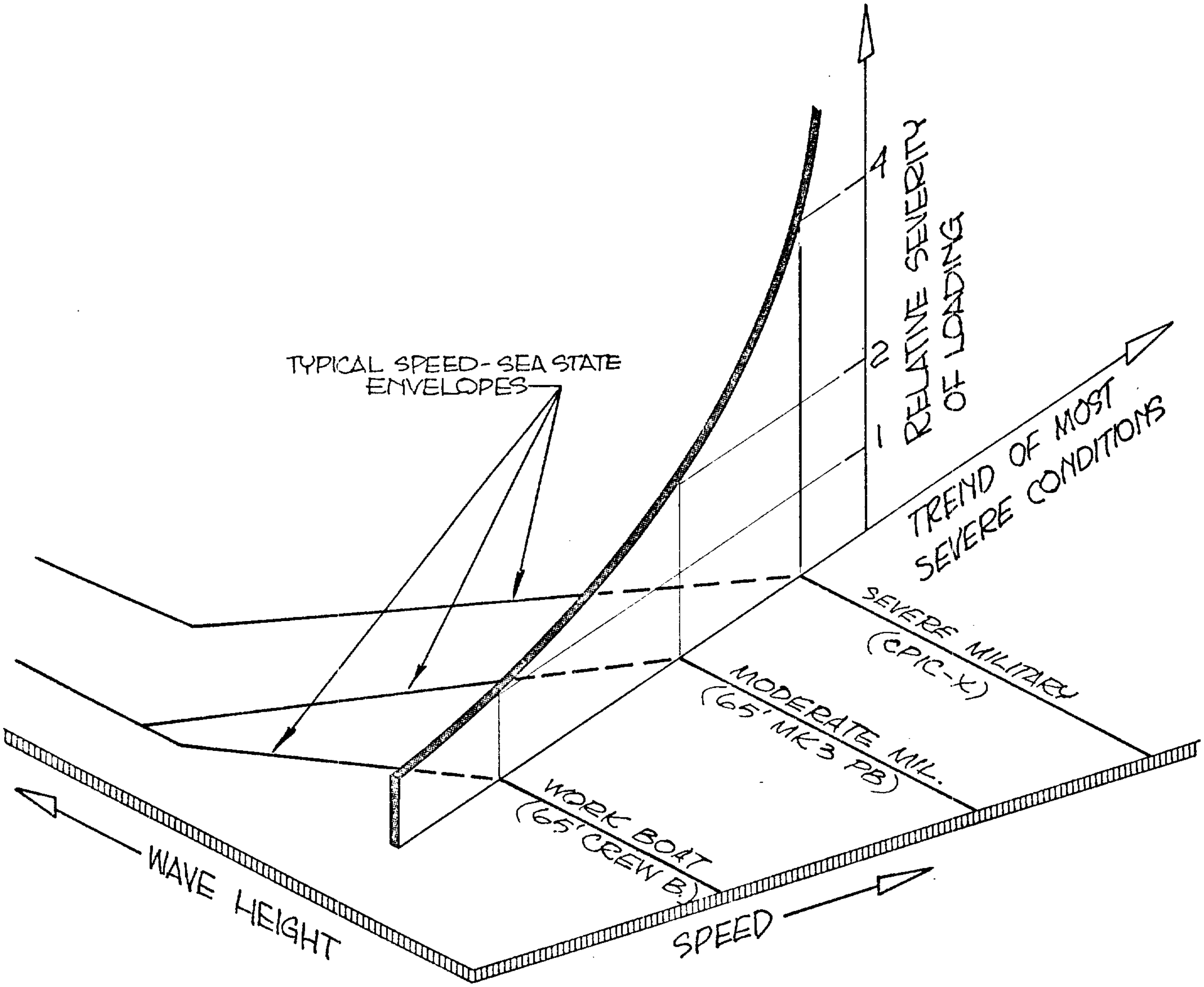
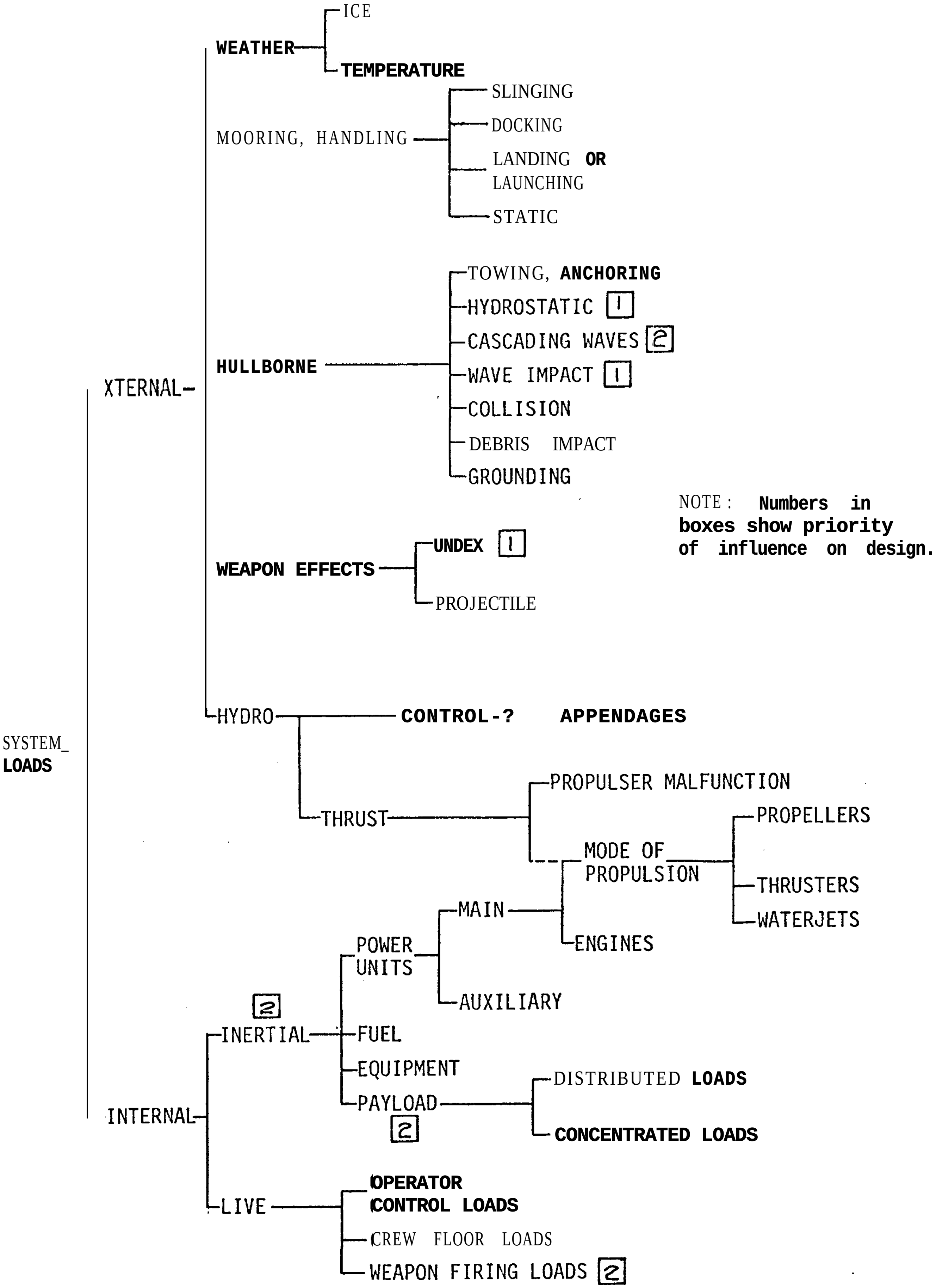


Figure 34 - Sea State-Speed Operation Interactions (U)



NOTE: **Numbers in boxes show priority of influence on design.**

Figure 35 **- General** Load **Diagram-Planing Hulls** (U)

2) The methods used to determine loads for scantling selection tend to vary in complexity with the severity of the requirements. Figure 36 illustrates this from a displacement/length point of view. Interestingly, the figure shows that loadings do not always play a major role:, since minimum fabricable thicknesses are still a consideration for a large segment of the fast patrol craft population. This is especially true for steel construction.

3) Figure 37 shows the general methods used to determine either loadings and scantlings, or both simultaneously, for various tonnages and speed requirements. It should be noted that many of the methods do not require loadings per se, to select the proper scantlings. These "rules of thumb" [43,46] have been developed empirically over the years to the point where the number of failures has reached an acceptable level. There is nothing wrong with this approach and the methods must be considered good design for the craft to which they are applicable. However, the use of these rules tends to produce a heavy hull, which while allowable for the commercial craft, cannot be tolerated for higher performance military craft. Examples of bottom and side scantlings derived from rules of this type are given in Figure38 for steel construction and Figure 39 for aluminum construction. The aluminum scantlings are compared with the actual scantlings of the MK-1 PCF, the PTF-25, the 65 ft MK 3 PB, and the CPIC-X. The MK-1 PCF reflects standard practice, the PTF-25 and the MK 3 PB are somewhat less conservative, and the CPIC-X is well outside the rules for these hulls. This is not surprising, because the CPIC-X was designed based on expected loadings specific to that hull, not on a general rule basis. The methods used for CPIC-X involved model tests and the Heller-Jasper [49] method for

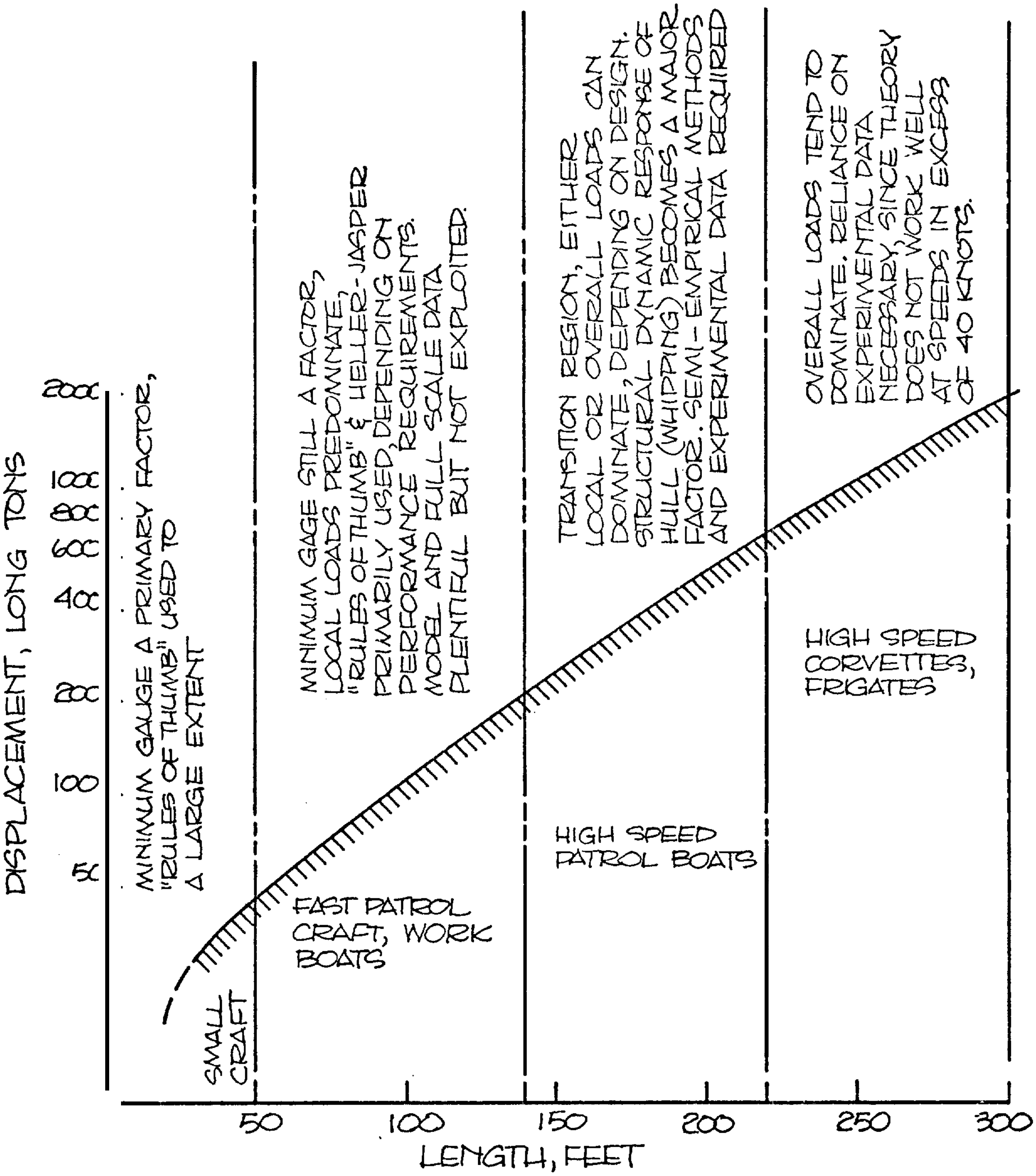


Figure 36 - Governing Factors in Hull Scantling 'Selection (U)

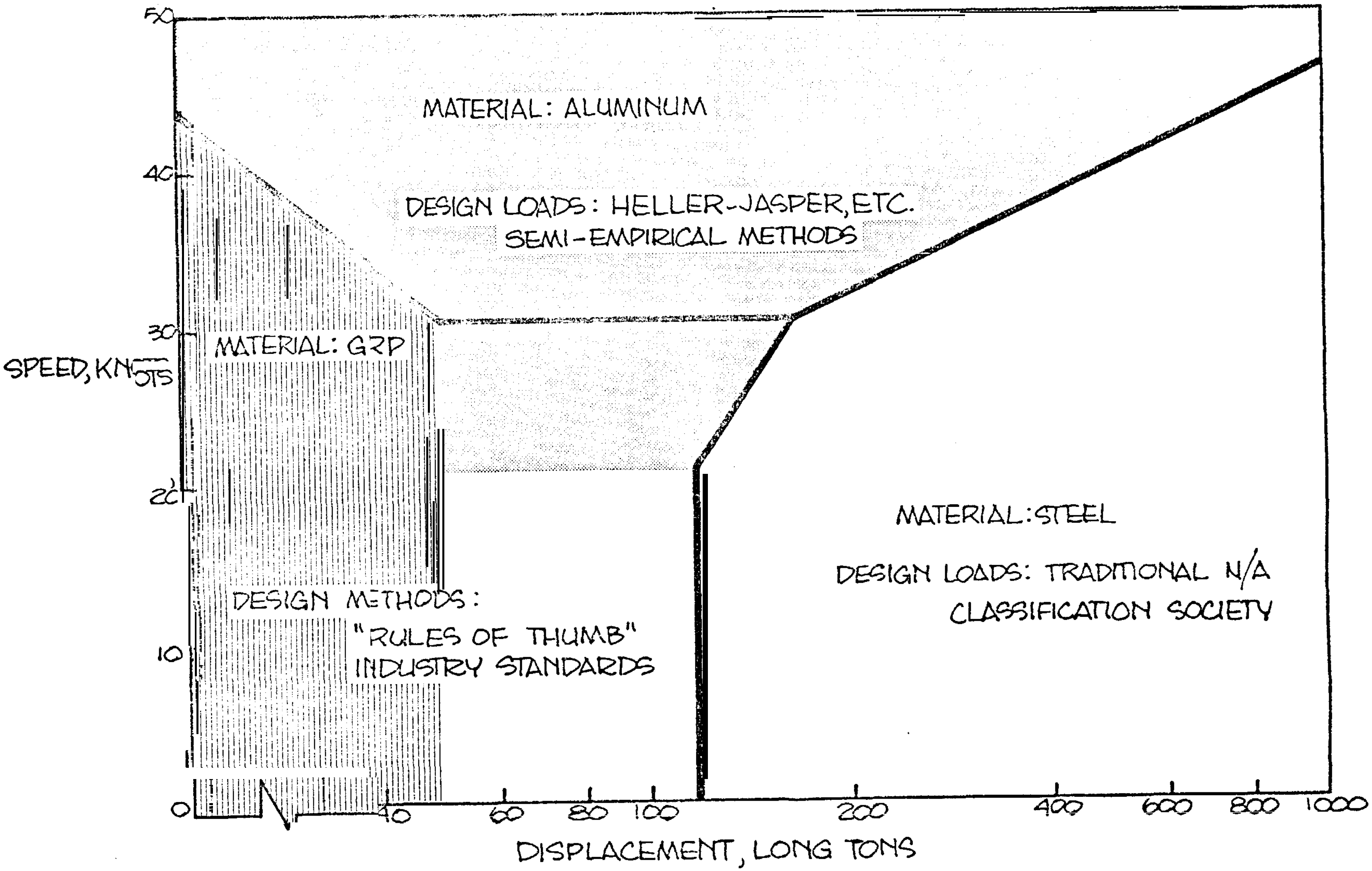
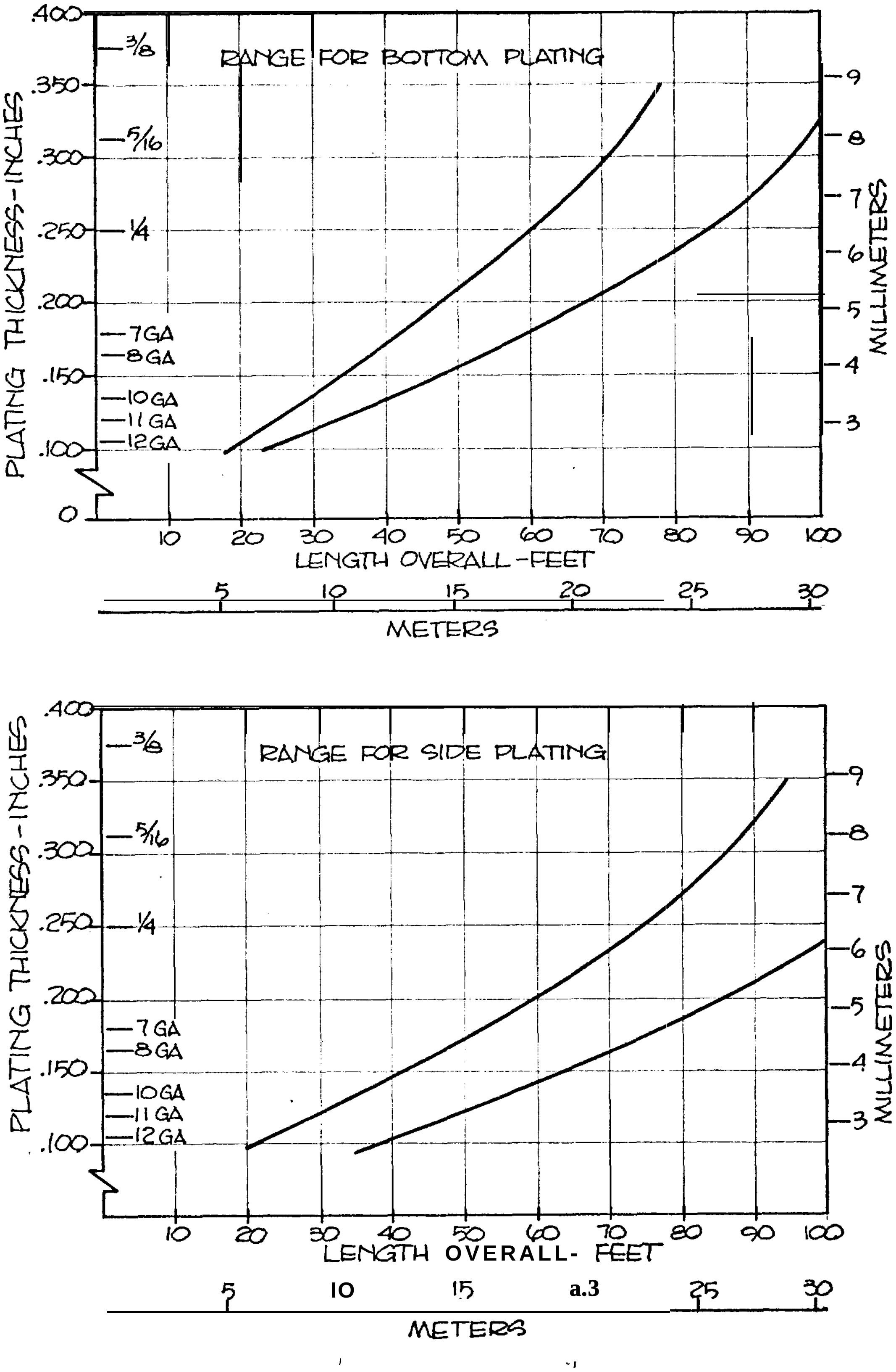


Figure 37 - Methods Used to Select Design Loads and Scantlings (U)



NOTE:
AFTERMOST 10-20% OF HULL BOTTOM PLATING SHOULD BE ONE THICKNESS INCREMENT HEAVIER

Figure 38 - Recommended Plating Thicknesses for Steel Hull Plating [31](U)

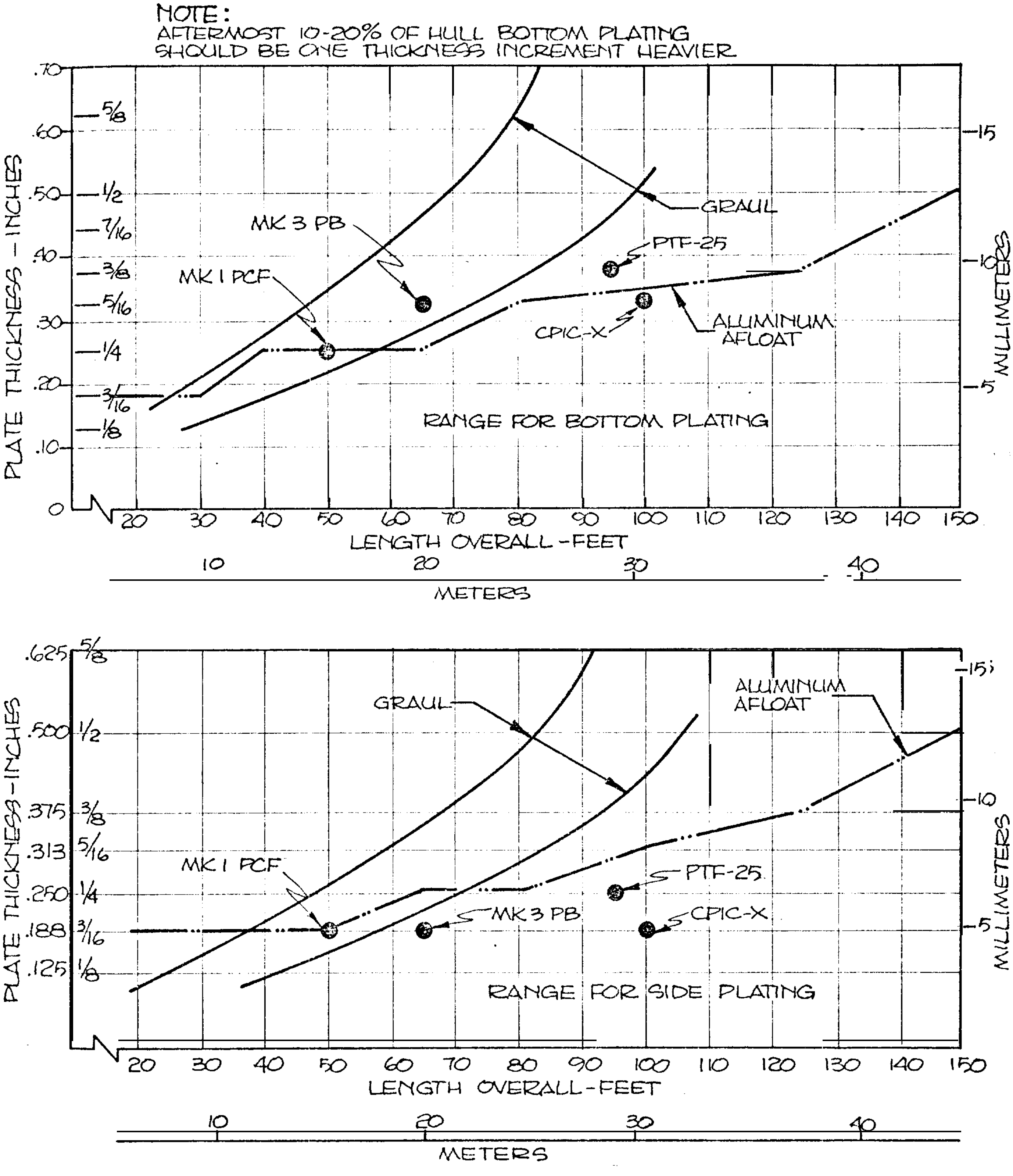


Figure 39 - Recommended Thicknesses for Aluminum Hull Plating [28, 31] (U)

predicting loads. As is noted in Figure 37 , the higher speed craft must rely more on experimental data, semi-empirical design methods such as He Heller-Jasper, and on other methods such as Jones, Allen [50], and Spencer [51]. These methods should produce good-to-excellent results except in the higher lengths and tonnages.

4) For the higher length and tonnage standard naval architectural practices such as those of the Classification Societies [52,53] and Navy standard practices [54] will suffice as long as high speed (30+ knots) and severe structural weight fraction restructions are not required. If the latter constraints are imposed, one must use experimental data and theoretically or empirically developed equations in addition to the standard methods.

5) As mentioned previously the "rules of thumb" [43,46] and classification rules [52,53] do not in general develop loadings as a recognizable output. The other methods, however, develop loadings to varying extents; the Navy method as outlined in the various Design Data Sheets (DDS) probably provides the broadest coverage. Table 7 outlines three specific methods that are useful for higher performance hulls. Of the methods outlined, Heller-Jasper, modified by the use of newly acquired experimental data, is most generally applicable until arger tonnages are reached. Note that several of the references are repeated, as they are equally applicable to all methods.

e. (U) Influence of Vertical Acceleration on Hull Design.

1) Since all of the methods proposed in Table 7 rely on values of acceleration to varying degrees, it would be well to explain the significance of the parameter to design. Acceleration heavily influences three areas:

TABLE 7 - THREE METHODS FOR DEVELOPING STRUCTURAL LOADINGS. (U) .

HELLER-JASPER METHOD

REFERENCE FOR THEORY:

Heller, S. R. & Jasper, N. H., "On the Structural Design of Planing Craft," Quarterly Transactions of the Royal Instituion of Naval Architects, July 1960 [49]

PRIMARILY DEVELOPED FROM:

Data gathered from the trials of the YP-110 and reported by Jasper in "Dynamic Loading of a Motor Torpedo Boat (YP-110) During High-Speed Operation in Rough Water," NSRDC Report C-175, September 1949, (Now Unclassified) [37].

APPLICABILITY:

Simple, direct method for finding pressures and hull bending moments for any planing hull form with reasonable deadrise and length to beam ratio

REQUIRED INPUT:

Basic craft characteristics such as length, bean, displacement, and the accelerations at the center of gravity and the bow (or stern)

OUTPUT:

Provides local effective design pressures for plating, stringers, and frames. Also gives longitudinal bending moment, and suggests safety factors

COMMENTS:

(1) Straight forward method, easy to use, well accepted by the design community.

(2) Accelerations must be determined by model test, by estimation methods (usually semi-emperical), or by arbitrary selection (limit of tolerance of crew a good example).

(3) Longitudinal pressure distribution factor becomes conservative as the length/beam ratio increases beyond 4.0.

(4) Predicted longitudinal bending moment due to impact is quite conservative.

(5) Very accurate for predicting pressures on plates and stringers but frame design pressures are excessively conservative.

CORRELATION:

(1) The fact that the Heller-Jasper has been used with success for a number of years is a testament to its predictive ability.

(2) Also, the Heller-Jasper method was extensively compared with data recorded during recent trials of the CPIC-X, and generally good agreement was found. The results are documented by Critchfield, Jones, and Allen in "Combined Full Scale-Model Analytical Evaluation of the Coastal Patrol Interdiction Craft (CPIC-X) Hull Structure,'* (U) NSRDC Report C-4725, December 1975 (CONFIDENTIAL) [56]

Table 7 (cont'd)

JONES-ALLEN METHOD

REFERENCE FOR THEORY:

Jones, R. R. and Allen, R. G., "A Semi-Emperical Computerized Method for Predicting Three Dimensional Hull/Water Impact Pressure Distributions and Forces on High Performance Hulls," NSRDC Report COOS, Dec 1972. [50]

PRIMARILY DEVELOPED FROM:

Rigid hull model data, other earlier semi-emperical methods developed for V shaped prismatic wedges, and classical theory. Some further background is provided by the report by Gray, Allen and Zones, "Prediction of Three-Dimensional Pressure Distributions on V-Shaped Prismatic Wedges During impact and Planing," NSRDC Report 3795, February 1972 [57]

APPLICABILITY:

The basic tool of this method is a computer program,' IPPRES. The program allows any form of hull and will produce detailed pressure versus area or load versus area relationships, plus the tonal load on the craft. Any impact situation can be handled provided the initial conditions just prior to impact are known. The program is most valuable for more novel hull forms where simplified methods cannot be utilized with confidence.

REQUIRED INPUT:

Molded lines of the hull at various stations, hull immersion depth, trim angle, linear and angular velocities, position of the hull with respect to the wave, and characteristics of the wave.. Hull displacement and acceleration is not required as an input but one must judge the "reality" of the situation simulated, by the output acceleration from the program, therefore, some knowledge of acceleration is necessary.

OUTPUT:

Detailed pressure/area or load/area relationships for each condition simulated, plus total load and average pressure. The output can be plotted and used to select *scantlings* on a basis of the area involved (such as a plate, a stringer, a panel, or a frame).

COMMENTS:

(1) The method employed by IPPRES is quasi-static in that no inertial terms are involved unless manual feed-back is employed. The reason for this assumption is that the peak impact pressures and loadings usually *occur* before significant deceleration of the hull has begun.

(2) The method solves a number of equations through numerical integration, therefore, its computer time to real time is relatively high. For this reason, it is not recommended for hull types that can be safely modeled by the use of the Heller-Jasper method, or when precise values of loading are not really required. Its major use *is for* novel hull types where there are no available simplified predictive methods.

(3) Since the output will vary significantly depending on the initial conditions selected, considerable judgement must be used by the engineer in selection of initial conditions, and in the interpretation of the results. The results also exhibit behavior similar to the Heller-Jasper method, in that the degree of conservatism tends to increase with increasing design area as a percentage of hull area. However, it is a reasonably accurate method (through conservative) and can predict pressures and loads for hull shapes for which no other method is readily available.

CORRELATION:

The method has been extensively compared with full scale data from the PTF-25 and the CPIC-X and additionally with data taken from a 1/10th scale rigid vinyl model of the CPIC-X. Good agreement was found in all cases, The primary documentation for these comparisons are found in;

(a) Jones, Allen, and Soule', "The Prediction of Hull-Wave Impact Loads on High Performance Marine Vehicles - A Computerized Design Tool,"(U) Proceedings of the Second Ship *Structures* Workshop, Structures for High Performance Ships, February 1973, CONFIDENTIAL [58].

(b) Critchfield, Jones, and Allen, "Combined Full Scale-Model-Analytical Evaluation of the Coastal Patrol Interdiction Craft (CPIC-X) Hull Structure,"(U) NSRDC Report ~~4005~~ 4725, December 1975, CONFIDENTIAL [56].

Table 7 (cont'd)

SPENCER METHOD

REFERENCE FOR THEORY:

Spencer, J. S., "Structural Design of Aluminum Crewboats, Marine Technology, Volume 12, Number 3, July 1575 [51]

PRIMARILY DEVELOPED FROM:

This method is a melding of known methods applied to a set of crewboat characteristics taken fron a survey of Gulf Coast Crewboats. In his method Spencer uses:

(a) For determining running trim - Savitsky, D , "Hydrodynamic Design of Planing Hulls," Marine Technology, Volume 1, Number 1, October 1964. [17]

(b) For determining acceleration - Fridsma, G., "A Systematic Study of the Rough - Water Performance of Planing Boats (Irregular Waves - Part II)" Stevens Institute of Technology, December 1973, [35]

(c) For determining maximum effective pressure - Heller, S. R., and Jasper, N. H., "On the Structural Design of Planing Craft," Quarterly Transactions of the Royal Instituion of Naval Architects, July 1960. [49]

(d) For determining pressure/area distributions - Jones, R. R. and Allen, R. C., "A Semi-Emperical Computerized Method for Predicting Three-Dimensional Hull/Water Impact Pressure," Distributions and Force on High Performance Hulls, NSRDC Report 4005, December 1972. [50]

These separate methods are applied to a generalized set of crewboat data so that parametric variations from the original design point can be made.

APPLICABILITY:

Fairly direct method and is useful for most crewboats and other deep-vee-hulled planing boats constructed of aluminum as long as very high speed is not required (30 + knots). Parametric data is limited to L/B ratios of 4-5 and deadrise angles of 12° - 20°.

REQUIRED INPUT:

Length beam displacement, location of longitudinal center of gravity, design speed, average deadrise, full load draft

OUTPUT:

Design pressures for plates, stringers, frames, and keelsons. Also guidance given for side, deck and bulkhead loadings. A design example is included.

COMMENTS:

(1) The method has the advantage that motions are not required as an input.

(2) Since the procedure was developed around the output of a parametric study, it is limited to the variations originally chosen i.e. L/B = 4 to 5, deadrise angle 12°-20°. Also there is conjecture as to how well the procedure would predict at higher speeds (30 + knots).

(3) The method is useful in that it touches on structural design methods as well as load prediction, particularly with regard to the difficulties that can be encountered by over-extrapoltation of standard crewboat design practices.

CORRELATION:

No direct correlation of this method with full scale data is known, but the data certainly exists for this to be done. This data was acquired during the sea trials of the PTF-2.5 and the CPIC-X, and summaries of the dsta are found in:

(a) Soule', S. B., "Structural Trials of a 95 Foot Aluminum Fast Patrol Boat (PTF-25) (U)," NSRDC Structures Department Technical Note 173-233, December 1972 (CONFIDENTIAL). [4]

(b) Critchfield, Jones and Allen, "Combined Full Scale-Model-Analytical Evaluation of the Coastal Patrol Interdiction Craft (CPIC-X) Hull Structure (U)," NSRDC Report C-~~4125~~ 4725, December 1975, (CONFIDENTIAL). [56].

- Structural Design
- Crew Habitability
- Equipment Design

2) The characteristics of the acceleration are also important. These are:

- The frequency of occurrence (number/minute of operation)
- The magnitude
- The shape of the pulse with time

3) The interactions of these parameters are shown in Table 8. Since equipment is usually less affected than the structure, it was eliminated from the table.

4) The magnitude of the acceleration is the most important. The problem involved is, what is an acceptable upper limit of crew tolerance? Obviously, the crew's frame of reference will change depending on the situation. If they are closing a target, or retreating from an engagement under fire, they will accept more punishment than if they are on a training exercise. Since there is no quantitative data available under these conditions, the best that can be done is to simulate these conditions during sea trials.

5) From observed personnel reactions during the sea trials conducted to date [3 ,4], the limiting value of crew tolerance is thought to be that at which the average of the 1/10th highest acceleration at the C.g. exceeds 1.5g's. Accelerations of this magnitude can only be tolerated for 15 minutes or less. In other words, the crew is primarily concerned with avoiding injuring due to the excessive motions. The maximum accelerations associated with these 1/10th highest levels are in the neighborhood of 3.0 g's, which for a balanced design, should be approaching the elastic structural limits of the hull. For further discussion of the effects of accelera-

TABLE 8 - EFFECT OF ACCELERATION ON STRUCTURE AND HABITABILITY (U)

CHARACTERISTIC OF ACCELERATION	EFFECT ON STRUCTURE		EFFECT ON HABITABILITY	
	ORDER OF EFFECT	REMARKS	ORDER OF EFFECT	REMARKS
Magnitude Of Acceleration	Primary	Maximums usually taken, but other statistical values (such as average of 1/10th highest) can be used, provided factors of safety are adjusted.	Primary	Statistical values (RMS, 1/3, 1/10) are of most significance. Average of 1/10th highest has proved a good estimate from sea trials.
Frequency of Occurence	Secondary	Has an effect on how soon a maximum may be encountered, but not a large effect on the magnitude. Has an effect on Hull Fatigue.	Primary	Most likely has a substantial effect on long term crew fatigue, but no quantitative values available.
Shape of Pulse With Time	Either Primary or Secondary	Effects magnitude of dynamic load factor, and can be a major factor, depending on hull natural frequency.	Probably of Primary Significance	The rate of change of "jerk" seems to be highly associated with crew comfort. But again, no hard data is available.[62]

tion and motion on the crew see Section II.A.7 and II.B.4.

6) The frequency of occurence has a lesser effect on the structure. In general, the time spent operating on the limits of the speed/wave height envelope where impact is most frequent is a rather small percentage of the vehicle's operational profile. As such it has relatively little effect on fatigue failure of the hull structure, even if the stresses are quite large. Also when operating under these conditions, a relatively large number of variations will occur rapidly (large from a statistical view point, i.e., several hundred or more) and therefore the probability of seeing the maximum or a near maximum will also be quite high.

7) However, from a habitability point of view, the crew cannot withstand exposure to these conditions without periodic rest, i.e., during the trials, each run lasted from 10-15 minutes maximum, with a typical 10-15 minute break before another run. At the end of a 4 hour trial period under these severe conditions, the best description of all aboard would be total exhaustion.

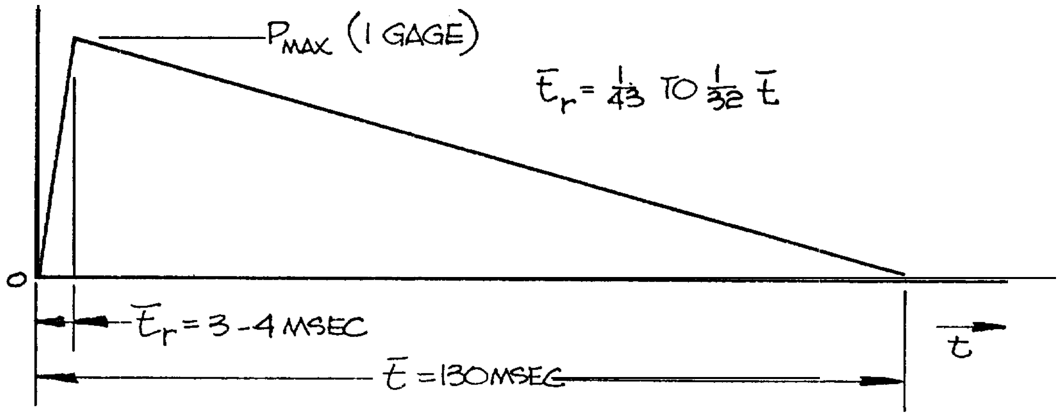
8) The shape of the positive portion of the acceleration pulse is important to the structure because it can affect whether the structure will respond to the load essentially as a static load or as a dynamic load. The general shape of the acceleration pulse is well known and can be adequately modeled by an unsymmetrical triangular pulse, but the values to be assigned to the rise time and duration are not generally available, and of course will vary, depending on hull form. In general, the lower the hull deadrise, the shorter the rise time and duration of the pulse. Individual pressure pulses measured at a point are of the same general shape, but have much shorter rise time and shorter durations. As the individual pressures are

summed instantaneously the result tends toward the shape of the acceleration trace as illustrated in Figure 40, derived from PTF-25 and CPIC-X data.

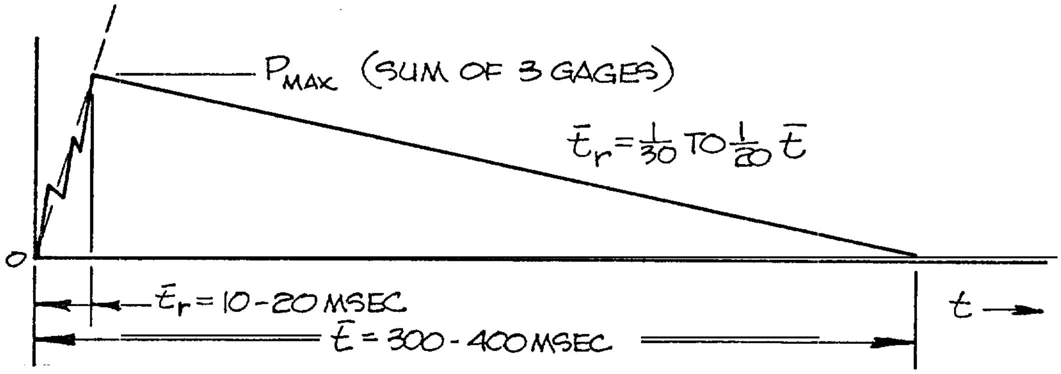
9) If these pulse characteristics can be estimated and if the natural period of the portion of the structure involved is known, then a dynamic load factor (DLF) can be determined. For most planing hulls it will be found that local structure (plating, stringers, panels, frames) will be in a range where the DLF is around 1.0 to 1.1 [49,37]. However, the overall hull girder response can be affected substantially. Fortunately, the most accepted method of design (Heller-Jasper) is very conservative in hull girder load prediction, so this has not been a factor to date.

10) The crew is affected most by initial rise time. Qualitative comments from crew experience would indicate they prefer the more gradual time histories of the deeper-vee hulls such as CPIC-X. The only quantitative measure of the effect on the crew due to this rise time (also the time rate of change of acceleration or "jerk") is found in Dr. Moulton's discussion [62], where it was stated that the higher the "jerk" the greater the fatigue on the crew. From discussing the ride of various hulls with former crew members, one gains the same impression, but again no really quantitative data has been published. Unreduced data is available from both the PTF-25 and the CPIC-X sea trials that could well be of use, but at present there is no funding for pursuing this line of work.

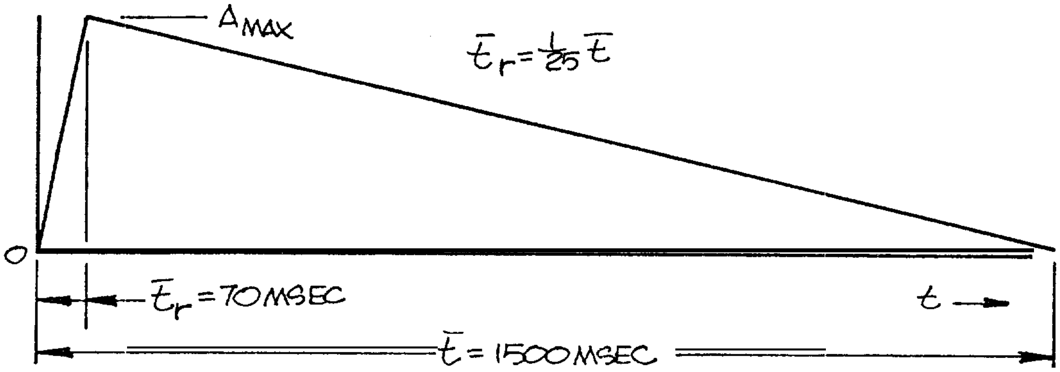
11) In the past, crew habitability had little effect on the hull structural design and almost all hulls could withstand far more punishment than the crew could inflict. This occurred because the lower deadrise and lighter beam loadings of the older designs caused them to generate high vertical rigid-body accelerations compared to the newer designs which have



TYPICAL PRESSURE PULSE CHARACTERISTICS DERIVED FROM PTF-25 DATA



TYPICAL SUMMED PRESSURE PULSE CHARACTERISTICS (FROM CPIC-X DATA)



TYPICAL ACCELERATION PULSE CHARACTERISTICS (FROM CPIC-X DATA)

Figure 40 - Typical Loading Pulse Shapes for Large Planing Hulls (U)

greater deadrise and heavier beam loadings. The newest designs such as the prototype CPIC-X in particular, are more balanced in that they are lightly enough constructed that a very determined crew can approach the structural elastic limits of the vehicle. This philosophy should be continued since it makes for a more efficient overall platform design.

f. (U) Methods of Predicting Accelerations for Use in Structural Design.

1) There are three basic approaches to selections of a value (or values)of acceleration for use in design, these are:

- Conduct model tests
- Use one of several empirically derived methods
- Select a value (or values) based on past experience

All have merit depending on the situation. Obviously, model testing is the best approach if one is preparing to construct a substantial number of hulls, since model tests would be a small portion of the cost. On the other hand, if only a feasibility study is required a value based on experience, or some other empirically derived method will probably be the approach selected. Empirically derived methods for-determining acceleration have. been presented by Roper, [63], Fridsma [64], and Savitsky and Brown [36]. The equations presented by Savitsky* are as follows:

a) Average Impact Acceleration at C. G. and bow, g units.

$$\bar{n}_{CG} = 0.0104\left(\frac{H_{1/3}}{b} + 0.084\right) \frac{\tau}{4} \left(\frac{5}{3} - \frac{\beta}{30}\right) \left(V_K/\sqrt{L}\right)^2 \frac{L/b}{C_A}$$

Note: Precision ± 0.2 g

$$\bar{n}_{Bow} = \bar{n}_{CG} \left[1 + \frac{L/b - 2.25}{V_K/\sqrt{L}} \right]$$

Note: Precision ± 0.2 g

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[*] See footnote, next page.

where:

$\bar{n}_{CG}$ = average acceleration at the center of gravity, g-units

"bow = average acceleration at the'bow, g-units (at 0.9 L forward of transom)

$H_{1/3}$ = significant wave height in ft

b = chine beam, ft

τ = Trim angle of the planing surface in degrees

β = Deadrise angle in degrees

L = Length on waterline in ft

V = Speed in ft/sec

C_Δ = Load Coefficient = $\Delta/wb_x{}^3$

A = Displacement in pounds

b_x = Maximum beam at the waterline in ft

w = Weight density of water in pounds per cubic foot

NOTE :

Savitsky also states that the average $1/N^{th}$ highest

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* Since the equations for added resistance and acceleration are empirical and based on limited data, it is necessary to respect the range of applicability. Extrapolation beyond these limits is unjustified.

Range of Applicability

Parameter	Range
$\Delta_{tn}/(.01L)^3$	100 - 250
L/b	3 - 5
Trim, degrees	3 - 7
Deadrise, degree	10 - 30
$H_{1/3}/b$	0.2 - 0.7
$V_K/\sqrt{L}$	2 - 6

acceleration, $\eta_{1/N}$ is related to the average acceleration $\bar{\eta}$: $\eta_{1/N} = (1 + \log_e N)$

Therefore, 1/10-highest acceleration is 3.3 times the average acceleration.

b) A more pragmatic approach is presented in Figure 41. In this case acceleration data developed from model tests [26, 56, 65] and full scale tests [37,49,56,4,66] have been plotted versus a wave height displacement factor. This method was first used by Silverleaf [67] and more recently by Buck et al [68].

2) The advantage of this approach is that one needs very little information to proceed. The range of applicability is as follows:

(1) It should only be used for vehicles with L/b greater than 4-5.

(2) The beam loading (Δ/wb_x^3) should be greater than 0.20.

(3) The deadrise should be 15 to 25 degrees.

(4) The acceleration will obviously vary with speed. The curves shown are good for a range of 35 - 45 knots.

3) These requirements do not pose a great problem since most good ocean capable planing hulls will fall within these guidelines. The curves of Figure 41 can also be written in equation form. These are as follows:

Average of the 1/10th highest accelerations at the center of gravity:

$$\eta_{1/10} = [H_{1/3}/\Delta^{1/3}]^{1.6}$$

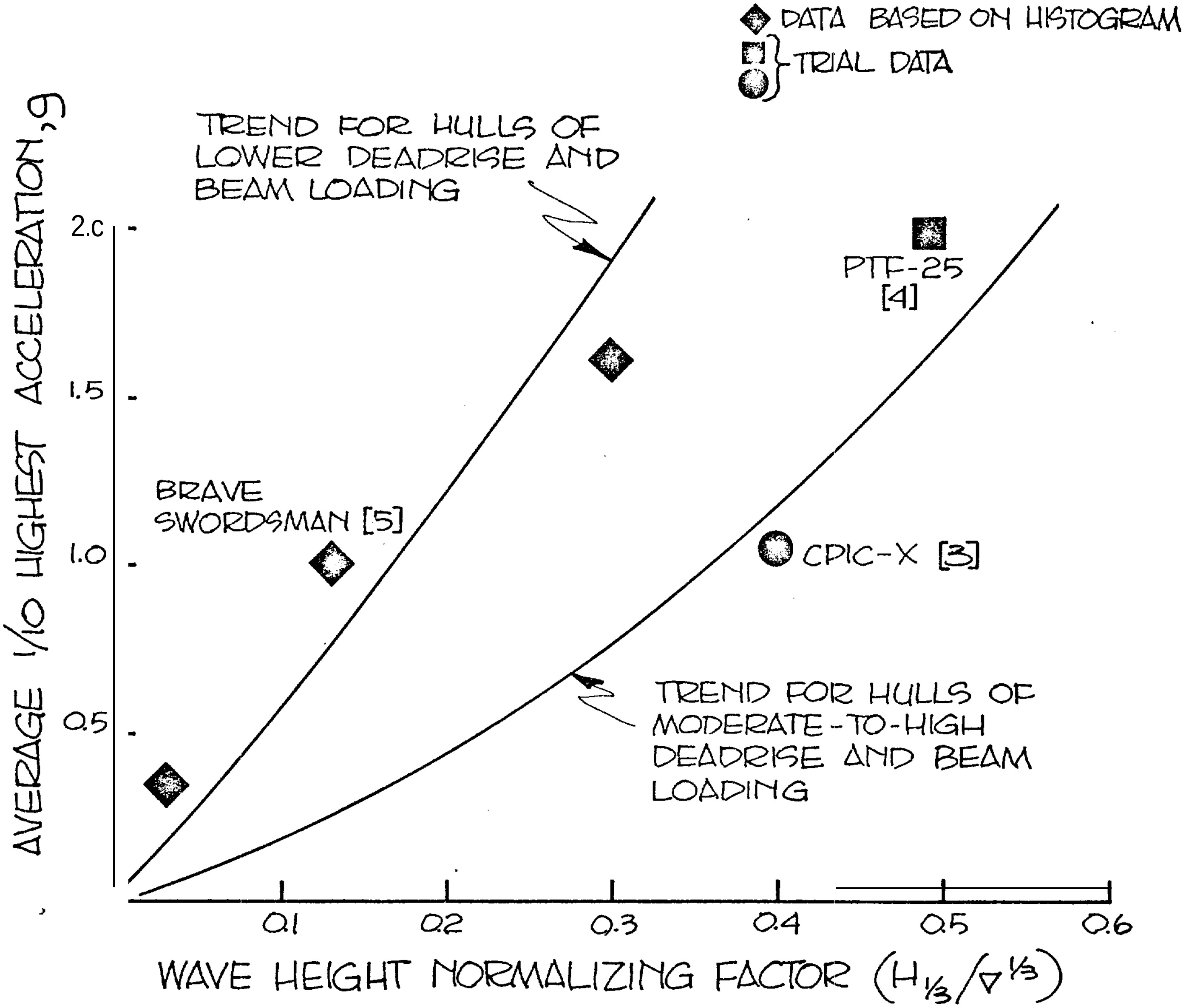

Figure 41 - CG Accelerations for Planing Hulls, $F_{n\nabla} \approx 3$ **(U)**
(Repeat of Figure 6)

The maximum* acceleration at the center of gravity

$$\eta_{\max\ CG} = [H_{1/3}/\Delta^{1/3}] + [H_{1/3}/\Delta^{1/3}]^{1.6}$$

The maximum* acceleration at the bow

$$\eta_{\max\ bow} = 2\ [1.6\ (H_{1/3}/\Delta^{1/3}) + (H_{1/3}/\Delta^{1/3})^{1.6}]$$

where: $H_{1/3}$ = significant wave height

Δ = displacement in long tons

g. (U) Structural Design Criteria.

1) The primary emphasis of structural design criteria is to select allowable stresses and deflections. Allowable working stresses are obtained frc the material characteristics (usually the tensile yield stress or tensile ultimat stress) by application of appropriate factors of saftey. This allowable working stress is simply the maximum tensile stress which members are permitted to reach under design loads, based on rational calculation methods.

There are a number of methods available to define allowable stress, and not surprisingly, they are fairly consistent. Table 7 listed some of the various methods and their results, when applied to 5086-H32 alluminum alloy.

2) While Silvia's method [69] yields an allowable working stress of 12,500 psi, Spencer [51] notes that Silvia used a value of 14,300 psi in an example. It is suggested that a value of no less than 14,000 psi should be used if reasonably light structure is to result. However, care should be used if one desires to use a higher value, and the values given by yield stress as modified by factor of safety of 1.1 ($\sigma_y/1.1$) or the NAVSHIPS equation developed

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[*] Maximum was derived from 400-500 data points which is consistant with crew tolerance. Notice that this is reasonably consistent with the statistical relationship presented by Savitsky and Brown [36].

in [70] and shown in Table 8a should be the absolute upper limit and used only when the loads are the maximum peak loads determined from tests including at least 500 encounters. Interestingly enough, the maximum stress recorded during the sea trials of the CPIC-X (an example of a highly stressed design) was slightly over 14,000 psi, and the structure appeared to suffer no ill effects whatsoever. No matter what rationalization is used, it must be recognized that "safety factors" are really "ignorance factors", which arise due to lack of definition of loadings, material characteristics, or analysis methods. The values used reflect this amount of uncertainty.

3) With regard to deflection, the second criterion, a value of beam deflection under load of $\ell/200$ where ℓ = length of unsupported span, is recommended by Ashey [71]. There are practical reasons for limiting deflection, such as the psychological effects on the crew of "oil canning" of plating while underway, relative deflection between gun mounts and directors, etc. Another important concern is local flexibility of the structure in way of the foundation for high speed machinery where resonances can develop. However, as treated by an experienced engineer during the design process, these effects of deflection are usually small.

4) The term "rational calculation" as used here relates to the assumptions made in the stress analysis of the structure of a planing hull. The local structure of a typical planing hull is usually modeled using a beam analogy with the assumption that the loads can be represented by an equivalent uniform static pressure load. The end conditions of the beam are usually assumed to be fixed, commonly referred to as "fixed-fixed" end conditions. This resultsin the maximum bending moment occurring at the ends of the beam and having a value of

TABLE 8a - METHODS TO DEFINE ALLOWABLE WORKING STRESS (u)

METHOD	SAFETY FACTOR OR PROCEDURE TO FIND VALUE	VALUE WHEN APPLIED TO 5086-H32 ALUMINUM*
DANAHY [73]	$\sigma_y/1.5$ OR $\sigma_{ULT}/2.0$ WHICH EVER IS LESS	12,700 PSI
HELLER-JASPER [49]	$\sigma_y/1.1$	17,300 PSI
SILVIA [69]	$[(\sigma_{ULT}/2)/1.4]$	12,500 PSI
SPAULDING [72]	$\sigma_y/1.1$, PROVIDED THAT LOADS ARE "TRULY MAXIMUM" AND STRESS VALUES ARE THE "TRUE" MINIMUM INCLUDING ALL REDUCTIONS FOR WELDING, CREEP & FATIGUE	17,300 PSI
SPENCER [51]	BASED ON FATIGUE	14,000 PSI
NAVSHIPS [70]	$[(\frac{1}{2}\sigma_{ULT} + \sigma_y)/2.4] \times 0.90$ THIS USES σ_y & σ_{ULT} FROM PARENT MATERIAL PROPERTIES	18,000 PSI

$$\left.\begin{array}{ll} *\ \sigma_y = 28\text{ KSI},\ \sigma_{ULT} = 40\text{ KSI} & \text{(PARENT MATERIAL)} \\ \sigma_y = 19\text{ KSI},\ \sigma_{ULT} = 35\text{ KSI} & \text{(1" FROM WELD)} \end{array}\right\} \text{FROM "ALUMINUM AFLOAT" [43]}$$

$$M = p\ell^2 / 12$$

where

M = Maximum moment

p = uniform pressure load

ℓ = unsupported span

Spaulding [72] suggests an intermediate value of fixity producing a moment of

$$M = p\ell^2/10$$

He suggests that this be used for all portions of the beam. Recent studies [56] have shown that while truly fixed end conditons rarely exist, the value of the moment produced by fixed-fixed end conditions using pressures predicted by Heller-Jasper will not be exceeded. However, this value of moment must be used for all portions of the beam.

5) Recent investigations of the CPIC-X data [56] have indicated that a multiplicity of loading conditions exist, and that end conditions vary from primarily pinned, to primarily fixed, with average pressures on the beam of about 1/2 that predicted by Heller-Jasper. However, from a pragmatic viewpoint, it is suggested that a uniform pressure loading, derived by the Heller-Jasper method be used (subject to the reductions of pressure recommended in [56]) and that fixed-fixed end conditions be employed. Again this moment should be considered to be over the entire beam, rather than only at the ends. While this does not truly model the physical condition, it does provide satisfactory results.

6) The amount of plating that should be considered acting with a beam can be taken as

$$b = 2t\sqrt{E/\sigma y}$$

where: b = effective width of plating, in

t = thickness of plating, in

E = Modulus of elasticity of material

σ_y = Yield stress of material, lb/in^2

The combined section properties of typical aluminum beams and plates have recently been published by Lev and Nappi [74]. This is an extremely useful guide for use in design. With regard to detailed structural design practices, such as joints and connections, common sense and experience are valuable assets. Documentation of service experience is available in recent studiies accomplished by the Aluminum Company of America (ALCOA) for the Naval Ship Engineering Center [75] which provide a very useful summary for proper design of joints and connections for aluminum hulls.

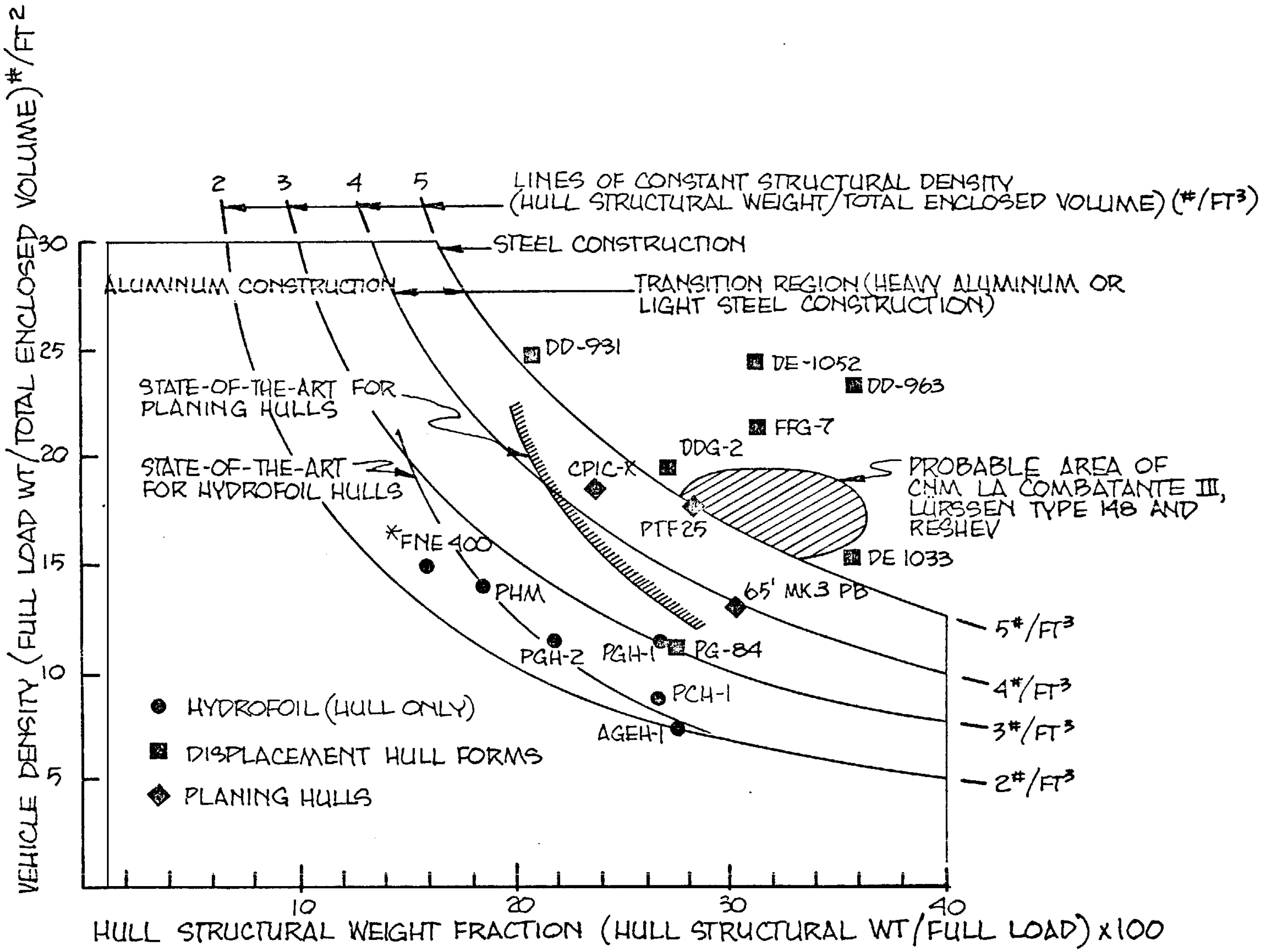
h. (U) Interdependencies of Design Parameters

1) The effects of the various design requirements discussed previously can best be summarized by use of three parameters. These are:

- Vehicle density (the full load weight of the vehicle divided by the total enclosed volume of the hull structure). This parameter shows how tightly the vehicle is packaged.
- The structural weight fraction (the hull structure weight divided by the full load weight x 100). This shows the percentage of full load weight allocated to structure.
- The structural density (the hull structure weight divided by the total enclosed volume). This number cannot really be set i.e., one does not design to a certain structural density, but rather it falls out as a result of the other two parameters. (The structural density is equal to the vehicle density multiplied by the structural weight fraction).

2) The advantage of using these parameters is that platform requirements, i.e., vehicle volume, vehicle full load weight, and allowable structural weight, can be shown on one plot, and based on prior experience one can tell almost immediately whether one has a feasible design,, Such a plot, patterned after that used by Heller and Clark [76] is shown in Figure 42. Included are hydrofoil hulls (because they are ship-like hulls, and are usually planing hull forms), and high speed displacement hulls. The end product desired is a low structural weight fraction. As such, the hydrofoil hulls offer the ultimate in least weight construction. This is due in some degree to the fact that they are separated from the sea surface and therefore are not subject to as severe loadings, but more importantly, they are forced to this level because they have foil/strut structural weight with which to contend. This requirement for low hull structural weight is a costly one, and hydrofoil hulls typically cost more per pound than planing hulls. On the other hand, most displacement hulls (particularly the newer designs) tend to be heavier, primarily because they are of steel construction (the exception is the PG-84 (PG-92 class), which is all aluminum). The round-bilge high-speed semi-displacement hulls prevalent in foreign Navies are theorized to be in the same region (23-34% structural weight fraction), though they are somewhat less dense. This is a rather remarkable achievement for hulls in the displacement range of 500-1000tn and require very thin gages of steel to achieve such low weight fractions.

3) Planing hulls fall between these two extremes, primarily because the requirement is not only for low weight but also for durability and acceptable cost. It was for this last reason that the CPIC-X is somewhat off the state-of-the-art line. The CPIC-X hull could have been lighter, and been no more expensive to construct. The other U.S. Navy planing hulls are also well



*RCN "BRAS D'OR"

Figure 42 - HULL STRUCTURAL WEIGHT FRACTION VERSUS VEHICLE DENSITY (U)

off the line. The PTF-25 represents standard crew boat commercial construction, which is not light, but is inexpensive. The 65 ft PB MK 3 has a lower structural density but the craft density is much lower also, which forces a higher weight fraction. If the 65 ft Patrol Boat MK 3 were as dense as the CPIC-X, it could have a comparable weight fraction.

4) For weight fractions of 20-27% to be attained, aluminum is the only practical material. Where higher weight fractions (27%) can be tolerated, steel construction can be used. In all cases the vehicles must be quite dense, approaching 20 lb/ft^3 vehicle density, for these structural weight fractions to be achieved.

6. (U) Propulsion

a. Open water propulsor design technology for planing craft is well in hand for conventional subcavitating propellers at speeds below 35 knots (65 km/hr). The operational speed range can be extended to approximately 60 knots (111 km/h) with only moderate risk through the use of existing experimental data on transcavitating and supercavitating propellers. The use of ventilated propellers, partially submerged propellers, and waterjets appears to be feasible and may prove beneficial for certain applications, but all of these propulsors are lacking in design technology and therefore are considered high risk items.

The high design speed goals of the other craft concepts, e.g. SES, necessitated development of waterjet, partially submerged propeller, and ventilated propeller technology which could possibly be used in the design of high speed planing craft propulsion systems. However, most of these propulsion data cannot be applied directly to the planing propulsion problem since the planing hull is free (unrestricted) in trim and heave, whereas these attitude parameters for concepts such as SES craft may be controlled by bubble and seal pressure variation. This difference in attitude control between the two craft types is important to the interactions between the thruster and hull. For example, the change of pressure due to a waterjet inlet acts over a much greater bottom area on a planing hull than it does on the narrow sidewall hull of an SES. Thus, the hull-thruster interaction contributes to dynamic trim and heave changes on planing hulls which may be controlled on the SES.

A characteristic of the partially submerged: propellers negating direct application to planing hulls is the large vertical and tranverse components of the steady and oscillatory propulsion forces. The vertical force on a partially submerged propeller effects a bow down trim moment on planing hulls which is difficult to counter. In summary, application of propulsor technology requires consideration of the interaction forces with the hull as well as the thrust and efficiency characteristics. There is a planned ANVCE task to examine the semisubmerged propeller data base to assess its application to large planing hulls.

Propulsor-hull-appendage interaction is no problem with subcavitating conventional propellers. For transcavitating, supercavitating, and ventilated fully submerged propellers these interactions can be estimated using data from subcavitating model experiments with moderate risk. Propulsor-hull-appendage interactions for partially submerged propellers and waterjets are still unknown and the use of either of these types without extensive testing will result in a high risk design.

The following explanation of these conclusions will consist of a general discussion of all the propulsor types.

b. (U) General Discussion

1) This discussion of planing boat propulsion will include thrusting devices, the appendages associated with them and their interaction with the hull. Model experimental techniques (or lack of them) will be discussed primarily from the standpoint of the hull-propulsor interactions.*

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* Hull configuration, or draft limitations usually limit the propeller diameter, therefore limiting the efficiency that can be attained.

TECHNOLOGICAL PERFORMANCE FEATURES

The following propulsor types will be covered:

- Conventional subcavitating propellers.
- Transcavitating propellers
- Supercavitating propellers
- Ventilated propellers
- Partially submerged propellers
- Waterjets

There are numerous other types of propulsors that may be applied to planing hulls, but most have propulsive efficiencies too low for the larger craft generally in use by the Navy and for large planing ships.

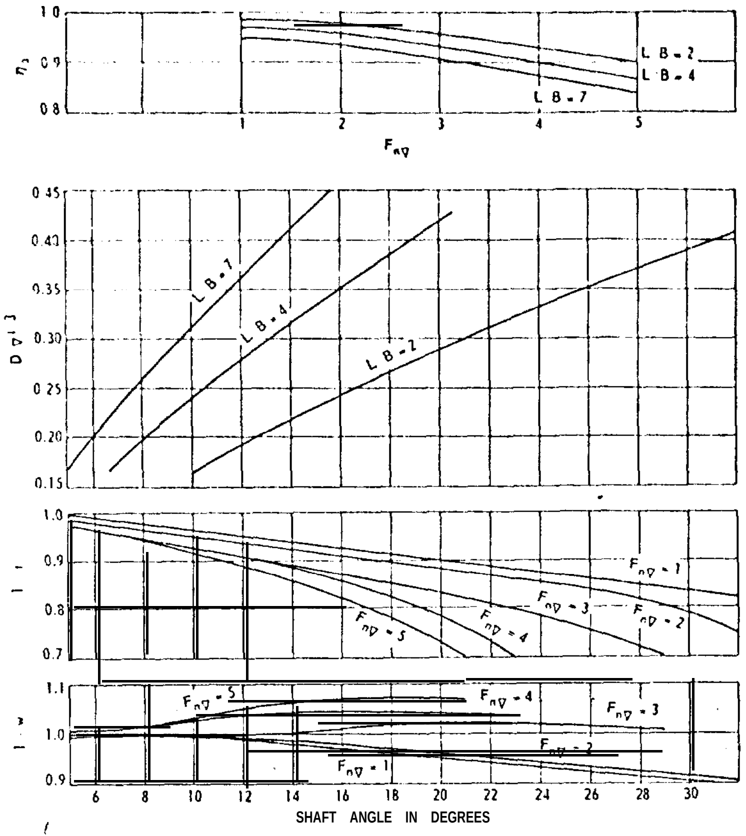
2) Conventional subcavitating propellers of commercial manufacture are the most common propulsor type found on naval planing craft. Commercial propeller designs and manufacturing tolerances give acceptable performance on all sizes of planing hulls up to a speed of approximately 33 knots. Above 30 knots commercial propellers have had serious erosion problems. The 50 in. (1.27m) diameter propellers of the 95 ft (29m) OSPREY class patrol craft eroded badly in only 4-5 hours of high speed operation.

a) The selection of a commercial propeller is usually made with the help of standard series propeller charts. The Gawn-Burrill series [77] for propellers operating at low cavitation numbers is usually used for estimating the performance of three bladed commercial propellers. For estimating performance of four-bladed commercial propellers the Troost [78, 79] open water and cavitation data has, until recently, been the primary source of information. A recent paper by Peck and Moore [80] presents the results of open water and cavitation tunnel experiments on a series (four pitch ratios) of four-bladed commercial propellers. Cavitating performance characteristics were obtained on these propellers at 0, 7.5, and 15 degree shaft angles. Cavitation tunnel data are available on many other individual propellers.

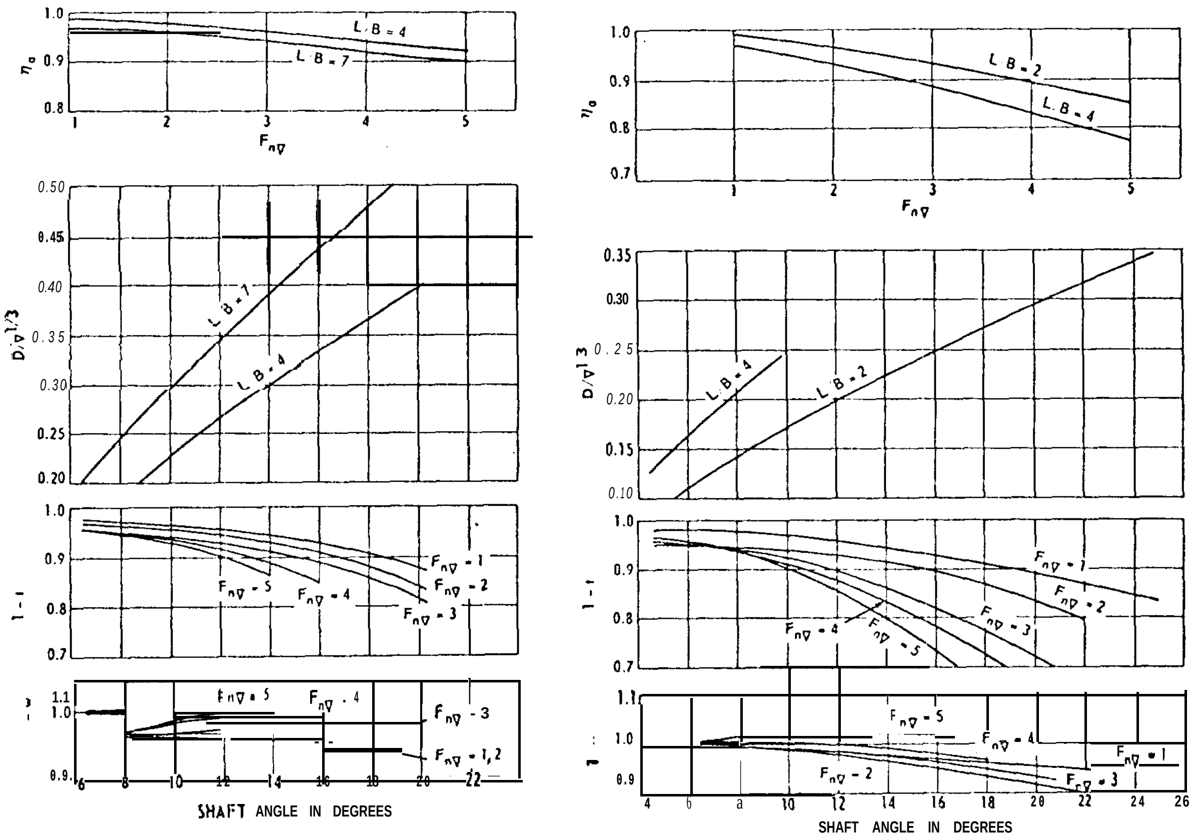
b) Through custom design and close tolerance manufacturing the useful speed of subcavitating propellers can probably be increased to approximately 37 knots (67 km/h). Design procedures based on lifting surface theory are well established for subcavitating propellers.

c) Propulsor-hull-appendage interaction is reasonably well defined for planing craft using conventional subcavitating propellers. Since these propellers operate virtually cavitation-free the propulsive coefficients can be derived from standard self-propelled model experiments only slightly more complex than are presently in use for large ships. Most of the model and full scale data on propulsive coefficients of planing craft has been reviewed by Blount and Fox [20]

Propulsive data, the transfer functions which describe hull-thruster interrelations, are essential for accurate speed-power predictions. Hadler and Hubble [24] developed and presented analytical models for propulsive data for single, twin, and four screw planing craft as a function of shaft angle. These data, presented in Figure 43 , agree very well with a collection of model and full-scale experimental propulsive data reported by Blount and Fox [20]. These latter data cover a range of normal shaft angles (from 10" to 16°), and are repeated here as Figure 44 showing probable values and band width of experimental data as a function of $F_{N\nabla}$.



B. Variation of wake, thrust deduction, and appendage **efficiency** for the basic twin-screw configuration



A. Variation of wake, thrust deduction, and appendage efficiency for the basic single-screw configuration

C. Variation of wake, thrust deduction, and appendage efficiency for the basic quadruple-screw configuration

Figure **43. Propulsive Characteristics versus Shaft Angle For 1, 2 and 4 Shafts.**

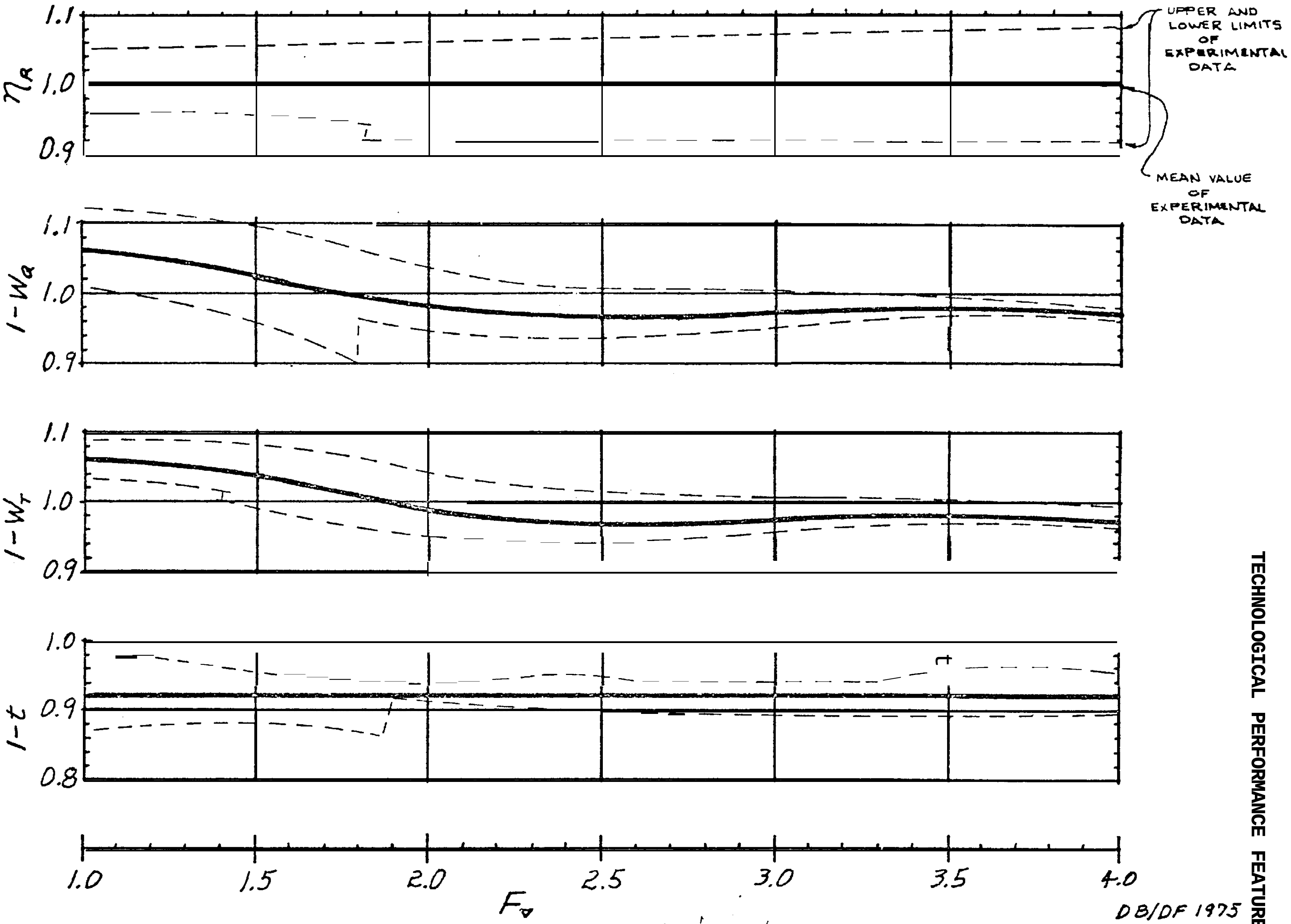


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Figure - Twin Screw Propulsive Data (U)

Quantification of scale effect on propulsion data is limited but [81] reported some model and full-scale uronulsive data comparisons (see Figure 45). Thrust and torque wake factors, and relative rotative efficiency have less than four percent difference between model and full-scale data taken at planing speeds.

The above discussion and data relate to conditions of minimal propeller cavitation. The quantitative effects of cavitation on propulsive data are ill defined. A recent effort [82] using planing craft trial data to define the combination of correlation and propulsive data (as it appears in the propulsive coefficient calculation) is shown in Figure 46 as a function of cavitation number. This figure implies that, for cavitation numbers less than 1.7, cavitation effects are important modifiers of propulsive data and correlation factors so that full-scale speed-power performance will be less than predicted when neglecting cavitation.

Hadler [19] provides propulsive coefficients for two twin screw models, one of conventional vee bottom form and the other a flat bottom form. The fore-aft location of the propeller was varied on the flat bottom hull form and differences in propulsive coefficients were noted. This paper also contains procedures for calculating appendage lift and drag as well as propeller forces. Reference [19] also contains an annotated bibliography of planing boat and other high performance craft propulsor-hull-appendage interaction investigations.

d) If conventional subcavitating propellers are used and planing craft speeds are kept below 35 knots (65 km/h) the propulsor design technology appears to be reasonably well in hand. Self-propelled model

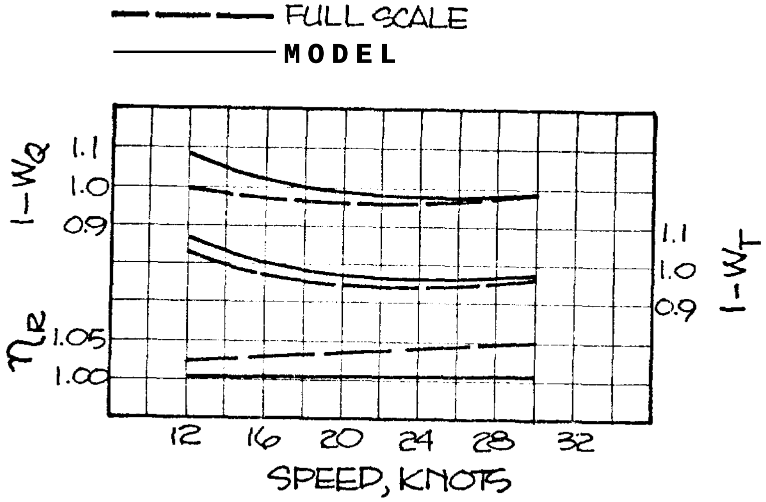


Figure 45 - Comparison of Model and Full-Scale Propulsive Factors [81] (U)

NOTE:

DATA POINTS FROM FULL SCALE TRIAL DATA OF MILITARY PLANING CRAFT.

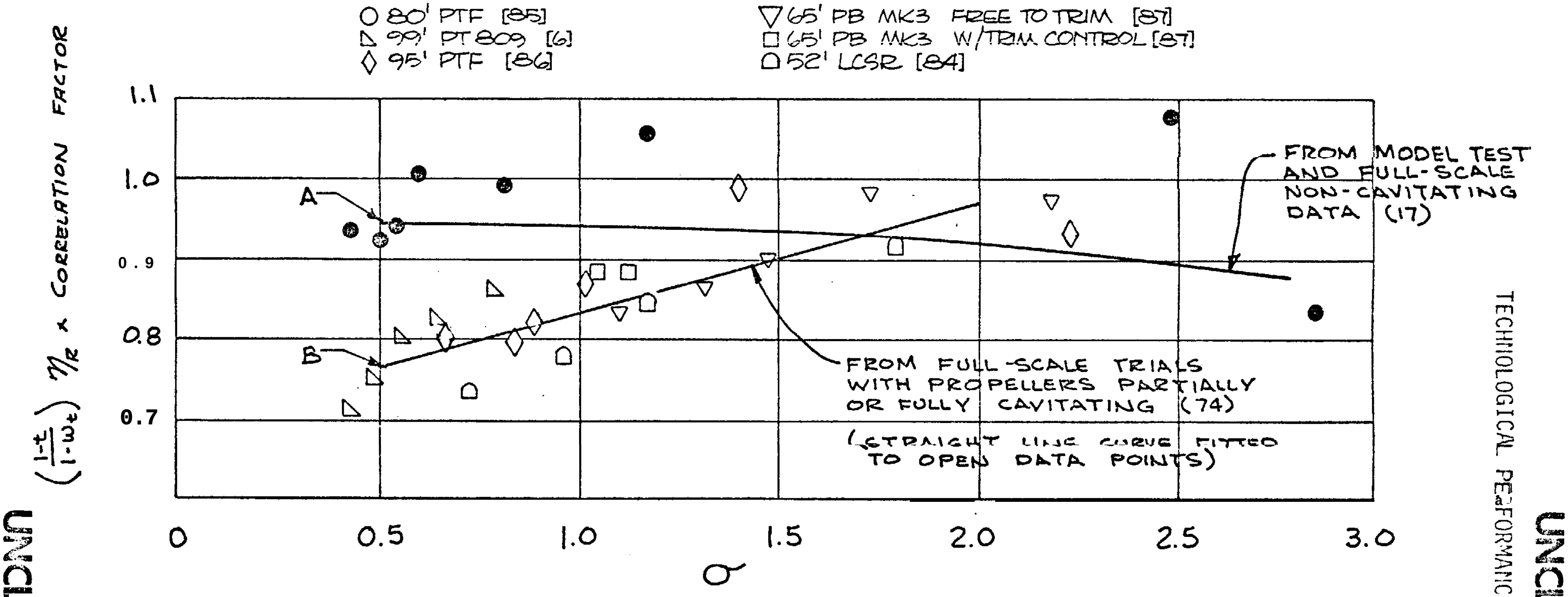


Figure 46. - Shaft Horsepower & Propeller RPM Correlation Factors For Craft With Flat Face Propellers (U)

experiments should, of course, be run to verify the design predictions and if custom propeller designs are required, inclined shaft cavitation tunnel experiments should be conducted to verify the propeller design.

3) Transcavitating and supercavitating propellers, although slightly different, can be combined for the purpose of this discussion. Although there is a fairly large data base of cavitation tunnel experiments on transcavitating and supercavitating propellers, the performance prediction methods for craft with these types of propellers are not as straightforward and well established as for subcavitating propellers. Blount and Fox [20] present a method for estimating the performance of planing craft by using cavitation tunnel propeller performance characteristics. These procedures use propulsive coefficients derived from subcavitating model experiments with cavitating propeller characteristics being substituted for the non-cavitating propeller characteristics.

a) These assumptions seem to yield reasonable results; however, there are indications that the thrust deduction fraction may be substantially changed by the use of supercavitating propellers with fully developed cavities. Experimental investigations by Bavin and Miniovich [88] indicate that the thrust deduction factor (l-t) tends toward 1.0 of slightly higher when fully developed cavities are present on high speed displacement ships. No known work of this type is available for planing craft and model experiments' of this type are extremely difficult. For a conservative estimate, it is recommended that the thrust deduction factor obtained from conventional model tests be used. However, self propelled model tests do not properly predict power for a full scale hull with fully cavitating propellers. For this reason, the required power should be calculated as described in [20] along with correlation experience reported in [82] by Blount and Hankley.

b) Transcavitating propellers such as the Newton-Rader series have been developed through the use of cavitation tunnel experiments and there are not theoretical design procedures available at the present time for these propellers. They are selected for a given craft by the procedures discussed above and the performance charts obtained from the cavitation tunnel experiments. The Newton-Rader design can be made to provide successful propellers for both small and large planing hulls in the 40-60 knot: (74-111 km/h) speed range [90]. (If the characteristics of this reference are used, the RPM will probably be under-predicted.)

c) Supercavitating propeller design methods are somewhat better developed than transcavitating propeller methods but not as well developed as those for subcavitating propellers. The supercavitating propeller design programs available at DTNSRDC basically use subcavitation lifting line theory with corrections of various types to account for the cavity thickness. In the past these methods have not yielded very good results, sometimes overpredicting and sometimes underpredicting the thrust. A 3-year research program is presently being conducted at DTNSRDC to develop and verify new design procedures for supercavitating propellers. Since this project only began this fiscal year (FY76) results are not available at this writing. There are, however, no plans to investigate the propulsor-hull interactions during this 3-year effort.

d) Hecker, Shields and McDonald [91] present cavitating performance characteristics for a 2,3 and 4-blade series of controllable pitch supercavitating propellers for a wide range of pitch ratios and cavitation numbers. Hecker, Peck and McDonald [92] present cavitating performance data for ten supercavitating propellers investigated by DTNSRDC.

This report includes most of the tests at DTNSRDC as of its publication date (1964). Data from these propellers is presently being cataloged and will be reported as part of the high speed propeller program.

e) While truly adequate design prodedures for supercavitating propellers are still not well established, the on-going effort in this area should result in a considerable improvement in the next 2-3 years. Until then the available series data will provide an adequate.assessment of supercavitating propeller performance for preliminary design purposes. The major problem area which has not been addressed in the past and is not being addressed now is that of propulsor-hull-appendage interaction.

4) Fully submerged ventilated propellers are designed using the present supercavitating propeller design method with the blade cavitation number at zero. Thus one can not expect significantly better predicted values of thrust and torque. Since it is almost impossible to predict ventilation boundaries there is no assurance that the propeller will ventilate properly.

a) In addition to thrust and torque, air flow requirements must be predicted for ventilated propellers since power is generally required to provide the ventilation air. This may be substantial so it must be considered in any performance prediction. Model test data is very limited on fully submerged ventilated propellers since they are very difficult to test in a cavitation tunnel due to the large amount of air that must be supplied which rapidly alters the tunnel test condition.

b) The benefit of using ventilated propellers on planing craft seem to warrant further investigation. Cavitation erosion problems generally found on propellers operating behind struts and inclined shafts may be greatly reduced through the use of forced ventilation. In addition an improvement in efficiency of 5 to 10% may be achieved. A report by Peck and Kelley [68] presents cavitation tunnel results on 2 forced-ventilated propellers including required air flow rates.

5) Partially submerged propellers have been in use for a number of years on racing hydroplanes, but in the past speeds on large craft have not usually been high enough to consider them. Relatively large partially submerged propellers have recently been applied successfully to the 100 ton SES test craft (100B). These propellers have the advantage of eliminating most of the shaft and strut drag since they operate with their centerline at or above the free surface.

a) Design procedures are essentially the same for partially submerged as they are for fully submerged ventilated propellers. The thrust produced however, is assumed to be equal to the ratio of the submerged area to the disk area times the thrust that would be produced by a fully submerged propeller. While these procedures yield reasonable results, they cannot be considered adequate for final design. Testing procedures have not been standardized for these propellers. Both DTNSRDC and Hydronautics have designed and tested partially submerged propellers in conjunction with the Navy SES program. A paper by Hecker [94] presents inclined shaft performance characteristics of several partially submerged propellers. Series experiments [96, 97] were recently conducted by Hydronautics on partially submerged propellers. The hydronautics data has been reanalyzed by Moore [98] and design charts to aid in propeller selection are included.

b) Although almost all partially submerged propeller experiments are conducted behind a body to provide a free surface, the propulsor-hull interaction forces have not been measured. These propellers generate large lift and side forces (in some cases 50-80% of the thrust) which cause severe propulsor-hull interaction problems. In the late 60's some exploratory model experiments were conducted with a partially submerged propeller fitted to a planing hull model with the intent of establishing preliminary data on the propulsor-hull interaction. The large lift forces generated by the propeller caused the model to trim by the bow excessively even before the model self propulsion thrust was achieved. Model displacement and longitudinal center of gravity was varied far beyond the normal limits in an attempt to achieve an acceptable running trim. In each case the model nose-dived severely with subsequent spray generation to the extent that the experiments had to be terminated. No further work has been done at DTNSRDC on partially submerged propellers fitted to planing hulls; however, these early results indicate that before serious consideration is given to partially submerged propellers for this application the propulsor-hull interaction problems should be fully investigated.

6) Waterjet design technology appears to be somewhat behind that for propellers, at least for planing boat applications. In part this is due to the larger number of complex sub-systems that must be combined to make up a waterjet propulsor system. Pump design technology appears to be well in hand if inflow characteristics, head requirements, and volume flow rate requirements are known. Pumps, like propellers, are prone to cavitation if the inlet velocity and rotational speed are too high. Since

cavitation causes choking and erosion problems in the pumps; pumps are generally designed to operate cavitation free. This is achieved by diffusing the flow ahead of the pump inlet to the desired inflow velocity to allow the impeller to operate cavitation free. Thus the inlet and diffuser become the major design problem for high speed propulsion applications.

a) Hydronautics [99] has developed a program to design flush Wets for SES craft which may be applied to planing craft, but its reliability has not yet been established, Currently tests of two inlet designs are underway for a planing hull using the Hydronautics procedure. These inlets are being investigated in a 10-ft model. The model test results will be compared with predictions and the design program will be updated based on the model test data. Inlet/hull interaction for various inlet velocity ratios will be established for the two inlet configurations under investigation.

b) Hundreds of papers and reports on waterjets are available. Most of these deal with momentum theory, ducting losses and predicted performance assuming some arbitrary loss coefficients for the inlet and diffuser. Ducting performance has to be determined experimentally. This presents a problem since on all but the simplest of installations the ducting configuration will vary from craft to craft. Accurate assessment of losses is difficult because adequate velocity surveys must be conducted in several places along the duct in order to establish the loss coefficient. The process is time consuming and expensive. Since waterjets have been installed primarily on small inexpensive planing boats and several Navy prototypes, very little data of this type is available.

c) Two small waterjet propulsors were characterized several years ago at DTNSRDC by Gregory and Hale [100], however, only overall performance characteristics were obtained. Velocity surveys in the inlet and diffusor were attempted in this characterization program but the flow was found to be so asymetric in the short ducting that loss coefficients could not be determined from the limited pressure surveys that were taken. Recently, pressure and velocity surveys were made at DTNSRDC on a Jaccuzzi waterjet with an NSRDC designed rotor. These surveys were made both statically in the towing tank, and underway in a PBR MK 1. The data will be published in the near future.

d) A three year waterjet technology development program which is being directed by DTNSRDC Annapolis is in its final year. This program has covered many aspects of waterjet design. The results should be valuable in providing the necessary data to design high speed planing craft waterjet propulsion systems. A final report should be available by the end of calender year 1976.

c. (U) Numerical Data

1) The maximum propeller loadings ever attained for several series of model propellers tested under cavitating conditions are shown in Figure.48 [101]. This figure is a composite plot generated from References [77, 79, 90, and 91]. These curves can be used to establish minimum diameter and blade area but could not be used for design. (For notation, see Figure 47.

2) Propellers are usually designed to a thrust-speed requirements but full scale performance is usually checked by measuring torque. Actual torque coefficients, Q_c, for the Newton-Rader propeller, plotted against

J_T **Thrust** advance **coefficient** $= \frac{v\,(1-w_t)}{nD}$

K_T **Thrust coefficient** $= \frac{T}{\rho n^2 D^4}$

τ_C **Thrust load coefficient** $= \frac{T}{1/2\rho A_P\, v^2_{0.7R}}$

Q_C **Torque load coefficient** $= \frac{}{1/2\rho A_p D\, v^2_{0.7R}}$

σ **Cavitation number based on forward velocity only** =

$$\frac{P_A + P_H - P_V}{0.5\,\rho v^2}$$

$\sigma_{0.7R}$ **Cavitation number based on resultant water velocity at 0.7 radius of propeller** =

$$\sigma\left[\frac{J_T^{\,2}}{J_T^{\,2} + 4.84}\right]$$

Where:

V = **Speed of vehicle, ft/sec**

w_T = **Wake fraction based on thrust**

n = **Rotative speed of propeller,** rev/sec

D = **Propeller diameter, ft**

P = **Propeller pitch, ft**

T = **Thrust of propeller, lb**

Q = **Propeller torque, ft lb**

P_A = **Atmospheric pressure,** lb/ft^2

P_H = **Hydrostatic pressure at center of propeller,** lb/ft^2

P_V = **Vapor pressure of water,** lb/ft^2 .

ρ = **mass density of water, lb** sec^2/ft^4

P/D = **Pitch/diameter ratio of propeller**

Ap = **Projected blade area of propeller**

EAR = **Expanded area ratio** =

$$= \frac{\text{Expanded blade area}}{0.25\,\pi\, D^2}$$

Figure 47. Notation for Propeller Charts shown in Figures 48 thru 55 (U)

SYMBOL	PROPELLER SERIES	NO. BLADES	EAR	REF.
– – – – – –	WAGENINGEN-B	4 & 5	.75-1.05	[102]
————	GAWN-BURRILL	3	0.70	[77]
—— ——	NEWTON-RADER	3	0.70	[90]
——·——	S.C. CRP	2	0.25	[91]
——··——	S.C. CRP	3	0.37	[91]
——···——	S.C. CRP	4	0.49	[91]

P/D=1.2

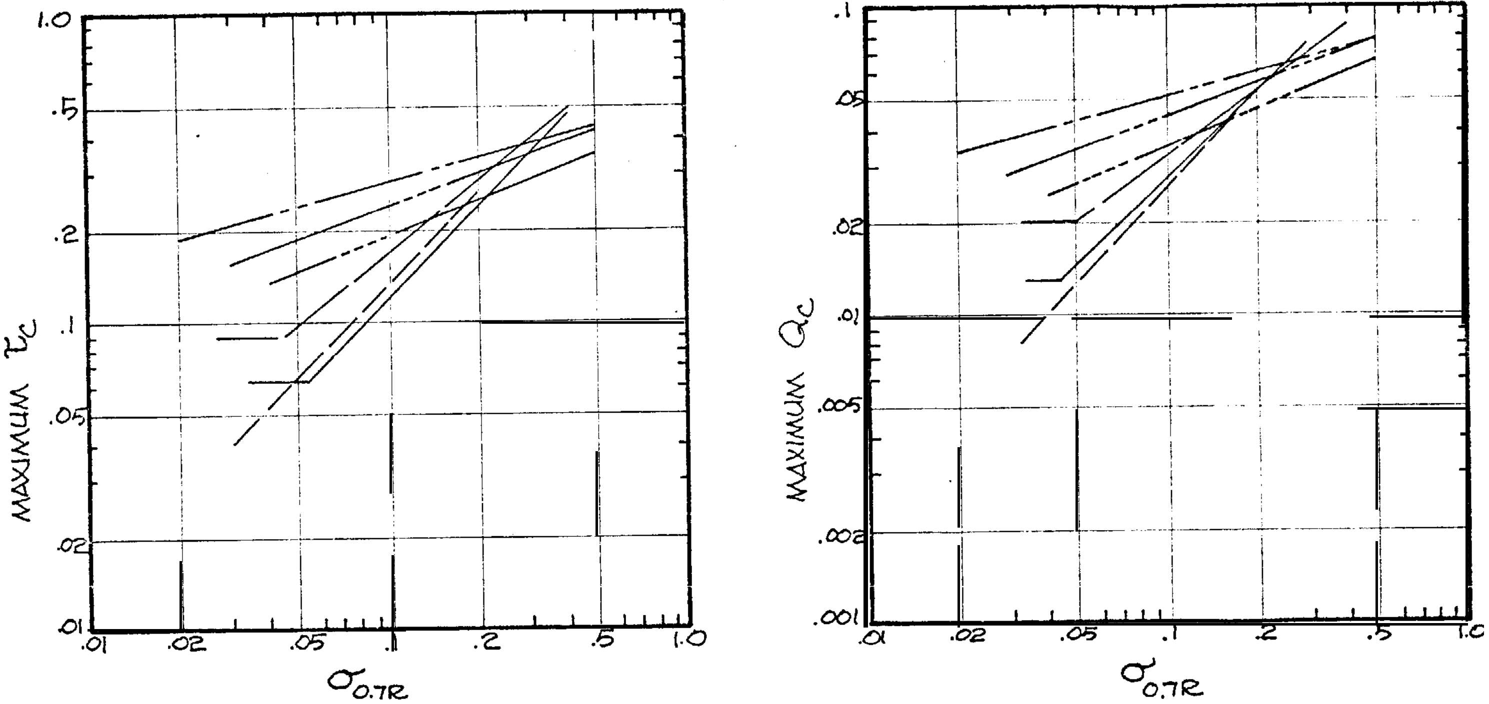


Figure 48 - Composite Plots of Upper Boundaries For The Transcavitating and Supercavitating Regions [101] (U)

cavitation number, σ, for several values of advance coefficient, J, are shown in Figure 49, [3] in which Q_c and σ are defined.

3) Propeller characteristics show distinct features depending on cavity development. During subcavitating operation torque loading (as well as thrust) is essentially constant with non-varying advance coefficient when the section cavitation number is sufficiently high. As the blade cavity develops in transcavitating operation, the Q_c vs. $\sigma_{0.7R}$ relationshi collapses with the identity of the advance coefficient being lost. The propeller becomes supercavitating as the blade cavity extends well beyond the propeller, and the torque loading (and thrust) again become functions of advance coefficient. The upper boundaries of the transcavitating and supercavitating regions for various propeller series data were summarized in Figure 48 to document the maximum attainable thrust and torque limits.

4) Trial data (uncorrected for l-Wq) from CPIC-X plotted on Figure 49 shows that these data follow the slope of the transcavitating propeller characteristics. Thus, increasing propeller RPM (lowering J) in the transcavitating region does not give proportionate increases in thrust and torque as experienced in subcavitating operation. This trend is also shown in Figure 50 [81] for both thrust and torque data from trials of the experimental landing craft, Vehicle, Personnel., (Twin Engine) or LCVP (T). This transcavitatirig propeller characteristic results in underpredicting propeller RPM and reduction ratio if not corrected by full scale experience during design. Figures 51 through 54 [77, 90, 91, 79] show experimental results which demonstrate open water efficiency in the transcavitating region at a speed near 30 knots (a = 1.00). These data

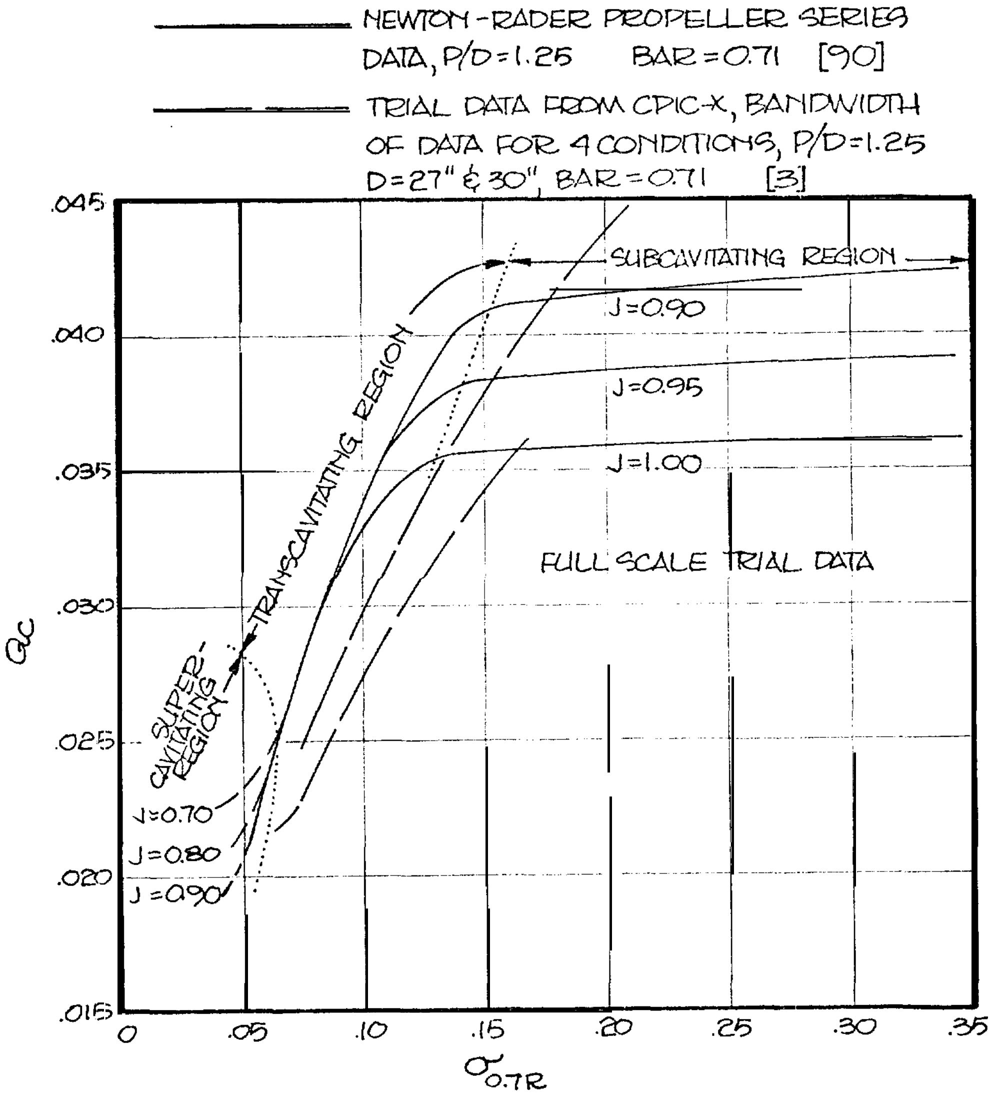


Figure 49 - Newton-Rader Torque Coefficients [3] U)

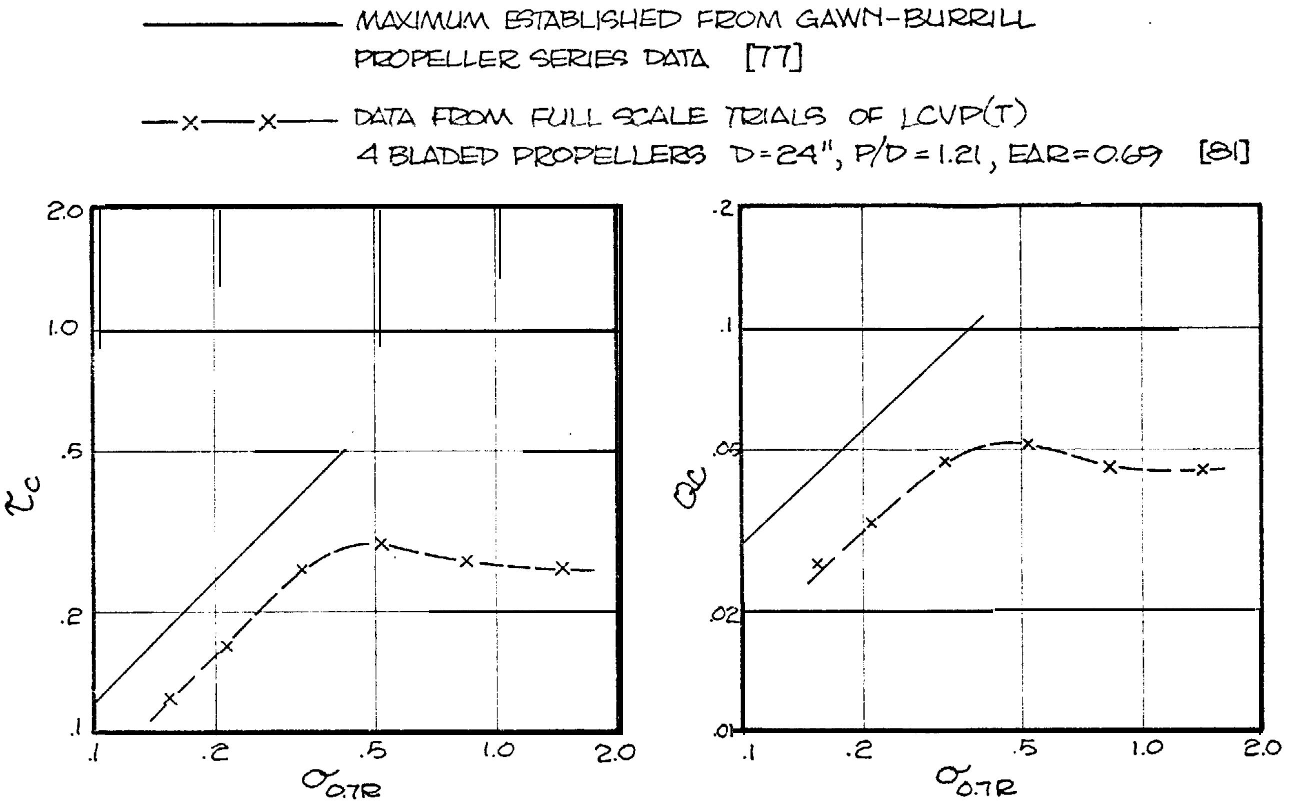
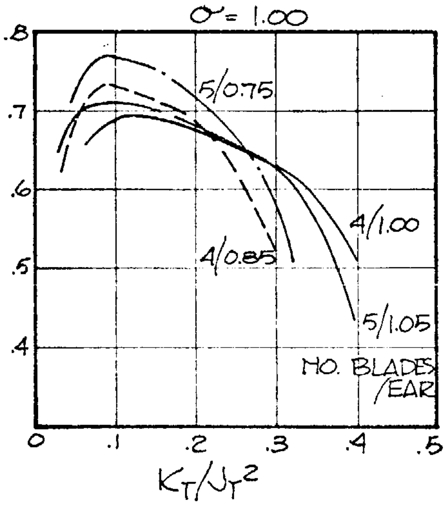
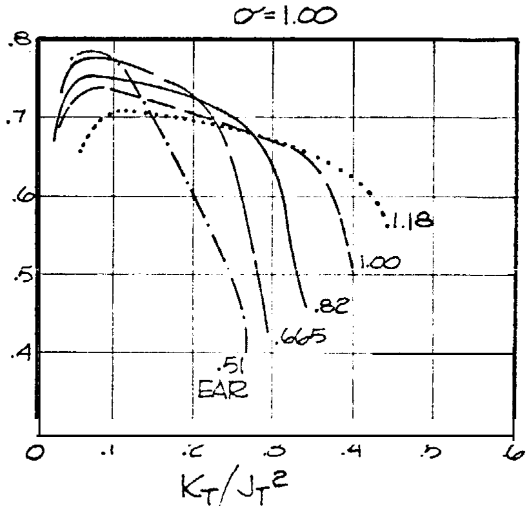


Figure 50 - Thrust and Torque Data From LCVP(T) Trials [81] (U)



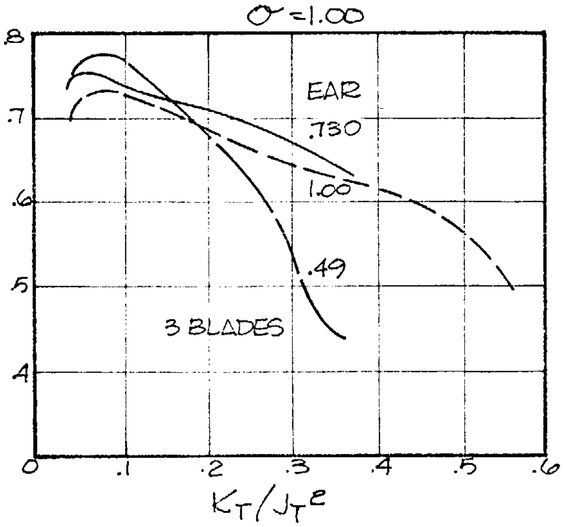
WAGENINGEN B PROPELLERS SUBCAVITATING [79] (U)

Figure 51



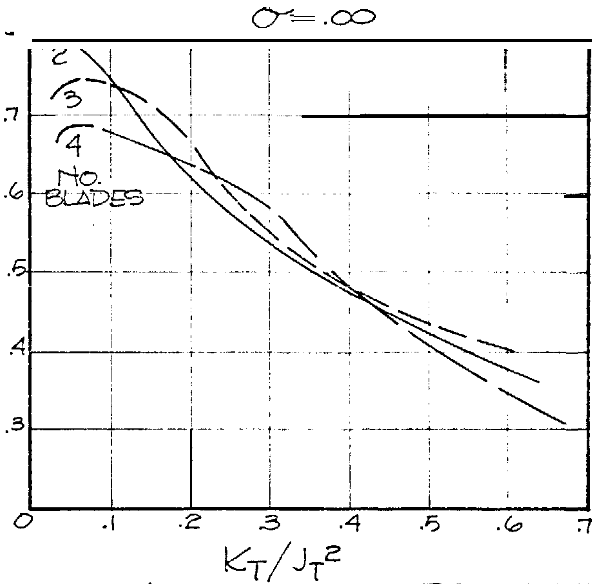
GAWN - BURRILL PROPELLERS SUBCAVITATING [77] (U)

Figure 52



NEWTON-RADER PROPELLERS TRANSCAVITATING [90] (U)

Figure 53



SUPERCAVITATING CRP PROPELLERS [91] (U)

Figure 54

(from four different propeller designs) show envelopes of maximum efficiency obtained from a number of propellers with same sections but with different pitch ratios, The general trend for subcavitating and transcavitating propellers is that blade area is important for developing thrust at high speeds, but is an efficiency penalty when the propeller operates at a light load $(K_T/J_T^2 = 0.1)$. Neither the supercavitating nor the partially submerged (not shown) propellers offer efficient thrust producing capability for normal design thrust loading. Thus, transcavitating propellers, which utilize characteristics from both supercavitating and conventional propellers, currently offer the widest range of efficient thrust loading up to 60 knots.

5) Propulsor efficiency is the major portion of the overall propulsive coefficient (OPC) and is frequently maximized during the design process. However, propulsor characteristics impact so heavily on machinery and off design performance that a system design approach is vital for advanced concepts. (See Figure 21, on p. 68) Analysis of model and full scale trial data defines a range of OPC showing the variation with speed, i.e., cavitation number (a). An overall propulsive coefficient of 0.60 has been attained on planing craft for speeds below 30 knots (with OPC = 0.55 being common, as compared to OPC = 0.50 about 15 years ago). For higher speeds, the OPC attained with conventional shafts and struts decreases at a linear rate from 0.60 at 30 knots to 0.43 at 55 knots. The normal range for OPC will not vary more than 5 points below the above values when existing technology is applied.

6) Propulsive (interaction) data at speeds greater than 35 knots are scarce and not well understood. Apparently, thrust deduction factor (1-t)

approaches 1.0 (from about 0.92 at lower planing speeds) at high speeds while relative rotative efficiency (η_R) tends to change in an opposite and offsetting manner. In practice this will not affect current design practices, but an understanding of the changing character of propulsive data is essential for optimum propulsor design as speed requirements increase.

'7) In practice propellers have suffered cavitation erosion damage, blade vibration (fatigue), and have induced blade rate pressures on the hull. On subcavitating propellers, the first two problems are often traceable to inclined flow due to shaft angle, and to the exceedingly thin blade sections employed to avoid cavitation inception. However, by designing to "live with cavitation" many successful craft are operating with transcavitating propellers without significant erosion damage during normal overhaul cycles. Likewise, nickle-aluminum-bronze has proven to be the outstanding propeller material considering all factors, such as manufacturing, repair, strength, and erosion resistance. Blade strength and natural frequencies are adequately predicted with existing techniques.

8) Cavitating propellers induce hull pressures significantly greater than subcavitating propellers having the same thrust loading and clearances. Current design practice calls for a hull clearance of 15% of the propeller diameter if blade area cavitation can be maintained at less than 10%. Propellers operating with a fully developed cavity must have a hull clearance of 25% diameter to have equivalent induced pressures an non-cavitating propellers.

9) The majority of the discussion has been about subcavitating and transcavitating propellers as estensive operating experience has been

obtained for those types. Virtually no quantified data has been obtained on full scale planing hulls using supercavitating, ventilated, or partially submerged propellers. These propulsors have been used successfully, primarily on racing craft, with optimization being accomplished mostly by "cut and try".

10) A large number of military craft have had flush inlet waterjets as propulsors. However, most have been of the mixed flow type pump, and were basically geometric variations of one design. Two experimental planing hulls (50 ft LOA) were evaluated during a prototype program and afforded the opportunity to obtain data on a mixed flow and an axial flow waterjet [31],Power, rpm and exit jet thrust were measured over a range of speeds for both pumps, and net reaction thrust was measured on the axial flow pump. When neglecting craft inlet speed, the jet thrust was equivalent to the net thrust measured on the waterjet assembly. The thrust-horsepower-rpm characteristics for each type were essentially equivalent no matter the speed of the test craft, except for raising the attainable thrust limit (with increasing speed) before cavitation breakdown. Jet thrust and torque load coefficients from these results are shown in Figure 55 [31].

11) Experimental data for overall propulsive coefficient are given in Figure 56 [29, 30, 31, 32, 33, 41]. These data represent flush inlet performance that was achieved without resorting to custom design. When lighter weight engines became available, two additional installations were made on the PBR MK 2 with changes in the pump impeller to accommodate the power changes. Full scale trials at higher than original speeds indicate that there is a minimum running trim angle below which the existing flush inlet cannot efficiently function. Presently, the running trim for best pump performance

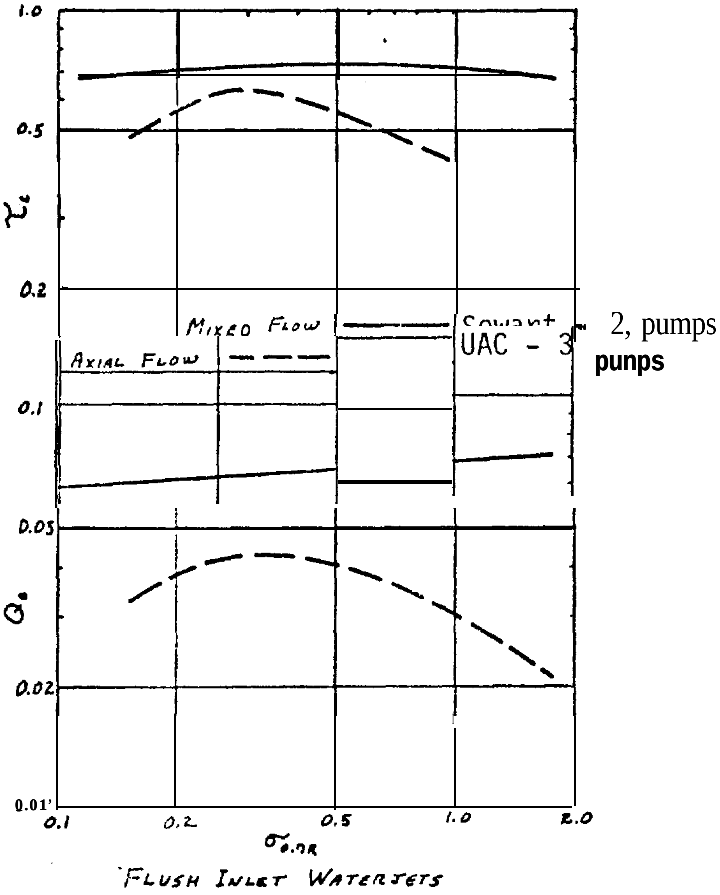


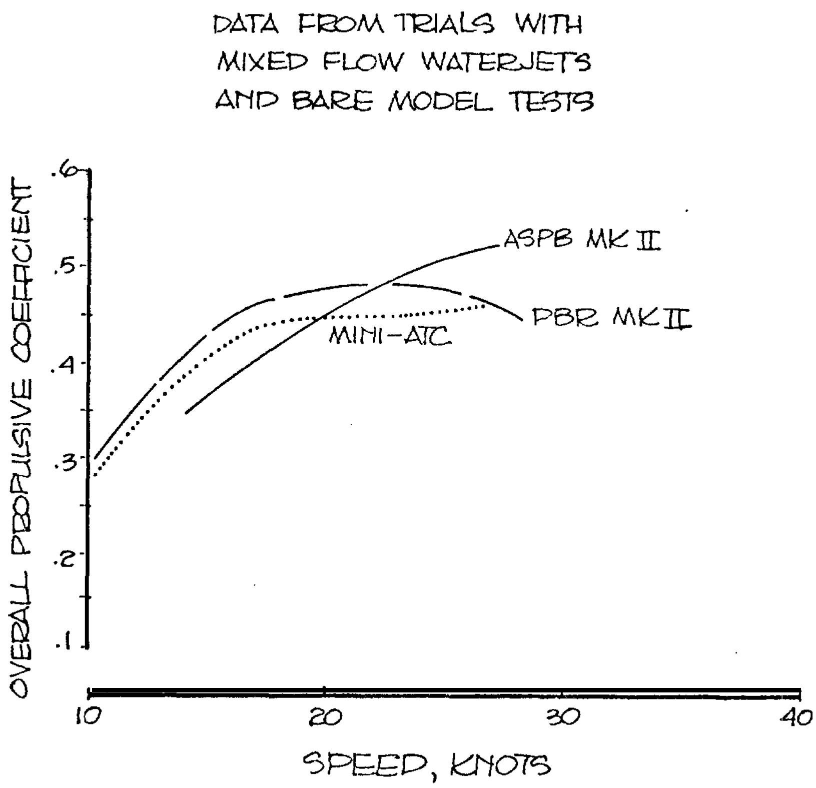
Figure 55 - Jet Thrust and Torque Load Coefficients

Measured on two 50 ft ASPB MK2 Experimental Planing Hulls [31] (U)

For Notation see Figure 47, p. 150

[redacted]

[redacted]



CRAFT	SOURCE OF DATA	
	MODEL	FULL SCALE
MINI-ATC	[29]	[30]
ASPB MK2	[41]	[31]
PBR MK2	[32]	[33]

Figure 56 - (C) (Waterjet) Overall Propulsive Coefficient (U)

[redacted]

[redacted]

is greater than desired for good seakeeping performance.

12) The overall propulsive coefficients for flush inlet waterjets have not yet attained the level of those for propellers. However, they may become more desirable in high speed applications when mission requirements dictate. Presently operational waterjet installations have viable application in extremely shallow water operations where vulnerability is more important than efficiency. Also, applications have been made with gas turbine prime movers when reverse gears were not available since waterjets are easily reversible,

7. (U) Human Factors

a. (U) The vehicle environment must be compatible with human operators and the-facilities they utilize. Typical environmental factors which affect the crew's effectiveness are temperature, ventilation, illumination, noise, vibration, motion, and acceleration. Most environmental conditions for manned and equipment spaces on planing vehicles can be properly accommodated and controlled. Though each of the above environmental factors impacts on planing vehicle design, the motion and acceleration factors are the most significant in developing advanced high performance designs. Motions and accelerations can be predicted from model tests. *However, quantitative criteria of crew functional limitations in a random motion environment are ill-defined.*

b. (U) Vehicle Motion and Acceleration Criteria

1) The motions and accelerations of high speed planing craft in waves are non-linear with wave height [35]. Therefore established linear superposition techniques are not applicable. As a consequence there is no analytical procedure for calculating the motions and accelerations of planing craft at high speeds. These must be estimated by model tests or semi-empirical procedures [35].

2) Figure 57 shows limits of human tolerance to vertical accelerations. The limit lines plotted above the frequency of 1 Hz are sanctioned by ISO and were reported in MIL-STD-1472B [87]. The limits shown below 1 Hz are those of Von Gierke for a 15% Motion Sickness Incidence [106]. Bender and Collins [105] questioned the validity of this ISO material however, because they found the low frequency data to be too disperse to establish meaningful criteria. These criteria, and the Von Gierke criterion as well, are based on periodic vibrations and it is not yet known if tolerance to the random vibrations of the marine environment corresponds to tolerance of periodic vibrations. Objective test information on reduced proficiency due to vehicle motion in a seaway is scarce and incomplete. It is concluded however, that human performance errors generally tend to increase with increasing impact levels and impact frequency. Recent speculation by various ANVCE Vehicle Advocate Groups indicates that for frequencies below 1 Hz each has in mind its own criteria for assessing crew limitations relative to the ride quality of its respective vehicle type.

The reanalysis of CPIC-X data to convert acceleration levels to RMS "g" is now complete. This data is displayed on Figure 57 where for frequencies below 1 Hz it falls generally beneath the limit for 15% MSI [106]. This evaluation of the craft's ride quality is substantiated by those who have ridden the craft for prolonged periods in such sea states. Only one crew member seemed prone to seasickness and he admittedly had a personal susceptibility to it.

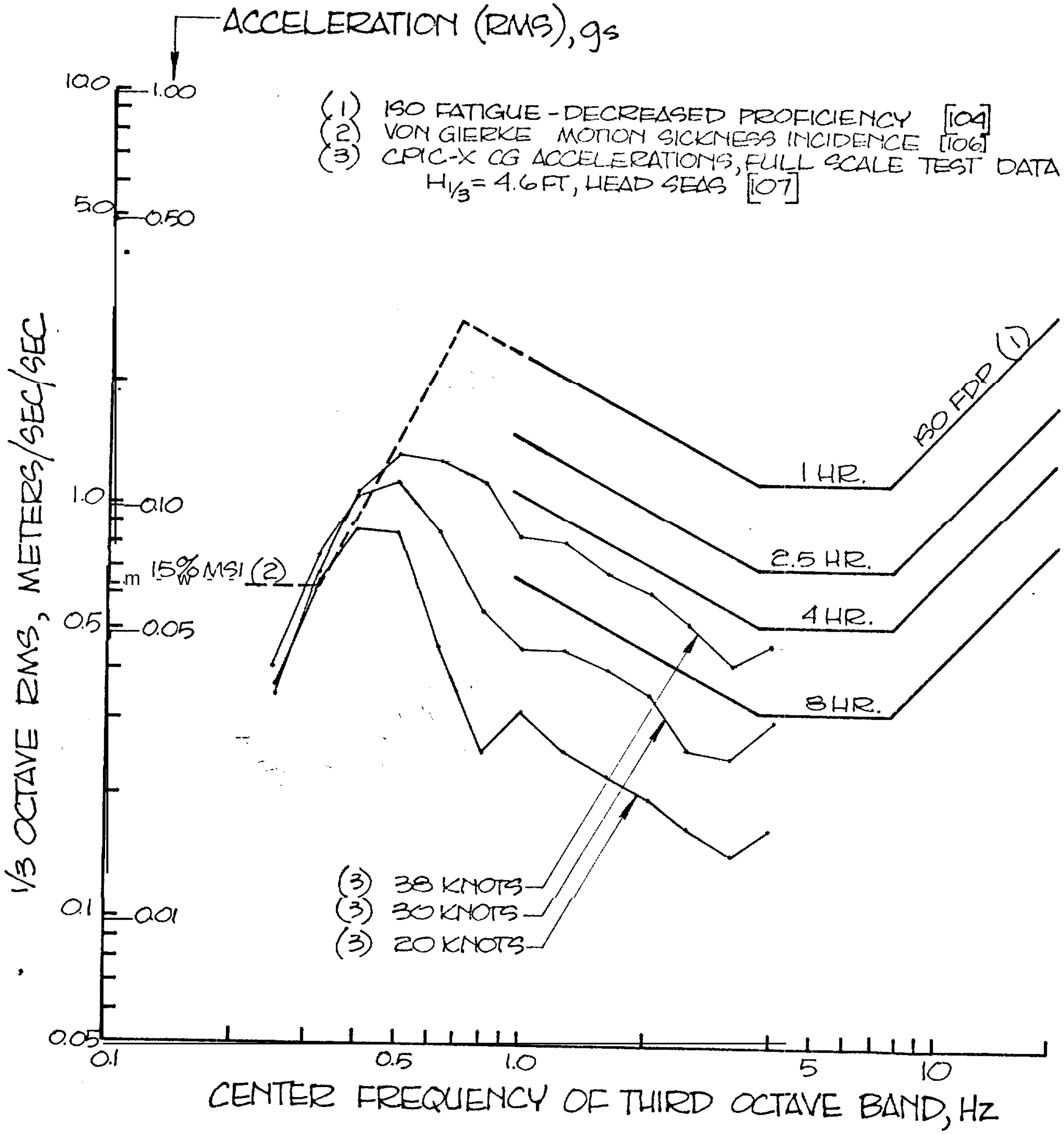


Figure 57 - (C) Limits of Human Tolerance to Vertical Accelerations (U)

At the higher frequencies addressed by the ISO limits, CPIC-X can maintain 38 knots in the design sea state ($H_{1/3}$ = 4.6 ft) for about 5 hours with no decrease in proficiency of the crew, and for longer periods at reduced speeds. These periods exceed the length of time the craft is expected to operate at the corresponding speeds according to typical mission profiles. Since this data will scale linearly with vehicle size and sea state, larger planing ships (such as the 1000 ton point design of Task IV of ANVCE) will experience nearly identical RMS "g's" at design conditions.

In the absence of more accurate standards the authors of this ANVCE Planing Vehicle Technical Assessment are using the RMS "g" levels plotted in Figure 57 as an interim guide line for minimum ride quality criteria.

3) Higher craft speed coupled with the ability to operate in higher sea states can produce maximum accelerations as high as 3 g at the CG. (See Figure 41, p. 125). Current test experience does not establish effects of these conditions on humans. The aircraft industry has extensive data on seated man's tolerance to a single impact (mainly for aircraft ejection system/design). These studies show that compression fracture occurs in three out of four men at a peak acceleration of 26 g for 0.005 sec. These studies do not speak to any reduction in effectiveness due to repeated slamming during an extended period of time, but rather to the single maximum impact which causes fracture. See also Section III.E., Ride Quality, p. 228.

4) Figures 58 and 59 adapted from [82], give typical pitch data for planing hulls of two different sizes and types, the 65 PB MK 3 having a lower L/B and lower deadrise than CPIC-X. Note also the difference in wave

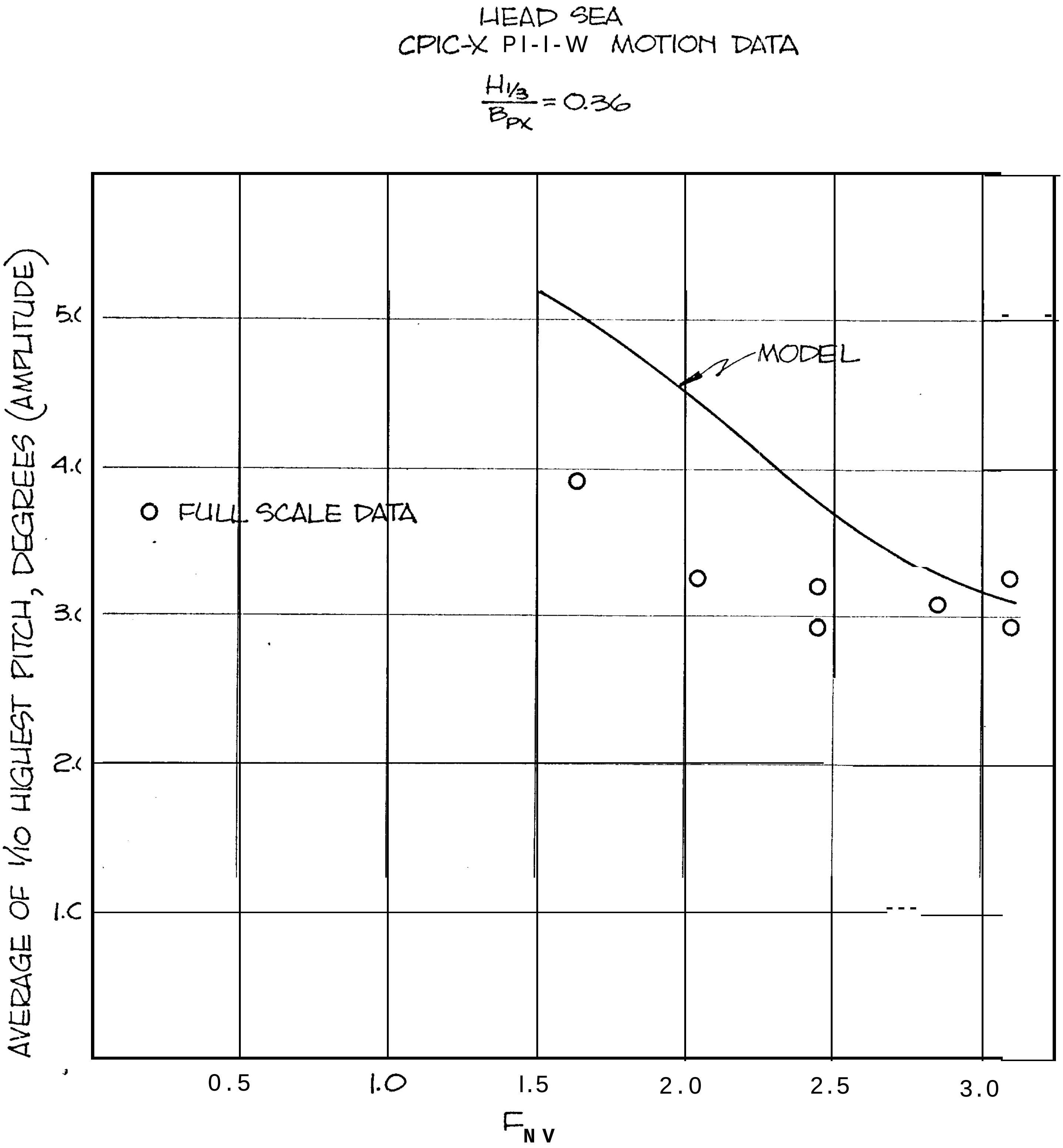


Figure 58 - Comparative Data for Pitch Motion of CPIX-X [89] (U)

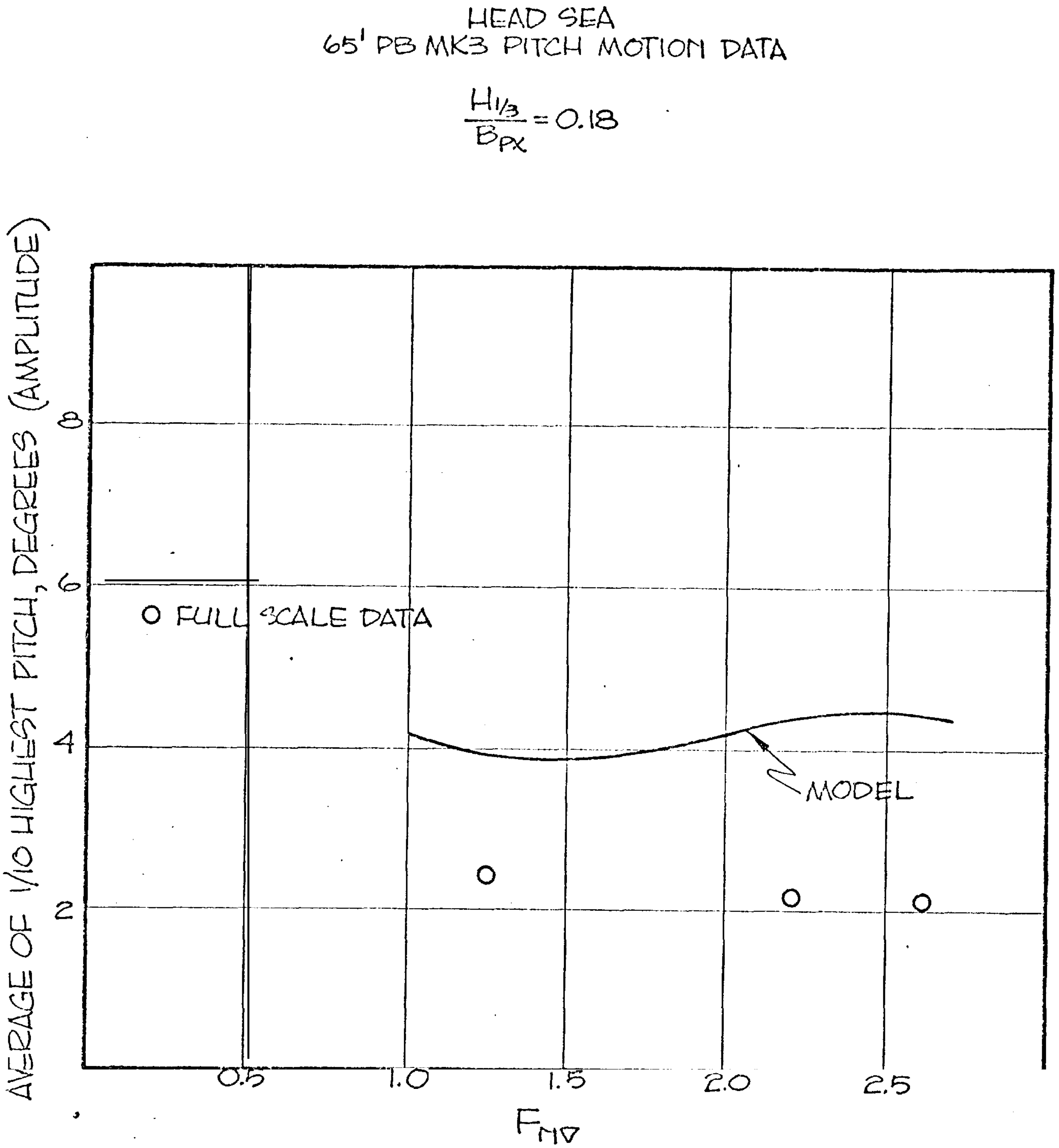


Figure 59 - Comparative Data for Pitch Motion of 65 PB MK3 [89] (U)

height/beam ratio for the two craft. The figures give a comparison of model predictions with full scale test results. These motions are considered moderate in both cases and would be for all well designed.planing hulls. Similar trial data is available for 10 other boats tested by NAVSECNORDIV. (See Table 12, p. 221). Roll motion data is given in Section II.B.6., p. 202, where the subject is discussed at length.

c. (U) Vehicle Noise Criteria

Noise criteria for design considerations are well established. Categories have been established for different spaces throughout the vehicle based on speech communication, deafness avoidance, and habitability. Noise tolerance levels are established for humans; however, quantitative measures of effectiveness of the crew during a specific mission when subjected to a range of noise up to the tolerance level has not been established. Many standard practices can be followed to silence planing vehicles, including proper arrangement to isolate certain spaces, enclosing equipment, resilient mountings, insulation of bulkheads, and utilization of silencers/mufflers. Economics and weight/volume effects on vehicle performance may limit the use of some or all of these methods in a particular design.

d. (U) Other Environmental Criteria

Environmental standards are well defined for such factors as temperature, ventilation, illumination, and noise. The majority of the present human factors design criteria are established by MIL-STD-1472B [87]. This standard covers such design factors as: environment, maintainability, placement of controls, visual displays, audio displays, etc. In addition, numerous charts are provided giving average heights and extensions for eye level, arm reach, leg room, weight limits, stair dimensions, electrical coding, etc. This standard is excellent and if followed will provide a habitable craft without undue impact on performance.

e. (U) Applications

The human factors criteria of [87] have been applied as far as reasonable to almost all new design vehicles in recent years (since 1971).

8. (U) Reliability/Maintainability/Availability (RMA)

a. (U) This section concerns the application of reliability, maintainability and availability in the development of an experimental prototype "weapon system" (herein defined as both the vehicle and its combat suite). RMA considerations will usually impact on high speed planing hull designs in the following significant areas:

7) The desired or specified RMA levels will be relatively high for the degree of complexity and sophistication of the vehicle.

2) The primary mission(s) of the vehicle will tend to utilize a very high percentage of the installed equipment's performance capability (there is usually minimal back-up or redundancy for this peak performance condition).

3) Typically one or more major subsystems will be new or developmental (i.e., propulsion, control, hull, structure, weapon, sensor, etc.). These new subsystems will generally have little or no proven RMA characteristics, and may be expected to exhibit relatively poor RMA characteristics until more mature.

4) The compatibility and mutual interference/influence of the total vehicle/combat suite system's RMA characteristics may create conflicting

and/or formidable logistic support requirements.

b. (U) For propulsion and other machinery systems, modern technology is generally available in the form of components and subsystems which can meet the performance requirements and exhibit acceptable RMA characteristics. RMA deficiencies usually occur in the integration of equipment within these systems. To be successful in this integration some trade-off must be made between performance, cost and RMA. Potentially critical and/or developmental subsystems and equipments must be identified early in the design process. A program for RMA growth, performance improvement and design development must be implemented in detailed analysis and hardware testing. Major constraints in this area are weight and size as they would affect hull and structural concepts.

c. (U) RMA characteristics of hull and structural components take on added significance over conventional ships due to the more severe hydrodynamic loadings. The degradation and failure modes of structural members from fatigue, due primarily to propulsion system induced vibration can be significantly different. In addition, high dynamic repetitive stress loadings are more common to a high speed planing hull than to most conventional ships, These and other unique conditions require the development and application of special RMA analysis techniques along with the normal design, development and testing of hull and structural characteristics.

d. (U) Although not unique to planing hulls, the compatibility and integration of the vehicle and the installed weapons system is most critical to satisfactory performance (refer to Section IV. A. for a detailed discussion of this subject". Since vehicle design and weapons system design normally do not occur concurrently, these factors must be coordinated in the initial conceptual design of each item.

e. (U) The importance of laboratory testing and extensive underway trials to verify RMA goals cannot be over emphasized, Their contribution to achieving successful operational hardware has been well demonstrated for high speed planing craft. The most effective high speed craft application of RMA has been in the development of the experimental prototype Coastal Patrol and Interdiction Craft (CPIC-X). The CPIC-X effort began with early feasibility studies, matured with preliminary and contract design, and concluded with the integrated Technical Evaluation/Operational Evaluation. Heavy emphasis was placed on the development of the Integrated Logistics Support Plans, Maintenance Engineering Analyses, Accessibility Studies and other areas affecting RMA.

f. (U) The reliability growth observed in the CPIC-X Program [108] best illustrates the value of early RMA analysis and testing with respect to performance and cost. Early in CPIC-X development, the propulsion machinery was defined as a potential RMA problem area. The CPIC-X propulsion machinery consists of three high-speed, main propulsion shafts, using AVCO TF '25A gas turbines, Sier-Bath gear boxes, Precision V-Glide vee-drive-type gear boxes. Two low-speed Stewart and Stevenson diesel outdrive assemblies (later replaced with Volvo Penta Diesels and outdrives) served for low speed propulsion. The high speed equipment underwent extensive shorebased testing at NAVSECPHILADIV while the low-speed diesel system was extensively tested at DTNSRDC, Annapolis. The entire machinery package was subjected to further in-craft testing during the CPIC-X trial program.

g. (U) The shore-based testing of high speed machinery began on 15 June 1972 and terminated 8 October 1974, accumulating 1.337 hours of operation. Only the AVCO turbine has seen marine service. This early text program encountered several failures and identified associated design deficiencies, which helped initiate redesign and maintenance procedures modification. A total of eight failures occurred during the test:

GAS TURBINE - 3
SIER-BATH - 1
VEE-DRIVE - 4

As a result of this test and associated machinery component modifications, reoccurrence of these failures during the craft underway trials was virtually eliminated, thus minimizing extensive craft downtime for these equipments.

h. (U) 1) Underway test and evaluation of the CPIC-X accumulated 860 hours of operation between May 1973 and December 1974. The following failures were experienced during the test period in the machinery areas [108]:

GAS TURBINE VOLTAGE REGULATORS - 3
PROPULSION DIESEL VOLTAGE REGULATORS, - 2
VEE-DRIVE - 3
PROPULSION DIESEL OUTDRIVES - 11

During the period May, 1973, through February, 1974, the low-speed Stewart and Stevenson outdrives with DDAD 6V53 diesel engines accounted for all eleven failures of the propulsion diesel outdrives, as expected based on similar experience from earlier testing at Annapolis. This situation was corrected for the remainder of the test with the exchange of Volvo Penta units for the Stewart and Stevenson units.

2) (U) The test and evaluation of the craft also exhibited other problems/failures that were corrected via redesign of subsystems or equipments. These problems degraded performance, but were not of a magnitude to cause mission unreliability or mission abort. They occurred in the propeller shaft fairing, the 400 cycle power supply, the roll fin system, and the chip detectors in the V-Drive.

3) (U) The shaft fairing problem occurred due to vibration and propeller loading. The propeller transmitted the vibration to the strut which, combined with the loading, caused the fairing to 'crack and separate from the shaft and hull plating. The shaft support was redesigned to eliminate the fairings. To eliminate the 400 cycle power supply problems, motor generator sets of adequate capacity for the craft replaced solid state frequency converters. The fin system accumulated a total of fifteen failure related actions during the test period. Most failures were related to the hydraulics in the control system. A fail safe resolution was accomplished by redistributing the fin area relative to the stock so that the fin would trail if the control system failed. The chip detector problem occurred early in the test program as a result of burn-in tests and the alarms occurred as a result of the small metal chips being picked up in the gears. After run-in this problem essentially disappeared.

i). (U) The T & E performance of CPIC-X was greatly enhanced as a result of the shorebased testing. The CPIC-X machinery plant was essentially debugged prior to the at-sea T & E phase. None of the failures experienced at NAVSECPHILADIV were experienced during the underway trial period.

j) (U) A brief explanation of the CPIC-X reliability test results is given in the following paragraphs. Data used in the preparation of the figures were derived from reference [108]. Interpretation and use of the presented results must be based on a thorough understanding of the mission definition, reliability models and block diagrams, and other pertinent backup data in the test report [108].

k. (U) The 18 month at-sea test period was divided into two phases for the purpose of evaluating reliability growth:

Phase I - from craft delivery to the Navy through the time (approx. 1/31/74) the craft underwent major modifications at a repair yard. For the ordnance suite, data from the On-Shore Systems Integration Test (OSSIT) were used.

Phase II - From the time the craft resumed testing after the yard availability (approx. 6/1/74) through and including completion of Mission Suitability Tests (12/6/74). Since weapons firing aboard the craft did not begin until 9/14/74. Phase II for ordnance was taken as 9/1/74 through 12/6/74.

1. (U) For each of the two phases, equipment operating hours and mission-critical failures were obtained from the test documentation and used to calculate the respective reliability levels shown on the figures. Figure [60] is a composite bar chart which summarizes test period reliabilities as well as predicted potential levels for specific 60 hour mission requirements. The heights of the blocks are proportional to the reliability levels indicated on the top of each block providing a visual comparison of reliability growth. Time is generally indicated from left to right but is not shown to any scale. Figures 60 through 64 provide details for a 60-hour and 14-hour mission of the craft.

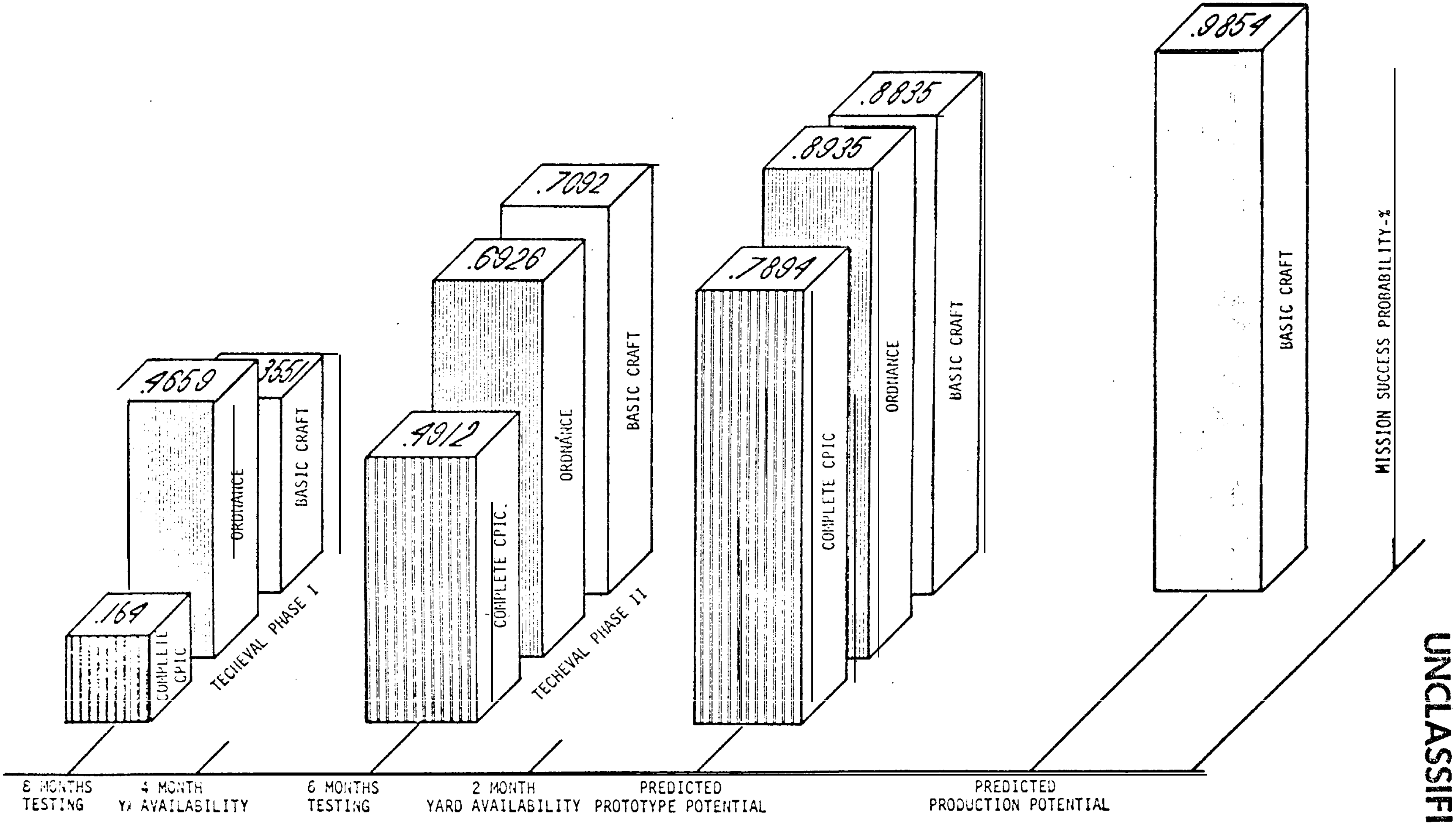


Figure 60 - CPIC-X Reliability Levels (60-Hour Mission) (U)

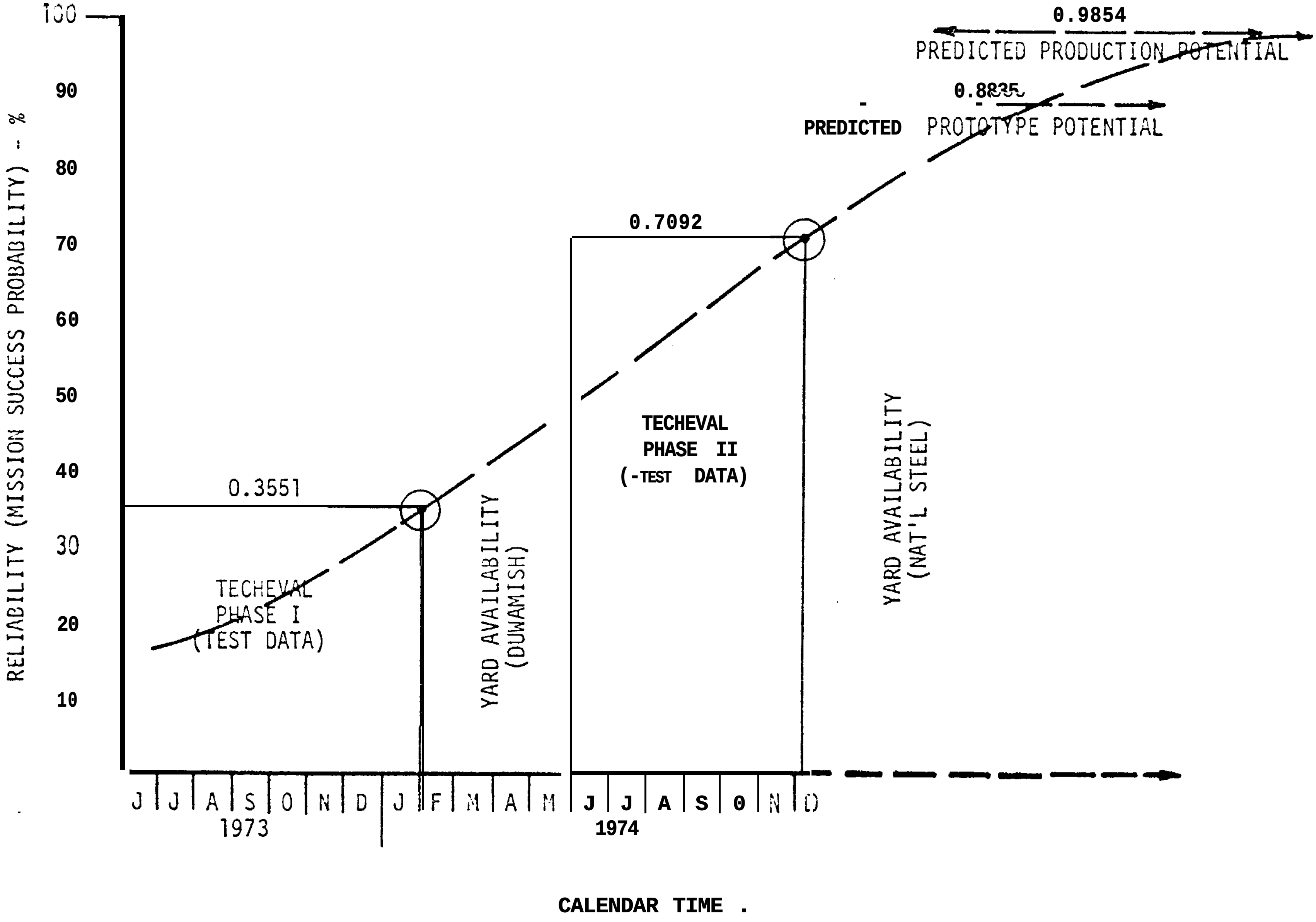


Figure 61 - CPIC-X Reliability Levels (Basic Craft With No Ordnance For 60 Hour Mission) (U)

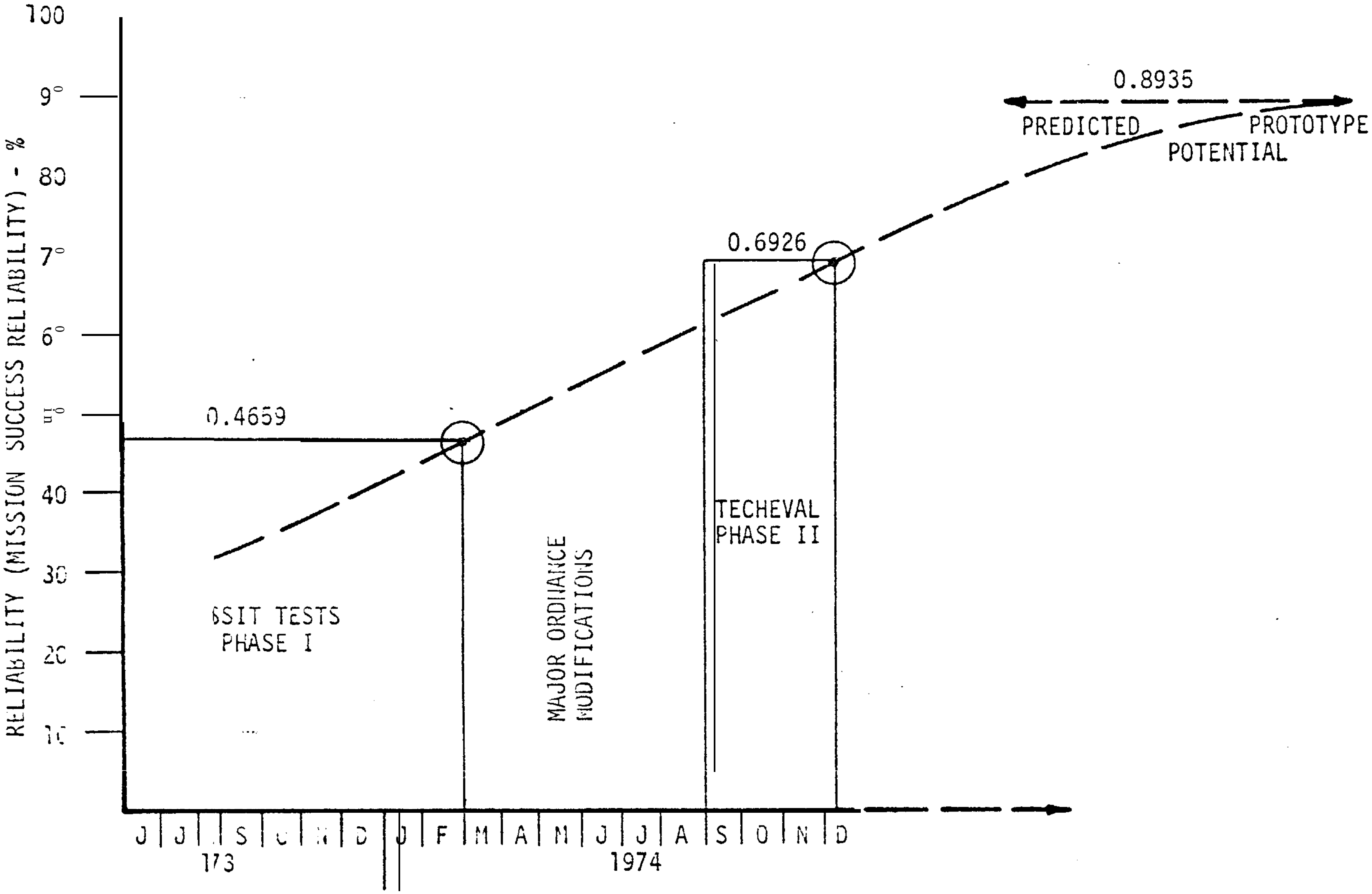


Figure 62 - CPIC-X Reliability Levels(Ordnance for 60 Hour Mission iring 500 Rounds)(U)

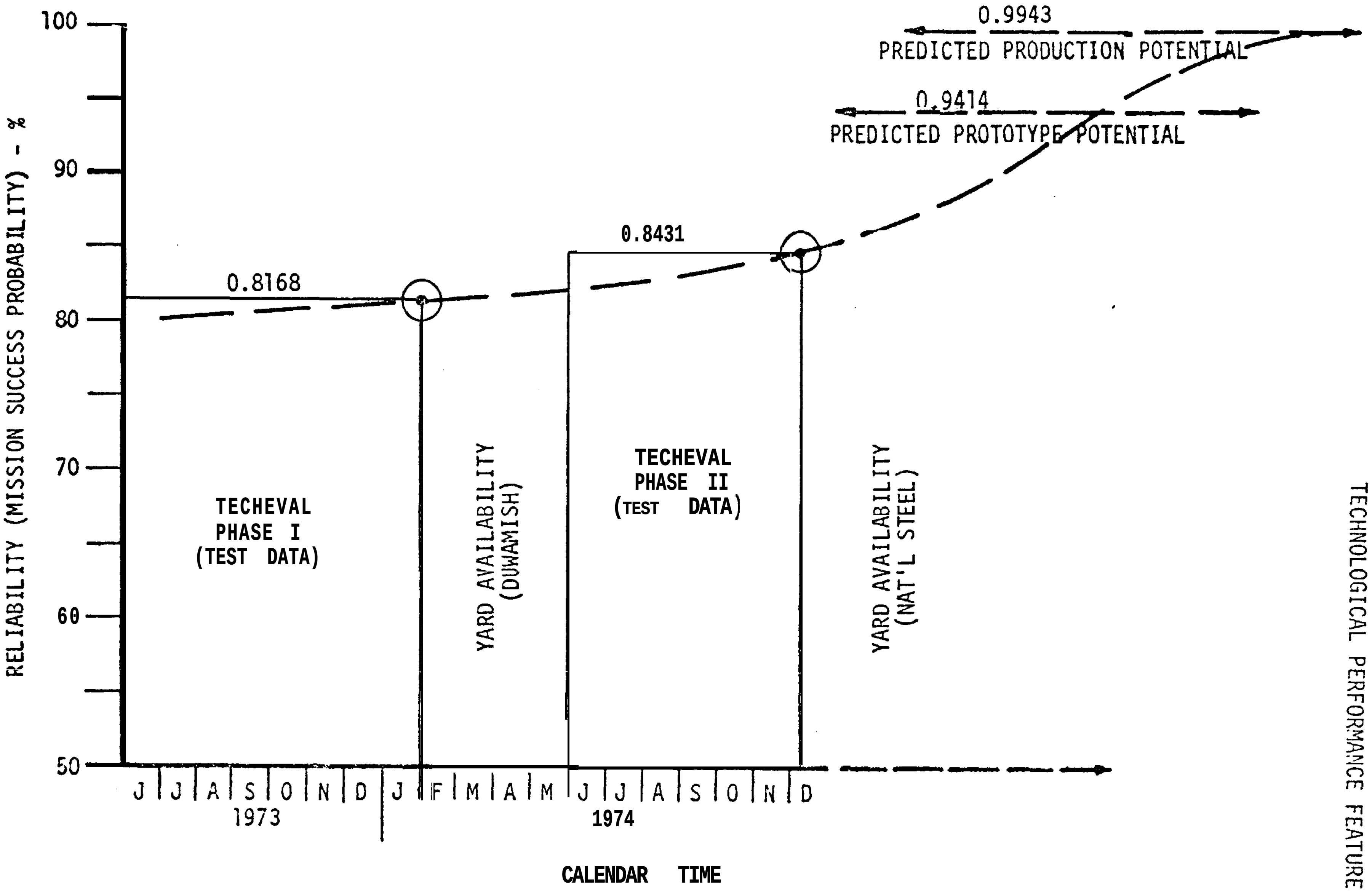


Figure 63 - CPIC-X Reliability Levels (Basic Craft With No Ordnance, For 14 Hour Mission)(U)

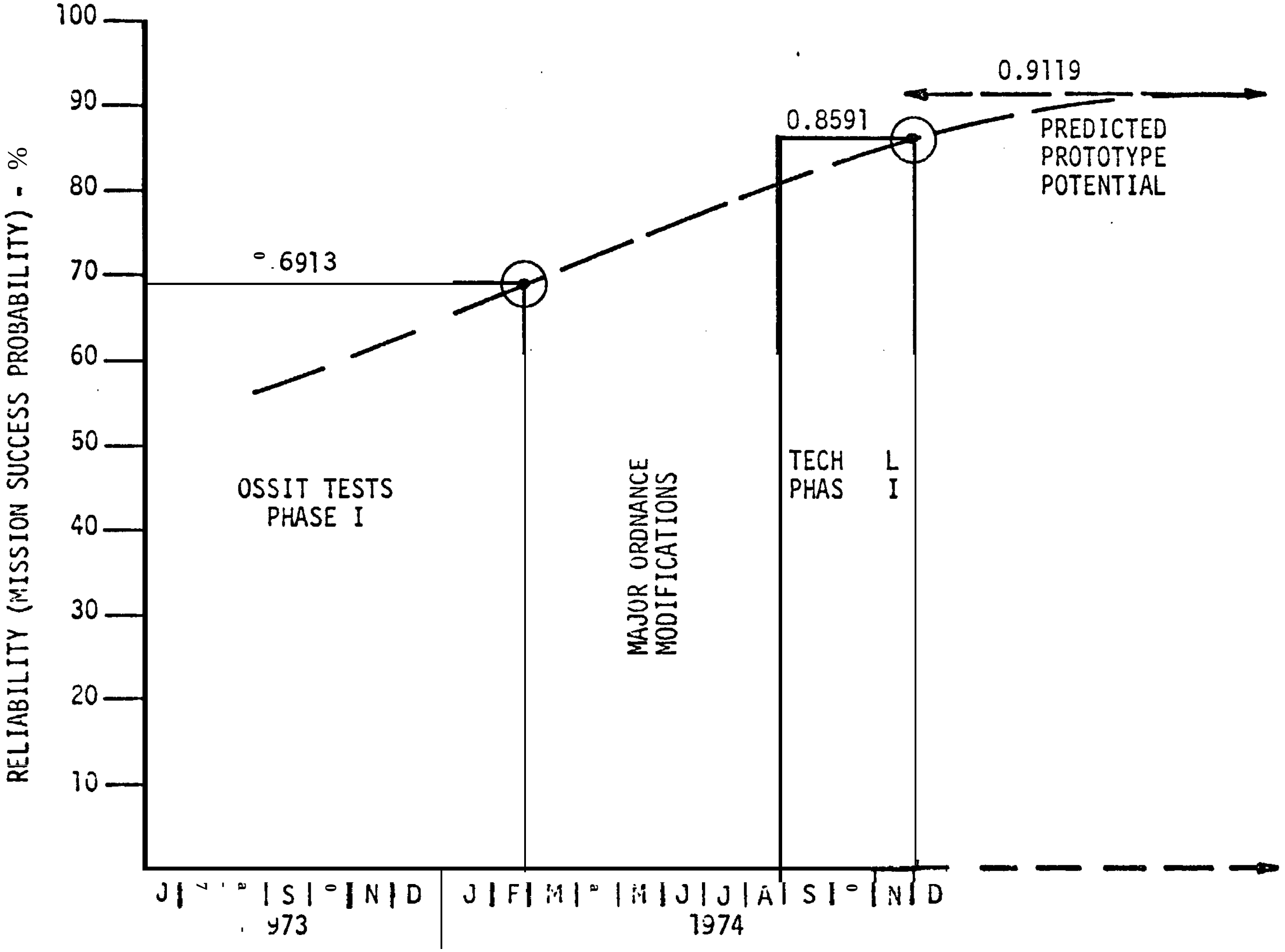


Figure 64 - CPIC-X Reliability Levels Ordnance For 14 Hour Mission Firing 500 Rounds (U)

m. (U) The higher levels observed in Phase II (vs. Phase I) provide an indication of reliability growth resulting from experience gained from testing and improvements made to the craft. On Figure 63 note the two reliability levels for the basic craft 14-hour mission indicate a comparatively small growth (.8168 in Phase I to .8431 in Phase 11). This is due to both the relatively high level of reliability inherent in the short mission time plus the comparatively low dependence of this mission on the more troublesome low-speed propulsion system which was aboard at that time. The levels identified on the figures as "predicted prototype potential" are based on the Phase II calculated levels. The reliability levels identified as "predicted production potential" were calculated from generic failure rates.

9. (U) Unique Features

a. (U) There are no features of the planing hull concept which are truly unique in the sense that no other concept has them, but the combination of useful features possessed by the planing hull concept is unique. This section, therefore, consists of a listing of the advantages of planing hulls and comparisons, in each case, with those concepts which are lacking in that particular area. The SWATH concept will receive little attention because, in general, the range of sizes and mission applications envisioned in the context of the ANVCE study appears to have little or no overlap with the planing concept.

b. (U) Following the above approach, it can be said that planing hulls:

1) Exceed displacement speed limitations, as do hydrofoils and

ACSC*, but normally with much less hump resistance for given vehicle gross characteristics.

2) Can operate at any speed from zero to maximum, as do displacement ships, but with a higher maximum and without noticeable transition from one regime to another.

3) Have acceptable sea-state capability without the weight, encumberances or expense of a lift system as in hydrofoils and ACSC or the great draft of a SWATH (or of a hydrofoil with foils down in the displacement mode).

4) Have relatively shoal draft in all normal configurations and can be designed with very shoal draft when required.

5) Are more readily transportable (including by aircraft) than hydrofoils, and no less so than other craft of similar size.

6) Cost less to build than hydrofoils and ACSC, and yet are comparable in cost to high performance displacement ships.

7) Are inherently less vulnerable (and more reliable) than hydrofoils and ACSC which must depend on an additional, mechanical system (the lift system) to remain fully operational.

8) Are very maneuverable at low speed compared with ACSC (and sometimes hydrofoils) with disabled lift systems**, and are generally more maneuverable than SWATH.

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* Air Cushion Vehicles (ACV) and Surface Effect Ships (SES) will be collectively referred to as Air Cushion Supported Craft (ACSC) in this section.

** An exception to this is the Surface Effect Boat, a hybrid design described in Section II. E. 2.i., p. 215, which can continue to operate as a planing or displacement catamaran should the air cushion be inoperative.

9) Achieve at least partial shielding from enemy fire, of the fuel when it is placed in the bottom of the hull.

10) Have a higher useful load fraction than other advanced concepts.

11) Are very tolerant of load variations and particularly of overload conditions.

12) Are not subject to large vertical C.G. shifts (such as those due to foil retraction) and the consequent impact of intact and damaged stability requirements on the hull form and compartmentation.

B. SUBSYSTEMS AND DESIGN AND CONSTRUCTION FEATURES

1. Hull/Airframe (Containment System)

a.(U)Arrangements

1) Most high speed patrol vehicles tend to have similar hull arrangements because of the similarity of both operational requirements and the hull forms generally employed. Resolution of conflicting requirements of both calm and rough water performance in the planing regime, general operation in the displacement regime, and static flotation, usually results in a center of gravity location well aft of amidships (compared to displacement ships) and a need to control longitudinal c,g. movement with varying load conditions.

2) Because of these considerations heavy items tend to be located aft and the consumable weights, fuel in particular, are located as close to the center of gravity as possible. Water ballast or a fuel transfer system may be employed to control the position of the longitudinal center of gravity. Machinery systems are located from amidships aft to keep shaft lengths short, and, in the case of turbines, to place them in an area of lower vertical accelerations and reduced spray ingestion.

3) Locations of battle stations for the crew tend to be in the aft two-thirds of the length to minimize the effects of motions and accelerations. Living spaces can be located forward but are not very habitable during high-speed, rough-water operations. The use of shock-mitigating seat systems for the pilot house and other manned stations are practical and help alleviatesuch habitability problems. High performance vessels of the type being considered will not generally offer the space for crew habitability that is normally available on the newer conventional ships.

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Every aspect of the design must be developed with first consideration given to performance of the mission.

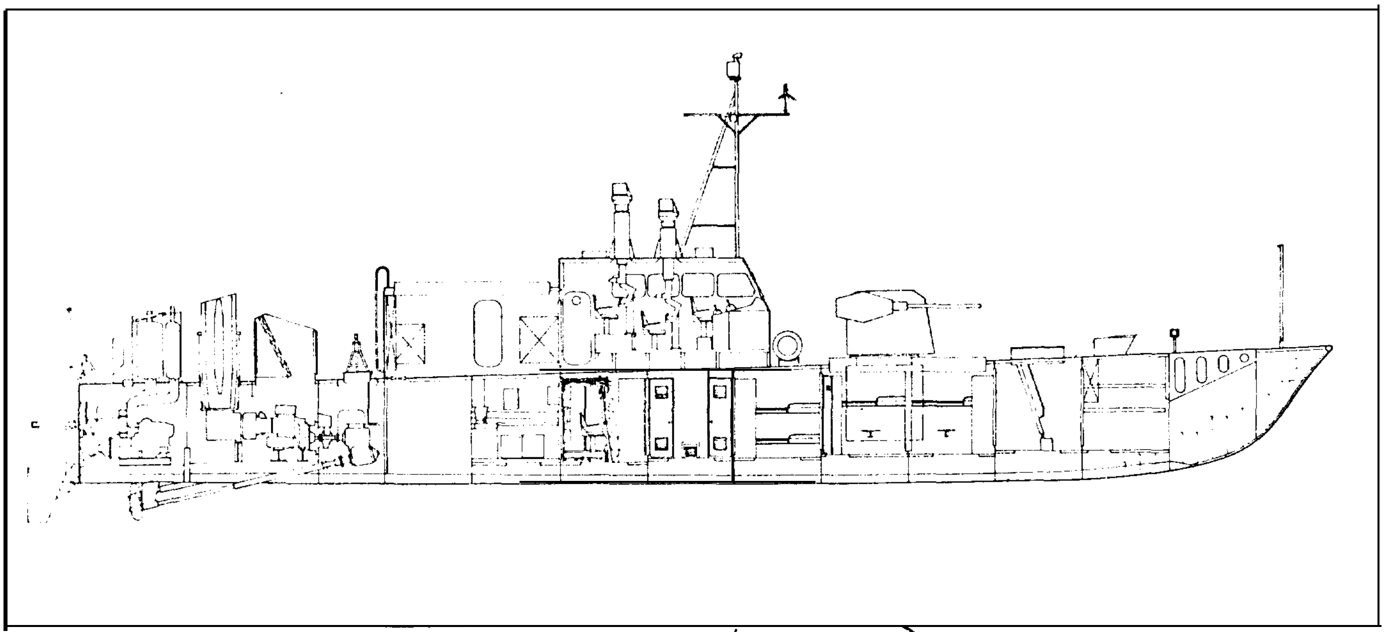
4) A portion of the vessel's military payload generally has to be located forward. This is particularly desirable to capitalize on the use of modularized payload items for interchangeability and LCG balance. Typical internal arrangements are shown in Figure 65.

b.(U)Subdivision (See also para. 3.a. on p. 95)

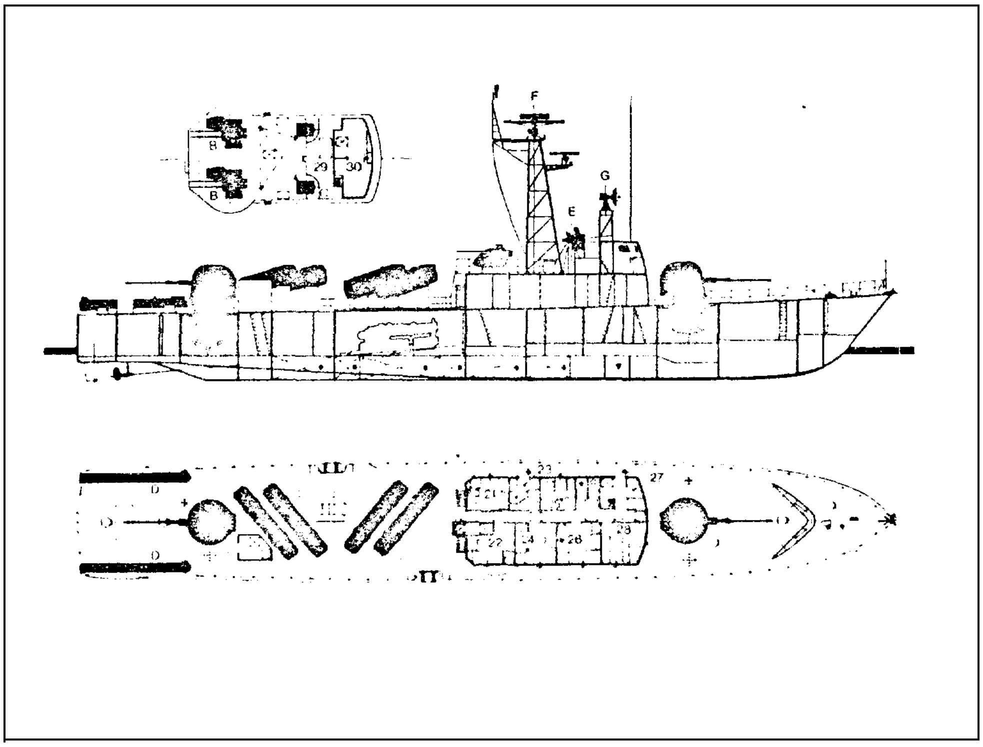
Although it is difficult to attain a two-compartment standard of subdivision for smaller planing hulls, due to the very small compartments required in the smaller hulls, it is nevertheless most desirable because damage is almost as likely to involve a bulkhead as not. Usually the machinery space is the most difficult from this standpoint. As craft size gets smaller it is necessary to accept a lower standard and sometimes it is necessary to use buoyancy chambers or rigid foam flotation, because additional watertight bulkheads are not practicable. For larger planing ships up to 1000 tons, less than a two-compartment standard could not be accepted, therefore, trade-offs between floodability and arrangement flexibility must be made.

c.(U)Structures

1) The structural framing arrangement can be either longitudinal, transverse, or mixed in nature. Usually, there are no longitudinal bulkheads of any length, due to the narrow beam associated with these hull forms, although an exception is frequently made in the machinery areas. Most U. S. designs in aluminum will be mixed framing systems in which the shell plating is stiffened longitudinally and the longitudinals are supported by intermediate transverse frames and by transverse bulkheads. The intermediate transverse frames are usually "fixed" frames in that the web extends to the skin plating



CPIC-X (L=30.5M)
OPTIONAL AFT MOUNT NOT SHOWN



LA COMBATTANTE III (57.4 M)

Figure 65 - Typical Internal Arrangements (U)

for direct shear transfer. However, the so called "floating" frame is also utilized. It is in fact the form of construction generally employed by crew boat builders. In this case shear transfer is through the flange of the longitudinal to the flange of the frame and this is the only connection of the frame to the plating. This type construction was used in the PTF-25 planing hull and the FHE-400 hydrofoil hull Bras d'Or. The latter method is usually considered cheaper to construct (no cutouts required in way of longitudinals), which is probably the reason for its extensive use in commercial vessels. Illustrations of both types of construction are shown in Figures 66 through 69.

2) An exception to this "mixed" framing philosophy was the CPIC-X which was totally longitudinally framed. This resulted in a weight penalty and higher stresses compared to a mixed framing system, but was selected because it provided more usable internal volume and also because it offered reduced construction cost,

3) The steel hulls of foreign patrol boats are almost always transversely framed, with use of a double bottom prevalent. If they were constructed of aluminum, a mixed framing system would probably be used as it would offer more material for longitudinal strength, which is not required in steel construction of this size since minimum gage usually governs the scantlings.

4) Non-tight bulkheads can be made lighter by use of composites such as sandwich construction and this is often done. Joiner work and outfit should be of the lightest feasible construction, not Navy standard which is heavy.

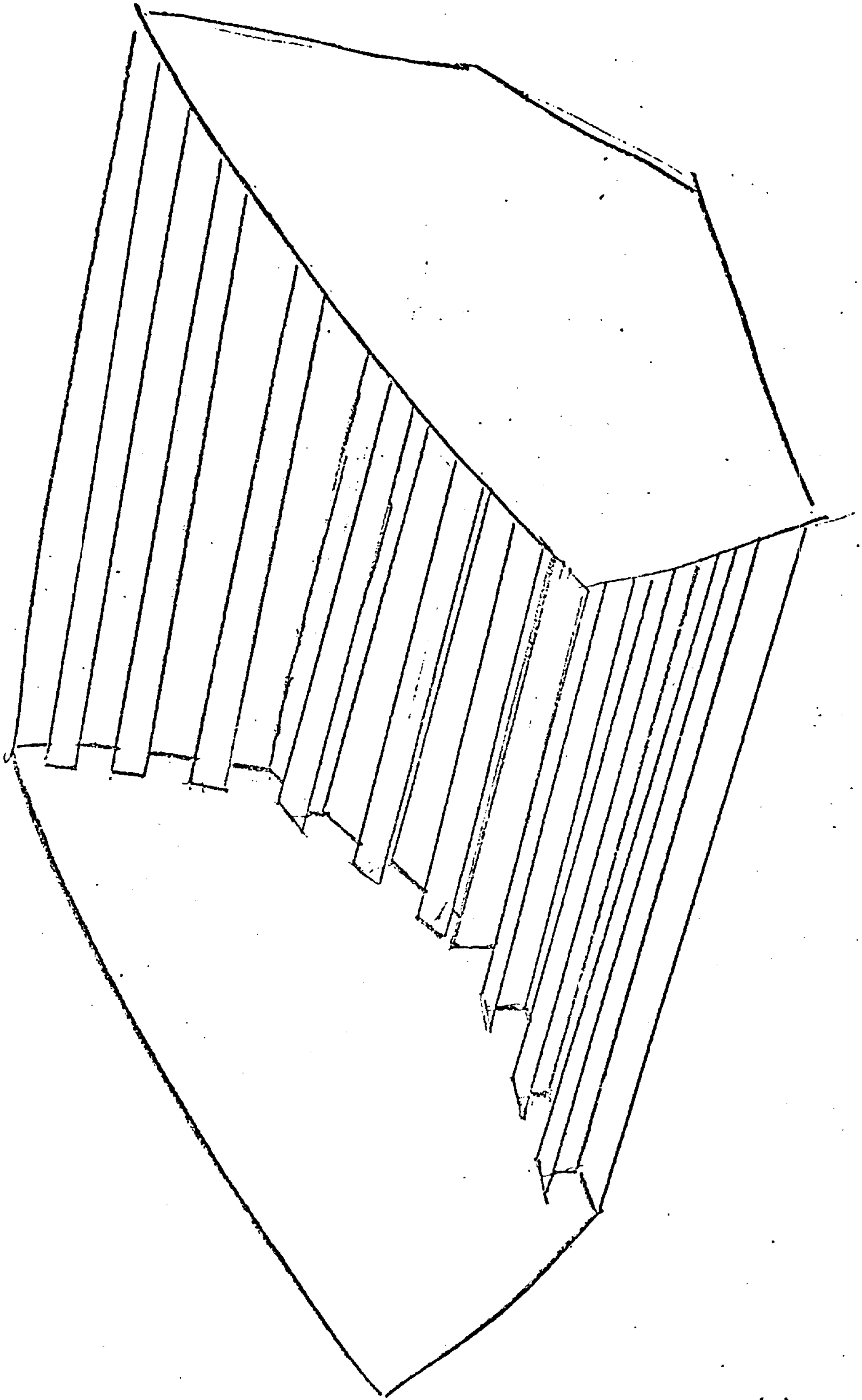


Figure 66 - Sketch of Longitudinal Framing (U)

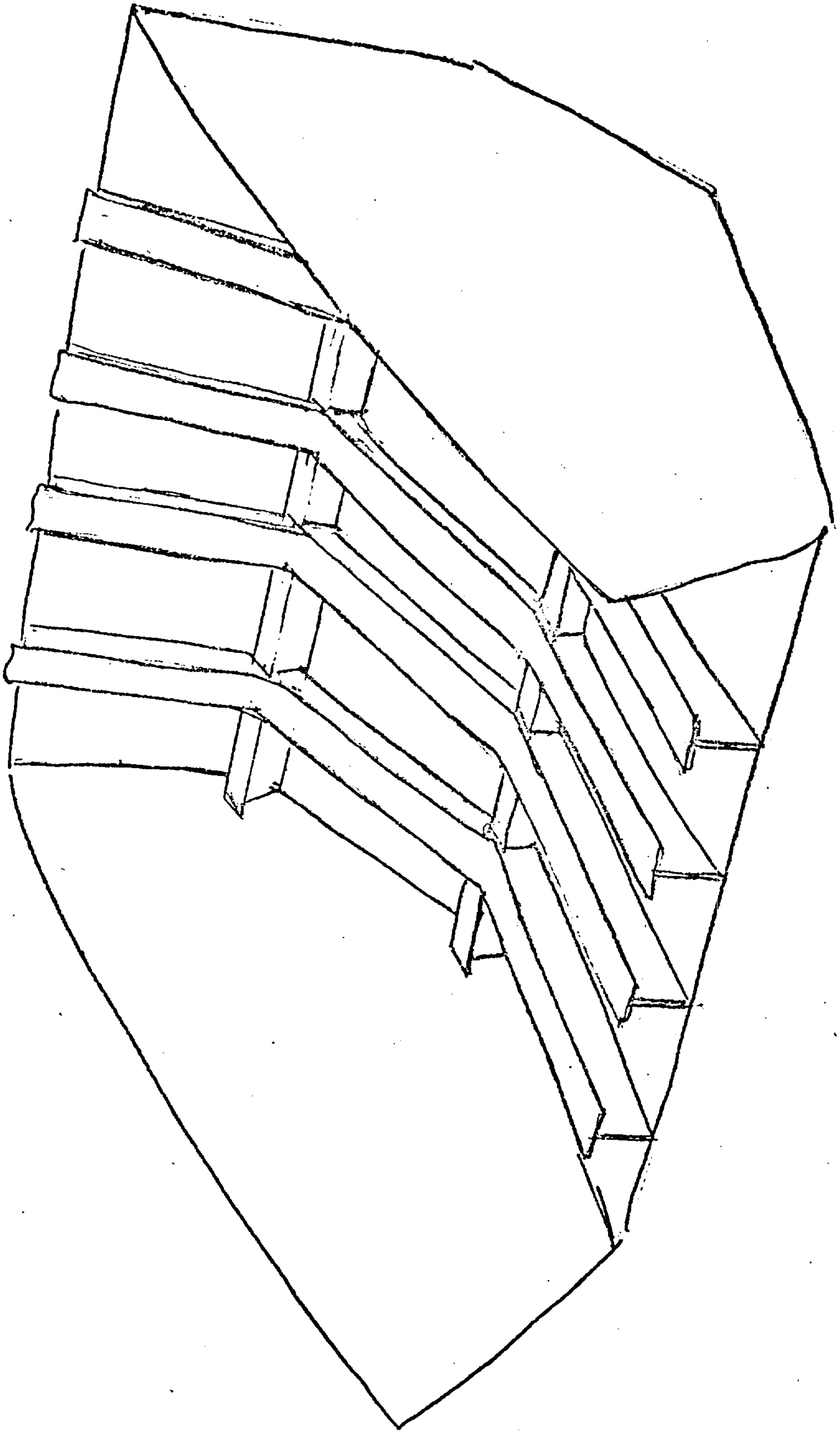


Figure 67 - Sketch of Transverse Framing (U)

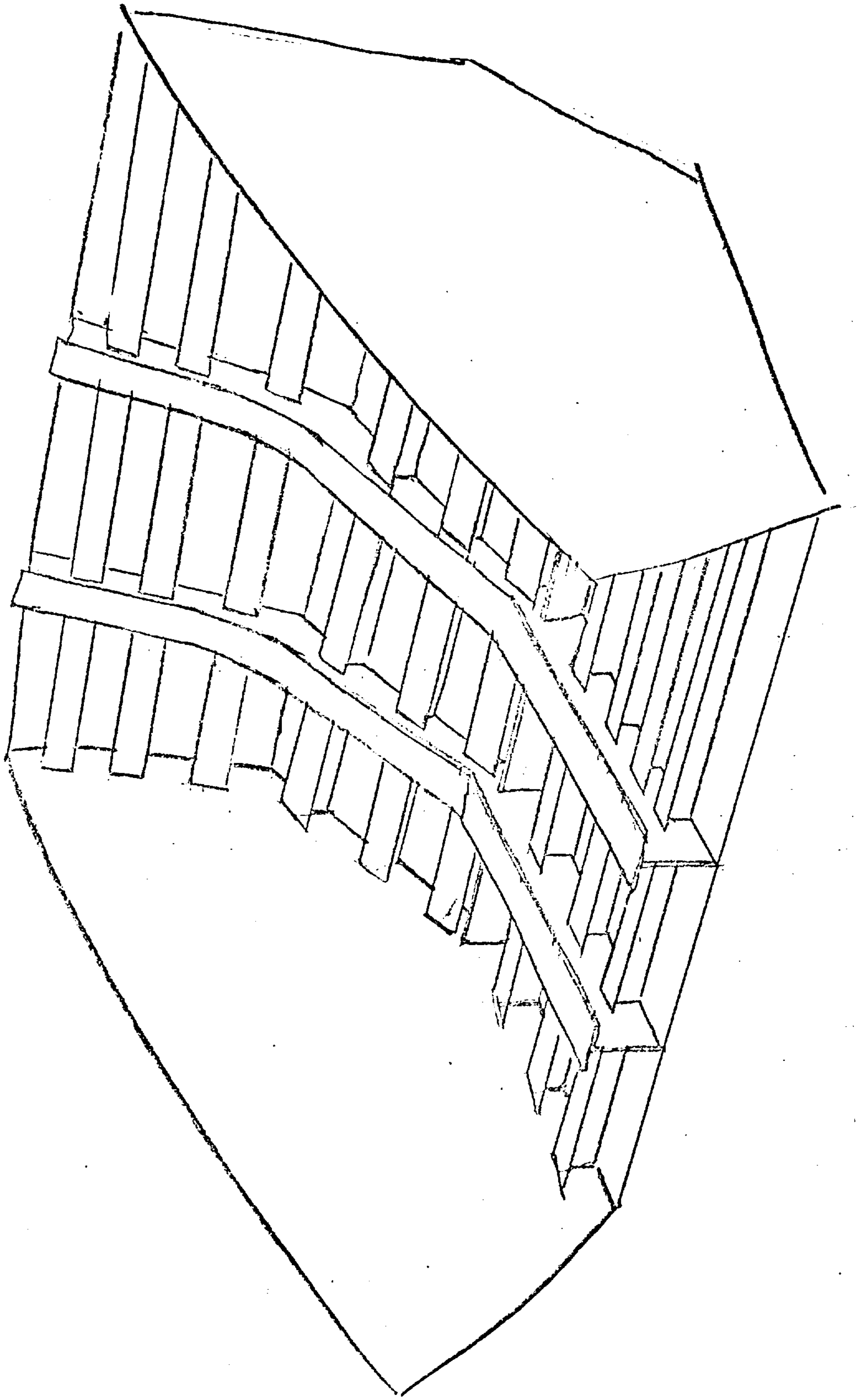
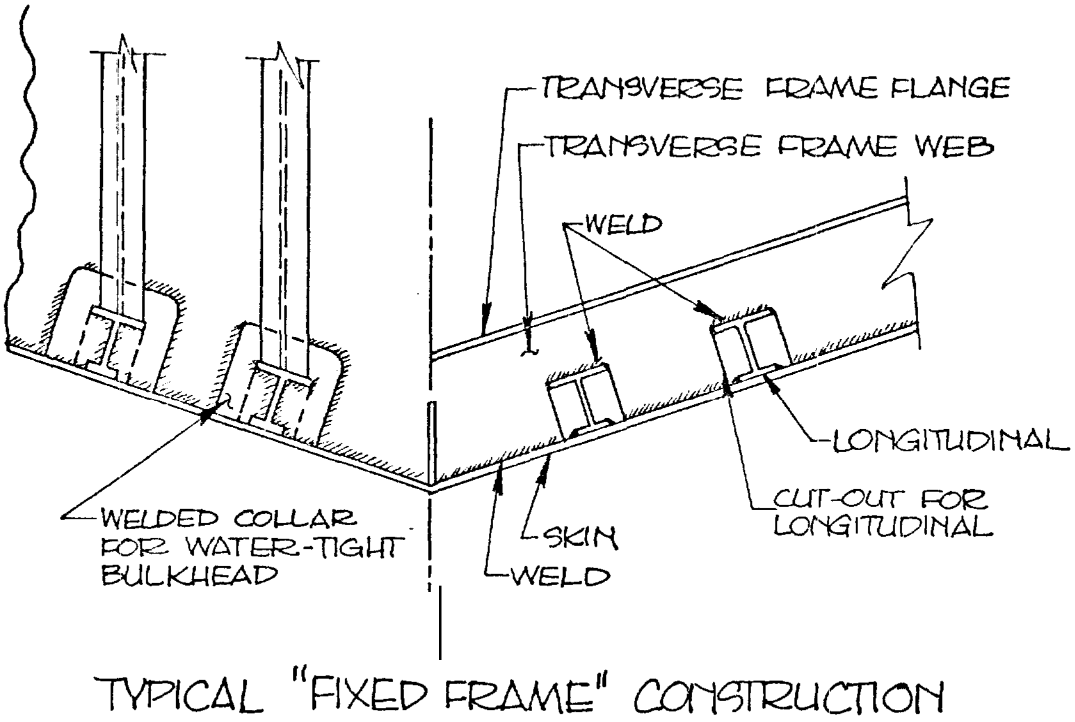


Figure 68 - Sketch of Mixed Framing (U)



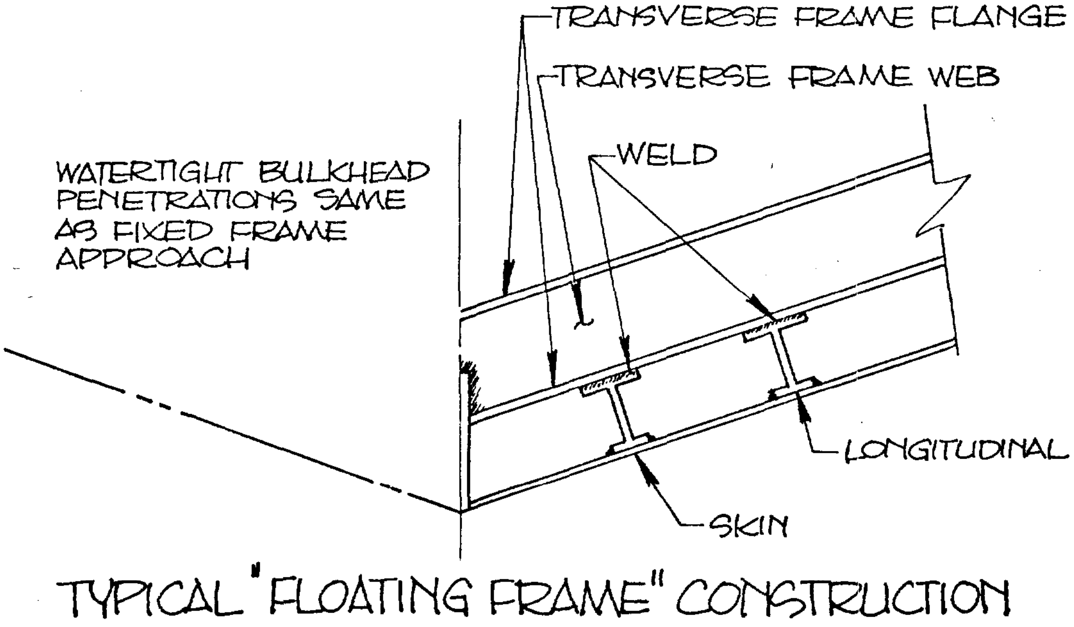


Figure 69 - Two Types of Transverse Frames (U)

5) Care must be exercised in the local design of the aft portions of a hull driven by high speed, heavily loaded propellers. These propeller loadings can cause premature failure due to vibratory fatigue.

6) Aluminum construction is particularly susceptible to galvanic corrosion therefore care must be exercised in the use of dissimilar metals. Meticulous design practices will prevent a great deal of trouble later.

2. (U) - Propulsion Systems

a. (U) The propulsion systems discussed in Section II.A.6 were all water propellers or waterjets. In all existing or foreseeable Navy applications these are driven by a gas turbine, a diesel engine or some combination. Reverse and/or reduction gearing is provided in the drive train as required to match the torque-RPM characteristics of the machinery to those of the propulsor.

b. (U) There are relatively few machinery systems #available which are adequate for the high horsepower requirements of large fast planing hulls. This is due primarily to the lack of demand in the private sector. Commercial vessels normally require speeds under 30 knots.

c. (U) Gas turbines with various reduction gears have been installed in the following craft:

Experimental Coastal Patrol and Interdiction Craft (CPIC-X)

Assault Support Patrol Boat (ASPB) Mark 2 prototype

Armored Troop Carrier/Command and Communication Boat (ATC/CCB)
Mark 2 prototype

Patrol Gun Boat (PG 84/92)

Patrol Gun Boat (Hydrofoil) (PGH-1)

d. (U) An important backlog of experience has been accumulated through the test, evaluation and operation of these vehicles. Similar installations are planned for the Surface Effect Ships (SES) and the Amphibious Assault Landing Craft (AALC).

e. (U) Experience with high horsepower diesels has been limited to the Patrol Boat Fast (PTF) which uses the Napier-Deltic diesel and reduction gears. This application of the Napier-Deltic has not been successful primarily because of the stringent limitations on fraction of continuous operation time and of total operating time permitted at maximum power; and on cost, complexity and special facilities required for overhauls.

f.(U)Machinery systems that have been tested and used successfully are listed in Table 9.

g.(U)Main engines.

1. The following types of gas turbines are currently in use by foreign countries as well as the U. S.:

AVCO-Lycoming TF-25, TF-35

General Electric LM 1500, LM 2500

Pratt Whitney FT 4A-2, FT 12

Detroit Diesel Allison Division 501-KF

Rolls Royce Proteus

2. Among high horsepower diesels the most prevalent are the various MTU (Motoren und Turbinen Union) of German origin. Reduction gearing of various types are used, but these have been developed for each particular application. Commonly used U. S. diesel engines are the Detroit Diesel (Allison Division) 8V71TI and 12V71TI.

TABLE 9

U. S. NAVY OPERATIONAL PLANNING CRAFT PROPULSION SYSTEMS (U)

CHARACTERISTIC	CPIC-X	PTF	PG	65' MK 3
HIGH SPEED MODE	THREE TF 25A AVCO GAS TURBINES	TWO NAPIER DELTIC DIESELS	ONE GE LM 1500	THREE DDAD 8V71TI
LOW SPEED MODE	TWO VOLVO PENTA DIESELS WITH RETRACTABLE OUTDRIVES	SEE ABOVE	TWO CUMMINS DIESELS	SEE ABOVE
REDUCTION GEARING (HIGH SPEED ENGINES)	SEIR-BATH PRIMARY; PRECISION V-GLIDE V-DRIVE SECONDARY	NAPIER PRIMARY/ NAPIER V-DRIVE (NASTY only)	TRIPLE "S" OR BALDWIN-LIMA-HAMILTON	TWIN DISC MG-514
THRUST PRODUCER	THREE - 3 BLADE PROP., TWO - 3 BLADE PROP. (DIESEL)	TWO - 3 BLADE PROP.	TWO CP PROPS.	THREE - 3 BLADE PROP.

3. (U) - Electrical and Auxiliary System (Vehicle Support System, Not Including Support for Lift System)

a. (U) The primary function of the vessel's electrical system is to provide a continuous, uninterrupted source of electric power to vital auxiliaries and equipment.

b. (U) As an example of a modern electrical system, in CPIC-X it consists of a 450V and 120V, 60 and 400 Hz AC System and a 24-volt DC system. Power is supplied for the battle, cruise and dockside conditions. The AC system consists of generating sets with associated controls; power.and isolation transformers; control and distribution switchboard; shore power connections and instrumentation; and the power and lighting distribution panels. The DC system consists of generators, rectifiers, storage batteries, switchboard, and distribution panels. The sources of power for driving the generators are generally a combination of the vessel's primary and secondary propulsion engines and auxiliary engines.

c.(U) Historically, for small combatants to best survive battle damage and still maintain a self-defense and come-home capability, they need heavily redundant electrical (and auxiliary) systems [103]. This is provided by oversized (approximately twice the required ampere hour capacity) 24V battery banks for main and secondary propulsion engines and ship service generators. Each of these battery banks would ideally be located in the same space as the engine it services. Cross-connections are desirable for charging all such battery banks in case any individual generator should fail, and to provide a starting capability for a given engine in the event its battery bank should fail, The generators (on alternators) on any one of thes e engines should be. sized to supply the total power needs of the DC vital bus. This includes for example: critical emergency power for the largest single communication unit; navigational radar; at least one fire pump; some portion of the electric bilge pumps (depending on how many and the type); battle lighting; signal lamps; running lights; windshield wipers; battery chargers; and some weapons which can, at a minimum, be manually directed and fired in self defense.

d. (U) The AC power system should be sized to provide all normal requirements, except engine starting, but including those described above on the DC vital bus, using a converter to change alternating to direct current as may be required. Further, the craft should carry redundant generators to provide a 100% back-up capability in the event of single generator failure. The back-up generator should be located apart and in a different compartment from the primary unit so as to minimize the possibility of simultaneous damage to both units. Each of the generators should be cross connected and should be capable of sharing the load while operating in parallel. Additionally, each generator set should be sized to accommodate a 33% growth in hotel and mission equipment power requirements to forestall the premature retrofit of larger units during the service life of the craft.

e. (U) Traditionally, the approach used to design the electrical systems in planing vehicles has been to use commercially available equipment suitably marinized, and Navy qualified, to satisfy pre-established minimum underway watchstanding requirements. The centralized control of electrical load manipulation and distribution from the pilot house is preferred which permits minimum manning under all watch conditions.

f. (U) The design and installation of the system should be such that performance and safety of operating personnel are maximized, and operational manning, training, and skill requirements are minimized.

g. (U) The evolution of this type of electrical system, and the use of commercially available equipment, introduces a weight penalty when compared with the use of special components developed for more exotic applications such as aircraft and space vehicles. There are alternatives available to provide electrical power with less weight. Among the most promising is the use of lightweight 400 Hz systems, and gas turbine driven auxiliaries, including lightweight, high speed APU's to handle peak loads and to provide casualty redundance. Efforts are being initiated in the area of total energy concepts to provide alternate energy forms for shipboard systems, such as using waste heat to provide hotel heating and reduce installed electrical generating capacity. Alternatives to electrically-powered air conditioners may also be available for cooling shipboard electrical generating (equipment and electronics systems, such as ducted air, water- and hydrogen-jacketed sinks, and/or heat pipe techniques.

4. Manning Concept and Human Support System (U)

a.(U) In general, manning requirements for naval vessels are governed by the number of watchstanders required to operate essential systems and equipments, while providing for crew rest and essential on-board servicing. Manning may be estimated by defining essential positions to be manned to accomplish the mission/task assigned (i.e., its operating concept). This requires mission/task definition, an operational scenario, performance goals (strengths and limitations) of the vehicle weapon system and maintenance requirements. The first two factors (task definition and operational scenario) can be somewhat independent of configurations except in specialized situations (e.g., amphibious landings). The third and fourth factors, performance and maintenance, are in fact totally dependent on configuration, and therefore provide a point of departure for determining manning requirements. This approach to manning is best explained by examining specific examples, such as the Experimental Coastal Patrol and Interdiction Craft (CPIC-X) and the Experimental Shallow Water Attack, Medium (SWAM-X) Craft.

b[redacted] CPIC-X is a 100 ft (30.5 meters), high performance planing craft. The original design goals were to perform at40 knots in 4.6 ft significant wave height with a maximum CG vertical acceleration of less than 1.0g (see pp.30 and 122) recognizing that aft of the CG the accelerations would be somewhat reduced while forward of the CG accelerations would be higher. Rationalizing these craft factors with human factors developed a general philosophy for manning an operating concept, as follows:

- Pilot house personnel are to be seated and belted at their stations during high-speed operations. Operational tests had indicated that shock mitigating seats were highly effective.*

- Design craft to insure that weather deck movement of personnel while underway in a high motion environment will be normally unnecessary. For the CPIC-X mission and its duration, subsystem requirements typically required a two-section watch routine with an originally designed total crew of 13 personnel (see Table 10). As built and tested, the craft uses a crew of 11, which is adequate with cross training. The preliminary work accomplished so far on a large ocean-capable planing hull (CPIC-X scaled up by a factor of 2), a nominal 200 ft (61m), 576 tn (585t) vessel, indicates the manning philosophy used for CPIC-X will generally not apply due to different on-board maintenance requirements and the more sophisticated combat suite.

c. (U) The Experimental Shallow Water Attack Medium (SWAM-X) Craft, as designed conceptually, is a nominal 65 ft (19.8m), 75 tn (76.2 t) craft, fully capable of operating in riverine environments, and (with some limitations on sea state) in the estuaries and coastal areas adjacent thereto. Many of the guidelines established for CPIC-X are still generally applicable to SWAM-X since the CG acceleration specifications are similar. The major difference between the CPIC-X and SWAM-X manning philosophies is the extensive modularity envisioned for the SWAM-X which consists of a baseline vehicle with seven variant themes, each with at least one portable module. Preliminary investigations indicate a basic crew of 9 would be required for SWAM-X (see Table 11) with the philosophy of cross training employed to keep manning at a minimum.

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* Note: The shock-mitigating seat is important for the achievement of safety and reduction of fatigue for the crews in high-motion environment [62, 110]. See also Figures 77, 78 and 79.

TABLE 10 - (C) CPIC MANNING PROJECTION [111] (U)

BILLET TITLE	RANK/ RATE/RATING	POSITIONS MANNED CONDITION I	POSITIONS MANNED CONDITION II
OFFICER IN CHARGE(OIC)	LT/LTJG	CONNING OFFICER	OOD
ASSISTANT OIC	BMC	WEAPONS OFFICER	OOD
HELMSMAN	QM1	HELM	HELM
ENGINEERING OFFICER	EN1	ENGINEERING	ENGINEERING
ENGINEERING ASSISTANT	EN3	#1 PINTLE GUN MOUNT	ENGINEERING
ENGINEERING ASSISTANT	ENFN	LOOKOUT	LOOKOUT
FIRE CONTROL TECH.	FTG2	CIC/FIRE CONTROL	CIC/FIRE CONTROL
GUNNER	GMG2	REMOTE GUN SIGHT CONTROL	GUNNER
GUNNER ASSISTANT	GMGSN	MAIN GUN MOUNT	GUNNER
ELECTRICIAN	EM2	#2 PINTLE GUN MOUNT	HELM
ELECTRONICS TECH.	ETN3	#3 PINTLE GUN MOUNT.	CIC/FIRE CONTROL
HULL MAINTENANCE TECH.	HT2	DAMAGE CONTROL	LOOKOUT
FIREMAN	FN	#4 PINTLE GUN MOUNT	SEE NOTE

Note; Under watch condition II the firemen would be a non-watchstander, During these periods the FN would be required to perform normal shipboard housekeeping functions/prepare meals, perform PM, etc.

TABLE 11 - PROJECTED CONDITION I MANNED POSITIONS FOR SWAM-X BASELINE AND VARIANT CRAFT [110] (U)

SWAM-X AND VARIANT CRAFT / CONDITION I MANNED POSITIONS	Baseline craft	Troop Carrier	Command & Comm.	Fire Support	Advanced Base Defense	MEDAID/ Air Support	Mine Laying/ Counter-Measures	Logistics Support
Conning Officer	X		X	X	X	X	X	X
Helmsman	X	X	X	X	X	X	X	
Navigator/ Communicator	X	X	X	X	X	X	X	
CIC/Weapons Control	X	X	X	X	X	X	X	X
Engineer/Damage Control/Loader	X	X	X	X	X	X	X	X
Gunner No.1 (Note 1)	X	X	X	X	X	X	X	X
Gunner No.2 (Note 1)	X	X	X	X	X	X	X	X
Pintle Gun Mount No. 1/Ammo Passer	X	X	X	X	X	X	X	X
Pintle Gun Mount No. 2/Ammo Passer	X	X	X	X	X	X		X
Command and Control Mobile Force Commander			(Note 2) X					
Command G Control Communicator			(Note 2) X					
Howitzer (105 mm) Pointer/Gunner				(Note 3) X				
Howitzer (105 mm) Ammo Loader				(Note 3) X				
Howitzer (105 mm) Ammo Loader				(Note 3) X				
Mine Warfare Equipment Handler							(Note 3) X	
Mine Warfare Equipment Handler							(Note 3) X	
Medical Attendant						X		
Helicopter Handler(s)						(Note 3) X		

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[redacted]

TABLE 11 (Cont'd) - PROJECTED CONDITION I MANNED POSITIONS FOR SWAM-X BASELINE AND VARIANT CRAFT [110] (U)

Note 1. It is assumed that both the Rapid Fire Twin Gun & Mount and the Rapid Fire Anti-Aircraft Weapon System will be installed on the baseline craft and all variants.

Note 2. It is assumed that certain tactical information (e.g., navigation, surveillance) will be provided the Command & Control Variant Module by the baseline craft CIC.

Note 3. Dependent upon the promulgated Required Operational Capabilities (ROC) statement, there is a possibility that manning of some of these positions may be satisfied by cross-training/cross-utilization of the baseline craft crew, (e.g., Condition IM, a special readiness condition applicable to certain mine operations, permits some reduction of normal systems manning, including armament, to facilitate such operations). The extent to which cross-utilization of personnel may be practical should be the subject of a follow-on study.

5. (U) Lift System

This subject is generally not applicable to the planing hull concept. However, several of the special designs in Section II. E., p. 239, are partially supported by a lift system. They are the hydrokeel, the Surface Effect Boat (SEB), and the Ski-Cat. Only the last two show promise for possible future use. The SEB is a catamaran hull which uses an air cushion, contained between the hulls by flexible seals both fore and aft, for lift augmentation on demand. The Ski-Cat is also a catamaran hull but is supported at speed by a hydrofoil mounted between the hulls. Trim control is provided by a hydroski which planes on the surface of the water at the bow of each hull.

Technological assessments of air cushions and foils are not a part of this report, but are covered in other reports in the ANVCE study.

6. (U) Specialized Systems

a. (U) Particular areas requiring, special consideration are roll stabilization, shock mitigating seats for ship's company, skin coolers for heat-exchange functions, and special designs of items for outfit such as lightweight furniture and commercial-aviation-industry-style messing facilities.

b. (U) Roll Stabilization:

1) Recent developments in weapons technology and the changing nature in the use of such weapons allow relatively small combatants to be configured as economical solutions for some applications heretofore accomplished with much larger ships. Most small combatants are basically not the most stable weapons platforms when operating in rough open water, so major

[redacted] [redacted]

consideration has to be given to reducing the pitch and roll motions and vertical accelerations of the craft-weapon system. It follows then, that the designers of the weapons and the vehicle will have to collaborate, paying particular attention to interfacing the two parts of such a system.

2) Normally, longitudinal and transverse accelerations can be ignored due to their relatively small magnitudes. Two approaches to stabilization can then be employed: stabilize the weapon mount itself, and/or stabilize the vessel. To obtain 100% attenuation of craft motions and accelerations in open water is impossible from a practical engineering point of view. Since craft stabilization affects the important aspect of crew effeciency which, in the final analysis, determines mission effectiveness, both vessel and weapon mount stabilization should be considered.

3) The effectiveness of a fin stabilization system is illustrated in the case of a 65 ft Torpedo Weapon Retriever in which weapon effectiveness tests with manual weapons showed that hit probability was quadrupled when the fin system was activated [39].

4) In the case of the 100 ft CPIC-X the effectiveness of such a system has been measured during trials [3] in a mid-sea state 4 the characteristics of which are shown in Figure 70. The significant wave height, $H_{1/3}$, is approximately 7 feet. Trials were run with and without the fins. The results for roll motions are plotted in Figures 71 for beam seas, 72 for bow quartering seas, and 73 for stern quartering seas. The results for roll rates are plotted in figure 74 for beam seas, 75 for bow quartering seas, and 76 for stern quartering seas. The measurements for beam seas are summarized in the following tabulation;

[redacted] [redacted]

[redacted]

[redacted]

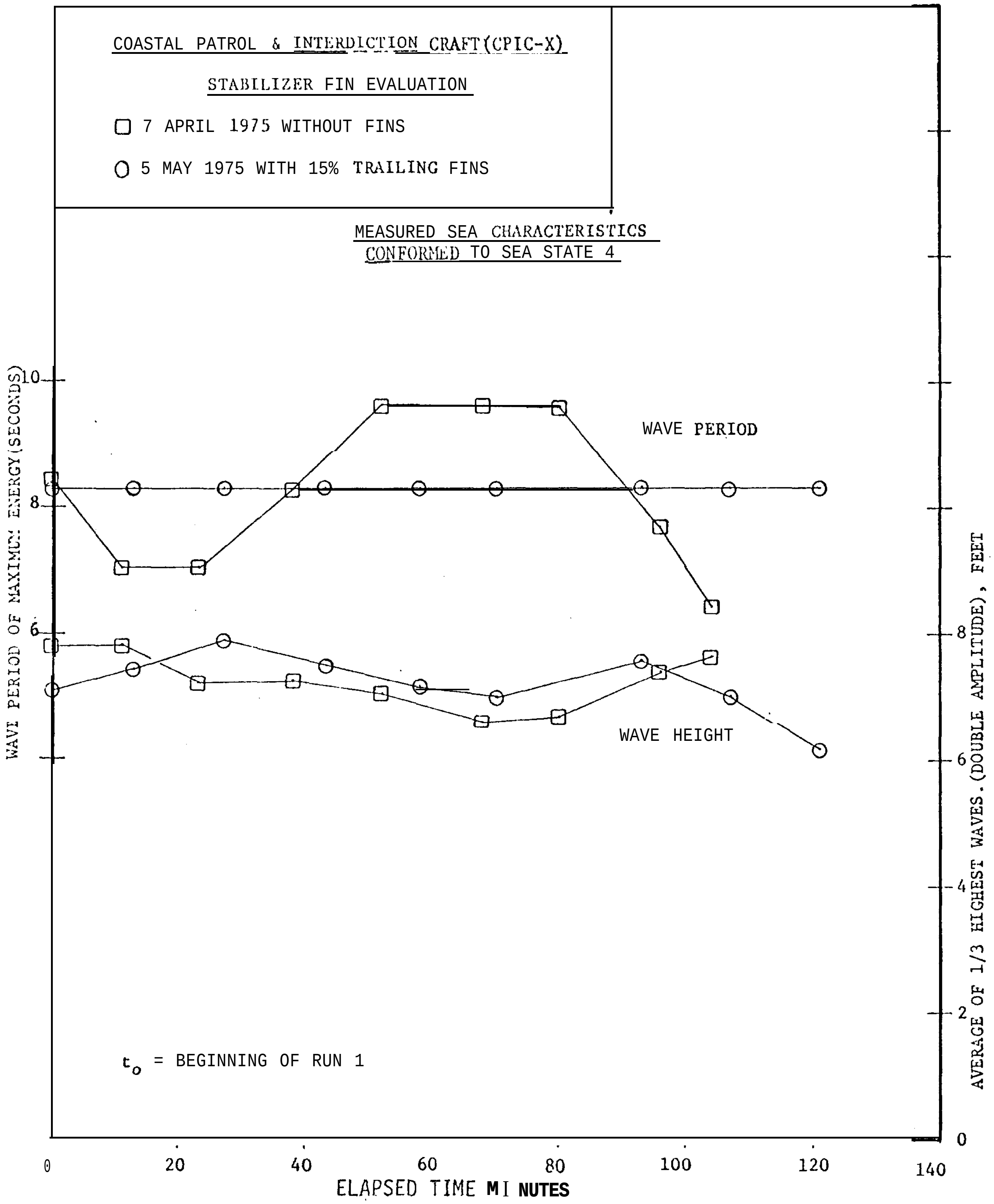


Figure 70 - (C) Measured Sea Characteristics (U)

[redacted]

[redacted]

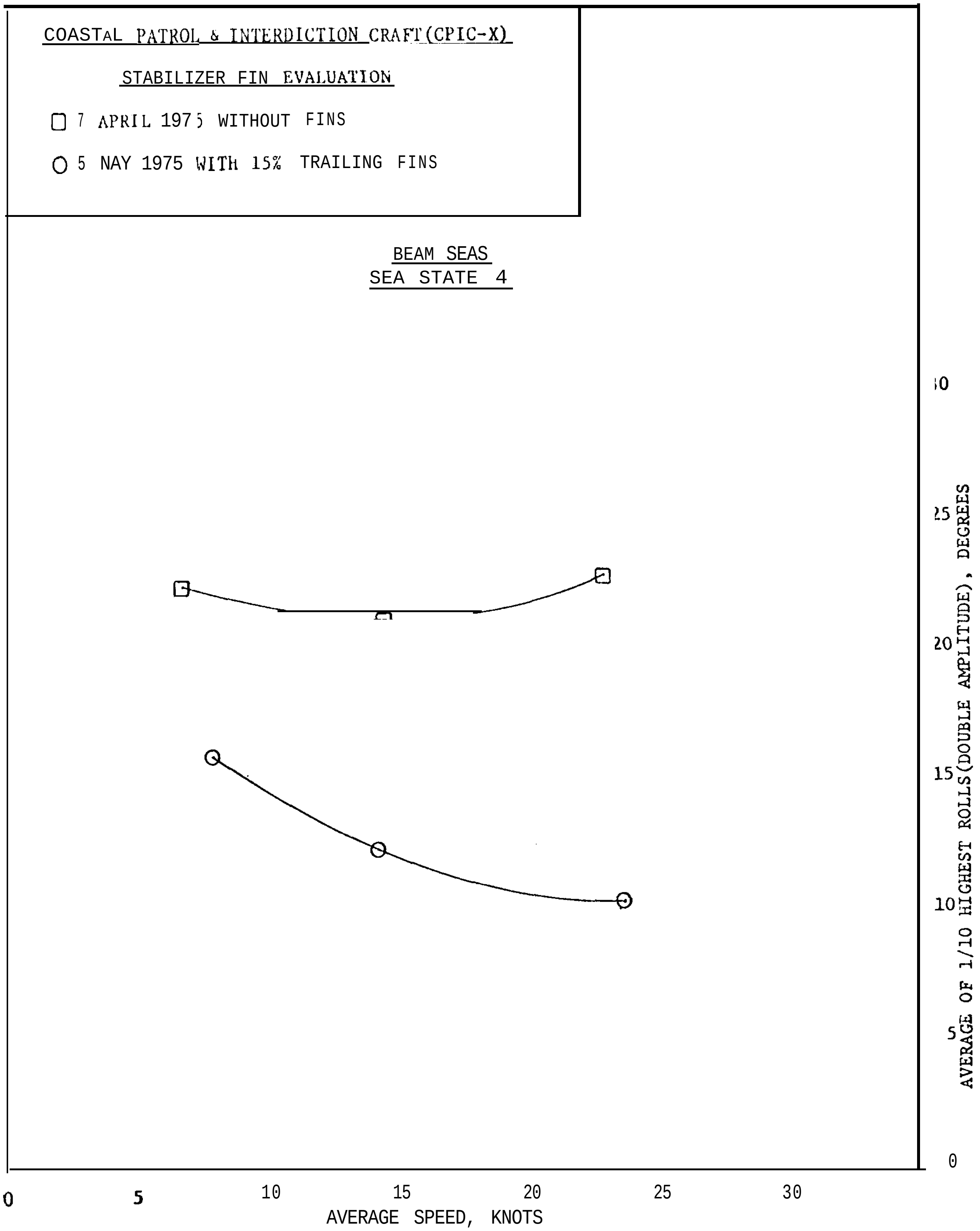


Figure 71 - (C) CPIC-X **Roll Motion,** Beam-S[illegible]U)

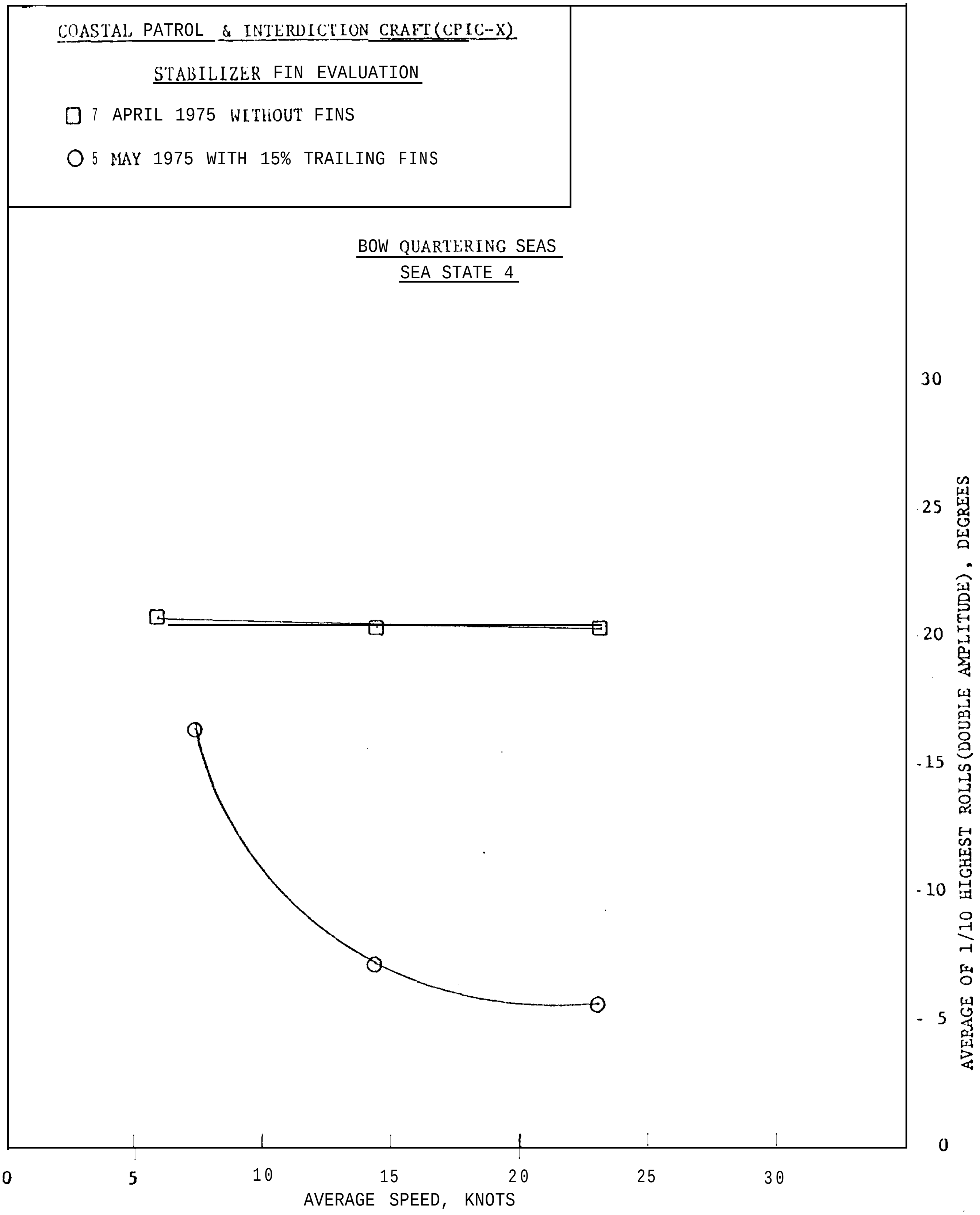


Figure 72 - [redacted] CPIC-X **Roll Motion, Bow Quarterins Sea** (U)

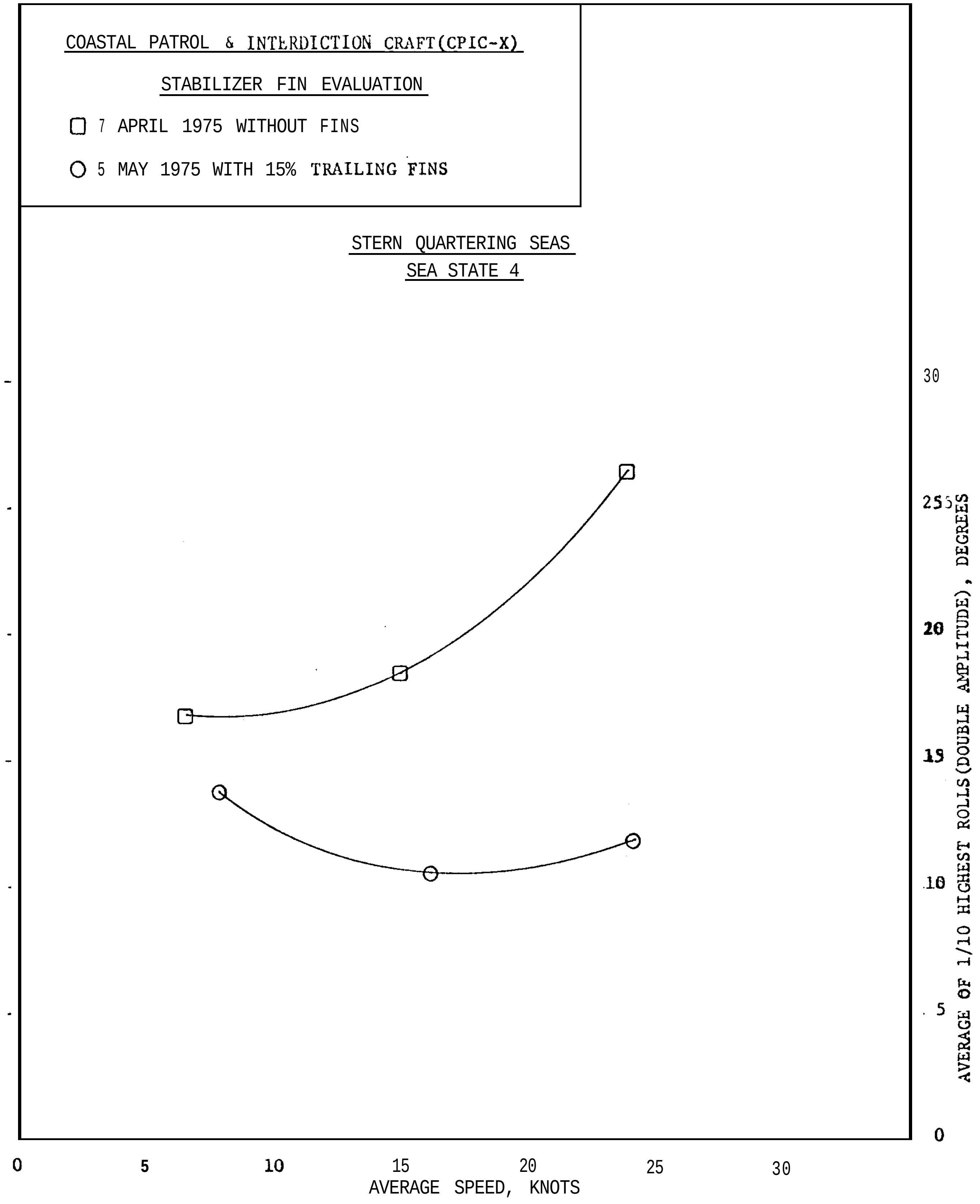


Figure 73 -[redacted] CPIC-X **Roll Motion, Stern Quartering Sea** (U)

COASTAL PATROL & INTERDICTION CRAFT(CPIC-X)

STABILIZER FIN EVALUATION

7 APRIL 1975 WITHOUT FINS

5 MAY 1975 WITH 15% TRAILING FINS

BEAM SEAS
SEA STATE 4

NOTE:
THE BANDWIDTH OF DATA REPRESENTS THE RANGE OF LARGER INSTANTANTEOUS ROLL RATES AS READ FROM OSCILLOGRAPH RECORDS. THIS DATA IS INDICATIVE OF THE EFFECTIVENESS OF THE TRAILING FINS ON CPIC-X.

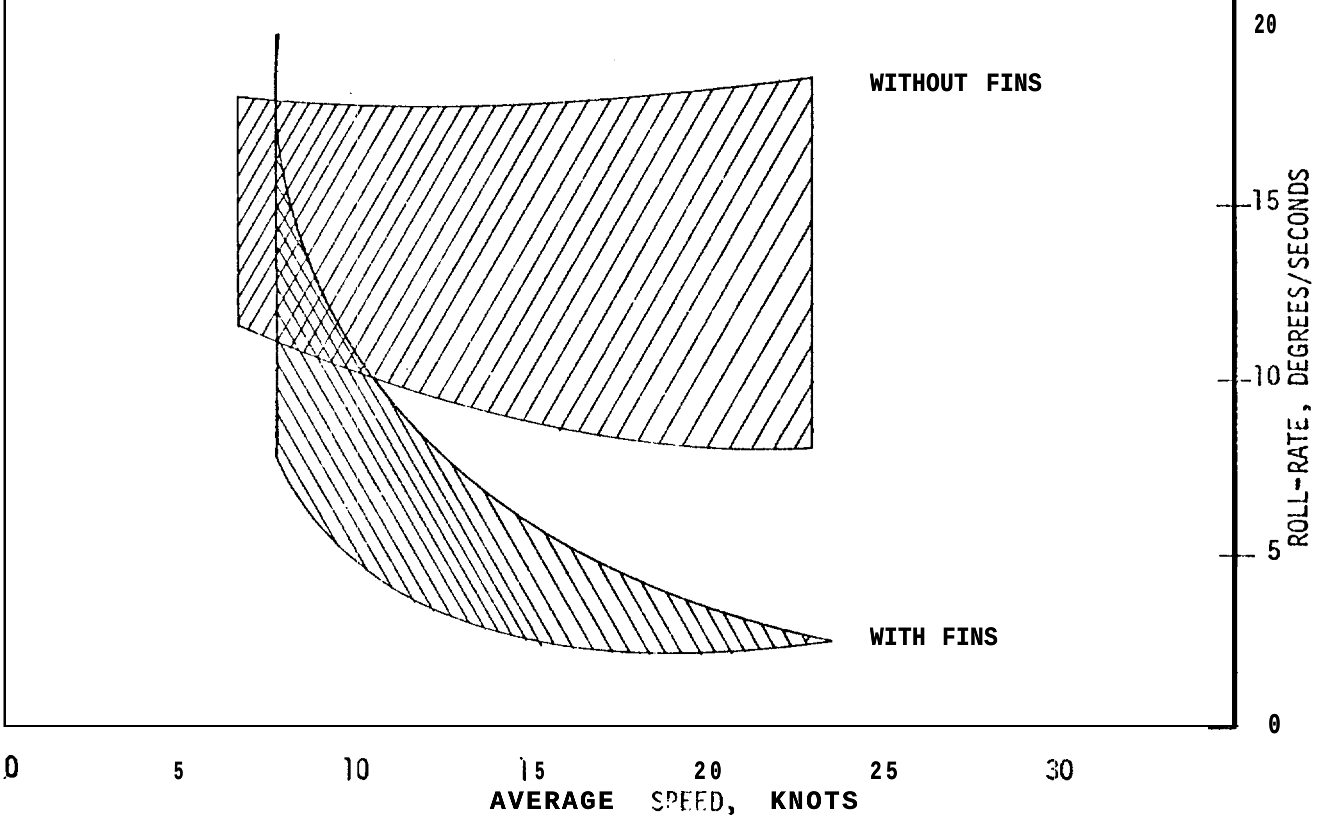


Figure 74 - (C) CPIC-X Roll Rate, Beam S[redacted])

[redacted] [redacted]

COASTAL PATROL & INTERDICTION CRAFT(CPIC-X)

STABILIZER FIN EVALUATION

7 APRIL 1975 WITHOUT FINS

5 MAY 1975 WITH 15% TRAILING FINS

BOW QUARTERING SEAS
SEA STATE 4

NOTE:
THE BANDWITH OF DATA REPRESENTS THE RANGE OF LARGER INSTANTANTEOUS ROLL RATES AS READ FROM OSCILLOGRAPH RECORDS. THIS DATA IS INDICATIVE OF THE EFFECTIVENES: OF THE TRAILING FINS ON CPIC-X.

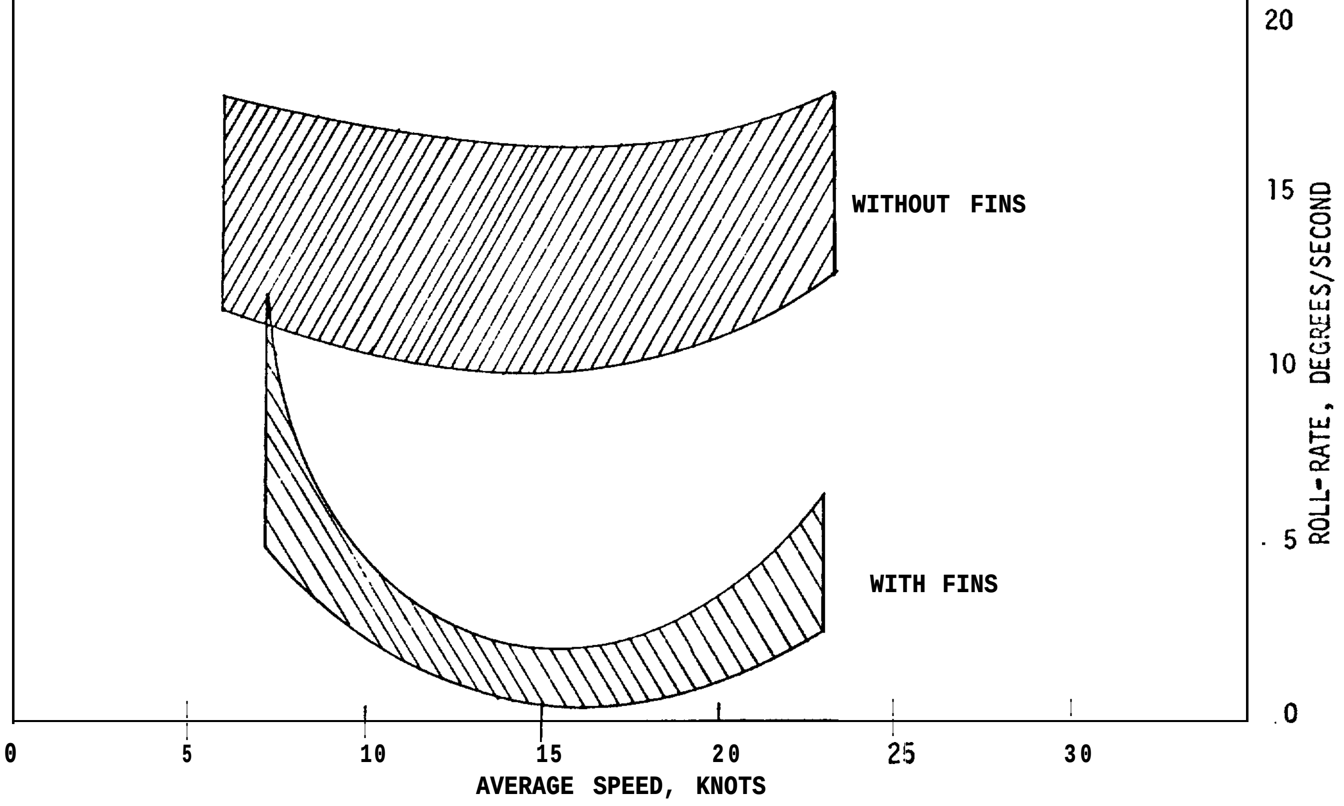
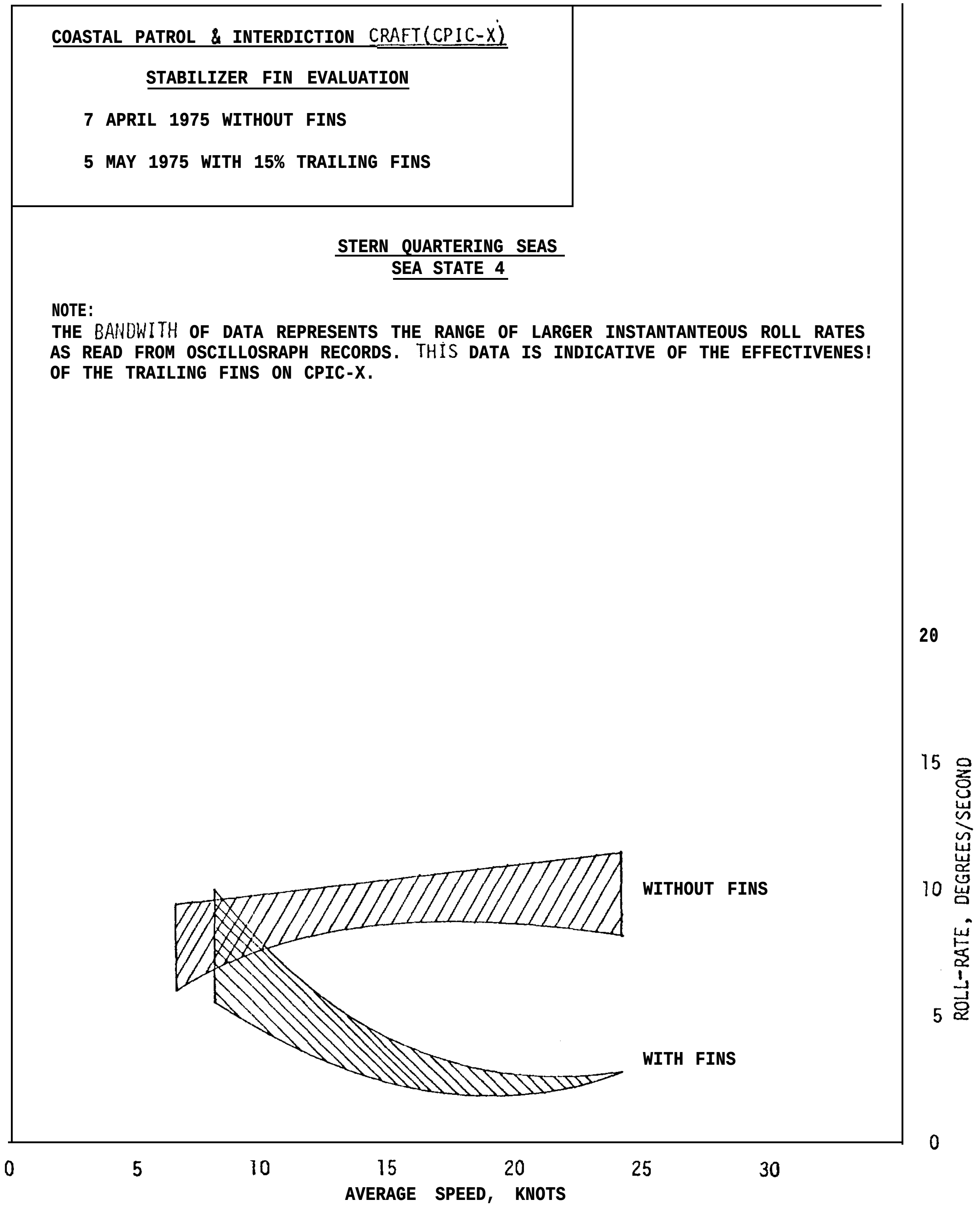


Figure 75 - (C) CPIC-X Roll-Rate, Bow Quartering Sea (U)

[redacted] [redacted]



COASTAL PATROL & INTERDICTION CRAFT(CPIC-X)

STABILIZER FIN EVALUATION

7 APRIL 1975 WITHOUT FINS

5 MAY 1975 WITH 15% TRAILING FINS

STERN QUARTERING SEAS
SEA STATE 4

NOTE:
THE BANDWITH OF DATA REPRESENTS THE RANGE OF LARGER INSTANTANTEOUS ROLL RATES AS READ FROM OSCILLOSRAPH RECORDS. THIS DATA IS INDICATIVE OF THE EFFECTIVENES! OF THE TRAILING FINS ON CPIC-X.

Figure 76 - (C) CPIC-X Roll-Rate, Stern Quartering Sea

ROLL MOTION AND ROLL-RATE WITH AND WITHOUT STABILIZER FINS IN BEAM SEAS

SPEED.	WITHOUT FINS		WITH FINS		ROLL,	ROLL-RATE.,
KNOTS	ROLL,	ROLL-RATE,	ROLL2	ROLL-RATE2	ROLL2	ROLL-RATE2
10	22	14	15	8	1.47	1.75
15	20	13	12	4	1.75	3.25
20	22	13	11	3	2.00	4.33
25	24	14	10	3	2.40	4.67

Fewer personnel were seasick when operating with the fin system activated. All the above information and figures are from [3].

5) It is recognized by designers that round bilge ships are, for many operational conditions, subject to roll excursions large enough to require a stabilization system. The speed loss due to the added appendage drag of active roll fin stabilizer devices is a welcome tradeoff for added platform stabilization. This appendage drag can be reduced by utilizing a retractable roll fin stablilizer design.

6) Consideration has been given to stabilizing the other basic hull form, that of the vee-bottom, hard-chine, planing hull configuration generally intended for much higher speed capability. High speed hard/chine craft are inherently more stable than round bilge craft due to high hydrodynamic lifting forces and large roll damping coefficients resulting from their chine shape. Still, all operations are not conducted at flank speed (the most stable condition in roll for hard chine craft) so it is recognized that for certain conditions and circumstances roll stabilizing devices must be employed at the lower speeds where roll motions can be excessive.

7) Active roll stabilization systems have desirable characteristics, for example:

a) Active tank systems have the potential to stabilize from dead-in-the-water to full power with no external appendage drag. However, these would be a development item.

b) Active fin systems appear attractive from a more mature state-of-the-art point of view. Here stabilization is essentially a function of velocity squared and almost vanishes at low speeds. Thus, the designer needs a well defined mission profile with weapons characteristics to determine control requirements for the fin. As craft speeds exceed 35-40 knots, external appendages i.e., roll fins, can become a significant drag consideration (unless retractable).

c) Development of a flush-flap type of roll stabilization system is being evaluated from recent model test data [112]. The success of the concept will depend on the ability to generate significant roll moments without unusual pitch and yaw interactions. Preliminary assessment of data indicate that flush-flap roll stabilizatjon is a viable concept for reducing high speed planing hull roll.

c. (U) Shock Mitigating Seats:

1) The primary reason for shock mitigating seats is to reduce the accelerations delivered to members of the crew and lower the slope of the acceleration curve (time rate of change of acceleration or "Jerk") they would be subjected to during rough sea operation. Recent developments with shock mitigating seats have been very encouraging from the point of view of improving the crewman's ability to perform in

planing hulls at very high speeds in very rough seas. For 90% of the impacts encountered on planing hulls, accelerations can be attenuated by 50% or more. For the largest impacts (the top 10% or higher) the reduction in acceleration is occasionally less than 50% because of seat "bottoming", but the reduction is always significant. (See Figures 77, 78 and 79)

d. (U) Skin Coolers:

Skin Coolers have been employed successfully on high speed-hulls for example, CPIC-X, to minimize through-hull penetrations and thereby reduce appendage and inlet drag [113]. The advantages of transferring waste heat through the skin of the hull are even greater on aluminum structures than steel hulls due to its higher heat transfer capability. This form of cooling offers closed system anti-freeze , anti-rust, and anti-silting protection; but require the external hull surface to be maintaned free of marine growth to retain the low drag achieved and a uniform heat transfer factor.

e. (U) Outfit and Furnishings:

1) Most of the berths, lockers, furniture, etc. used on planing hulls have been selected from commercially available stock used in the yachting industry. This method of selection can present a problem. The yachting industry items in some cases are too fragile since they are designed for only occasional use and have unnecessary esthetic appeal.

2) Navy standard items , on the other hand, are normally designed for relatively heavy ships with very long useful lives. Such items are frequently too heavy for use on high performance hulls.

3) The gap which existed when trying to provide furnishings for the high speed planing hull, CPIC-X, was filled by having the contractor design and manufacture the furniture.

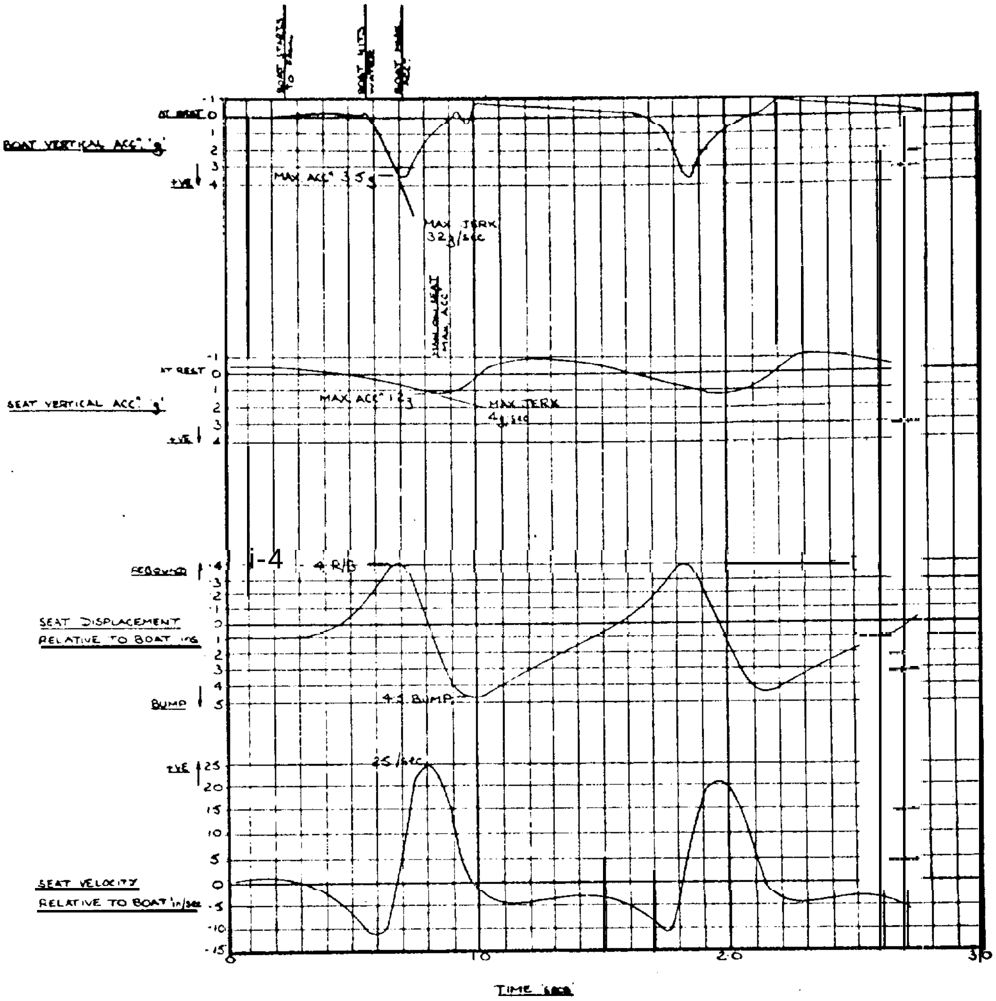


Figure 77 - Shock-Mitigating Seat Operational Performance (U)

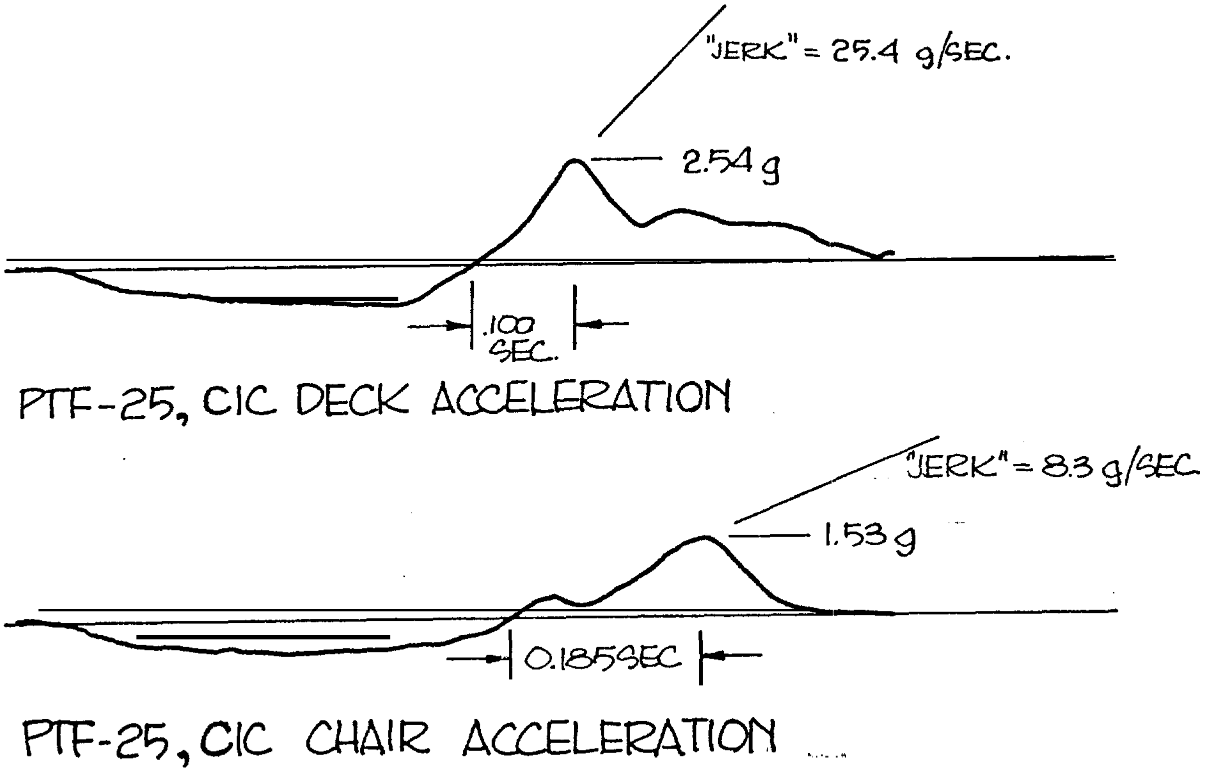


Figure 7% - Seat Shock Attenuation (U)

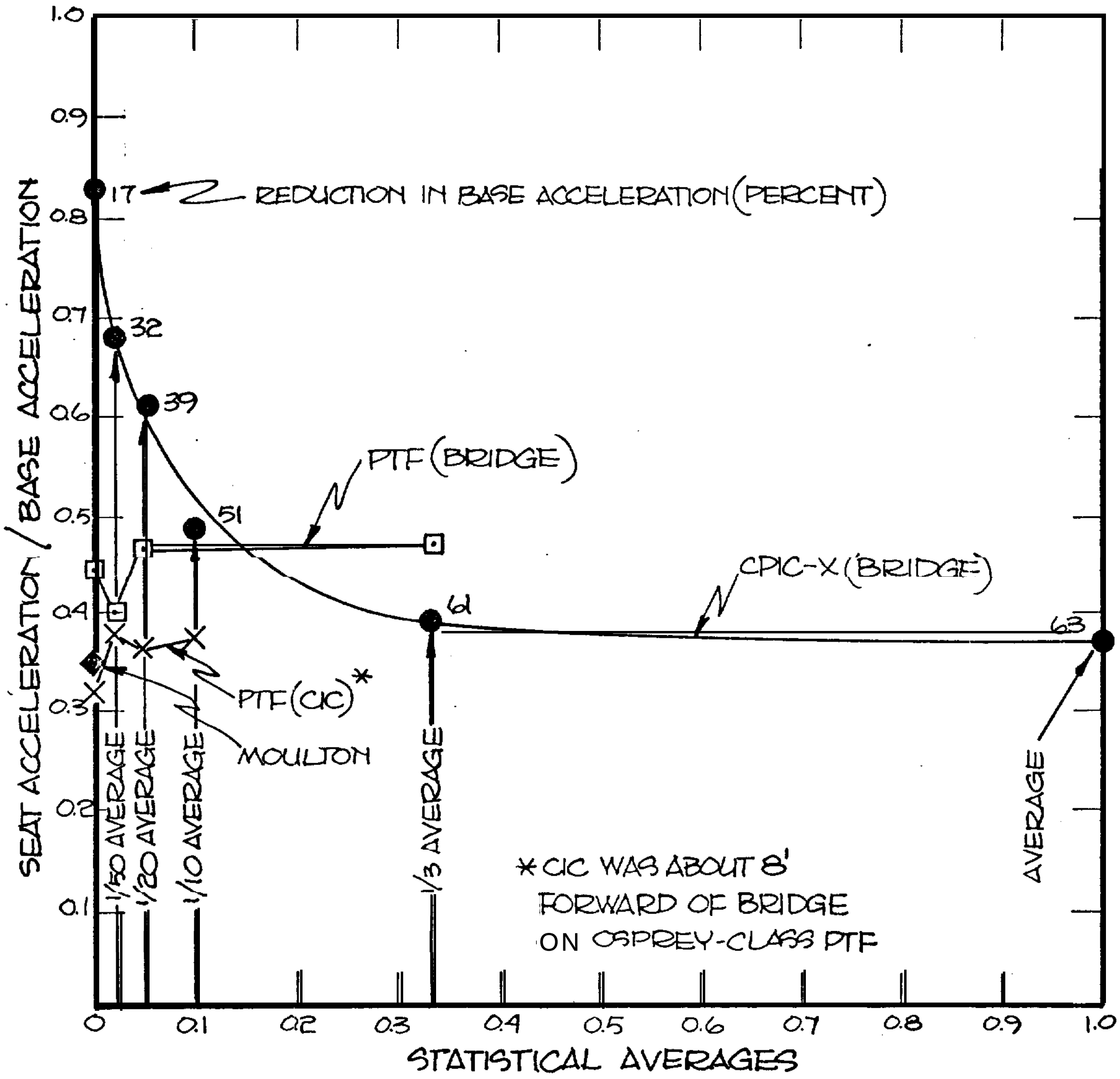


Figure 79 - Seat/Base Acceleration Ratio vs; Statistical Average for Shock-Mitigation System (U)

7. (U) External Support Systems

Dedicated external support systems are not required by the planing craft concept.

8. (U) Margins

a. (U) The application of margins in the design of planing hulls has differed from that in the design of large conventional ships. In the latter case, margins for "Future Growth" have great significance because these ships have service lives of 30 years or more. In contrast, the high performance planing craft in the U. S. Navy to date have service lives of only about 10 years and consequently a policy requiring margins for "Future Growth" is off the mark. Because of hydrodynamic considerations primarily, planing hull "on-design" conditions must be targeted accurately during design and meticulously maintained during the life of the vehicle,as the penalty for operating "off-design" for any length of time is unacceptable, generally speaking. Therefore, the need exists for unusually candid and thorough dialogue between designer and "customer" (OPNAV) to identify all expected missions/tasks for a given design. The effect of each on the design can be evaluated thus permitting the customer to choose from an informed point of view.

b. (U) As planing hull technology is applied to ship-sized, open-ocean-capable platforms, a re-examination of Navy ship design margin policy is in order, as has been confirmed by two recent ASNE papers [114, 115]. One interesting view now being discussed in the community is that trends toward lighter weight, less volume, and less crew (more automation) are already the rule rather than the exception in newly evolving component and sub-system designs. These trends are all moving toward less need for "Future Growth" margins, and are more in keeping with the margin policy now used for planing hulls. This policy does not penalize the shorter-lived, high-performance vehicles for unforseen future uses nor does it thwart the benefits of advancing technology in providing greater capability in a given size package,

c. (U) The only weight margins used now in planing hull designs are the "design margin" and the "building margin". An allowance of 2% of light ship weight is made for each. They are defined as follows:

1) Design margin: A weight representing additional items such as brackets, gussets, and other structural members required on fabrication drawings that do not appear on contract drawings or contract guidance drawings. "A weight to compensate for the added weight due to the design development of working drawings".

2) Builder's margin: A weight representing uncontrollable variations such as mill tolerances in rolling plating, etc.,

d. (U) Margin policy determinations are presently underway between the ANVCE Project Office and the Navy technical community whereby specific guidance on. margin policy will be provided to each ANVCE advocate point design team. This guidance may prove to be appropriate for adoption by the planing vehicle design community in the future.

C. (u) - PERFORMANCE INTERDEPENDENCIES (SPEED, ENDURANCE RANGE, ENDURANCE PERIOD, AND PAYLOAD CARRYING CAPABILITY)

1. (U) It is not possible at this time to provide the results of a comprehensive study showing the interdependence of speed, endurance and payload over a wide range of ship sizes. This type of work has not been funded in the past. But in support of the Advanced Naval Vehicle Concept Evaluation Study a mathematical model is being prepared to provide such information. It will also be used in the parametric studies leading to point designs. The very limited amount of such work which has been done as part of specific design studies is not sufficient to present here.

2. (U) On the other hand, load carrying capability is well defined. There are many craft for which full scale trial data exist and a number of these have detailed weight estimates confirmed by total craft scale weighing (Table12). In these cases the load items can be extracted and the craft's actual load-carrying capability can be compared with that of other craft.

3. (U) For the purposes of this study the word "payload" will be used only in the sense of Military Payload as defined in ANVCE Project Office Memo No. 25-76 of 9 Apr 76, with Enclosure 1 (WP-002 Definition of Terms) and will include the following items:

- Command and Surveillance Equipment less Navigation and Interior Communications
- Armament
- Ordnance and Ordnance Delivery Systems
- Embarked aircraft, helicopters, RPV's and their fuel and armament
- Embarked troops, their combat supplies, and armament, where applicable
- Special military cargo or modular units, e.g., a Med-Aid Station.

TABLE 12 -CRAFT WITH INSTRUMENTED FULL SCALE TRIALS (U)

UNCLASSIFIED

THE FOLLOWING LIST GIVES CRAFT FOR WHICH FULL SCALE TRIALS HAVE BEEN CONDUCTED WITH INSTRUMENTATION TO MEASURE DESIRED INFORMATION.

LENGTH OVERALL (FT)	CRAFT	ENGINE TYPE	PROPULSOR TYPE	WEIGHT (LB)	SCALE WEIGHED	TYPE TRIALS				
						STANDARDIZATION	ENDURANCE	SEA KEEPING	STRUCTURAL	MANEUVERING
24	STEPPED HULL	DIESEL	OUTDRIVE			X				
25	MRBX	"	WATER JET			X	X	X		X
31	PBR MK-I	"	WATER JETS	15,600		X	X			
31	PBR MK-II	"	"	17,700		X	X			
31	PBR MK-II MOD. I	"	"	17,500		X	X			
32	HSPB	GAS	PROPELLERS	11,504	X	X	X	X		X
32	DYNAPLANE	"	"			X		X		
36	LCPL	DIESEL	"	19,290	X	X	X			
36	LCVP (T)	"	"			X	X	X		
36	MINI-ATC	"	WATER JETS		X	X	X	X		X
36	MSSC	GAS	OUTDRIVES			X	X			
36	GREBE LCSR (L)	GAS TURBINE	CRP	31,400	X	X	X	X		X
36	HARCO LCSR(L)	" "	"	29,200		X	X	X		X
40	PPRB	DIESEL	PROPELLERS	23,950		X	X			
50	PCF MK I	"	"			X	X			
50	PCF MK III	"	"	50,200	X	X	X			
50	ATC / CCB	GAS TURBINE	RIGHT ANGLE DRIVES			X	X		X	X
50	ASPB MK II	" "	WATER JETS			X	X			X
51	AVR (EXPERIMENTAL)	GAS	PROPELLERS			X	X	X		X
52	LCSR	GAS TURBINE	"		X	X	X	X		X
52	LCSR	DIESEL	"			X	X			
56	LCM-6 ATC	"	"			X	X			
63	AVR MK III	GAS	"			X		X		X
65	PB MK I	DIESEL	"			X	X			
65	PB MK I MOD. I	"	"			X	X			
65	PB MK III	"	"		X	X	X	X		X
74	LCM-8	"	"		X	X	X			
74	USAT-1	"	STEERING NOZZLES			X	X			
80	PTF (NASTY)	"	PROPELLERS		X	X	X			
90	PT 810	GAS	"			X				
94	PT 811	"	"			X				
95	PTF (OSPREY)	DIESEL	"		X	X	X		X	
99	PT 809	GAS	"	185,600		X				
100	CPIC-X	GAS TURBINE	"	158,000		X	X	X	X	X
105	PT 812	GAS	"	185,750		X				
165	PG 84/92	CODOG	"	560,000		X	X	X		X

11-6-75

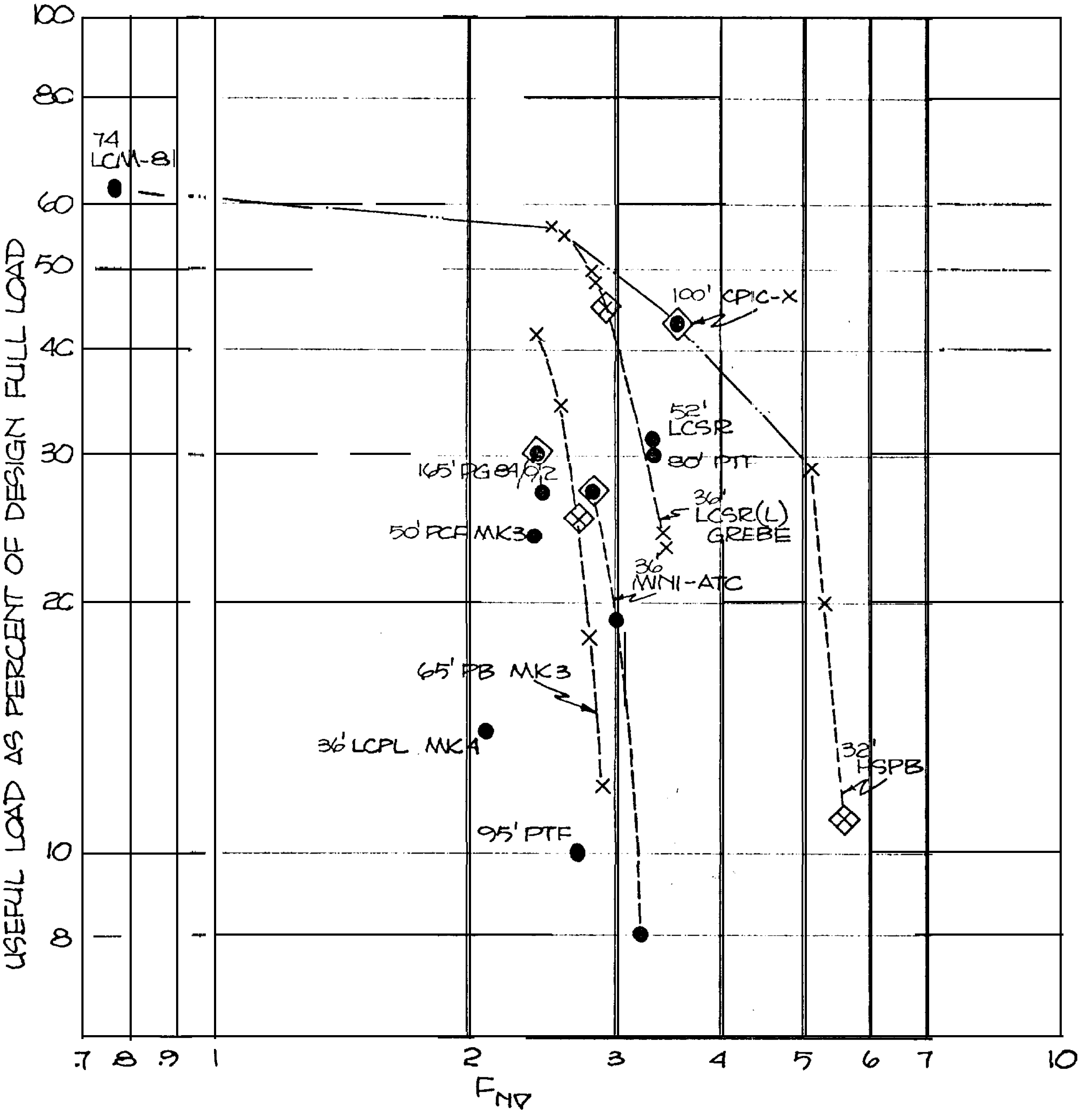
4. (U) The term useful load (also defined in WP-002, cited above) will include the following:

- Military Payload as listed above.
- Useable ship fuel and potable water.
- The ship's complement and effects.
- Stores.

The inclusion of fuel in the useful load is logical since endurace and speed are both functions of the mission definition and would, therefore, vary as a design is varied to suit different specific missions.

5. (U) The upper boundary for useful load fraction actually attained in full scale trials is shown as a function of maximum speed-displacement Froude number in Figure 80. Some of the craft were tested at a number of displacements, including a heavy overload.

The results of these tests are shown in the figure as nearly vertical curves beneath a double-dot-dash line which gives an approximate indication of the current state-of-the-art. It does not exactly represent the state-of-the-art, but only the maximum useful load fractions at which full scale trials have been run. Higher useful load fractions can be attained. For example, model tests have been run on CPIC-X at overload conditions corresponding to a useful load fraction of 48% with no more speed reduction than that expected due to the increase in displacement. If full scale trials had been run with a corresponding load the state-of-the-art line would have been raised in the vicinity of $F_{N\nabla}$ = 3.5. Similarly, the HSPB shows no sign of performance degradation and may have been capable of useful load fraction greater than 30% at $F_{N\nabla}$ greater than 5. On the contrary, the Grebe 36 ft LCSR(L) does



NOTE:
FOR CRAFT TESTED AT VARIOUS
DISPLACEMENTS THE DESIGN
CONDITIONS ARE NOTED BY: ◇

Figure 80 - Useful Load Fraction Upper Boundary (U)
(Repeat of Figure 23)

show signs of performance drop-off at a useful load fraction of about 55%. Although this is at least partially due to overloading of the propeller, it probably is close to the state-of-the-art at $F_{N\nabla} = 2.5$. Regardless of the exact limits of useful load fraction, it can be concluded that the planing hull, as a type, can be relatively insensitive to overloading.

6. (U) The matter of insensitivity to overloading must not be misunderstood. During design and construction every effort consistent with good practice must be made to keep the weight to a practical minimum. Nevertheless planing hulls are, as 'a type, forgiving of overload conditions because usual design practice results in a hull which departs in both size and proportions from the values which would produce the minimum smooth water drag. If minimum smooth water drag were the only consideration, the optimum hull would be (compared to usual design practice) short, wide, flat and small, and would run at a high trim. When the typical planing hull is overloaded the trim angle increases (toward the optimum value thereby improving the lift/drag ratio) and therefore the drag and required power increase at a lower rate than the displacement and payload. The reasons why planing hulls usually differ from the optimum size and proportions and are therefore forgiving of overload condition are:

- Greater length-beam ratio is required for seakeeping and handling, at high and low speeds.
- Greater volume is required for internal arrangements, survivability.
- Lower trim angle is required for reduced rough water impact and porpoising stability.
- Keeping the hump drag below the thrust capability of the propulsion system usually also requires greater planing area and therefore

lower trim than optimum at design speed.

- Gun depression angles at speed require low trim.
- Although not strictly technical reasons, the appearance of the vessel at speed, and the amount of wake; are important and are both improved by a low trim angle.
- Because burst speed is required only a small percentage of the time (usually 20% max.) it is necessary for the vessel to be efficient at displacement speeds. A longer, more lightly loaded hull accomplishes this.

D. (C) SPECIFIC DESIGNS OF EXISTING CRAFT (U)

1. (U) General Discussion

a. (U) Four specific planing hull designs are discussed here: the CPIC-X, the Open Ocean Planing Hull, the SWAM-X and LVA (Landing Vehicle Assault). They have been selected for discussion here for the following reasons:

- CPIC-X and the Open Ocean Planing Hull represent an excellent technology base to realistically demonstrate the potential of an ocean-going planing combatant to satisfy the vehicle functional requirements now being promulgated in Task I of this Advanced Naval Vehicles Concepts Evaluation (ANVCE). All the model testing done for CPIC-X is equally applicable to the Open Ocean Planing Hull. CPIC-X has been subjected to the most rigorous technical evaluation ever performed on such a vehicle. This not only confirms the validity of the original tank-sized model tests, but now CPIC-X can be considered a one-half-scale, manned model of the Open Ocean Planing Hull to illustrate the practicality of a 576 tn (585 t) planing ship. Preliminary work on the Open Ocean Planing Hull has been sufficiently promising to warrant discussion here.

- The SWAM-X and LVA represent two very different and very arduous applications of planing hull technology to the difficult naval tasks of riverine and amphibious warfare. These two applications would have been too risky around 1974, given our data base then; they are still risky enough to justify their residence in category 6.3. RDT&E(N) (Advanced Development), but not so risky as to be impractical.

b. (U) Each of the four designs discussed should be viewed as technical summaries backed up by data produced by two on-going Navy Department

Advanced Development Programs. The sole purpose of these discussions is to illustrate specific examples of applied planing hull technology; matters related to applicable mission/task relationships, planned mission equipment suites, configurations and/or arrangements, or other specific point design issues will be treated in Task IV of the ANVCE,

2. [redacted] Experimental Coastal Patrol and Interdiction Craft (CPIC-X) (U)

a. (U) The operational requirements of this craft are patrol, interception, and interdiction of combatant craft in the coastal environment. The following key characteristics of this craft, subject to the notes following them, are based on the ANVCE standard engine rating at 59°F. For a more complete description of the craft's performance and other characteristics see pp. 74-85 (including Figures.24 through 29 and Table 4). the tabulation on pp. 36 and 37, and Section II. D.2.e below.

1) Flank speed, smooth water: 41.1 knots (76.1 km/h)
2) Flank speed, $H_{1/3}$= 4.6'(1.4m): 38.8 knots (71.9 km/h)
3) Maximum speed on diesels, smooth water: 8.8 knots (16.3 km/h)
4) Range, at 38.8 knots (71.9 km/h) $H_{1/3}$= 4.6' (1.4m): 313 NM (580 km)
5) Useful Load (Military Payload + Fuel) : 30 tn (30.5 t)
6) Turning diameter at 40 knots (74.1 km/h): 10 boat lengths.
7) Range at 8.0 knots (15.4 km/h), $H_{1/3}$ = 4.6': 2492 NM (4615 km)

The following notes are keyed to the above characteristics:

1) 2) Maximum speed at full load displacement and at the continuous rating of the 3 turbine engines at the temperature noted above (2180 BHP per engine at 59°F).
3) At continuous power (435 hp total) [3].
4) 7) Ranges calculated with 16 tons of fuel (three main tanks 95% full). The bow tank provides an additional 5 tons of fuel which increases the range to 421 NM (780 km) at 37.8 knots (70.0 km/h) and 3360 NM (6223 km) at 8.2 knots (15.2 km/h). The diesel range is calculated at 8 knots (14.8 km/h) rather than 8.8 knots (16.3 km/h) because it is a more economical speed.
5) Useful load and military payload are as defined in ANVCE WP-002 previously cited.

b. [redacted] Seakeeping at high speed in rough water was the most important design consideration. Specifically, the rough water design requirement as originally stated in 1971 was that the average acceleration at the center of gravity in a head sea of $H_{1/3}$ = 4.6 ft. (1.4m) should not exceed 0.40 g at a speed of 40 knots. As built and tested, CPIC-X was operated at 37 knots in seas of $H_{1/3}$ = 4.6 ft, and the average of the 1/10 highest accelerations measured at the center of gravity was 1.1g (See Figure 41, p. 125).

c. [redacted] The design philosophy of effective hydrodynamic tradeoff [redacted] studies to meet the smooth and rough water operational requirements is given in [38]. The CPIC-X configuration is shown in Fig. 9, p. 38.

d. [redacted] The following principal design features were developed during the preliminary design study:

1) <u>Hull Form:</u> CPIC-X has a long slender hull with moderate deadrise aft and high deadrise forward for high speed operation in rough water. Hydrodynamic analysis indicated that both resistance and seakeeping characteristics would be optimized by minimizing beam. This is consistent with the high beam loading required to reduce wave impact loads as discussed in Sect, I.A.8, p.11; II.A., p. 54; and III.E, p. 270 . Unfortunately hydrostatic stability requirements favor a hull with wider beam. These conflicting demands are reconciled in a double chine configuration in which the lower chine has a minimum beam for good high speed impact characteristics while the beam at the upper chine satisfies the stability requirements.

Another advantage of the double chine afterbody over the single chine configuration is that it more readily fairs into the convex sections of the forebody. This hull form minimizes impact loads, not only when running directly into head seas but also at other relative headings and combinations of roll and pitch. Careful placement of the spray rails provides the flow separation necessary for planing performance and makes for a "dry boat in rough weather.

Model tests on this hull, and experience with other double chine hull forms, indicate there is the possibility of developing a hull which will achieve complete flow separation from the lower chine with no reattachment to the hull area between the chines thus providing a reduction in wetted area and frictional drag. The achievement of this condition is facilitated by narrowing the chine beam toward the stern. This reduces internal volume near the stern which is sometimes at a premium, as it was in CPIC-X. Therefore, development work will be required in this area.

The center-of-gravity of the craft was located relatively far forward to reduce the equilibrium trim angle and thus further contribute to reduced impact accelerations as discussed in I.A.8, p. 11, II.A, p. 54 and III.E, p. 270. To provide an efficient hull in the cruise condition, the slenderness ratio was selected to be $L/v^{1/3} = 7.0$. This results [38] in the minimum resistance in the pre-hump region. At the maximum speed and full load displacement (see above) the hull has a lift drag ratio of approximately 6. and runs at a trim angle of 3 degrees which is lower than the optimum for smooth water resistance. Thus, the lift-drag ratio will increase with increased loading. This is a desirable trend when future growth is considered. See Section II.C.6, p. 224, for further discussion of this feature.

2) <u>Propulsion Machinery:</u> CPIC-X has two completely independent propulsion systems. The main propulsion system which provides power for high speed operation, consists of three 2,000 bhp AVCO Lycoming TF25A gas turbine engines, (see pp. 36 and 79) each driving a non-reversing, fixed-pitch propeller through primary reduction gear box and a secondary V-drive reduction gear. The main propellers are 30-inch diameter Newton-Rader transcavitating series for which water tunnel data at appropriate cavitation indices exist [90]. This simple drive train was selected because it is cheaper, lighter, and incurred fewer technical risks than an equivalent water jet or reversing gear box, or controllable pitch propeller system. A three-engine arrangement was selected to provide efficient

[redacted] [redacted]

operation over a wide range of operating speeds, to keep draft low, and to enhance redundancy and reliability.

Power for low speed operation, backing, and maneuvering is provided by two Volvo diesel engines with a total of 370 rated hp at 2200 rpm*. Each engine drives a fixed pitch propeller through an outdrive unit which is steerable, reversible and retractable. All propellers, 3 turbine and 2 diesel, are same handed for ease of logistic support.

3) <u>Cooling System</u>: Machinery cooling is provided by a heat exchange system mounted against the hull bottom plating. This system has a minimum of hull penetrations and obviates taking sea water aboard except for the low speed propulsion diesel engine cooling.

4) <u>Roll Stabilization:</u> The craft was provided with active roll fins which were mounted normal to the bottom between the upper and lower chines. At cruise speed, the fins reduced the roll motions by a factor of 2. This made the craft much more habitable and the crew more effective. For further discussion of roll fins see Section II.A.l.h, p. 89 and sections cited there.

5) <u>Material</u>: The craft is constructed of all welded aluminum alloy.

6) <u>Steering</u>: CPIC-X is controlled by transom mounted rudders.

e. [redacted] The final dimensions, in round numbers, and operating characteristics of CPIC-X are summarized along with those of the Open Ocean Planing Hull in Section II.D.3 below. .

The prototype CPIC-X appears to have closely satisfied its original design specifications. It has demonstrated excellent seakeeping characteristics and load carrying ability without too much powering penalty.

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* The measured output of these engines on sea trials was 538 total hp at 2150 RPM. (See also pp.36, 75, 77 and 78)

3. [redacted] Open Ocean Planing Hull (U)

a. (C) A brief study was recently made of the feasibility of developing a large planing hull capable of sustained operation in the open ocean. For this purpose, it appeared appropriate to double the scale of the existing 100′ (30.5m) CPIC-X planing hull to "planing ship size" having a length of 200 ft. (61m). The smooth and rough water performance of the CPIC-X have been well documented in extensive full-scale trials so that Froude scaling these results to a craft twice its length should produce reliable Performance . estimates. The weight breakdown for the Open Ocean Planing Hull has also been estimated by appropriate scaling of each weight group from CPIC-X.

b. [redacted] The scaling procedures used to develop these performance estimates are given below, where λ is the linear scale ratio = 2:

Gross Weight:	$w = W_{CPIC}\lambda^3$
Speed:	$v = V_{CPIC}\lambda^{1/2}$
Length:	$L = L_{CPIC}\lambda$
Sea State:	$H_{1/3} = H_{1/3\ CPIC}\lambda$
Power:	bhp = 10.75 bhp_{CPIC} *

To determine the speed of the Open Ocean Planing Hull the actual power rating for the engine and conditions in question was divided by the scaling factor (10.75) to get an equivalent bhp for CPIC-X. Figure 24, p.76 was enter[redacted] this bhp and the corresponding CPIC-X speed read off the curve for smooth or rough water as appropriate. This speed was then multiplied by the speed scaling factor ($\lambda^{1/2} = 2^{1/2}$ = 1.414) to obtain the speed for the Open Ocean Planing Hull. Calculations involving these procedures are referred to throughout Section II.A.1,p.54 .

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* If it were Froude scaled, power would vary as $\lambda^{7/2} = 2^{7/2} = 11.31$. However, only the power required to overcome the wavemaking resistance scales in this manner. The power to overcome the frictional resistance (approximately half of the total) is Reynolds scaled thus effectively reducing the exponent. The amount of the reduction was estimated at the design speed.

[redacted] Characteristic		CP IC-x		Open[illegible]n Planing Hull
Length Overall		100 ft. (30.5m)		200 ft. (61m)
Beam, Deck		18 ft. (5.5m)		36 ft. (11m)
Beam, Upper Chine		15 ft. (4.9m)		32 ft. (9.8m)
Beam, Lower Chine		14 ft. (4.3m)		28 ft. (8.5m)
[redacted] Draft, Navigational		6.5 ft. (2.0m)		13 ft.. (4.0m)
Displacement	100%	72 tn (73.2t)	100%	576 tn (585t)
Group 1, Structure	24%	17.02tn (17.3t)	22%	125.4tn (127.4t)
2, Propulsion	17%	12.14tn (12.3t)	12%	71.8tn (73.0t)
3, Electrical	6%	4.66tn (4.7t)	6%	35.2tn (35.8t)
5, Aux.Systems	6%	4.16tn (4.2t)	5%	31.1tn (31.6t)
6, Outfit, Furn.	5%	3.83tn (3.9t)	5%	29.8tn (30.3t)
Empty Weight	58%	42tn (42.7t)	51%	293tn (298t)
Useful Load (Disp-Empty)	42%	30tn (30.5t)	49%	283tn (288t)
Military Payload*	20%	14tn (14.2t)	19%	110tn (112t)
Fuel (Useful-Military)	22%	16tn (16.3t)	30%	173tn (176t)
Reserve Fuel		5tn (5.1t)		105tn (107t)
Main Machinery, Turbines		3-AVCO TF25A		3-GE LM2500
Rated bhp, 59° day, total		6540 (6631)		8[illegible]750 (82884)
Speed, 59° day		41 knots (76.1 km/h)		62 knots (114 km/h)
Rated bhp, 100° day total		5400 (5475)		67500 (68436)
Speed, 100° day		38 knots (70.7km/h)		57 knots (106 km/h).
Low Speed Machinery, diesel		2 VOLVO w/O'Drive		3 - MTU 12V331TC
Rated Horsepower, total		550 (558)		3624 (3674)
Speed		9 knots 16.3 km/h)		12 knots (22 km/h),
For Range see Table 4, p. 66				

* Military payload includes Group 4, Communications and Control, Group 7, Armament, Ammo, Crew, Personal Effects, and Potable Water.

d. [redacted] The craft can be driven by either fixed pitch propellers or by water jets. Power for high speed operation is provided by three 25000 bhp GE LM2500 gas turbines rated at 22500 cont. bhp at 100°F and standard conditions, Each gas turbine drives a fixed pitch 66 inch (1.68m) diameter Newton-Rader propeller through a double helical reduction gear and conventional shafting. Geometrically similar propellers have been used on CPIC-X, and on the Brave class patrol boats where they have operated at speeds up to 55 knots (102 km/hr.)

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A reduction gear can be built using conservative design factors for gears and bearings, which will transmit 25000 hp with an input speed of 3600 rpm and a reduction ratio of 3:1 to the propellers. Pitch line velocity will be less than 15000 ft/min and the maximum K factor will be less than ZOO. Gear and bearing design factors are within the state-of-the-art.

e. [redacted] Power for low speed operation, maneuvering, and backing is provided by three MTU 12V331TC diesel engines rated at 1208 cont. shp at 100°F. Each diesel is equipped with a conventional marine gear and can be clutched into the main reduction gear.

f. [redacted] If water jet propulsion is used, then the three GE LM 2500 engines can be connected to an existing Aerojet AJW-18000 water jet pump for high speed operation. For low speed operation, propulsion is provided by two MTU 16V652 diesel engines connected to 24 in. (0.61m) Rocketdyne Powerjet pumps. Each diesel develops 2200 hp at 1600 rpm.

g. [redacted] A study was made of the feasibility of arranging the machinery space in the Open Ocean Planing Hull to accommodate these power plants and to drive the craft by either conventional propellers, surface piercing propellers (to avoid shaft drag) or water jets. It was found that each is possible although, because of the large diameter and low rpm required for the surface piercing propellers, these are not recommended.

4. (U) Experimental Shallow Water Attack Medium (SWAM-X) Craft

a. (U) The Experimental Shallow Water Attack Medium (SWAM-X) Craft is envisioned as a 65 ft (19.8m) craft with a nominal beam of 22 ft (6.1m) which displaces approximately 160,000 pounds (72,600 kg). It is designed to operate primarily in a riverine environment with limited capabilities for coastal operations. The basic configuration is designed to accomodate the retrofit of modules for seven variant configurations as follows [116];

- Troop Carrier
- Command and Control
- Fire Support
- Advanced Base Defense
- MEDAID/Air Support
- Mine Laying/Countermeasures
- Logistics Support

Military payloads for the above variants range from 45,000 pounds (20,400 kg) to 60,000 pounds 27,200 kg).

b. (U) SWAM-X represents the most comprehensive utilization of a small craft which achieves versatility through modularity and arrangement flexibility.

c. (U) A summary of the overall performance characteristics of SWAM-X follows:

1) Gross Weight: W = 160,000 lbs (72,600 kgs)

2) Speed: V = 30-40 knots (56074 km/h) Smooth Water
25 knots (46 km/h) $H_{1/3}$ = 2.9 ft (0.9m)

3) Length (Overall): L = 65 ft (19.8m)

4) Sea State: Fight and Maneuver: $H_{1/3}$ = 4.6 ft (1.4m)
Survive: $H_{1/3}$ = 6.9 ft (2.1m)

5) Required Power: Approximately 5000 bhp

a) It has been estimated on the basis of an L/D of 6 to 7 and an OPC ≃ 0.55 that approximately 5,000 bhp would be required for primary propulsion of SWAM-X [9]. The alternatives for powering in this range are somewhat limited to multiple installations of the AVCO family of gas turbines with 85°F (32" C) continuous ratings of 1250 bhp, 2000 bhp, 2500 bhp, and 3000 bhp for the TF 14, TF 25, TF 35, and TF 40 respectively. An alternate turbine may be found in the Garrett GTPF-990.

rated at 5400 bhp, 85° F day (32" C), but a single turbine installation would be unsatisfactory from maneuverability and vulnerability standpoints. Diesel propulsion has also been considered but the lower horsepower ratings of available diesels, e.g. DDAD 6V71TI and 12V71TI diesels have 85" F (32° C) ratings of 325 and 650 hp respectively,are insufficient to make even multiple installations practical. However, combination turbine and diesel systems remain candidates for powering SWAM-X.

b) Propulsors under consideration for SWAM-X include fixed and controllable-reversible pitch (CRP) propellers and waterjets. Due to the shallow draft requirement of SWAM-X, the tunnel-hull appears most practical for a propeller configuration. Investigation of 100% tunnels will be completed shortly at DTNSRDC [117]. Waterjets under consideration include the Rocketdyne PF-16 (1500 hp), PJ-20 (5000 hp), the Aerojet AJW-800 (1200 hp), and the Jacuzzi 28-JY (1400 hp). [9].

c) The following typical machinery installations are the prime candidates for SWAM-X propulsion:

- 2 TF 35 Gas Turbines with 2 Waterjets (PJ20)
- 2 TF 35 Gas Turbines with 2 12V71TI Diesels with 2 Waterjets (PJ20)
- 3 TF 14 Gas Turbines and 3 6V71TI Diesels with 3 CRP or fixed. pitch propellers in a triple tunnel hull configuration.

6) A preliminary weight summary follows:

Displacement, full load	160,000 lb	(72,600 kg)
Group 1	32,800 lb	(14,900 kg)
Group 2 (average) [9].	24,500 lb	(11,100 kg)
Group 3 [116]	8,600 lb	(3,900 kg)
Group 4 (Included in military payload)		
Group 5	7,700 lb	(3,500 kg)
Group 6	7,500 lb	(3,400 kg)
Group 7 (Included in military payload)		
Empty Weight	81,100 lb	(36,800 kg)
Useful Load (Displacement - Empty Weight)		
160,000 - 81,100 =	78,900 lb	(35,800 kg)
Fuel Weight (average) [9]	23,500 lb	(10,700 kg)
Military Payload (Useful Load - Fuel Weight)		
78,900 - 23,500 =	55,400 lb	(25,100 kg)
Group 4	2,500 lb	(1,100 kg)
Group 7, [116] Armament, depending on variant selected:	from 16,500 lb	(7,500 kg)
	to 24,800 lb	(11,300 kg)
Protection Systems	15, 000 lb	(6,800 kg)

5. [redacted] Landing Vehicle Amphibious (LVA)

a. (C) A study is currently underway to design and construct a 28 ft amphibious landing craft for the U. S. Marine Crops. One of the hydrodynamic concepts being considered is a planing hull. The uniqueness of this planing craft is that its bottom loading is nearly 100% larger than conventional planing craft of comparable size and hence will produce excessive hump trim and drag. In addition, the craft must run through head seas of $H_{1/3}$ = 2.2 ft (0.7m) at 30 kts (56 km/h) and not exceed the "g" levels defined by MIL-STD-1472 B [87] for 1-hour proficiency.

b. [redacted] The general characteristics of the LVA are:

Length Overall, ft (m)	28	(8.5)
Chine Beam, ft (m)	11	(3.4)
Bottom Deadrise, degrees	0	
Displacement, lb (kg)	55;000	(24,900)
Maximum Speed, Smooth Water, knots (km/hr)	35	(65)
Maximum Speed, Sea State 3, knots (km/hr)	30	(56)

c. [redacted] The hydrodynamic characteristics of the LVA as determined by model tests are as follows:

Speed		Trim	L/D	Drag	
knots	km/h			lb	kg
10	19	1°	17.0	3,200	1450
15	28	22°	2.6	21,000	9500
20	37	17"	3.2	17,400	7900
25	46	12°	4.0	13,600	6200
30	56	9°	5.0	11,100	5000

d. [redacted] It will be noted that the hump trim, which occurs at 15 knots (28.0 km/h) is very large and consequently results in a lift-drag ratio of only 2.6. This intolerable situation was alleviated by (1) the addition of a controllable transom flap which, when deflected downward, produces a nose down pitching moment to reduce the hump trim, and by (2) the addition of retractable chine flaps which reduce the bottom loading. The transom flap had an area of 21 ft^2 (2.0 m^2) and could be deflected downward 15". The chine flaps each had an area of 58 ft^2 (5.4 m^2) and were a horizontal extension of the bottom. With these additions, the hydrodynamic characteristics of the craft were as follows:

Speed		Trim	L/D	Drag	
knots	km/h			lb	kg
15	28	12"	3.7	15,000	6800
20	37	11"	5.5	10,000	4500
25	46	4"	7.6	7,200	3300
30	56	2°	10.8	5,100	2300

e. [redacted] It is to be noted that hump trim was reduced by about 50% and hump resistance by about 30% of the unflapped hull values. Seakeeping tests indicated that the impact loads in a seaway were approximately 25X less than the MIL-STD-1472B level [87].

f. (U) The propulsion machinery and propulsors have not as yet been selected for this craft since the development is still underway. Further, the empty weight, payload, and range are presently being evaluated.

E. (C) SPECIAL DESIGNS (U)

1. (U) General Discussion (Hybrids and Innovations)

a. A number of unusual designs have been generated, some capitalizing on older principles, some created using newly evolving technology. Not all have equal merit for naval missions but, in order to cover the entire field of planing technology ten of these "special" designs are discussed below: 1) the Hickman Sea Sled; 2) the Dynaplane; 3) stepped planing hulls; 4) the Sea Knife; 5) planing catamarans; 6) the Hydro-Ski; 7) partial hydrofoil support; 8) hydrokeels; 9) surface effect boats, and 10) the Ski Cat.

b. These unusual designs, with few exceptions, attempt to emphasize one or two parameters of performance to the degradation, or even neglect, of' all others. Some examples follow: smooth water drag reduction at the expense of rough water behavior in the case of the Hickman Sea Sled, the Dynaplane, and stepped hulls; rough water behavior at the expense of drag (requiring very high power) and very limited usable interior volume and exterior deck space (from amidships forward) in the case of Sea Knife; rough water performance at the expense of mechanical and arrangements sophistication in the case of the Hydro-Ski, some partial hydrofoil support configurations, and the hydrokeel (in the case of hydrokeel, there was no measurable benefit). Each of the above seven concepts has, at one time or another, been examined as a candidate to perform certain naval tasks; each one of the seven was eliminated in the design trade-off process primarily due to lack of overall utility and mission flexibility/suitability; and each of the seven has been placed "on the shelf" should its speciality be required. In the case of Sea Knife (and partial hydrofoil supported configurations), additional data will be evaluated shortly from ongoing Task II ANVCE experiments.

c. The remaining three special designs (planing catamarans, surface effect boats and the Ski Cat) have shown potential for future coastal patrol missions, and perhaps ocean patrol as well. They may be considered, where appropriate, as point design candidates in Task IV, or in subsequent efforts.

d. A brief discussion of all ten special designs will follow, but first, it is necessary to state the philosophy which must prevail in order to develop well reasoned planing hull combatants. This philosophy requires establishing the broadest practical specifications from which hull and arrangement characteristics are developed. This development follows the traditional pattern of successively more detailed design iterations. Each of these iterations stems from an exhaustive trade-off analysis whereby a vehicle's hull form, structure, and arrangements are made as broadly accommodating to the payload (placement, size, and weight) as possible while operating in a wide range of environments and threats. Adapting to future missions is provided by modularizing the mission equipment to the greatest extent possible.

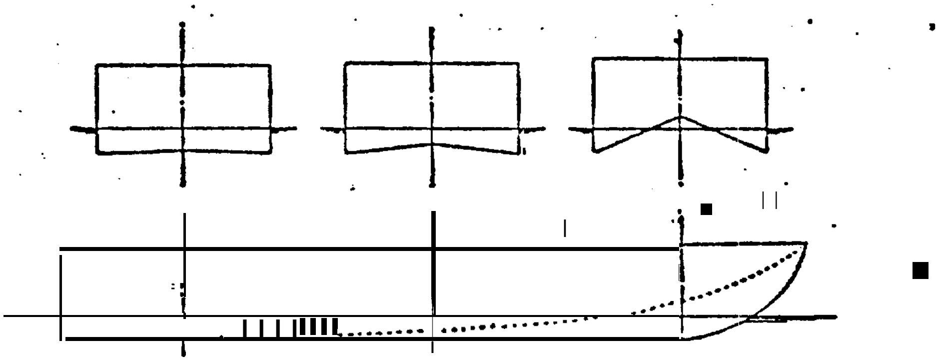
e. For example, highly unusual hull forms are undesirable if, due to planform geometry, they tend to drive the structural weight fraction up, or detract from accomodating the military payload, the fuel load, or propulsion equipment. In addition, designs which require specific adaptation of weapons subsystems and sensors are impossible in today's funding climate.

f. These factors are creating an awareness in the design community that the platform, or vehicle, is a taxi for the weapons and mission-specialized equipment, which must change whenever the threat dictates. Therefore, the taxi must provide a high degree of flexibility and universality to be cost effective and suitable in tomorrow's Navy.

2. (U) Special Design Descriptions

a. (U) Hickman Sea Sled

(U) This planing form consists essentially of an inverted "vee" or tunnel as shown in the following sketch:



(U) The lift characteristics of an inverted vee-bottom have been shown to be somewhat better than a flat plate. In addition, this bottom form tends to suppress the spray and contain it within the tunnel formed by the inverted "vee" section.

(U) Because of the good lift characteristics of the inverted vee-bottom, the impact loads in a seaway can be excessive--although there is some claim that the air cushion formed between the hull bottom and wake surface serves to alleviate the impact loads.

(U) An interesting feature of the Hickman Sea Sled is the use of surface-piercing propellers. In this application, the propellers are located just aft of the transom with the shaft axis level with the lower edge. This results in elimination of appendage drag normally resulting from an immersed inclined shaft as well as from the support strut. For high-speed craft, the effect of these appendages on resistance and propulsion is very important, especially when cavitation may be present. It may be that the improved overall efficiency claimed for the Sea Sled may be attributed more to the propulsion system than to the hull form.

For further qualification of these remarks on surface-piercing propeller propulsion see Sections II.A.6., and II.B.2.

b. (U) Dynaplane

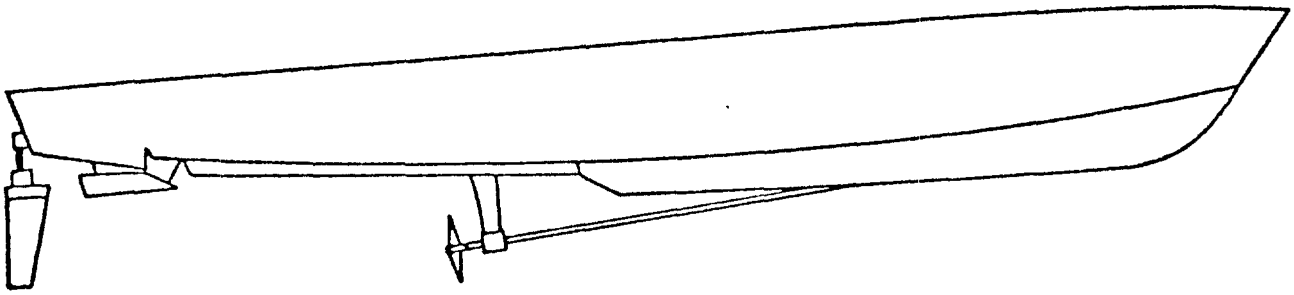
(U) The Dynaplane is a stepped planing hull with a cambered forebody and an adjustable planing surface aft. The forebody step area has positive camber to the buttocks in the direction of flow to increase the lifting efficiency and can be designed for a specific running trim angle due to the flexibility of position of the aft stabilizer. The stabilizer is adjustable both vertically and angularly by a pneumatic control. This adjustable stabilizer also reduces the risk of porpoising instability. The concept has been verified by full scale tests on a 32 ft. craft which show that its smooth water efficiency exceeds that of conventional planing hulls at high speed ($F_{N\nabla} > 3.5$) as shown on the next page.

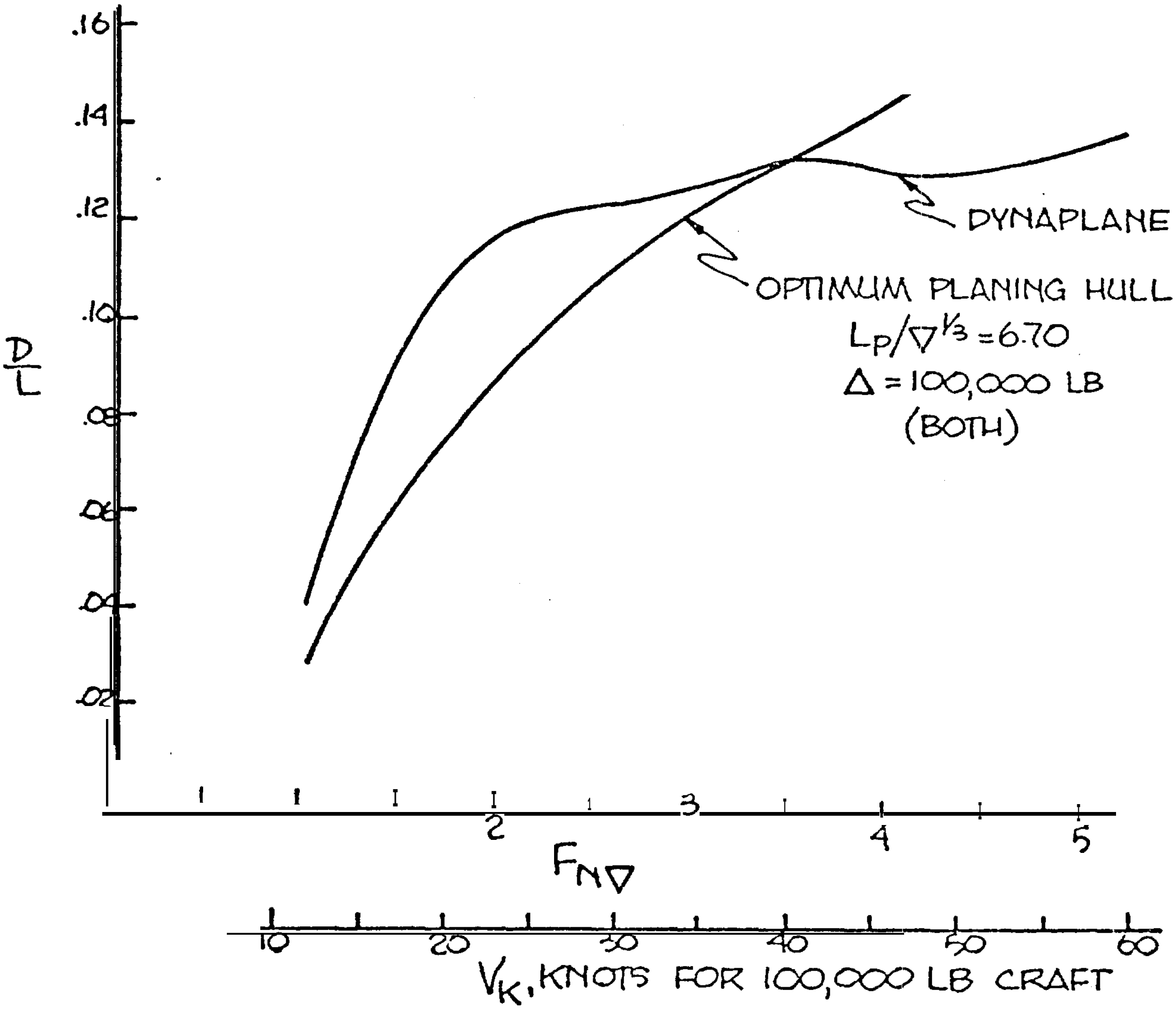
The advantages of this concept are as follows:

- Optimum running trim can be maintained over a wide speed range.
- High speed smooth water efficiency.
- Location of loading not critical within reasonable variations.
- High speed longitudinal stability.

The disadvantages are as follows:

- Controllability in a seaway is difficult.
- High resistance at low speed.
- Seakeeping is poor as compared with conventional craft.

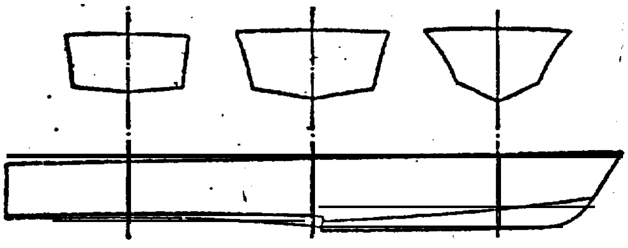




Dynaplane Compared to Optimum Planing Craft

c. (U) Stepped Planing Hulls

(U) A stepped planing hull is a hard-chine boat which is characterized by the introduction of a transverse break or step in the bottom in the vicinity of mid-ship (just aft of the LCG). At high speeds, a well-designed stepped planing hull carries the entire load on a small portion of the planing area just forward of the step while the bottom area aft of the step is ventilated and runs clear of the water. In this operating mode, the stepped planing hull can run at optimum trim and, hence, develop large lift-drag ratios in smooth water. Unfortunately, when the craft is running on the forebody alone, the center-of-gravity travel is limited in order to keep the running trim optimum and the afterbody dry. For this reason, stepped hulls invariably run with both afterbody and forebody loading. This allows for greater variation in the location of the center-of-gravity, but at the expense of increased drag and the risk of inducing porpoising instability.



(U) At lower speeds, the bottom area aft of the step becomes wetted and, thus, increases the hull drag due to both an increase in wetted bottom area and to a form drag increment due to flow separation at the step. This is a disadvantage in a military boat where the maximum range at low speeds is a desirable characteristic.

(U) Stepped hulls have poor performance in rough water. This results from the fact that the boat runs at relatively high trim angles (to attain maximum lift-drag ratio in smooth water) and with a small wetted area just forward of the step which results in a large unwetted forebody hull bottom area. This trim angle causes large wave impact loads and corresponding large "g" loads as the long forward unwetted bottom area impacts oncoming waves.

(U) It appears that a stepped planing hull is best utilized only for those operations where high speed in smooth water is desired.

d. (U) Sea Knife

(U) The sea knife is a craft with a flat triangular bottom, apex forward. The section shape has vertical sides near the planing bottom and flares out rapidly near the deck edge. The concept is shown in the attached figure. The craft operates with its forefoot out of the water in calm conditions, and in the water in rough seas. This trimming function is obtained by adjusting the outdrive. Dynamic tranverse stability is accomplished by controlling the spray separation. This concept has been demonstrated in craft up to 22 feet in length.

(U) Compared with conventional planing hulls, the Sea Knife has the following advantages:

- Easy motion, especially in head seas, at planing speed enabling work to be performed in severe sea states.
- Handled well and turned positively at planing speeds.

The design features of this craft result in the following disadvantages:

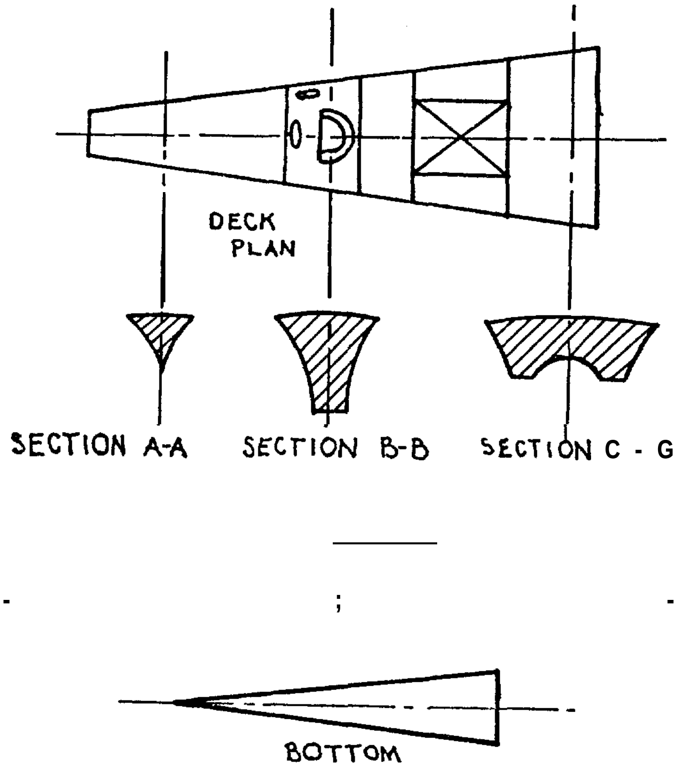
- Low static stability.

A Poor low speed maneuverability.

A Very low lift-drag ratio,-i.e., requires more power than traditionally proportioned planing craft.

A Possible erratic response to beam, quartering and following seas.

A Arrangement limitation forward.



Seaknife

e. (U) Planing Catamaran

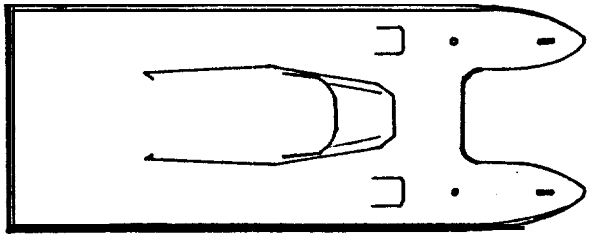
(U) The planing catamaran is a twin-hull craft connected by a structural bridge section which restrains the two hulls rigidly, relative to each other. This bridge structure has its lower surface above the water surface. Each hull has a very high length-beam ratio (higher than normally acceptable for static stability considerations for a monohull craft) with either symmetrical or unsymmetrical transverse section shape. Round bilge hull sections are used for low design speeds and hard chine (planing) sections are used for high design speeds. Existing planing craft technology can be applied to the hydrodynamic design of the catamaran hulls. A sketch of a planing catamaran is shown.

The advantages of planing catamarans are as follows:

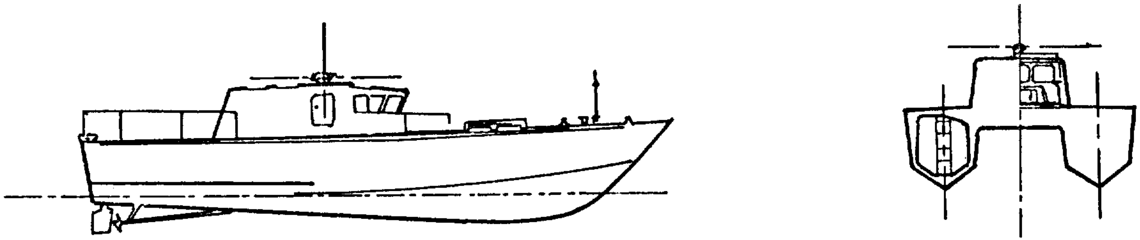
- High beam loading of the hulls reduce the impact loads during high speed wave encounter.
- Increased deck area relative to monohull of same length.
- Stable platform.

The basic disadvantages are:

- The limiting height of the main hull bridging structure above the water surface to avoid high speed wave impact.
- The additional structural weight involved.
- In general, steering is more difficult in a planing catamaran than in a monohull.



DECK PLAN



PROFILE

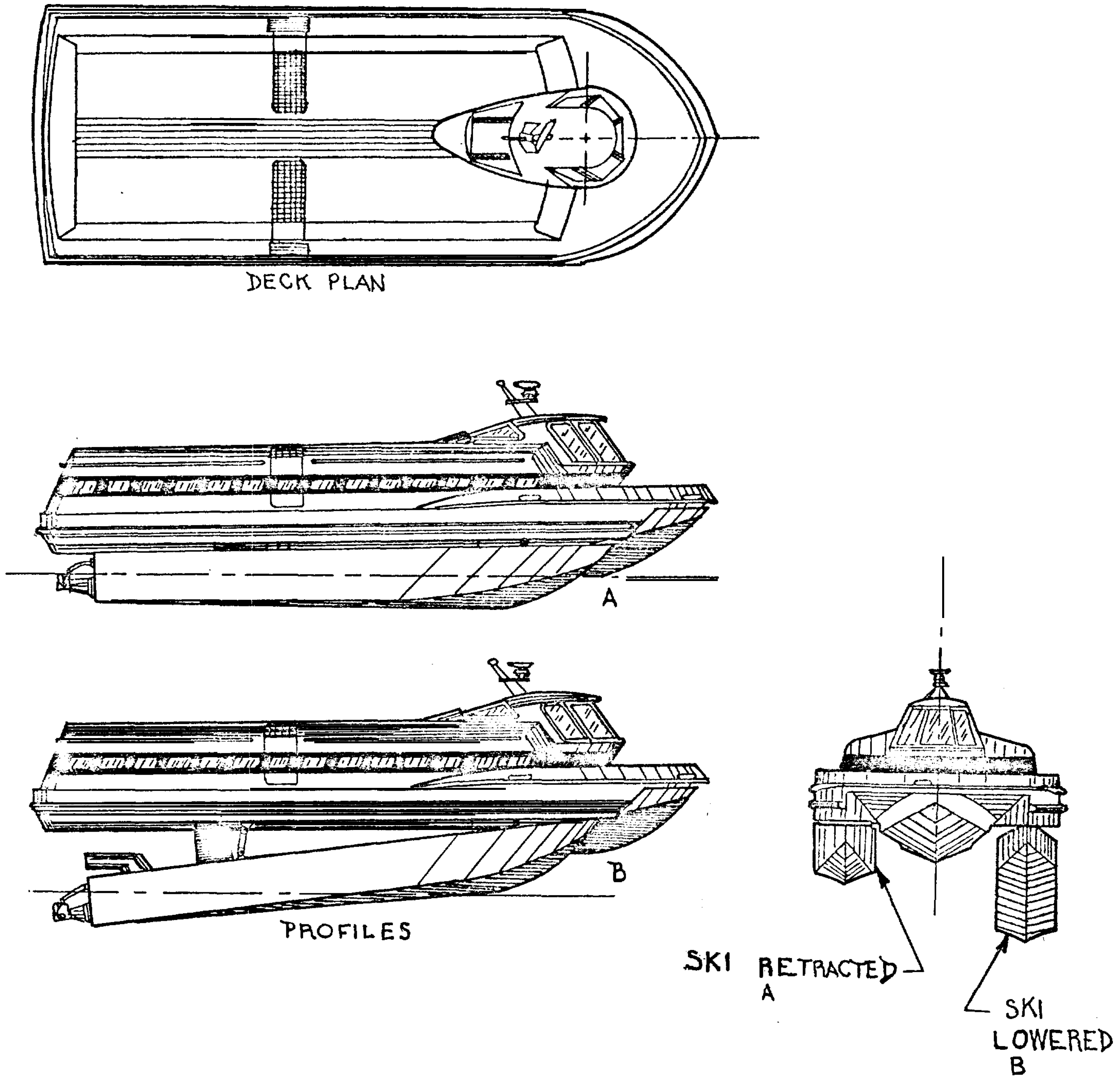
FRONT

CATAMARAN

f. (U) Hydro-ski

(U) The hydro-ski concept was developed as a high speed take-off/landing system for water based aircraft capable of operating in the open ocean. The principle is basically a variable geometry planing hull, similar to a catamaran, but with distinct differences. The craft has multi-hulls with two outboard buoyant skis which may be lowered relative to the main center hull by rotation of a linkage. Thus, the skis are displaced downward and a LCG shift may be effected relative to the main hull if a four bar linkage is used. The thruster, propulsion machinery, and fuel are housed within each ski as this simplifies transmission of power. A sketch of a hydro-ski craft appears on the next page.

(U) A 25 foot test craft was built by Lockheed Aircraft Corporation (LAC). Evaluation in rough water was supported by the Office of Naval Research. Under a license from Lockheed, a private firm built a 50 foot (15.2m)/ 45,000 pound (20400 kg) craft, but was unsuccessful in marketing it



Hydro-ski

(probably due to a $0.5M 1969 price).

The advantages of the hydro-ski principle are as follows:

- High beam loading of the skis reduce the shock loads during high speed wave encounter.
- A sprung ski, utilizing a shock absorbing mechanism for attachment to the main hull, provides a very stable platform as well as isolation from propulsion machinery noise.
- The skis, when retracted, fit into recesses in the hull which allows very shallow draft for low speed operation.

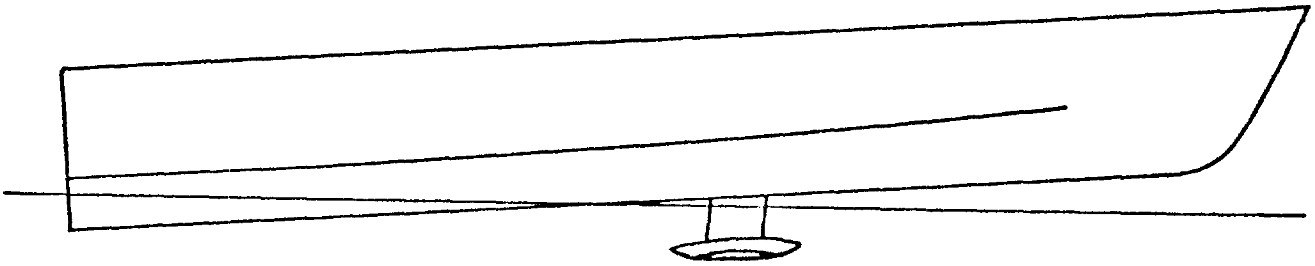
The principal disadvantages are:

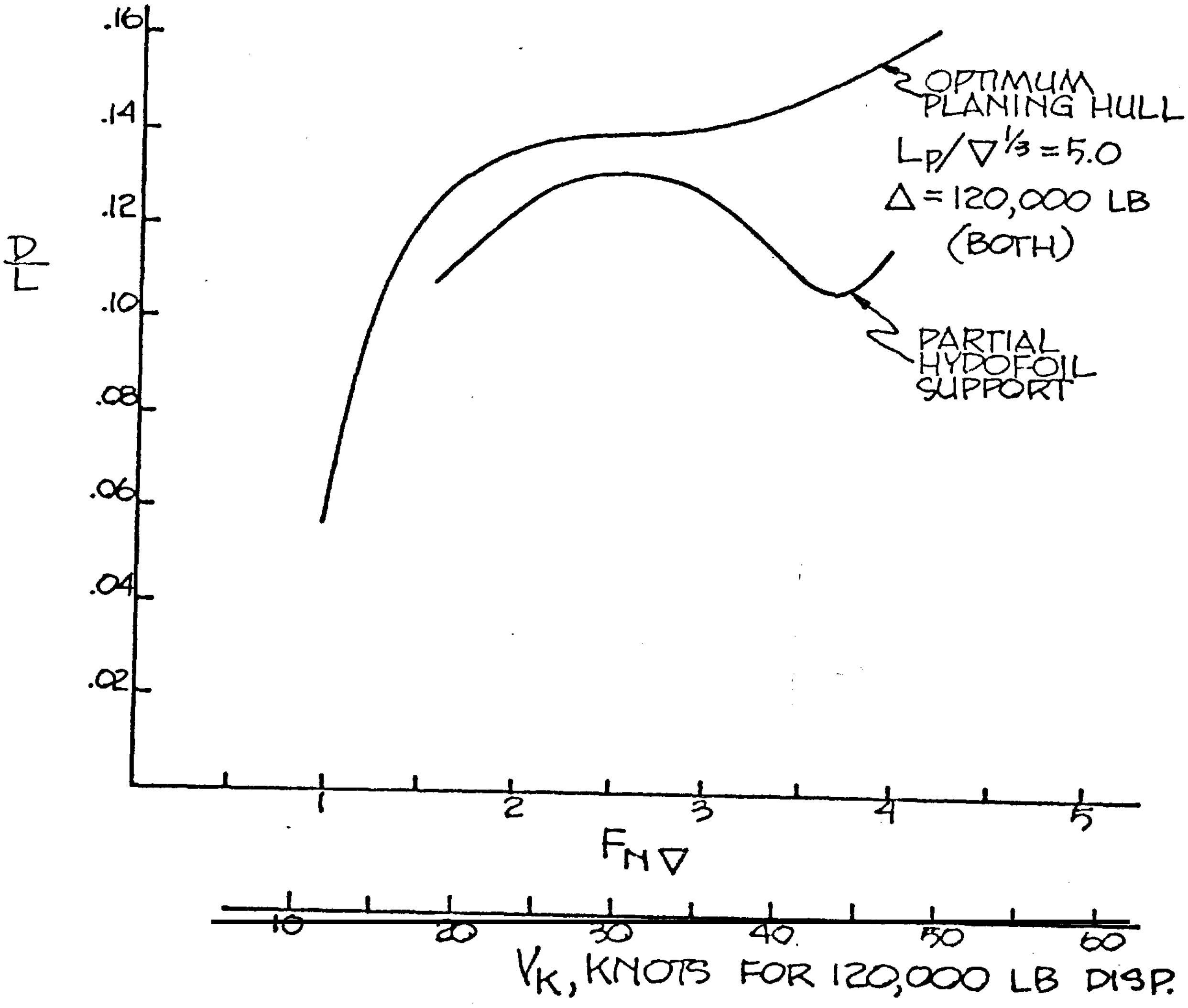
- The expense and complication of the ski system.
- The limitation of the height of the main hull above the water surface, causing risk of high speed wave impact.

g. (U) Partial Hydrofoil Support

This hybrid configuration involves the introduction of a hydrofoil under a conventional planing hull, as illustrated on the next page. From model experimental work done to date, it appears that a hydrofoil which carries about 40 percent of the load and is longitudinally located in the vicinity of the C.G. gives the best power performance. The hydrofoil is vertically located about one chord length below the planing surface and has a dihedral angle the same as the deadrise of the planing hull in the region where the foil is located.

This configuration can reduce the drag at the high speeds without any significant increase at the lower speeds. The addition of the foil introduces additional damping, hence the motions at low speed are expected to be less than for a conventional hull. At high speeds, the foil damping





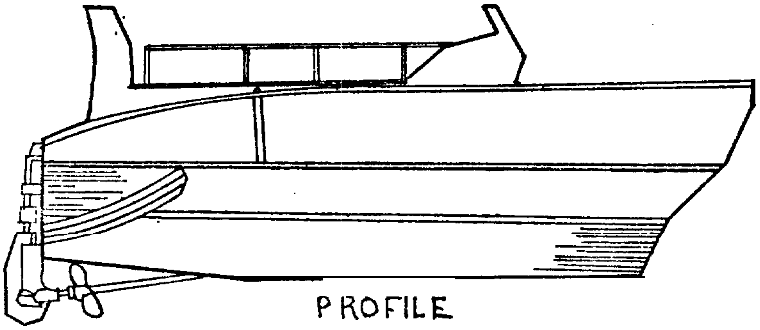
Partial Hydrofoil Support

should also be helpful but the reduced beam loading and possible higher trim angle on the planing hull could cancel this effect. This effect will be fully evaluated by model experiments planned as part of Task II of ANVCE.

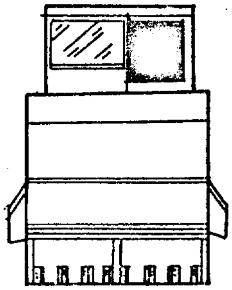
h. (U) Hydrokeel

(U) The Hydrokeel is a partially air supported planing craft. The air cushion is contained by a forebody flap, non-buoyant rigid side walls, and planing action aft. Air is injected under the hull just aft of the flaps. The principle was to have the air cushion ease the slamming loads in a seaway and to "air lubricate" the planing surface to reduce frictional drag. Two craft were built and tested as landing craft: Landing Craft, Vehicle Personnel (Hydrokeel) (LCVP-K) and Amphibious Research Craft,(Hydrokeel Experimental) (ARC-Xl);and several were built for commercial applications. Both single and divided air cushion compartments were evaluated.

(U) There are no distinct advantages of this concept over planing craft, Neither seakeeping nor efficiency advantages could be confirmed by model or full scale tests. The weight of the air handling system reduced the payload capability, and air was ingested in both propellers and cooling water intakes.



PROFILE



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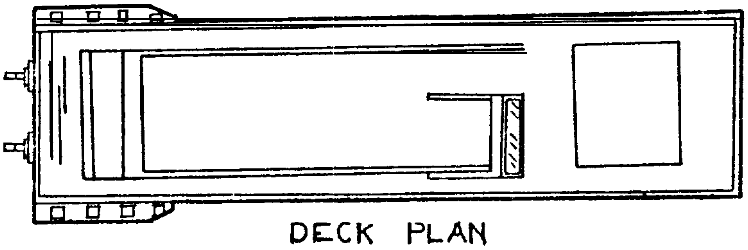

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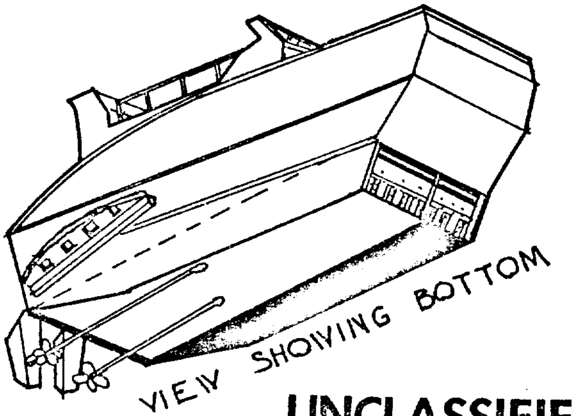


VIEW SHOWING BOTTOM

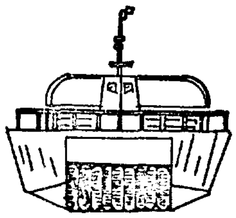
[redacted]

i. (U) Surface Effect Boat

(U) The Surface Effect Boat (SEB) is a cat[redacted]n hull with an air cushion for lift augmentation. The significant difference in concept between the SEB and the SES (Surface Effect Ship) is the large size and immersion of the hulls compared to the typical SES sidewall. This feature provides pitch and roll stability and, in the event of the loss of cushion pressure, enables the SEB to continue operation as a hullborne catamaran, retaining its maneuverability and much of its speed. The hulls are non-symmetrical, having inner walls straight, with flexible seals both forward and aft for cushion control. The craft will normally operate as a catamaran at low speeds when the advantages of an air cushion are less pronounced, and with the partial air support functions at high speeds where the cushion not only reduces drag, but also reduces rough water impact by raising the hulls partially out of water. The SEB transits from low to high speeds with reduced air pressure alleviating the high hump drag problem. The concept has been demonstrated full scale with a 38 ft craft financed by private capital. Both calm and rough water tests were conducted with encouraging results.

(U) The advantages and disadvantages are similar to those listed for catamarans.

[redacted]



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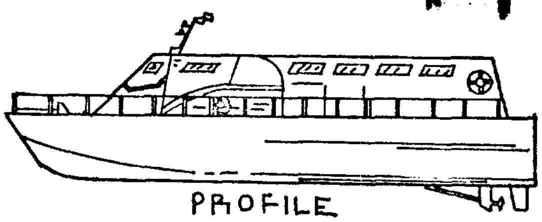

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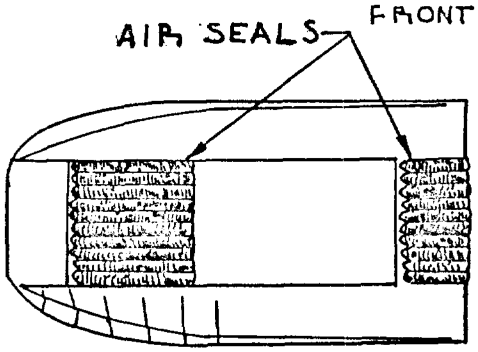
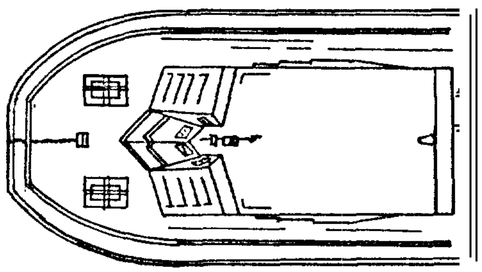


BOTTOM VIEW



DECK PLAN

j. [redacted] Ski-Cat

(U) This is a hybrid configuration which consists of catamaran planing hulls supported by a high-aspect-ratio submerged hydrofoil just aft of the LCG and approximately one chord-length below the hull keels. Pitch control is provided by a hydroski located at the bow of each hull while pitch damping is provided by a submerged horizontally mounted plate attached at the stern of each hull. There are no active pitch and heave controls. The free surface effect on the main foil and ski lift provides heave control while pitch control is achieved by the hydrodynamic action of the hydroskis and damping plates.

(U) The planing hull design philosophy is to provide a hull of very high length/beam ratio and very high beam loading which runs at nearly zero trim angle and, hence, can operate close to the water surface without developing large "g" loadings when encountering waves. This excellent rough water planing hull allows the use of relatively short support struts for the hydrofoil (compared with conventional hydrofoil craft). This short strut length makes either a propeller or water jet propulsion system feasible.

[redacted] The high aspect ratio submerged hydrofoil has a low induced drag and, hence, provides a large lift-drag ratio at high speed compared with normal planing hulls. In addition, since the induced drag is small, the craft has weight growth potential without the penalty of a proportionate increase in drag. It is contemplated that a cavitation-free foil can be designed for speeds up to 60 knots. In fact, cavitation-free operation has been obtained for the surface piercing hydrofoil ships Bras d'Or and Dennison at speeds of approximately 60 knots.

[redacted] A feasibility study has been made for a 90-ft. long, 135,000 lb. SKI-CAT with a maximum speed of 60 knots. Towing tank model tests were conducted on this configuration and a 1/3-scale manned model was built and operated. A sketch of the manned model is attached. Based on tank model tests, the smooth and rough water performance was evaluated and is compared below with model test results for an equivalent well-designed planing hull.

SMOOTH WATER LIFT-DRAG RATIO COMPARISON AT 135,000 LB.

Speed	Lift-Drag Ratio	
V_K	90' Ski-Cat	100' Planing Hull
20	20.0	12.5
30	16.5	9.1
40	12.2	6.6
50	8.9	5.7
60	6.3	No Model Data

ROUGH WATER IMPACT COMPARISON AT 135,000 LB.

Waves $H_{1/3}$ = 4.6'

Speed	1/10 Highest C.G. Acceleration, "g"*	
V_K	90' Ski-Cat	100' Planing Hull
20	.34g	.48g
30	.48	.69
40	.64	.85
45	.74	1.09
50	.83	No Model Data
60	1.03	No Model Data

It is clear from the above comparison that the SKI-CAT *hydrodynamic performance is* expected *to be substantially better than* a *conventional planing hull.*

Advantages and disadvantages are similar to those of any other catamaran.

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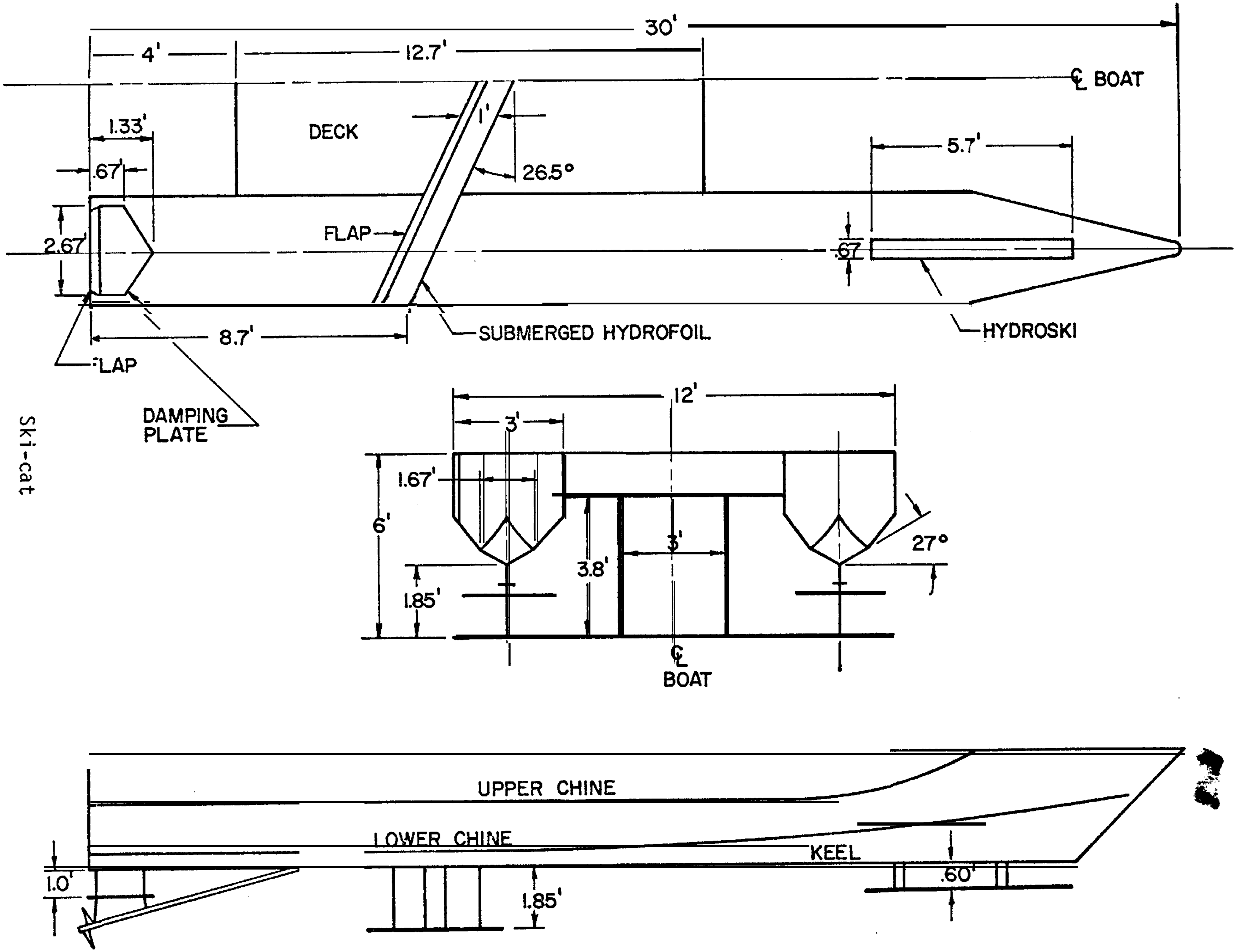
* See Sect. II.A.5.f. for discussion of impact accelerations.


30'
4'
12.7'
℄ BOAT
DECK
1'
1.33'
.67'
26.5°
5.7'
2.67'
FLAP
.67
SUBMERGED HYDROFOIL
HYDROSKI
8.7'
FLAP
DAMPING PLATE
12'
3'
1.67'
6'
3.8'
3'
27°
1.85'
℄ BOAT
UPPER CHINE
LOWER CHINE
KEEL
1.0'
1.85'
.60'

Ski-cat

III. (C) STATUS OF PERFORMANCE DATA (SUMMARY OF EXPERIMENTAL RESULTS) (U)

A. (U) SPEED-POWER (U)

1. (U) The experimental data base for planing craft smooth water performance technology is extensive. Model tests have been conducted for a number of specific designs, and systematic series test data have been reported. In addition, analytical models for planing craft performance predictions have been developed and are widely used. The confidence for predicting performance is high as a result of the number of full scale trials which have been conducted. These full scale data also provide the basis for establishing performance quality, or state-of-the-art, while avoiding the approximations and assumptions often necessary in making performance predictions.

2. (U) Following the treatise of Gabrielli and Von Karman [118] we can consider the propulsion problem from the viewpoint that all forms of resistance and losses within the propulsive mechanism must be overcome by the total power delivered by the propulsion machinery. Likewise, the gross weight of the craft is transported at a given speed for that power. In [118], a coefficient of specific resistance was used to relate weight, power, and speed for comparative purposes. Using the reciprocal of this coefficient permits measured full-scale data to become a tool for comparing total system transport efficiency (η_x), with the highest value representing the most efficient craft. Thus, $\eta_x = \Delta v/P = \eta_D/(D/L)$

Where: η_D = propulsive efficiency (including appendages) = Dv/P

= total power output divided by total power input.

D/L = drag/lift ratio of the vessel

D = total drag, including appendages.

L = A = total weight on water, lb

v = speed of vessel, ft/sec

P = total power used at speed v, ft-lb /sec

To be meaningful, the comparison of the transport efficiencies of several craft must be made at comparable speeds which have been normalized on vessel size, not at the same absolute speed. One suitable way of doing this is by use of the volume Froude Number ($F_{N\nabla}$). This is defined as

$$F_{NV} = \frac{v}{\sqrt{g\nabla^{1/3}}}$$

Where: v = speed of vessel, ft/sec

V = volume of displacement, ft^3

= Δ/ω

uJ= weight density of water, lb/ft^3

g = acceleration of gravity, ft/sec^2

3. (U) A sample giving comparative data for a range of patrol craft based on full scale trials is shown in Figure 81. The number of craft/trim conditions included makes a rather cluttered picture; however, it serves to show the wide variation of performance that has been attained. Using these and other available data, full-scale, state-of-the-art smooth water performance has been established by contouring the highest boundary for specific hull types. These state-of-the-art contours for available data are shown in Figure 82 and represent different craft throughout the speed range. (NOTE: A craft whose design mission resulted in a $F_{N\nabla}$ = 3.0 may be less efficient at $F_{N\nabla}$ = 3.5 than a craft designed for that higher volume Froude number.)

4. (U) An important feature of this comparison by hull types is the

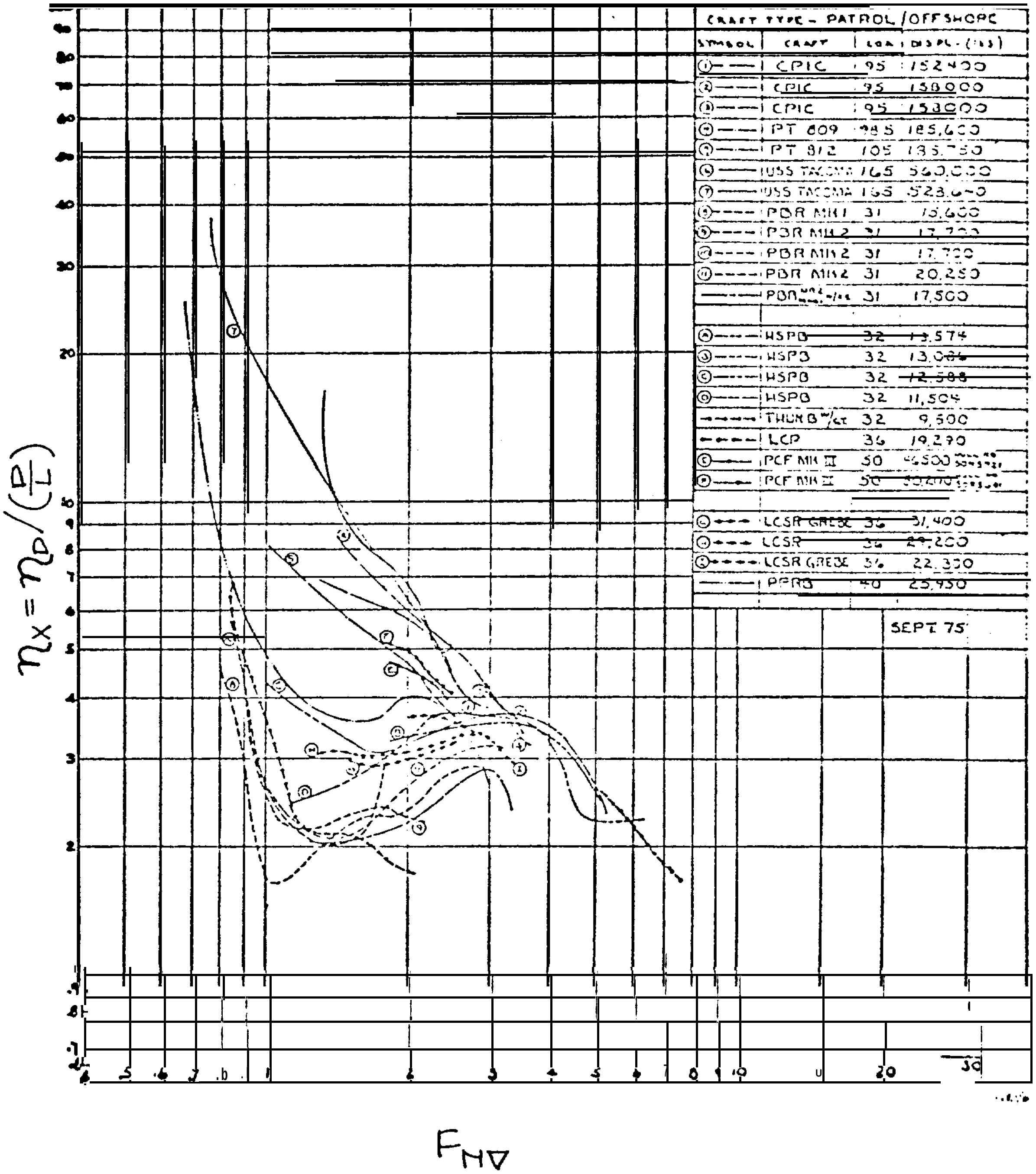


Figure 81 - Transport Efficiencies for various craft (U)

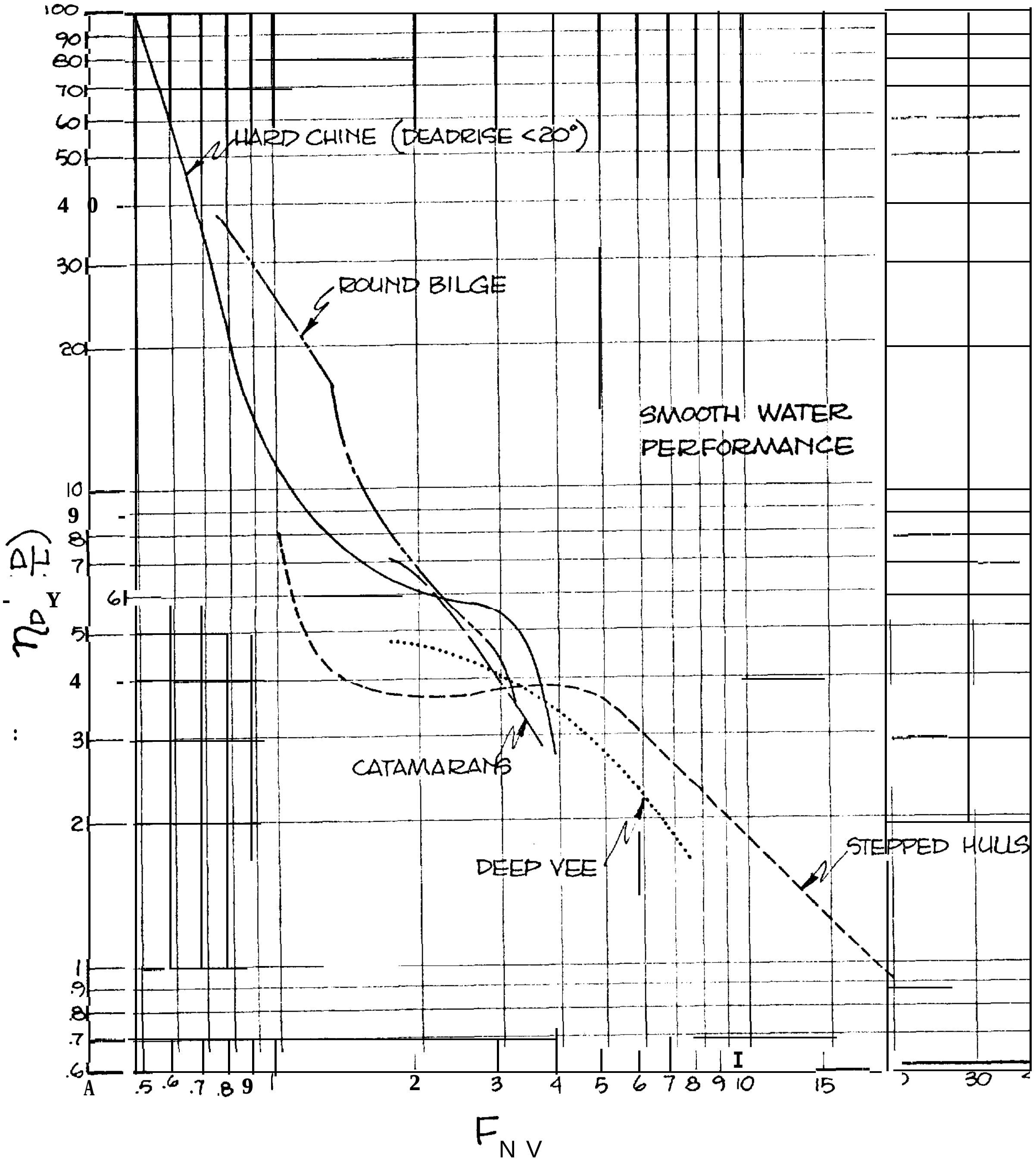


Figure 82 - Contours for State-of-the-Art Transport Efficiencies (U)

logical suggestion that for smooth water performance, hard chine craft are preferred for $F_{N\nabla} > 2.3$. Stepped hulls become most efficient when $F_{N\nabla}$ is greater than 3.7, but only in smooth water.

B. (U) RANGE-ENDURANCE (U)

1. (U) The range of a craft is part of the total mission definition and cannot be separated from the military payload required for the complete mission. In this sense, the fuel necessary for the specified endurance is considered an essential part of the useful load because the mission could not be accomplished without it.

2. (U) Range is an important trial item because it is a key mission requirement. Range trials are run in conjunction with speed-power trials to facilitate characterization. Low range could be due not only to inadequate fuel tankage, but also to other factors such as high engine fuel rate, incorrect speed-power prediction or low propulsor efficiency. It is important to be able to operate at any speed below design with constant or increasing range.

3. (U) Range curves for the 65 ft PB MK 3 are shown in Figure 83. These are typical for diesel powered craft. At planing speeds the range is relatively constant and increases significantly with reduced speed, This is also shown in the diesel curves of Figure 84 which were developed from full-scale test data [3]. Range variation with speed for gas turbines is also shown [3]. Table 13, a repeat of Table 4, is inserted for convenience, for ready comparison of a scaled-up CPIC-X.

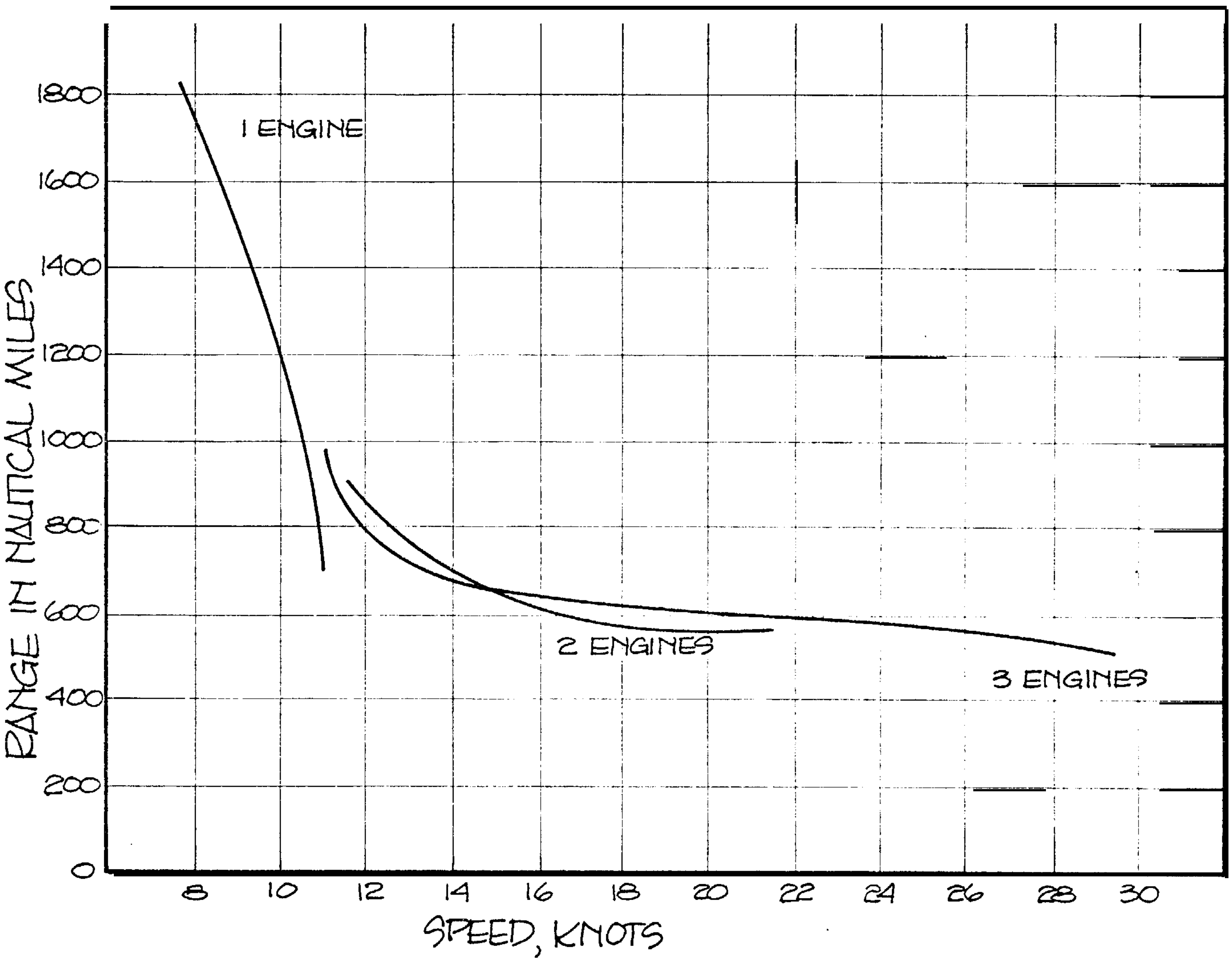


Figure 83 - 65 ft PB MK3 Range (U)

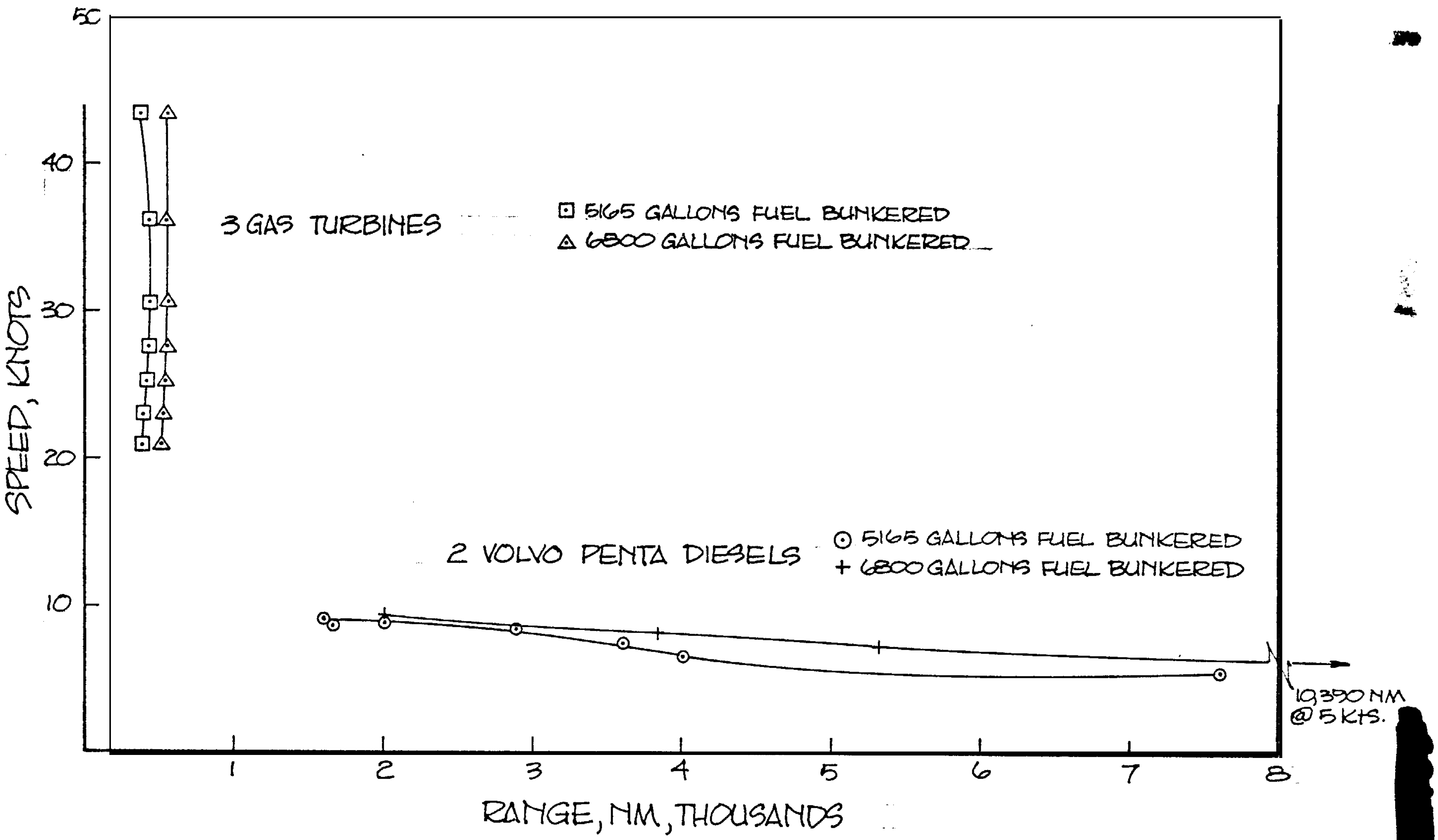


Figure 84 - CPIC-X Range [15] (U)

TABLE 13 [redacted] SPEED, ENDURANCE AND RANGE FOR 100 FT. & 200 FT PLANING SHIPS (U)

(Same as Table 4)

Intake Air Temp °F	No. and Type of Engines	Continuous Engine Rating; Standard Fuel Load											
		100 l-t.; 72 tons (Fue tons)						200 Ft.; 57 6 (Fuel, 173 tons)					
				$H_{1/3}$ = 0	$H_{1/3}$ = 4.6 ft.					$H_{1/3}$ = 0	$H_{1/3}$ = 9.2 ft.		
		TF 25A bhp (1)	En-durance Hrs.	Speed Knots F.F.(4)	Speed Knots F.F.(4)	Speed Knots (5) Av	Range NM (6)	LM 2500 bhp (1)	En-durance Hrs.	Speed Knots F.F.(4)	Speed Knots F.F.(4)	Speed Knots Av. (5)	Range NM (6)
59°	3 TURBINES		8.31	41.1	38.8	40.8	313	81750	12.88	61.7	58.3	61.0	733
85°		6000	8.71	39.7	37.6	39.4	330	75000	13.49	59.5	56.3	59.0	770
100°		5400	9.26	38.2	36.1	37.9	353	67500	14.35	57.1	54.0	56.6	821
59°	2 TURBINES	4360	12.47	30.7	28.9	30.5	352	54500	19.32	46.0	43.6	45.7	826
85°		4000	13.06	29.7	27.9	29.4	369	50000	20.24	44.5	42.1	44.3	867
100°		3600	13.89	28.4	26.6	28.2	394	45000	21.53	42.7	40.2'	42.4	923
59″	1 TURBINE	2180	24.93	17.0	16.2	i6.9	383	27250	38.64	25.3	24.0	25.3	909
85"		2000	26.12	16.4	15.7	16.3	410	25000	10.48	24.6	23.3	24.6	963
100°		1800	27.78	15.8	15.0	15.7	438	22500	13.06	23.6	22.5	23.6	1027
(5)	DIESELS	300(2)	292	8.3	8.0	8.5	2492	3225(3)	300	il.7	11.3	12.0	3643

		Continuous Engine Rating; With Reserve Fuel											
		100 Ft.; 77 tons (Fuel, 21.2 ton-s)						200 Ft.; 681 tons (Fuel, 278 tons).					
59″	3 TURBINES	6540	8.31	40.1	37.8	40.2	421	81750	12.88	60.2	52.9	58.5	1139
59°	2 TURBINES	4360	12.47	29.6	28.3	30.0	472	54500	19.32	43.0	40.4	44.4	1297
59°	DIESEL	300	292	8.2	7.9	8.4	3360	3225	300	11.5	11.2	11.9	5530

TABLE 13 - Continued

NOTES:

(1) bhp - rated brake horsepower of turbine at stated temperature and standard conditions. See Figure 24 for map of TF25A performance.

(2) The horsepower shown for the 100 ft boat is well below the continuous power of the Volvo diesel engines. On trials CPIC-X has made 9 knots with the engines developing 538 hp. A lower speed (8.3 knots) is used here because of the better fuel economy. See pp. 36, 77, 78 and ' for further Volvo Diesel information.'

(3) Continuous rating of the MTU 12V331TC at 100" F inlet air temp.

(4) Speed with full fuel, at beginning of run.

(5) Average speed over entire distance run.

(6) Range calculated with the Breguet equation; fuel load of 100 ft. hull is 16 tn (22 % A); fuel load of 200 ft hull is 173 tn (30% A).

Breguet Range (Nautical Miles) $= \frac{\bar{V}_K \bar{\Delta}}{C P_e} \ln \frac{A}{A - W_F}$

where: $\bar{V}_K$ = average speed (knots) through range run

$\bar{\Delta}$ = average weight of craft (pounds) throughout range run

C = net specific fuel rate (lf/hp-hr) for total powering system

P_e = actual power used (not necessarily total installed power)

A = initial total weight of vehicle

W_F = weight of fuel used (pounds) for range run

C. (U) MANEUVERABILITY (U)

1.(U)High speed planing craft are an.important part of any Naval force and are on call to perform missions in confined waterways as well as in the open ocean. It is important that they have good maneuvering and control characteristics. However, most hydrodynamic research effort on planing craft has been concentrated on developing hulls for low drag and good seakeeping with little effort on enhancement of maneuvering performance. Most experimental effort has been related to control surface characteristics. The exception is the extensive model scale maneuverability experiments conducted by Sugai [119] on a radio-controlled, twin-screw, twin-rudder, high speed craft which correlated well with the full scale craft. These tests related rudder and skeg areas to turning diameter.

2.(U)Full scale trial data provide most of the design guidance when a tactical requirement is stated for new craft characteristics. A summary of full-scale data for full rudder angle is shown in dimensionless format in Figure 85.

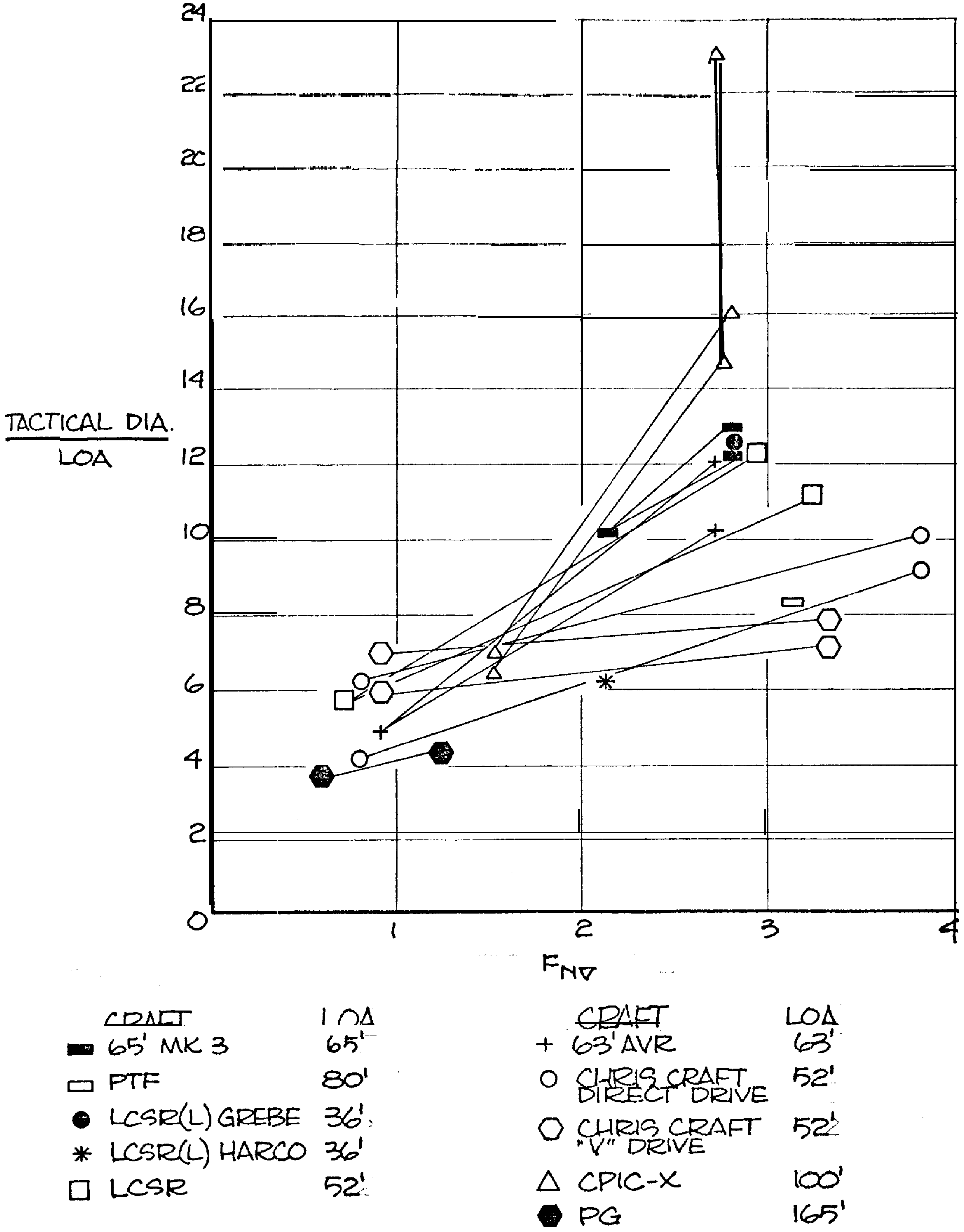


Figure 85 - Turning Characteristics (Full Scale, Full Rudder) (U)

D. (U) STABILITY (U)

1.(U)This area has received very little research effort to date as part of planing hull development. At present there is no published procedure for estimating the hydrodynamic derivatives required for a reliable prediction of coursekeeping stability and longitudinal stability. Fortunately, instability has not been a serious problem. If it does occur in the longitudinal plane (porpoising), it can be corrected by means of trim flaps or forward movement of the center of gravity, This phenomenon was observed during trials of the Harbor Security Patrol Boat, but was easily controlled with trim tabs. If directional instability occurs, it can be corrected by appropriate location Of skeg area. Directional (coursekeeping) instability has been observed on trials of low deadrise, water jet propelled craft such as the PBR.

2.(U)It is essential that more research be carried out in order to quantify predictive techniques in this area.

E. (U) RIDE QUALITY (U)

1. (U) Seaworthiness trials have been conducted on twelve full-scale planing craft since W.W.II. (Table 14). Quantitative data in the technical areas of pitch and rolling motion, rigid body acceleration at various on-board locations, speed performance, structural loading, and sea state have been recorded, analyzed, and reported by various testing activities, primarily in connection with obtaining structural design data (see Table 8, Section II.A.5.e, p. 118). The most recent and thorough of these is the CPIC-X T&E report [3]. A collection of onboard positive peak acceleration measurements at the LCG for several comparable hard-chine, vee-bottom planing craft are presented graphically in a dimensionless format in Figure 86. Significant wave height and chine beam were used to reduce these data. Model predictive techniques are available for vertical accelerations. Figures 87 and 88 for CPIC-X show that model test results are slightly conservative compared to the full scale accelerations measured in random waves.

2. (U) Analysis of these full scale data agree well with trends and magnitudes of model data and most importantly show that planing craft acceleration levels can be very moderate if hull proportions are properly selected. Reference [38] presents a systematic procedure for doing this. It notes that, in addition to the overall proportions, the details of hull form (the section shape in particular) are important in reducing impact accelerations. In addition to the demonstrated ride quality, important development work has been made in shock-mitigating seats for crew members, by means of which vertical impact accelerations are reduced by 50% or more for 90% of the impacts encountered.

TABLE 14 - CRAFT WITH INSTRUMENTED FULL SCALE TRIALS (U)

UNCLASSIFIED

THE FOLLOWING LIST GIVES CRAFT FOR WHICH FULL SCALE TRIALS HAVE BEEN CONDUCTED WITH INSTRUMENTATION TO MEASURE DESIRED INFORMATION.

LENGTH OVERALL (FT)	CRAFT	ENGINE TYPE	PROPULSOR TYPE	WEIGHT (LB)	SCALE WEIGHED	TYPE TRIALS				
						STANDARDIZATION	ENDURANCE	SEA KEEPING	STRUCTURAL	MANEUVERING
24	STEPPED HULL	DIESEL	OUTDRIVE			X				
25	MRBX	"	WATER JET			X	X	X		X
31	PBR MK·I	"	WATER JETS	15,600		X	X			
31	PBR MK·II	"	"	17,700		X	X			
31	PBR MK·II MOD. I	"	"	17,500		X	X			
32	HSPB	GAS	PROPELLERS	11,504	X	X	X	X		X
32	DYNAPLANE	"	"			X		X		
36	LCPL	DIESEL	"	19,290	X	X	X			
36	LCVP (T)	"	"			X	X	X		
36	MINI-ATC	"	WATER JETS		X	X	X	X		X
36	MSSC	GAS	OUTDRIVES			X	X			
36	GREBE LCSR (L)	GAS TURBINE	CRP	31,400	X	X	X	X		X
36	HARCO LCSR(L)	" "	"	29,200		X	X	X		X
40	PPRB	DIESEL	PROPELLERS	25,950		X	X			
50	PCF MK I	"	"			X	X			
50	PCF MK III	"	"	50,200	X	X	X			
50	ATC / CCB	GAS TURBINE	RIGHT ANGLE DRIVES			X	X		X	X
50	ASPB MK II	" "	WATER JETS			X	X			X
51	AVR (EXPERIMENTAL)	GAS	PROPELLERS			X	X	X		X
52	LCSR	GAS TURBINE	"		X	X	X	X		X
52	LCSR	DIESEL	"			X	X			
56	LCM-6 ATC	"	"			X	X			
63	AVR MK III	GAS	"			X		X		X
65	PB MK I	DIESEL	"			X	X			
65	PB MK I MOD. I	"	"			X	X			
65	PB MK III	"	"		X	X	X	X		X
74	LCM-8	"	"		X	X	X			
74	USAT-1	"	STEERING NOZZLES			X	X			
80	PTF (NASTY)	"	PROPELLERS		X	X	X			
90	PT 810	GAS	"			X				
94	PT 811	"	"			X				
95	PTF (OSPREY)	DIESEL	"		X	X	X		X	
99	PT 809	GAS	"	185,600		X				
100	CPIC-X	GAS TURBINE	"	158,000		X	X	X	X	X
105	PT 812	GAS	"	185,750		X				
165	PG 84/92	CODOG	"	560,000		X	X	X		X

11-6-75

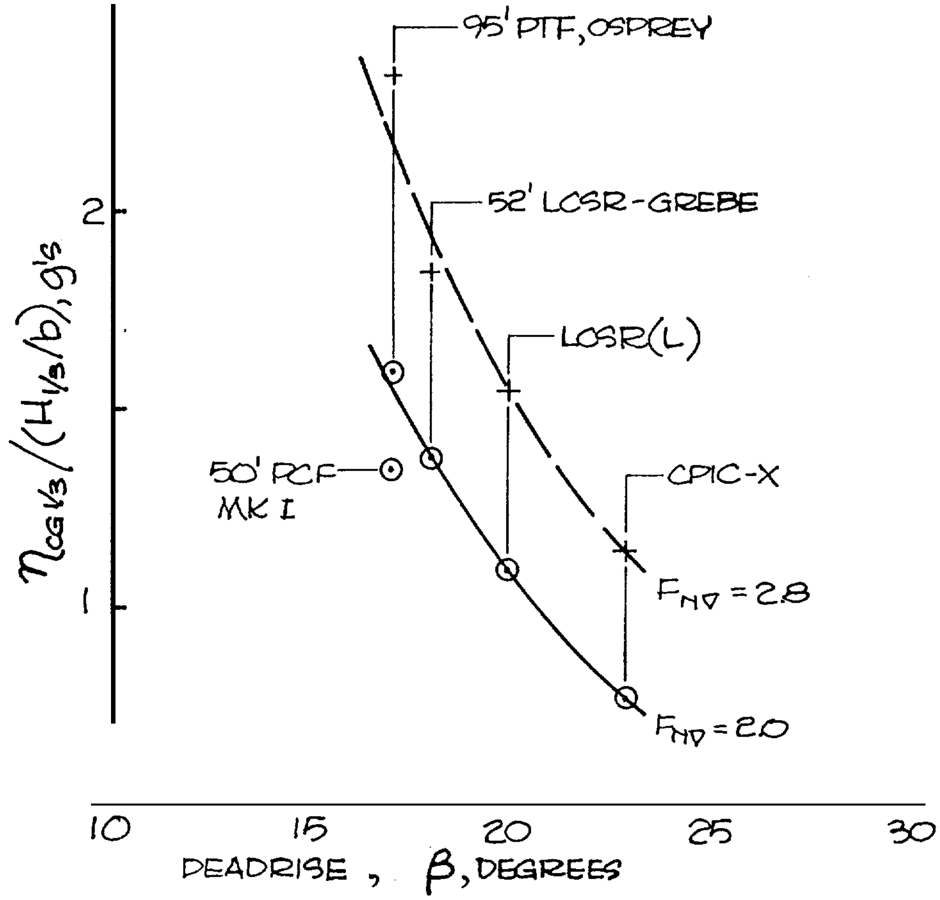
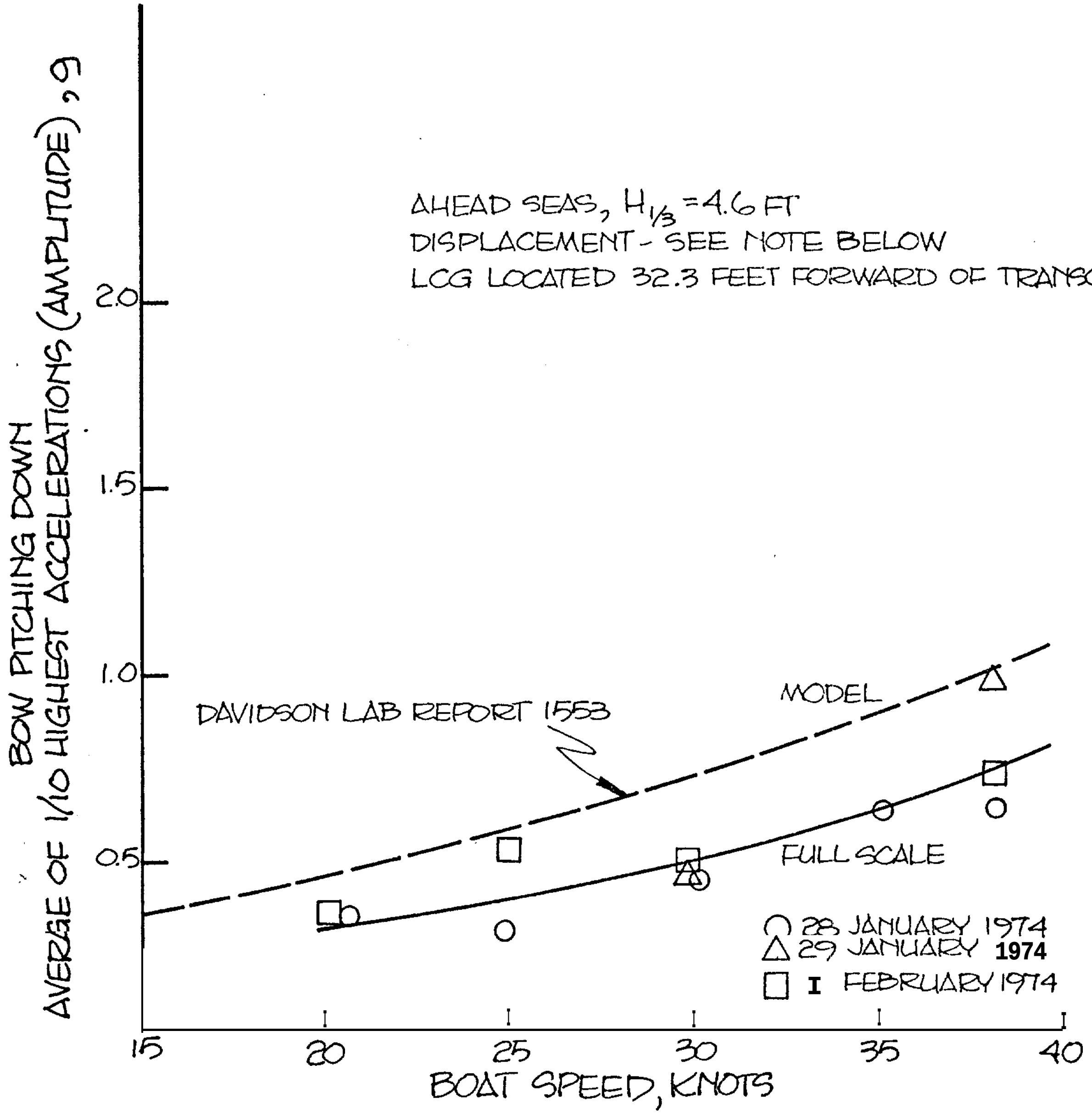


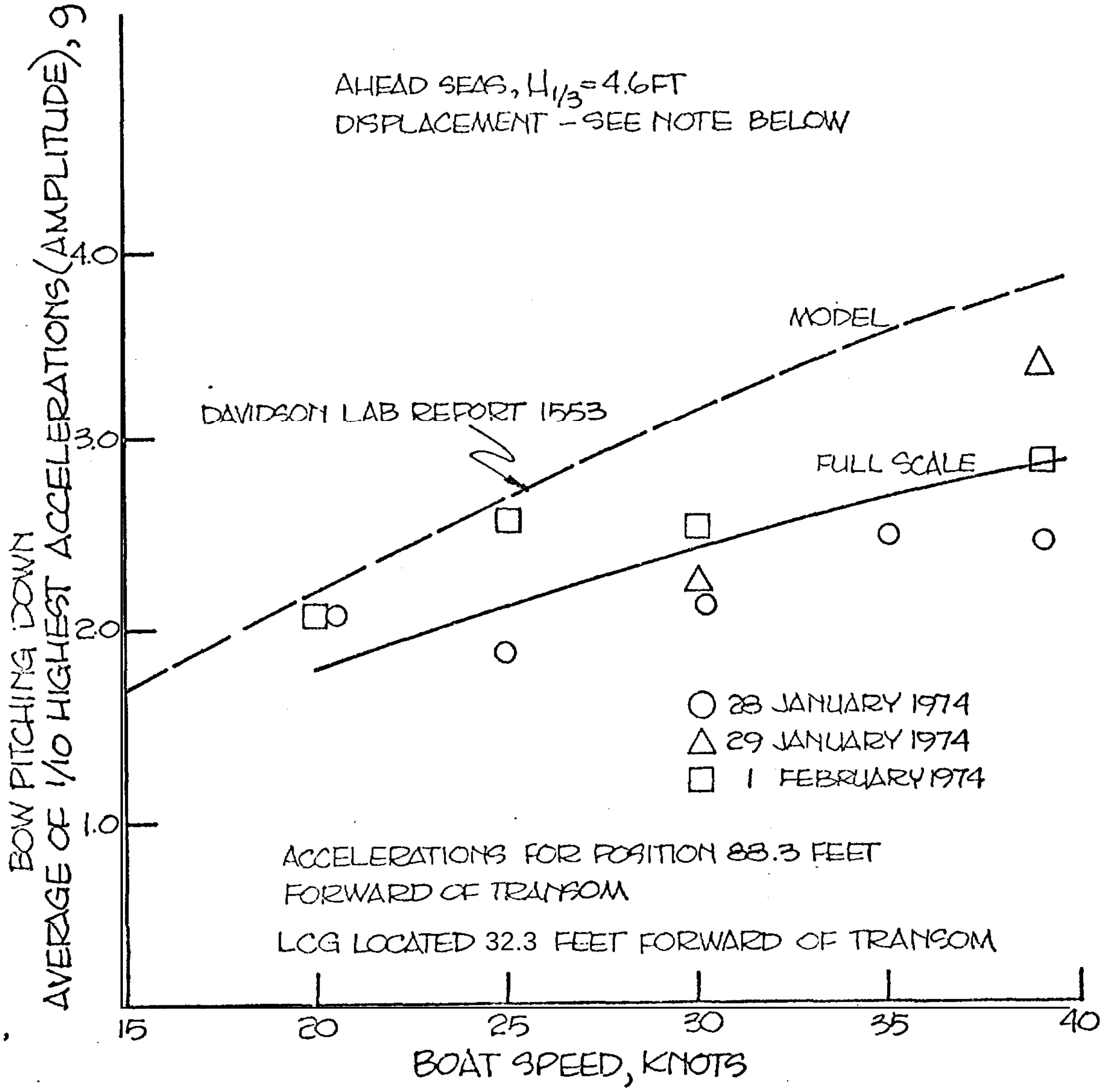
Figure 86 - Vertical C.G. Accelerations vs. Deadrise for Several Full Scale Experimental Craft (U)



NOTE:

The model was tested at a displacement corresponding to 150,000 lb full scale. The full scale trials were run at an average displacement of 155,459 lb. It varied with fuel burn-off.

Figure 87 - CPIC-X CG Accelerations (U)



NOTE:

The model was tested at a displacement corresponding to 150,000 lb full scale. The full scale trials were run at an average displacement of 155,450 lb. It varied with fuel burn-off.

Figure 88 - CPIC-X Bow **Acceleration** (U)

3. **(U) The following table shows the accelerations (g's) recorded onboard the CPIC-X when operating at the stated speeds in sea states 3 and 4 [3].**

Sea State	V(KTS)	**Frame 4**	**Frame 32**	**Transom**
				.7
SS3 ($H_{1/3}$= **4.6 ft**)	38	2.5	.8	.7
SS4 ($H_{1/3}$= **6.9 ft**)	35	3.0	**1.1**	.7
		2.3	.7	.6
	30			

Values are in g's and are the average of the 1/10 highest accelerations.

(U) **A comparison of the** CPIC's **accelerations with those measured on a PTF when both are operating at 34-35 knots in sea** of $H_{1/3}$= **6.9 has shown that the** CPIC's **accelerations are less than half as severe as the OSPREY Class PTF. Evaluations from experienced small craft operators are consistent in praising the** CPIC **as superior in seakindliness to all other Navy planing craft, demonstrating that high performance and seakindliness can both be designed into the same craft.**

4. **(U) The ride qualities achieved by proper selection of hull proportions can be enhanced by the use of shock mitigating seats (Section** II.B.6.c, **p.** 212), **thus creating a non-fatiguing environment for the crew.**

Section IV. (C) COMBAT SYSTEM AND VEHICLE COMPATIBILITY (U)

(U) Vehicle performance features and characteristics influence the integration of the combat system with the vehicle and impact the performance capabilities of the sensor and weapon systems. Characteristics such as military payload carrying capability, available space/volume, access for maintenance, flexibility for system changes, limited manpower/skills for operation and on-board maintenance and interfaces between systems and vehicle are representative factors in the selection of the combat systems and the internal/external arrangement in the vehicle. Performance features of the vehicle such as its speed, mobility, maneuverability, motion, weight, balance, and trim affect the performance of the installed systems.

A. PAYLOAD/VEHICLE COMPATIBILITY FEATURES (U)

1.(U)Efficient use must be made of the payload carrying capability in terms of allowable weight, space and volumes so as to realize the maximum offensive/defensive capability of the vehicle.

Z.(U) In recent years, there has been a growing interest by the majority of the ocean-going nations of the world in utilizing high performance combatant craft of relatively smaller size than the olcier ships they are replacing. This interest in small combatant craft is also widely prevalent among the younger Navies of the newly independent nations of the world. These Navies view such small, fast combatant craft as viable alternatives to the more expensive, more complex, warships of traditional size. Recent trends towards these small naval vessels with high striking power have benefited from the extensive

[redacted]

development of lightweight weapons and control systems; and which in turn has provided the impetus to refine such developments even further.

3. (U) This section describes the performance characteristics for weapons and sensors compatible with planing hulls. These systems represent the state-of-the-art for selected individual vehicles (in Sect. IV.B.) and include:

- Missile Systems
  - Surface-to-surface
  - Surface-to-air
- Gun Systems
- Fire Control Systems
- Sensor Application
  - Surveillance & Detection
  - Remotely Piloted Vehicles
  - Deception

a. [redacted] Missile Systems

1) Surface-to-Surface

a) The Soviets have pioneered the increases in high performance small combatant craft firepower, and beginning in the early 1960's had the Komar-type missile patrol craft in service armed with SS-N-2 STYX surfact-to-surface missiles (SSM's). The spectacular sinking of the Israeli destroyer EILAT off Port Said in 1967 provided the impetus for an accelerated effort in development of similar types of weapons in the Free World. Since that time, development of target seeking SSM's with considerable range, has provided a new stimulus to the design and construction of high performance (small) craft. This has been further enhanced by the fact that new technologies in the areas of materials, micro-circuits and

[redacted]

electronics have reduced the weight of such missiles (including their launchers) and their associated fire control and target-search equipment, making it possible to install highly effective, deadly systems with little (if any) adverse effects on <u>total</u> <u>system</u> performance [120].

b) The Free World's first generation SSM's, such as the SS-11 and SS-12, were introduced during the 1960's and used either wire guidance, beam guidance or target illumination warhead seekers. The majority of these have been replaced by missiles with larger warheads using either infra-red or television seekers for terminal guidance. Examples of these newer type missiles are the French-developed MM-38 EXOCET, France-Italian OTOMAT, and Israeli GABRIEL (see Table 15). The U.S.-developed HARPOON has the same autonomous characteristics as its current European counterparts, but has a slightly larger warhead and much greater range [121].

c) The majority of these missiles are launched from containers rigidly mounted on the ship's deck with fixed angles of azimuth and elevation. The GABRIEL uses a multiple trainable mount launcher. During the typical mode of operation, the majority of these SSM's obtain the target range and bearing from the ship's main fire control system or other sensors. SSM's usually fly at a low level cruise altitude over the water surface for the major portion of their flight and hence, are much more difficult to detect, deviate, or destroy. Most SSM warheads are designed to penetrate the target ship's superstructure and detonate below decks for maximum effectiveness [120, 121].

2) Surface-to-Air

a) The primary airborne threats to high performance combatant craft as now envisioned will consist of manned fixed-wing aircraft, helicopters, SSM's, and tactical air-to-surface missiles (ASM's).

TABLE 15 - TECHNICAL DATA ON SHIP-TO-SHIP MISSILES (U)

Designation	Manufacturer	Type of propulsion	R (NM)	Guidance System	Launch weight/ warhead weight(kg)	L (m)	D (m)	b (m)	V (m/s)
Penguin	Kongsberg	S	15	Inertial guidance and IR seeker head.	330/120	3.0	0.28	1.4	238
Gabriel 1	Israel Aircraft Ind.	S	11	Command guidance and semi-active radar seeker head with radio altimeter.	420/150	3.35	0.33	1.39	195
Gabriel 2	Israel Aircraft Ind.	S	22	Command guidance TV seeker head and radio altimeter.	NA/150	NA	NA	NA	NA
Exocet MM38	SNIAS	S	22	Inertial guidance, active radar seeker head and radio altimeter.	735/165	5.2	0.346	1.0	300
Sea Killer Mk3	Sistel	SB+S	25	as Exocet.	548/150	5.3	0.32	1.9	280
Otomat	OTO Melara	SB+T	44	as Exocet.	730/210	4.387	0.46	1.248	280
Teseo	OTO Melara	SB+T	108	as Exocet.	NA		NA	NA	NA
Otomat 2	Matra								
Harpoon RGM 84A-1	McDonnell Douglas	SB+T	55	as Exocet.	880/230	4.57	0.343	0.914	290
Smartroc	U.S. Navy Development	SB+X	12	Laser illumination LGB Seeker	603/227	4.98	NA	NA	NA
For Comparison:									
SS-N-2 Styx	USSR	SB+L	23	Inertial guidance and active radar seeker head	2500/500	6.7	0.8	2.5	300
SS-N-11	USSR	SB+S	29	as SS-N-2	NA	6.7	NA	NA	300

Key L-overall length; D-body diameter; b-span; v-cruise speed; R-range; S-solid fuel rocket propulsions;SB-solid fuel first stage; L-liquid rocket propulsion; T-turbojet engine; X-free fall; NA-not available

b) Since small to medium caliber rapid fire gun systems are considered marginal at best as an own-ship defense against this type of threat, the use of stand-off, point defense type surface-to-air missiles (SAM's) must be considered. There are many SAM's of this type currently in existence which are in use on, or could be adaptable to, this type of craft. Assuming that: (1) the system choice(s) would provide a significant increase in air defense effectiveness over gun systems alone; (2) they are modular for ease of installation; and (3) they have at least some potential of supplementing the gun system in the surface warfare role; then there are a number of systems such as STANDARD, SPARROW, REDEYE, CHAPARRAL, ROLAND, etc., which could be considered for application [122].

b. [redacted] Gun Systems

1) For fast combatant craft, guns and mounts from 20mm to 3-inch appear to be suitable for self-defense, namely air defense at medium and close ranges, as well as for combat against seaborne and landbased targets. This multi-purpose characteristic, their high degree of automation, increased muzzle velocity, rate of fire and the development of proximity fuses down to 40mm caliber are all further factors which improve the firepower of high performance combatant craft. Space and weight previously necessary for the gun crew can now, because of automation, be made available for other purposes, such as for greater ammunition stowage. For example, the World War II vintage 40mm Bofors mount required a crew of 4 to 6, the MK-75, 76mm mount installed on PHM-1 is remotely controlled by a single operator.

2) Characteristics of representative gun systems are shown in Table 16,

[redacted]

TABLE 16-CHARACTERISTICS OF REPRESENTATIVE GUN SYSTEMS

	Wt. Lbs. (kg)	Firing Rate Rds/Min	Range Yds (m)	Height Inches (cm)	Width Inches (cm)	Length Overall Inches (cm)	Stand Mtg. Dia. Inches (cm)	Working Circle Dia. Inches (cm)	AMMO	OPERATION	STATUS	NOTES
a. MK 75 Gun Mount U.S. Version Of Oto Melara 76mm/62 Mount	19,000 (0600) w/80 rounds	a s	18000 (16500)	86 (218)	115 292	277 (704)	84.6 (215)	210 (533)	High Explosive (H.E.) Point detonating, fused (PD) Variable time, fused (VT) Practice (TP) Ready service = 112 rds. (56/gun) 224 rds - quick reload	(1) Man-Remote or (1) Man-Remote (1) Ammo Loader	PIM-1 (installed) PHM (planned) PF (planned	Service app'd by USN Not service app'd by USN In production in Free World
b. Oerlikon Twin 35mm Gun Mount GDM-A	14,550 (5200) (with ammo)	1100	12000 (11000)	63 (160)		241 (612)	85 (216)	225 (572)		(2) Man-local on mount control or (1) Man Remote (2) Men-Ammo Reload		Not service app'd by USN In production in Free World
c. Emerlec 30 or EX-74 Gun Mount	9,000 (4100)	1200 Both Guns	5000 (4600)	60 (153) above mtg surface 69 (176) penetration	NA	-	64 (163)	187 (475) above deck 70 (178) below	Ready Service = 1970 rds	(1) Man Remote local manual	CPIC installed	Provisional Service Use; not Service-Approved. Does not use approved (GAU-8) type 30mm ammo. Mauser/G.E. 30mm Model 0 gun and Ford-Philco = USA Bush-aster 25mm cannon can be used on Emerlec mount
d. MK-15 Mod 0 (PHALANX) Close-In-Weapon System (CIWS)	10.000 (4500) 12.000 (5440) w/gun & ammo	3000 ourrt Selector 100 or 450 rds	2000 (1800)	185 (470)			146 (371)	156 (396)	Ready Service = 1000 rds.	(2) Man Remote	In development USN/ General Dynamics. Point defense anti-air, with two MK 90 pulse doppler radars for search & /track	Not service app'd by USN
e. 20MM VADS (EX-80) Navalized	5,500 (2500)	1000/3000 Burst Selections 10. 30, 60. 100 or 4010 rds.	2000 (1800)	51 (130) above mtg surface 53 (135) penetra.	NA	-	49 (124)	154 (391)	Ready Service = 1100 rds. M-50 series ammo electricallyprimed	i(1) an	In service use (USN)	Version of USA self-propelled Vulcan Air Defense System
f. MK10 Gun Mount (EX-81) with 20mm M197 Gun	1,200 (544) w/gun & ammo	600/1200	(1800)	58 (147)	NA	-	39.5 (75)	98 (249)	Ready service = 300 rds. M-50 series	(1) Man	One prototype built for USN	Not service app'd by USN Individual gun & mount in service
g. GAU-8/A (EX-33) Naval Gun "aunt	8,400 w/gun & ammo	2100/4200 Burst Selections 10, 30. 60, 100	2000 (4000)	70 (178) above mtg surface I a3 I penetra.			100 (254)	196 (498)	Ready service = 1369 rds (approx.) GAU-8 (TP, HEI, API)	(1) Man Remote	In development General Electric Co.	In-service (USAF) Gun and Ammunition. Developmental Mount
h. PintlMounts (Machine Guns) MK 26 Mod 9. 11 so Cal MK 46 Mod 0, 1. 2 .50 Cal & MK 19. 40MM GMG MK 56 Mod 0. 1 .50 Cal MK 58 Mod 1. 3. a M60-7.62mm MK 78 Mod 04 1 MK 19Modmm grenade machine gun Twin M60 - 7.62 mm												

[redacted]

[redacted]

c. [redacted] Fire Control Systems

1) Numerous efficient surveillance and fire control systems (FCS) are available which are particularly well suited for high performance combatant craft. A factor common to most of these systems is their suitability for both SSM's or SAM's as well as for one or more dual purpose gun mounts. Most FCS feature a combined radar antenna system for surveillance, target tracking and fire control. Most of these radars operate in X-band, which provides the best compromise between the requirements of accuracy and weather. Most modern trackers use the monopulse system, in which the output is compared to give elevation and training error signals, which are then fed to servos to position the antenna. To reduce the effects of sea clutter and jamming, two major techniques are currently in use:

a) MTI (Moving Target Indication) - This signal processing method uses a Doppler technique to reduce signals from low speed objects such as sea returns. This method has the advantage of improving the sea clutter visibility, important in the detection/acquisition, and tracking of low level targets [123].

b) Frequency Agility - This method varies transmitter frequency from pulse to pulse. This system has the advantage against air targets of better accuracy due to a reduction in glint and a better Electronics Counter-Counter-Measure (ECCM) capability.

2) Many fire control systems also incorporate TV or other types of optical tracking equipment. These devices can be used for target identification, damage assessment, and as an alternative control mode for use conditions of radar silence or malfunction of the radar.

[redacted]

3) Another important part of any fire control system is a predictor, to provide aim-off for remotely controlled gun mounts. The latest digital predictors offer high accuracy and speed with great operational simplicity in virtually all weather conditions.

4) Two better known FCS which are available from U.S. manufacturers are the MK 92/94 and MK 93 systems:

a) [redacted] MK 92/94 Fire Control System [123, 124]

1) The MK 92/94 Fire Control System is an Americanized version (licensed to Sperry) of the N. V. Hollandse Signalapparaten (WM 28) M20 series of fire control systems currently installed on PHM and planned for installation on PF ships. This FCS is designed to simultaneously engage two surface, two air and one indirect shore target. The surveillance radar is capable of two-target track-while-scan (TWS) operation against surface targets having speeds up to 100 knots over ranges from 600 yards (648.4 m) to 31,500 yards (28.8 km). The tracking radar is designed to track air targets with velocities of approximately 1600 knots at ranges from 300 yards (274 m) to 49000 yards (44.8 km). Target engagement can employ any combination of two gun mounts, surface-to-air missiles and surface-to-surface missiles, as appropriate. The MK 92/94 FCS consists of approximately 20 major units. These units weigh; approximately 8257 pounds (3753 kg) and occupy approximately 100 sq ft (9.29 sq m) of deck space.

2) Three operators are required for complete system manning during general quarters. One operator is required for reduced capability operation during condition watches.

b) MK 93 Fire Control System

The MK.93 Fire Control System was developed by Honeywell Marine Systems Division under U.S. Navy contract for the CPIC-X craft. The heart of the MK 93 is the system control console which provides the operator with:

- Digital fire control solution
- Multitarget Track-While-Scan (TWS)
- Multitarget motion analysis and display
- Multimode operation
- Navigation operation
- Gun orders for two gun mounts

The MK 93 also includes up to two optical directors (developed by Kollmorgen Corp.) that interface with the system console to provide manual surface/air target tracking. The system is capable of tracking two targets using radar TWS data and two targets using optical director data. A TPS-66 (modified KARR Model LN66-HP) radar set is used for surface search-track and surveillance. A number of air tracking radars may be incorporated into the basic system console for air targets. The maximum tracking range for the MK 93 system is approximately 10 nautical miles (18.53 km). Maximum surveillance range is out to the radar horizon, approximately 36NM (66.7 km) for CPIC-X. The system console weight for the MK 93 (including radar components) is approximately 1200 lb (544.8 kg). Each optical director, in addition, weighs approximately 775 lb (351.9 kg). The system is capable of tracking surface targets having speeds up to 100 knots (185 km/h), air targets up to 350 knots (648 km/h) using the optical directors, and medium to high speed aircraft depending on the type of air track radar utilized. A single operator is required to operate the system console. Each optical director requires one operator who can also remotely operate one or two gun mounts [124].

d. [redacted] Sensor Application

The ever-increasing sophistication of surveillance, detection, deception and jammers , and the difficulties of operating in an Electronic Warfare (EW) environment, have created considerable interest in passive or optical sensors either to replace or to operate with conventional radar systems. EW systems which are light enough to be fitted on the smallest craft, and which provide analysis and display of all radars in operation out to the radar horizon, are already very well established.

1) Surveillance and detection

The optical equivalent of the tracking radar is the television tracking system which may be used in its own right; or to provide an alternative or additional control mode for use in Electronic Support Measures (ESM) or in conditions of radar silence. It is currently in use for shorter range engagements, and laser range finders may be integrated to provide range data for prediction of aim-off for gun systems or laser-guided ordnance. The television systems may be laid on remotely from a surveillance radar in the same way as a tracking radar. Considerable development work is on hand in electro-optical systems and indeed, this is understandable when one considers the strike potential of a fast combatant craft which is able to operate in radar silence and is itself only a small target[125, 126].

2) Remotely piloted vehicles

Remotely piloted vehicles (RPV's) can provide fast patrol combatant craft with a means of extending the sensor and weapon delivery aspects of these vehicles. Ship launched RPV systems carrying TV and Forward Looking Infra Red (FLIR) equipment could provide a capability to search out enemy shipping, warships, and shore positions without giving away the position of the launch vehicle. RPV's could also carry weapons and sensors for ASW and air-to-surface attacks that would allow destruction of enemy forces with minimal risks to the launch craft. As an example, a PHM having a HARPOON capability can engage a surface warship at approximately20 NM (48 km) due to horizon limitations. The PHM must be within the target's radar horizon since the surface search radar is on the target's highest mast. By using an RPV as a target spotter, the full range of the PHM's missile? endurance (approximately 65 NM , = 120 km) can be used while the PHM would not be visible to the target's radar. Ordnance could be delivered against shore targets in a similar fashion. Targets could be designated by the RPV for laser guidance ordnance such as laser-guided bombs, SMARTROC and other SSM's.

3) Deception

Deception covers various types of countermeasure devices which can be deployed both on board and off-board, and which usually fall into the following categories:

- Active microwave devices (beacon decoys, hammers, gate stealers, etc.)
- Passive microwave devices (chaff and absorbent materials)
- Electra-Optical Screens (snake)
- Active RF signature generators
- IR decoys (flame)
- IR radiation suppression devices (heat shields)
- RF signature generators (active)
- Electra-Optical devices (active, laser gate stealers)

e. (U) <u>Anti-Submarine Systems</u>

For anti-submarine defense, the use of "dunking" or towed sonar systems provide a relatively effective invulnerable means of extending ASW search coverage from high performance combatants. Weapons such as ASROC can be used to deliver ASW weapons or other payloads out to considerable

[redacted] [redacted]

ranges. Target data may be derived from own-ship sonars, or may be received by data link from a consort ship, helicopter or possibly escort submarines. For cases where a submarine is detected at relatively short ranges, close range counter-attack weapons such as an ASW mortar or' rocket launcher, or ship launched ASW torpedoes, are also available to high performance combatant craft.

f. (U) Installation and Arrangement Considerations

1) Missiles, guns, communications, ECM, Electra-Optical, etc., (above-deck components). Some of the installation aspects are:

a) Height of radar above the water, the effect on its range and accuracy.

b) Clearance (physical and RF) with ships structure and other radars, communication, and ECM antennas.

c) Rigidity and stiffness of the mounts for tracking accuracy.

d) Restraints on the use of weapons due to mutual interference.

e) Weight distribution topside (radars, antenna and other above-deck equipment, ice) and effect on stability.

f) Structural loads - "g" loads on components - roll acceleration, pitch, yaw, heave, etc.

g) Weight penalty in structure to take out above-deck loads.

h) Electrical load on ship service generator.

i) Reliability performance record of similar vehicle installations.

j) Access for on-board maintenance.

2) Missiles (on-deck components). Installation aspects are:

a) Missile launcher location - clearance with ship structure, other equipment/weapons.

b) Restriction on vehicle during launch, i.e., attitude, speed, motion, roll, turns, and correction for vehicle motion.

[redacted] [redacted]

[redacted]

c) Trainable versus fixed azimuth/elevation.

d) Weight distribution - effect on trim and balance.

e) Booster blast effects.

f) Safety: hang-fires - provision for jettison, cool-down spray, etc.

g) Electrical, air, hydraulic - loads on ship services.

h) Selection - sequential firing - single shot - salvos.

i) Structural load on vehicle - launcher, blast, etc.

j) Test and check out.

k) Life of missile round - recycling to depot, replacement, etc.

1) Warm-up time; pre-launch check.

3) Gun systems (on deck components). Installation aspects are:

a) Location of mount, firing envelope, clearance with structure and other weapons.

b) Ship motion versus hit probability, restrictions on vehicle.

c) Weight distribution, and vehicle trim and balance.

d) Blast smoke - personnel comfort - ships structure.

e) Access for reload.

f) Structural loads into ship.

g) Safety - magazine, fire fighting hang-fire, cook-offs, etc.

h) Electrical loads on ship's generator.

4) Towed Arrays (on-deck components). Installation aspects:

a) Location - cable, over-the-stern - fair leading to winch, etc.

b) Launching and retrieving - hoisting and handling, stowing.

c) Ship stability - drag of array - dynamics of tow cable.

d) Weight distribution - trim balance.

[redacted]

5) Other on deck components, e.g. launchers, chaff rockets, mortars, IR decoys. Installation aspects:*

   a) Location

   b) Blast

   c) Interference with other weapons/sensors.

g. (U) Operation and Deployment Aspects

1) Speed vs weapon system capability

2) Ship motion vs weapon system capability

3) Replenishment concept

4) Speed/ Motion/Sea state vs operator capability

5) Integration with other task force elements

B. LIST OF COMPATIBLE SENSORS AND WEAPONS (U)

1.(U) The weapons/sensors selected in the following three tabulations are for particular mission requirements for the Experimental Coastal Patrol and Interdiction Craft (CPIC-X), Open Ocean Planing Hull, and Shallow Water Attack, Medium (SWAM) hull/variants. The Landing Vehicle Assault (LVA) is still in conceptual development. It is envisioned that these weapons/sensors will provide the Navy with efficient, lightweight systems which will exhibit superior fire power against air, surface and on-shore targets. It is also envisioned that each system will have the capability to take multiple targets (at least two) under fire simultaneously.

2.(U) All on-board ammunition will be either in a ready service mode, or will be readily accessible for rapid reloading. Stowed ammunition will be protected and easily accessible to the operator/loader without interfering with his actions. All ordnance options will be modular when feasible in order to permit vehicle reconfiguration to accommodate different missions, special equipment, and for logistic and personnel transport when required.

TABLE 17 [redacted] WEAPON/SENSOR SELECTIONS - EXPERIMENTAL COASTAL PATROL AND INTERDICTION CRAFT, CPIC-X (U)

ITEM	Wt. per Item lb	kg	SUITE NUMBER 1	2	3	4
			QTY. OF ITEMS			
MK-74 (Emerlec-30) Medium Cal. Mount	4200	(1907)	1	2	1	1
Ammunition-1970 Rounds-Ready Service	5000	(2270)	1	2	1	1
MK-93 (Honeywell) Gun Fire Control System	1200	(545)	1	1	1	1
MK-35 (Kollmorgen) Optical Director	775	(351)	1	2	1	1
4 Harpoon Surface-to-Surface Missiles & Launcher	8590	(3900)	1			
Harpoon Fire Control System (Console)	582	(264)	1			
MK-32 Mod 9 Torpedo Launchers	2010	(913)	-		2	
MK-46 Torpedoes	500	(227)	-		6	
MK-114 Mod 14 Torpedo Fire Control System	2700	(1226)	-		1	
ASW - Towed Array	1000	(454)			1	-
Mine Launching Equipment	2000	(908)	-			1
Mines (MK-36 or equivalent)	1000	(454)	-			8/10
Communication/Navigation System	2000	(908)	1	1	1	1
Small Arms/Mounts/Ammunition	2500	(1135)	1	1	1	1
TOTAL Wt. of Suite lbs. (kg) =			24,847 (11270)	25,650 (11634)	26,395 (11973)	26,675 (12100)

MISSION	SUITE NO.
Interdiction/Destruction of Enemy Coastal Combatants; Inshore Warfare; Coastal Patrol and Interdiction; Off-Shore Resource Protection.	1 & 2
Inshore ASW	3
Mine Warfare	4

[redacted]

TABLE 18 - [redacted] WEAPON/SENSOR SELECTIONS - OPEN OCEAN PLANING HULL (U)

ITEM	Wt. per Item l'b	Wt. per Item kg	SUITE NUMBER 1	SUITE NUMBER 2	SUITE NUMBER 3
			QTY. OF ITEMS		
MK-75, 76 MM Gun Mount (less ammunition)	17000	(7711)	3	1	2
Ammunition-76 MM-80 Rounds-Ready Service/Reload	3000	(1362)	9	3	6
MK-45 5" 54 Light Weight Gun Mount (less ammunition)	48000	(21772)		1	
Ammunition-300 Rounds 5" 54 projectiles	32000	(14514)		1	
MK-15 Close-in weapon (less ammunition)	10000	(4536)		1	
Ammunition-20 MM- 2000 Rounds-Ready Service/Reload	2000	(908)		3	
MK-74 (Emerlec-30) Medium Cal. Mount (less ammunition)	4200	(1907)	2	2	2
Ammunition-1970 Rounds-Ready Service/Reload	5000	(2270)	4	4	4
MK-94 (Sperry) fire Control System	8300	(3765)	1	1	1
MK-93 (Honeywell) Fire Control System	1200	(545)	1	1	1
MK-35 (Kollmorgen) Optical Director	800	(363)	2	2	2
4 Harpoon Surface-to-Surface Missiles Launcher	8600	(3901)	2	2	
Harpoon Fire Control System	600	(272)	1	1	
ASW Weapon (ASROC) Launcher	50000	(22680)			1
ASROC or equivalent weapon	1125	(511)			8
MK-32 Torpedo Launcher (or equivalent)	2050	(930)			2
MK-46 Torpedo	500	(227)			6
MK-114 Mod 14 (or equivalent) Torpedo Fire Control System	3000	(1362)			1
ASW Towed Array (or equivalent type sonar)	25000	(11340)	-		1
Communication/Navigation System	6000	(2724)	1	1	1
ESM/ECM System	3000	(1362)	1	1	1
Small Arms/Mounts and Ammunition	5000	(2270)	1	1	1
TOTAL Wt. of Suite lbs. (kg)			149,301 (67720)	191,700 (86954)	199,600 (90,537)

MISSION	SUITE NO.
Ocean Escort and Interdiction, AOA Perimeter Defense	1 & 2
Ocean Escort ASW	3

[redacted]

[redacted]

[redacted]

TABLE 19 - WEAPON/SENSOR SELECTIONS - SHALLOW WATER ATTACK MEDIUM CRAFT SWAM (U)

ITEM	Wt. per Item lb	Wt. per Item kg	SUITE NUMBER 1 QTY. OF ITEMS	SUITE NUMBER 2 QTY. OF ITEMS	SUITE NUMBER 3 QTY. OF ITEMS
MK-74 (Emerlec -30) Medium Cal. Mount	4200	(1907)	1	1	1
Ammunition-1970 Rounds-Ready Service	5000	(2270)	1	1	1
MK-93 Gun Fire Control System	1200	(545)	1	-	-
MK-93 Gun Fire Control System-Indirect Fire Cap.	2000	(908)	-	1	-
MK-93 Gun Fire Control System-Missile Cont. Cap.	2000	(908)	-	-	1
MK-35 Optical Director	775	(351)	1	1	-
EX-80 (Vulcan) AA and Surface Gun Mount with 1100 Rounds of Ready Ammunition	5000	(2270)	1		-
4 Surface-to-Surface and/or Surface-to-Air Missiles and Launcher (Harpoon type SSM primary w/Rodage/Dragon type SAM secondary)	9000	(4082)			1
Intermediate/Medium Automatic Gun Mount (105 MM Howitzer, MK-4 or Equivalent)	8500	(3859)	-	1	-
Ammunition 105 MM - 100 Rounds	5000	(2270)	-	1	-
Communication/Navigation System	2000	(908)	1	1	1
Small Arms/Mounts/Ammunition	2500	(1135)	1	1	1
TOTAL Wt. of Suite lbs. (kg)			20,675 (9378)	29,975 (13596)	24,700 (11204)

MISSION	SUITE NO.
Inshore Warfare, Riverine Troop Carrier, Command and Control, MEDAID, and Logistics Support	1
Inshore Warfare, Riverine Fire Support	2
Inshore Warfare, Offshore Resource Protection	3

Section V - [redacted]ULNERABILITY AND SURVIVABILITY (U)

(U) In performing their operational assignments, high performance planing hulls will be exposed to a broad spectrum of operational hazards similar to those faced by conventional displacement and other advanced naval vehicles having similar missions. Vulnerability and survivability considerations discussed below concern events that are likely to cause serious damage to vehicle operational capabilities. Damage-causing events and their potential consequences are indicated in Table 20. The susceptibility of planing hulls to damage from specific hazards is described below to define a basis for estimating vulnerability and formulating design factors to enhance survivability,

A. (U) VULNERABILITY TO NATURAL DISASTER (U)

1. (U) Collision and grounding hazards are second only to fire as causes of ship damage and material loss. The primary consequences of collisions and grounding incidents are damage to ship structure and installed equipment, flooding and personnel casualties. Not infrequently, fire will result.

2. (U) The deployment of high performance combatants can be expected to increase the collision hazard problem unless positive steps are taken to reduce the chances of collision. One authority has described the situation as being analogous to the superposition of high-speed maneuverable vehicles on normal country road traffic [122].

3. (U) Accidental explosions at sea are generally caused by munitions, fuel and equipment such as engines, high pressure systems and electrical power cables. Location is the major variable between accidental explosions and

TABLE 20 — CRITICAL DAMAGE CAUSES (U)

DAMAGE PRODUCING EVENT	Primary Consequences					
	STRUCTURAL DAMAGE	EQUIPMENT DAMAGE	SECONDARY EXPLOSION	FIRE	FLOODING	PERSONNEL CASUALTIES
Weapon Hit	X	X	X	X	X	X
Explosion	X	X	X	X	X	X
Fire	X	X	X			X
Collision	X	X		X	X	X
Grounding	X	X			X	X
Heavy Weather	X	X			X	X
Material — Failure or Malfunction	X	X	X	X	X	X

those resulting from hostile action. Locations where accidental explosions can be expected to occur can therefore be easily identified. Explosions from hostile attack, however, may occur anywhere.

4. (U)Fire has caused more damage and injury on Navy ships in peace time than any other event. Fire has also been a significant secondary cause in combat. Primary consequences of shipboard fires are damage to structure, equipment, explosions from munition cook-off, and personnel casualties [122].

B. (C) VULNERABILITY TO DETECTION (U)

1. (U) Features related to vulnerability of high performance small combatants by detection are being identified by signature measurement and testing. Currently the measurement and recording of combatant craft radar and infrared signatures is being performed by many navies throughout the world; most recently in the U. S., on the PHM, CPIC-X and 65 ft PB MK-3 craft. Acoustic (far field and hydrodynamic) and pressure signatures have also been measured on these craft, as well as various others. Facilities developed for signature testing of ships are readily adaptable.

2.(C)Radar signature state-cf-the-art provides three primary methods of reducing-vulnerability due to radar cross section [125,126]. The first method is to change the shape of the craft to reflect radar energy away from the angle of arrival (rake the superstructure back from the direction of arrival or avoid dihedral or trihedral corner reflector effects between intersectin[illegible] plane surfaces). This method has the advantage that no radar absorbent material is needed. A second method is to cover all windows and other hull or superstructure openings with screen where mesh size is less than one-tenth the wavelength. A third method is to use radar absorbent material. For a permanent installation, the absorber could be rigid foam protected by a t[illegible] epoxy fiberglass skin to reduce moisture absorption and physical damage.

3.(C)Recent radar cross section investigations performed by the Naval Surface Weapons Center (NSWC), Dahlgren Laboratory, [125] indicated that the bow-on cross section of a recently acquired 65 ft PB MK 3, was measured to be approximately 100 square meters before treatment and was reduced to approximately 2 square meters after treatment. The bow-on cross section of the prototype Coastal Patrol and Interdiction Craft (CPIC-X), as measured by NSWC, [126]was approximately 200 square meters before treatment and was reduced to 3 square meters after treatment.

4. [redacted] Acoustic signatures radiated by high performance small combatants have two general components; (1) the mechanical noise generated by propulsion machinery and (2) hydrodynamic noise caused by the movement of the hull through the water. Vehicles that have been extensively treated (acoustically) have far-field airborne noise levels which do not exceed the octave band levels described by the NC-50 noise criteria curve when measured at a distance of 100 yards in any horizontal aspect at speeds up to 10 knots. Noise levels lower than NC-50 may not be attainable due to the generation of hydrodynamic noise which is a function of vehicle design and speed through the water; the speed threshold at which this becomes impractical varies, of course, with design; however, at very low loiter speeds hydrodynamic influences tend to be minimal.

5. [redacted] Infrared detection vulnerability due to the threat posed by surface launched missiles to Navy ships has been recognized since about 1965 with recognition of the operational capability of the Soviet SS-N-2. Since that time, a family of anti-ship Soviet missiles has been identified with increasing range and detection capability.

6. [redacted] Infrared radiation (IR) is by far the major electromagnetic emission produced by an operating ship. It originates in the hot metal surface and gaseous exhaust from stacks and machinery and from the cooler larger surfaces such as the hull and superstructure. The radiant power increases both with the temperature and area. The state-of-the-art of infrared detectors is such that this radiation can be detected day or night at ranges in the neighborhood of 10 to 15 nautical miles.

[redacted] [redacted]

VULNERABILITY TO DETECTION

[redacted]

7. [redacted] R&D efforts in the area of ship IR signature suppression go back to about 1967. Since that time the stacks of two DD (destroyers) have been successfully back-fitted, on an experimental basis, with radiation suppressors. It was demonstrated that the radiant contrast of the stacks could be suppressed by about 90 percent. Additionally it was demonstrated that reduction in radiation from the hull and superstructure could be significantly reduced with water spray and the DTNSRDC developed low-emissive paint. With the introduction of gas turbine power into the fleet the IR vulnerability was significantly increased and attention was focused on this problem. [redacted]

8. [redacted]n the late 1960's work was started on predicting ship IR signatures by thermal modeling. The DTNSRDC Ship Infrared Signature (SIRS) model has been employed to predict the signature vulnerability of the Patrol Frigate (PF), the Patrol Hydrofoil Craft (Missile) (PHM) and the 65 ft Patrol Boat MK 3. Some verifications of this model have been made.

[redacted]

[redacted] [redacted]

[redacted]

C. [redacted]ULNERABILITY TO WEAPONS ATTACK (U,

This subject matter has been treated in depth by Dr. Fisch [122], who will be quoted frequently throughout the text. .

1. (C) Threats likely to be encountered by high performance planing hulls in conducting their mission/task range from large warhead cruise and guided missiles to medium and small caliber projectiles from other surface combatants, aircraft, and infantry-type automatic weapons (if within range). A summary of the general characteristics of these weapon threats is shown in Table 21.

2. [redacted]irtually all weapon attacks utilize one or more of three basic kill mechanisms: (1) Kinetic energy projectiles, (2) blast and (3)' shape charge jets. Kinetic energy projectiles are delivered by high explosive (HE), armor piercing (AP), or ball-type ammunition, fragments from projectile casings, missile bodies, and even the craft structure, and other high energy pieces of metal, except shaped charges. Blast is a high-velocity, high-pressure wave caused by the detonation of an explosive charge which propogates through the surrounding air or underwater. Shaped charge jets, described further in para. 5., travel at velocities between 15,000 to 25,000 feet/second and are capable of penetrating several inches of armor [127].

3. [redacted]enerally speaking, large warheads (charge weights greater than 100 pounds) in the type of weapon that penetrates and detonates internally, produce the greatest amount of damage and are most likely to generate flooding or sinking. This damage, resulting from structural failure, is produced primarily by blast. Blast loads the structure both impulsively and with a long duration pressure pulse (10 to 100 msec) which causes failure of the

[redacted]

TABLE 21 THREAT WEAPON CHARACTERISTICS (u)

	Range (miles)	Guidance	Warhead type	Charge wt. (lbs.)	Fusing
Cruise Missiles	10-400	Inertial navigation with Active Radar, IR or Television Homing Beam Riding	Blast Shaped Charge Semi-armor Piercing	100-1000	Contact Delay Proximity
Guided Missiles	2-30	Semi-active radar Passive radar Homing IR Homing Laser Homing Radio Command Wire	Fragmenting Shaped Charge Continuous Rod Semi-armor Piercing	5-50	
Rockets and Projectiles	2-10	None	Fragmenting Shaped Charge Semi-armor Piercing Armor Piercing	2-20	
Torpedoes and Mines	0-10	Gyro Passive Acoustic Homing Active Acoustic Homing Wire	Blast	100-2000	Contact Influence (magnetic acoustic or pressure)

NOTE: Information taken from Reference [122] structure at its weakest point (in most cases, a boundary). Internal blast may also impair weapon delivery and mobility [122].

4. [redacted]ragments are a by-product of internal blast. Large weapon blast damage normally extends beyond the fragment damage. In the case of projectiles, rockets and small guided missiles, or external bursts from large weapons, fragment damage will exceed blast damage, Primary fragments from the warhead casing can cut through equipment and cabling many feet from the point of detonation. If a fragment passes through a magazine it could initiate detonation of stored munitions. Fragments can produce weapon delivery impairment and damage mobility system components. Flooding from fragment damage is normally controllable [122].

5. [redacted] Weapons employing shaped charges will defeat heavily armored vehicles and hardened structures. When detonated, a plasma jet, formed by lining a special shape such as a cone or hemisphere in the warhead with a ductile material: projects from the warhead at very high velocity. This jet can penetrate large thicknesses of armor and will easily penetrate the relatively light structure of high performance planing hulls. It destroys equipment and cabling it its path. The jet's passage through structure generates secondary fragments which are projected in a conical pattern along with the jet trajectory. If the jet passes through a munition, detonation is nearly a certainty and mass detonation of the magazine containing the munition could occur. The shaped charge jet will impair weapon delivery components and mobility components and the hazard of explosion or fire will exist from any fuel it contacts [122].

6. (U) The damage producing phenomena associated with an underwater explosion include direct and reflected shock waves, pressure pulses from

gas bubble oscillation, the waterjet which may occur as a result of bubble contraction, and the plume. Depending on the attack conditions, direct damage is inflicted on the underwater structure, propeller shafts or internal equipment by rupture or severe deformation. Hull rupture causes flooding resulting in reduced seaworthiness and, if extensive, in sinking. For displacement hulls, the explosion loading can cause whipping response of the ship girder sufficient to break the back of the ship. Shock motions induced in the ship structure can damage equipment and injure personnel. Indirect damage to internal equipment, machinery or other components may result from flooding, fires or detonation of shipboard munitions [122].

[redacted]

D. SURVIVABILITY BY DESIGN (U)

The subject matter in this Section has been treated in depth by Dr. Fisch who will be quoted frequently throughout the text.

1. (U) Survivability, protection and safety features must be considered from the start of a new design. It is always expensive and usually difficult, if not impossible, to add such features as backfit after the vehicle has been built. In addition, the survivability goals the vehicle is to meet must be established so that the designers know what they must strive for. Given that quantitative survivability requirements are available, and even if they are not, analytic vulnerability and hazard assessments must be conducted as a part of the ship design effort.

2. (U) The Navy has developed several computer programs to simulate weapon/ship encounters. One such program is the Ship Vulnerability Model (SVM) developed by the David W. Taylor Naval Ship Research and Development Center. This is a Monte Carlo simulation which enables the rapid calculation of out-of-action probabilities for a given weapon attack situation and ship target. In addition, the Naval Air Development Center has developed a Combat-Induced Failure Modes and Effects Analysis (CIFMEA), to analyze the vulnerability of an aircraft weapon system to combat induced damage. This technique has potential for application in the survivability analysis of high performance ships [122].

3. (U) Features over which the designer has some control and which significantly influence the vessel's survivability after experiencing weapons hits or an accident, are those which affect its capability to sustain damage without sinking, loss of mobility or loss of weapons. The specific design features

[redacted]

involved are: (1) arrangement of vital systems, (2) structural protection, (3) damage control, (4) compartmentation, and (5) ordnance stowage.

4, (U) The manner in which components of the same system are arranged in a vessel can have a significant effect on the vulnerability of the system. Arrangement can be used to reduce system vulnerability by separation of components which perform a like function (i.e., parallel components), the desirable separation being not less than two damage radii for the largest weapon the ship is likely to be exposed to, However, any separation will be beneficial, since it will reduce the likelihood of both components being inactivated by a single hit. On the other hand, components that must function jointly,-or in series , should be consolidated, in order to minimize the size of the vulnerable zone for the system. Frequently, critical components can be provided with a significant degree of ballistic protection through shielding by non-critical components [122].

5. (U)Structural protection involves the selective use of ballistic armor, side protection systems, hardened topside structure, watertight and fire resistant bulkheads, and damage-tolerant primary structure to improve ship survivability. Since high performance vehicles tend to be weight limited, extensive application of ballistic armor and other heavy protection systems does not presently appear feasible due to unacceptable payload/range penalties. However, this should not preclude consideration of incorporating such protection into a high performance ship on a very selective basis when a vulnerability analysis can demonstrate a significant survivability pay-off for a limited weight penalty [122].

6, (U)Damage control is concerned with hull design features, systems and capabilities for fire detection and extinguishment, counter-flooding and dewatering, explosion venting, shock hardening of installed equipment, damage repair and care of injured personnel [122]. In the past, many damage control functions such as fire detection, extinguishment, containment of flooding and repair of damage have been labor intensive rather than equipment intensive. The highly automated nature of the propulsion and combat systems envisioned for future high performance planing ships, when coupled with the relatively small crews such automation will allow, will require new approaches to damage control in the form of automatic, possibly self-activating systems [122].

7.(U) Compartmentation refers generally to those structural features designed into a hull to preserve watertight integrity and limit the extent of flooding, maintain stability, retard the spread of fires and contain explosion effects [122]. In practice, the principal function of compartmentation is to subdivide the hull into watertight sections to provide reserve buoyancy, and stability in the event of hull damage and flooding of a portion of the ship. These subdivision bulkheads perform a secondary function as fire barriers and, to a limited extent, for explosion containment [122].

8.(U)Ordnance stowage practices can have a significant impact on survivability. Preferably, significant quantities of ordnance should be stowed in below-the-waterline magazines , with adequate ballistic and fire protection to minimize the likelihood of magazine mass detonation, the consequences of which are usually loss of the vessel [122].

SECTION VI - PRODUCIBILITY (U)

A. (U) INTRODUCTION (U)

1. (U) Fortunately, the technology for constructing both metal planing hulls (usually of small tonnages) and high speed displacement hulls (up to large tonnages) is readily available. Glass reinforced plastic technology must be considered to be less developed, but this is a factor only for the smaller hulls ($\leq$ 50 tn). A major problem area might arise if substantial numbers of larger hulls (500 - 800 tn) were to be constructed of aluminum or light-gage steel.

B. (U) ALUMINUM CONSTRUCTION (U)

1.. (U) While the technology is available for constructing large aluminum ships, trained non-ferrous welders are not readily available. Furthermore, due to this general dearth of qualified non-ferrous welders in the country, it might be difficult to retain workers once they are trained, since competing industries often offer higher wage scales. This situation should begin to improve with the construction of more Liquified Natural Gas tankers with large aluminum tanks, which will require more non-ferrous welders to be trained. There are a number of facilities in the United States that have constructed and could construct large aluminum hulls.

C. (U) STEEL CONSTRUCTION (U)

1. (U) With regard to thin-gage steel construction, the crew boat industry probably has the most experience. However, this country does not possessthe best technical knowledge. It is reasonable to assume that many suitable construction yards could be found in the U.S. for this type of steel construction, but it is doubtfulthat it could be "turned on"

as immediately as aluminum construction could.

D, (U) GLASS REINFORCED PLASTIC CONSTRUCTION (U)

1. (U) While the majority of the pleasure boat hulls built in the United States are glass reinforced plastic (GRP), there is a general lack of experience in building larger, high performance GRP hulls. Foreign countries are more advanced (Great Britain, Sweden). The leader in this technology is probably the Vosper Thornycroft Yard in Great Britain.

E. (U) MACHINERY, SYSTEMS (U)

1. (U) The other major equipment items required for the hull can be drawn from an already established industrial base, and would not be any more expensive to produce than other state-of-the-art items. Experience with existing high performance vessels indicated that items such as gear boxes, though not "off-the-shelf", can be designed and built with a minumum of risk, assuming time is available for repetitive design development and gear design refinement.

F. (U) COST ALGORITHMS (U)

1. (U) Very few general studies have been conducted to determine quantitatively to what extent producibility can be improved, and those studies that have been done are primarily concerned with reducing cost.

2. (U) Determining specific costs for hull construction is a difficult task, due to the number of variables involved. Attempts have been made to predict costs for Surface Effect Ships [128] but these mehtods when applied to the size planing hulls of interest, produce costs that hardly seem consistent with reality, i.e. costs of 20 to 35 $/lb for aluminum

construction. This may be due to the fact that most of the data is from hydrofoil construction, which, as a generic type, requires lighter structure to offset the penalty of strut/foil weight, and to the fact that all hydrofoils have been built by aerospace companies, not by shipyards.

3. (U) The most recent data point for predicting aluminum planing hull costs would probably be the procurement of the Aluminum Ship Evaluation Model (ASEM) which was constructed by Tacoma Boat Building Co. for the Structures Department at DTNSRDC. The ASEM was delivered in October 1974, at a cost of approximately $280,000 for 40,000 lbs. of structure, or a rate of 7$/LB. The ASEM lines were identical to the CPIC-X molded lines, and since both were built by the same concern, a savings undoubtably was incurred (primarily in lofting) that would not be incurred in procurement of a prototype. However, the internal structure was much different (and more difficult to fabricate) so the cost is probably a reasonable estimate, for construction in a typical shipyard. Considering the rise in price of aluminum and the recent wage inflation, an estimate in 1976 dollars would be in the neighborhood of 9-10 $/lb. (20,000-22,000 $/tn).

4. (U) There appears to be a consensus from the more recent algorithms and data available[129,130,131] that the number of parts required is the most influential factor, and that reducing the number of parts reduces cost. This was the concept employed during the design and construction of the CPIC-X where all intermediate transverse frames were eliminated, and replaced with deep web frames or bulkheads at greatly increased spans. This resulted in somewhat heavier structure, and higher stresses; but the number of pieces, amount of fit-up required, and linear feet of welding required were all reduced. The algorithm developed by Rohr [129], tends to show this same effect. Figure 89 shows the effect of employing this algorithm

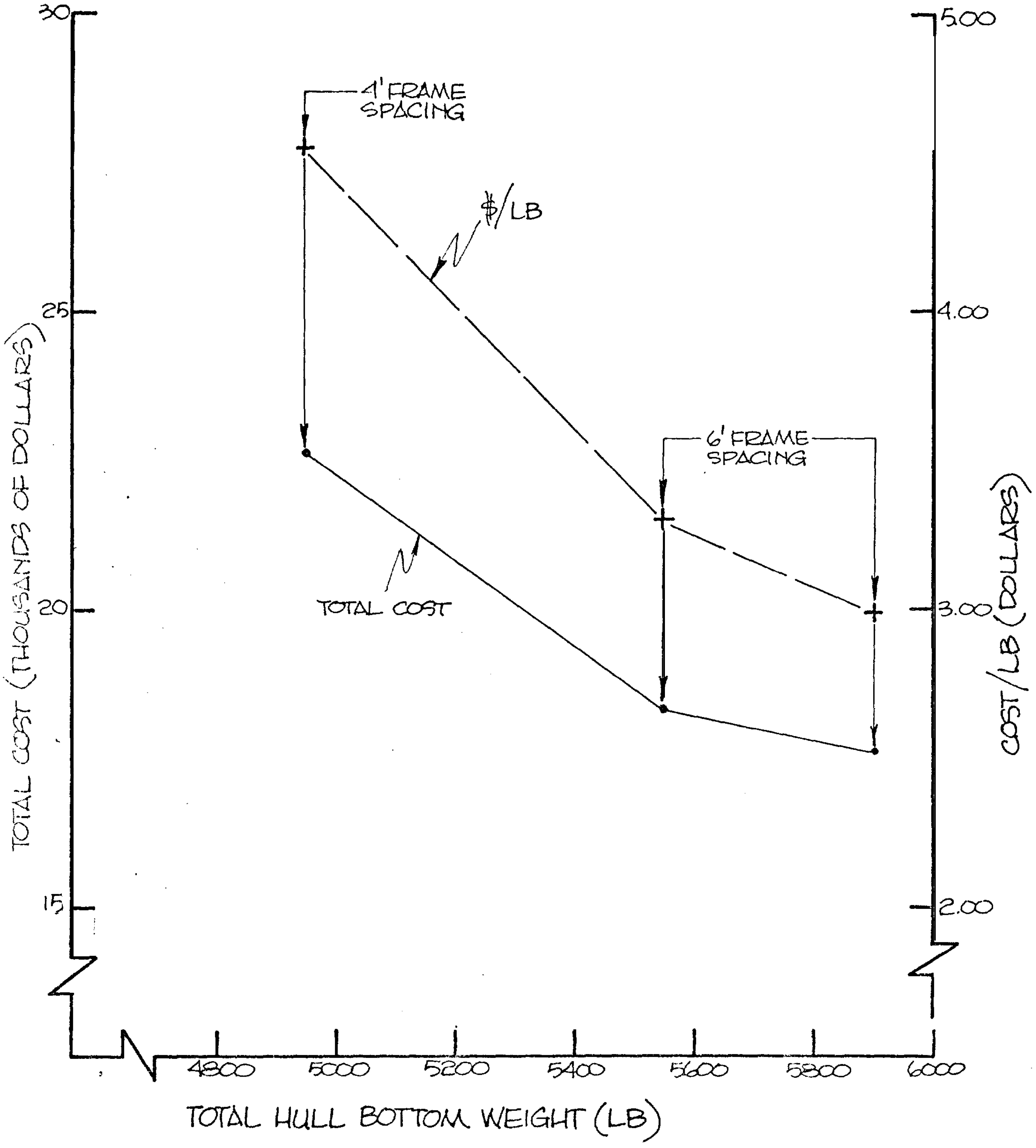


Figure 89 - **Cost Versus Hull** Bottom **Weight For Conceptual Shallow** Water **Attack Medium** (SWAM) **Craft Using Modification of Rohr Algorithm** [129] (U) for the hull bottom of a conceptual design for a Shallow Water Attack Medium (SWAM) craft. As can be seen, the weight increases fairly rapidly as the cost decreases. The same phenomenon has been shown for steel construction by Caldwell and Hewitt [131].

5. (U) For glass reinforced plastic, it is generally recognized that single skin GRP construction is more expensive than aluminum if the number of hulls to be constructed is small, because of the cost of the mold required for the GRP construction. This is discussed by Wildman [132] and fairly extensively by Guilton [133]. In the discussion of Wildman's paper, it was pointed out that the difference in cost is more pronounced, the more difficult the work required of the boat. Heavier scantling fishing hulls were running 30% more expensive than wood construction (which is typically at least as expensive as aluminum) and these were in production lots.

G. (U) LEARNING CURVES (U)

1. (U) With regard to learning curves, factors from 95% to 80% have been mentioned as typical of ship and aircraft production respectively [134], but no differentiation of which factors applied to each type was given. From Guilton's paper [133], the apparent learning curve assumed for GRP construction is 91%. Data from a prior amphibious assault landing craft proposal [135] would indicate a 94% learning curve for aluminum construction. From these indications the learning curves to be expected for the construction of planing hulls should be in the 90 to 95% range.

SECTION VII - BIBLIOGRAPHY

A. (U) SUBJECT MATERIAL

1. (U) Intent. The purpose of this bibliography is to document the state-of-the-art of planing craft design for use in the Advanced Naval Vehicles Concepts Evaluation Study. There are many references pertaining primarily to other types of craft (hydrofoils, air supported, and displacement craft) which are applicable also to planing craft. A few of these have been included.

2. (U) Emphasis. Chronologically the bibliography'emphasizes works produced since 1970, that is, since the previous "Bibliography of Power Boat Design" was completed. In regard to subject matter, the former bibliography emphasized hydrodynamics (performance prediction) almost exclusively. The present work broadens the emphasis to include hydrodynamic loads, structural design and engineering, and construction methods. Tt also includes material on many aspects of Marine Engineering and Naval Architecture as detailed below in the list of subject categories, but the depth of technical detail is generally less in these areas than in hydrodynamics.

Some older references are cited, either because they had not been included in the earlier bibliography or because they are still representative of the state of the art.

No attempt has been made to include reference to official Navy general guidance documents such as Military Specifications, standards, and handbooks. It is recognized that these may contain design data relevant to some of the included subject areas, but a search of these was beyond the scope of this effort.

for the hull bottom of a conceptual design for a Shallow Water Attack Medium (SwAM) craft. As can be seen, the weight increases fairly rapidly as the cost decreases. The same phenomenon has been shown for steel construction by Caldwell and Hewitt [131].

5. (U) For glass reinforced plastic, it is generally recognized that single skin GRP construction is more expensive than aluminum if the number of hulls to be constructed is small, because of the cost of the mold required for the GRP construction. This is discussed by Wildman [132] and fairly extensively by Guilton [133]. In the discussion of Wildman's paper, it was pointed out that the difference in cost is more pronounced, the more difficult the work required of the boat. Heavier scantling fishing hulls were running 30% more expensive than wood construction (which is typically at least as expensive as aluminum) and these were in production lots.

G. (U) LEARNING CURVES (U)

1. (U) With regard to learning curves, factors from 95% to 80% have been mentioned as typical of ship and aircraft production respectively [134], but no differentiation of which factors applied to each type was given. From Guilton's paper [133], the apparent learning curve assumed for GRP construction is 91%. Data from a prior amphibious assault landing craft proposal [135] would indicate a 94% learning curve for aluminum construction. From these indications the learning curves to be expected for the construction of planing hulls should be in the 90 to 95% range.

SECTION VII - BIBLIOGRAPHY

A. (U) SUBJECT MATERIAL

1. (U) Intent. The purpose of this bibliography is to document the state-of-the-art of planing craft design for use in the Advanced Naval Vehicles Concepts Evaluation Study. There are many references pertaining primarily to other types of craft (hydrofoils, air supported, and displacement craft) which are applicable also to planing craft. A few of these have been included.

2. (U) Emphasis. Chronologically the bibliography'emphasizes works produced since 1970, that is, since the previous "Bibliography of Power Boat Design" was completed. In regard to subject matter, the former bibliography emphasized hydrodynamics (performance prediction) almost exclusively. The present work broadens the emphasis to include hydrodynamic loads, structural design and engineering, and construction methods. Tt also includes material on many aspects of Marine Engineering and Naval Architecture as detailed below in the list of subject categories, but the depth of technical detail is generally less in these areas than in hydrodynamics.

Some older references are cited, either because they had not been included in the earlier bibliography or because they are still representative of the state of the art.

No attempt has been made to include reference to official Navy general guidance documents such as Military Specifications, standards, and handbooks. It is recognized that these may contain design data relevant to some of the included subject areas, but a search of these was beyond the scope of this effort.

3. (U) Limitations. The subjects included, for the purposes of this report, under the general headings of Naval Architecture and Marine Engineering are so broad and so numerous that an in-depth treatment was not possible within the scope of this effort. However, the most significant of the recent developments are included, as well as a few older references and standard design manuals to help define the state-of-the-art. In general, the tendency was to limit the references to those likely to be generally useful rather than attempt the in-depth listing which might be preferred by a researcher in a particular discipline.

4. (U) Abstracts and Comments. The bibliography is partially annotated. Where abstracts of reports were given in the source documents or in reviews, they are included verbatim. Occasionally, if the document's contents were known but no abstract given, appropriate comments have been added where they would augment the understanding provided by the title alone.

B. (U) USER'S GUIDE

1. (U) Arrangement. The subject categories used in the original work have been dropped in favor of a new set of discipline-oriented categories believed to be better suited to the present task. They are listed below. Choosing the categories was difficult, as occasionally was the assignment of references to the categories. However, it should seldom be necessary to search more than two categories to find all the references for a given application. The subject category heading appears at the top of each page of the bibliography. A listing is made only once in this bibliography: there are no multiple listings. If there was doubt as to the original subject category which should be assigned, the most likely one was selected and the entry appears nowhere else.

2. (U) Entry Format. Listings follow the following format:

Author's Last Name, First Initial, "TITLE OF ARTICLE IN CAPS"– Date of Publication and Source. Corporate publications are listed first in each category under the entry title of "Anon". AD Number or Advanced Ship Data Management System data bank number is shown if applicable. If the assignment of a data bank number is pending, this fact is noted by the entry "D/B Pend.".

3. (U) Subject Categories. Subject categories were selected to minimize redundancy in assigning articles to a particular group. Categories are to be interpreted literally as defined in the listing which follows:

4. (U) Late Entries. There are a few references which were picked up too late to be included in the Bibliography proper. These are listed at the beginning of Section VII.C. following, immediately preceding the listing by categories.

SUBJECT CATEGORIES

REGULATIONS	Codes, standards, regulations, Classification Society Rules
GENERAL	Works covering two or more of the below listed subject categories; basic texts, general specifications.
NAVAL ARCHITECTURE	Drafting, general design, hydrostatics, Weights, Outfit and furnishing; all subjects not included in the below'listed categories; full scale trials and vessel descriptions.
HYDRODYNAMICS	
General	Works which cover two or more of the below listed sub-categories.
Resistance and Trim	Bare hull resistance and trim, appendage resistance,
Propulsion	Hydrodynamic considerations only; propulsors, propulsor-hull interactions, powering, cavitation.
Steering	Maneuvering, coursekeeping, hydrodynamics of control surfaces.
Seakeeping	Motions - works emphasizing seaworthiness, deck wetness, crew comfort.

SUBJECT CATEGORIES

Impact pressures, loads	Works emphasizing hydrodynamic loads and acceleration relating to structure considerations.
STRUCTURES	Structural design and engineering; materials; foundations.
HABITABILITY & SAFETY	Human engineering; habitability; accessibility; layout of spaces; vibration and noise abatement.
RELIABILITY & MAINTAINABILITY	Reliability and maintainability engineering; logistics support; failure analysis and prediction.
MARINE ENGINEERING	
General	Auxiliary systems, including controls, steering, hydraulic, pneumatic plumbing, heating, ventilating, air conditioning. All subjects not included in the below listed categories.
Electrical	Electric power generation and distribution, most electrical loads; electronics.
Engines and Power Transmission	Mechanical considerations. Prime movers to propellers - all types; rating and selection of components; design and installation.
ARMAMENT	Armament, vulnerability, battle damage.

C. (U) BIBLIOGRAPHY

The pages following the list of late entries contain the bibliography listing by subject category. The subject categories therein are presented in order in which they are listed in the previous section.

LATE ENTRIES

Blount, D.L., Stuntz, G.R., Gregory, D.L., and Frome, M.J., "Correlation of Full-Scale Trials and Model Tests For a Small Planing Boat", Transactions, R.I.N.A., 1968.

Stenson, R. J., "Standardization Trial Results of a 52 Ft Landing Craft, Swimmer, Reconnaissance, (LCSR)", DTMB Report C-2086, August 1965. CONFIDENTIAL

Trials of MTB "HUGIN" off Horten, 10/30/61 to 11/8/61 (Translation)

NAVSECNORDIV, 95 Ft PTF Tests - Report 6660-C27 of 7/22/74

Von Gierke, H.E., Shock and Vibration Bulletin 45, Part 2, June 1975.

Clark, Walke and Savitsky, Daniel, "One-Third Octave Band Center of Gravity Accelerations for Full-Scale CPIC-X Head Sea Tests", Davidson Laboratory Report #1907. CONFIDENTIAL.

REGULATIONS

Brown, Cdr Richard L., Robinson, LCDR Thomas H., "WHAT'S HAPPENING WITH MARINE ENVIRONMENTAL REGULATIONS", Gulf Section SNAME, Feb 1975

Lippmann, G.J., "SMALL CRAFT STANDARDS", SNAME Spring Meeting April 1973

Anon., "SAFETY STANDARDS FOR SMALL CRAFT", American Boat and Yacht Council, Inc., 15 East 26th Street, New York, N. Y. 10010, Revised Every Year

GENERAL

Harrington, R. L., Editor, "MARINE ENGINEERING", 1971, SNAME

Anon., "STANDARD SPECIFICATION FOR U. S. NAVY CRAFT", NAVSEA 0902-LP-041-2010, developed by NAVSECNORDIV as specification standard for construction of all Navy craft

Sammis, G., "BASELINE SPECIFICATIONS FOR THE CONSTRUCTION OF PROTOTYPE SPECIAL WARFARE CRAFT, - PRELIMINARY EDITION", Dec 1973, Contract N00167-73-C-0191, NSRDC Special Warfare Craft Program Office, Code 114

Anon., "SPECIFICATIONS FOR BUILDING COASTAL PATROL AND INTERDICTION CRAFT (CPIC), " PRELIMINARY, approx Oct 75, NAVSEA, developed for CPIC Production craft by NAVSECNORDIV for PMS 300

Anon., "COASTAL PATROL AND INTERDICTION CRAFT (CPIC-X) CONTRACT DESIGN HISTORY (CONFIDENTIAL)", Atlantic Hydrofoils, Inc.

Anon., "PRELIMINARY DESIGN CALCULATIONS FOR CPIC-X (CONFIDENTIAL)", Atlantic Hydrofoils, Inc.

Simon, L. E., "ENGINEERS MANUAL OF STATISTICAL METHODS", John Wiley and Sons

Southampton, University of, "PROCEEDINGS OF THE SYMPOSIUM ON SMALL CRAFT", Sept 1971.

Papers on: No. 1. Offshore Racing Powerboat Design and Development, by W. H. Maloney; No. 2. Marine Jet Units, by A. C. Walker; No. 3. Pilot Launches-Design and Operation, by A. K. Sharples and J. D. McLeod; No. 4. Materials for Construction of Small Craft; Part 1, Aluminum for Small Craft by W. J. Allsday, Part 2, Ferro-Cement Construction by W. James, Part 3, Steel as a Boatbuilding Material by R. Clark, Part 4, The Use of Timber in Small Craft Construction by R. P. Sharphouse, Part 5, Glass Reinforced Plastics by D. Wildman; No. 5. Inflatable Craft, by M. Webb; No. 6. Navigational Aids for Small Craft, by G. A. G. Brooke, No. 7. Motor Yachts, by K. H. C. Jurd; No. 8. Fast Patrol Boats, by Commander Peter Du Cane.

It is a very good overview of the state-of-the-art of small craft design.

Anon., "SPECIFICATIONS FOR BUILDING COASTAL PATROL AND INTERDICTION CRAFT (CPIC) FY72 WITH APPENDIX A," NAVSHIPS-0902-026-4010, Oct 71, 10-C00649

NAVAL ARCHITECTURE

Hockberger, Wm. A. "THE IMPACT OF SHIP DESIGN MARGINS", NAVSEC Concept Design Division, 6112-082-75, 1 Sept 75, AD-A015 638/0WO

Baitis, A. E., and Stahl, R., "AN EVALUATION OF SYSTEMS FOR IMPROVING THE HABITABILITY, SEAWORTHINESS AND POWERING CHARACTERISTICS OF PCF'S", NSRDC T & E Report No. 289-H-03, Nov 1969

Momany, N. , "DESIGN GUIDELINES FOR PRESSURE RELIEF-FLAME DEFLECTORS FOR INBOARD/ OUTDRIVE RECREATIONAL BOATS", Wyle Labs, Huntsville, Ala., July 75, MSR-75-25, USCG-D-131-75, AD-A014 093/9WO

Sauthulis, C., Bowman, J., and Chadwick, T., "LEVEL FLOTATION STANDARDS ANALYSIS RESEARCH AND DEVELOPMENT REPORT", Wyle Labs, Huntsville, Ala., May 75, MSK-74-16, USCG-D-112-75, AD-A014 645/6WO

Polk, D. D., and Smith, J. E., Jr., EVALUATION OF VEHICLE PERFORMANCE IN COAST GUARD SEARCH AND RESCUE MISSIONS", Naval Post Graduate School, Monterey, Calif., September 75, AD-A017 538/0WO

Fry, E., and Graul, T., "DESIGN AND APPLICATION OF MODERN HIGH-SPEED CATAMARANS", SNAME Spring Meeting, 1971

Pike, J. W., "WEIGHT CONTROL ON A HIGH PERFORMANCE CRAFT", 11TH Annual Symposium of the Association of Senior Engineers, March 1974

This paper describes the weight control program, and results, on a new high speed fast patrol boat, the Coastal Patrol and Interdiction Craft. The Coastal Patrol and Interdiction Craft, called CPIC, is a 100 foot, high performance combatant craft.

Weight (and displacement) of combatant craft is critical to successful performance. The CPIC was designed to carry a specific weapon system and has a specific mission profile. Growth in displacement would seriously impact on the engine power required and impact on the size and cost of the craft. Differences in the designers and builders weight estimates were sufficient to question the adequacy of the main propulsion system with regard to speed, endurance and the attendant engineering review became the most significant controls over the contractor.

The weight control efforts and results are described with a general over-view of the project. No contract requirements existed for stringent weight control performance. The methods by which control was developed on the existing contract are discussed, and observations provided for consideration in developing improved control methods.

NAVAL ARCHITECTURE

Sejd, James J., "MARGINAL COST - A TOOL IN DESIGNING TO COST", 11th Annual Symposium of the Association of Senior Engineers,, March 1974

The concept of marginal cost, i.e., the cost of one additional unit at some specified level, can be applied to Naval ship design with considerable benefit. Weight, space, electric power and manning are commodities by wich most subsystems and equipments influence ship size and cost. By developing marginal cost factors about a base-line design for these commodities, it is possible to estimate the shipboard cost influence of a wide variety of subsystems without the necessity of a specific design studies. Answers can be provided in minutes rather than days or weeks. Additionally, marginal cost factors provide the naval architect with a new insight into his design, a guide for trading between commodities, and a means of quickly assessing his capability to reach a target cost.

This paper shows the development of marginal cost factors for a Destroyer Escort of about 3,500 tons full load displacement. Potential problem areas are discussed and an example of marginal cost application is offered.

Goldberg, L. L., and Tucker, R. G., "CURRENT STATUS OF U. S. NAVY STABILITY AND BUOYANCY CRITERIA FOR ADVANCED MARINE VEHICLES", AIAA/SNAME Advanced Marine Vehicles Conference, San Diego, Calif., Feb 1974

Hullborne stability and buoyancy criteria (intact and damage) are presented for advanced marine vehicles such as hydrofoil craft, air cushion vehicles, surface effect ships, and low waterplane catamarans. Not covered is stability during flying or on-cushion modes.

The criteria attempt to recognize special operations and hazards associated with the unusual characteristics of these types. Examples are: the danger of large rip damage when flying at high speeds, the potential of large unsymmetrical flooding, and the lightweight structure resulting in less resistance to damage. The criteria presented herein are likely to change as more design and operational experience is acquired.

Stevens, R., Carson, B. H., Krida, R. H., "TECHNOLOGICAL AND OPERATIONAL CONSTRAINTS IN ADVANCE MARINE VEHICLE DESIGN", AIAA/SNAME Advanced Marine Vehicles Conference, San Diego, Calif., Feb 1974

Rapidly developing new technology presents us with the prospect of transitioning to a new Navy that in the coming decades will bear little resemblance to what we consider the conventional Navy of today. Such a transition will undoubtedly entail problems of considerable technological, economic, and operational importance. Three significant problem areas are found in the propulsion, manning, and service acceptance of advanced ship types. The significance of the propulsion problem lies in the need to continually update and improve the technology. The matter of manning of advanced ships impacts heavily upon the concept of an all-volunteer Navy and the soaring percentage of the military budget allocated to manpower. With regard to service acceptance of advanced ship types, there is virtually no historic parallel for the tremendous change in overall naval operations that will be brought about by introduction of advanced marine vehicles into the Fleet. The Navy is occupied now with solving the technical problems involved in advanced marine vehicle technology; it must concurrently address itself to the problems attending its implementation.

NAVAL ARCHITECTURE

Nolan, T. J., and Bolivar, Vaca R., "OPTIMIZATION OF ARTESANAL FISHING CRAFT", Los Angeles Metropolitan Section SNAME, March 1974

A computer-aided scheme optimizes speed, hold capacity, length, beam, and block coeffient of a small fishing boat based on the requirements of Cooperativa Las Palmas in Esmeraldss, Ecuador. The design process considers three alternative types of low cost construction, a comprehensive list of locally available motors, weight, and stability. Capital recovery factor is the measure of merit determining the optimum vessel.

Lutkus, Anthony J., Piche, Gordon G., Wagner, Kenneth, "SEQUENTIAL OPTIMIZATION TECHNIQUE FOR TRAWLER DESIGN", University of Michigan, No. 097, Oct 1970

Aage, Christian, "WIND COEFFICIENTS FOR NINE SHIP MODELS", Hydro - Og Aerodynamisk Laboratorium, Lyngby, Denmark, Report No. A-3, May 1971

Jones, et. al., "DEVELOPMENT OF A HIGH SPEED RESCUE BOAT"; SNAME Spring Meeting 1973

Sinclair, "DEVELOPMENTS IN SMALL CRAFT DESIGN", Hawaii Section, SNAME, June 1974.

Dinsenbacher, Brauer, "MATERIAL DEVELOPMENT, DESIGN, CONSTRUCTION AND EVALUATION OF A FERRO-CEMENT PLANING BOAT", Marine Technology, SNAME, July 1974

Sharples, A. K., "SMALL PATROL CRAFT", RINA Small Craft Group, London, Nov 1974

The paper describes various problems associated with the design of small, fast, semi-displacement patrol boats. The subject is discussed in sections with the emphasis on hull form, speed, engine powers, machinery installation, armament and construction weight.

BIBLIOGRAPHY

HYDRODYNAMICS

Boswell, R. J., Moore, W. L., "REVIEW OF THE STATE OF THE ART OF FULLY SUBMERGED, PARTIALLY SUBMERGED, AND AIR PROPELLERS WITH EMPHASIS ON APPLICATION TO THE COASTAL (MEDIUM) DEVELOPMENTAL CRAFT (CMDC)", NSRDC TN-SPD-249, Feb 75 10-U05784L

The state-of-the-art for design and evaluation of several thruster candidates for the Coastal (Medium) Developmental Craft (CMDC) on Coastal Patrol Craft (CPC) are presented. The thrusters considered are subcavitating water propellers including controllable-reversible-pitch propellers, supercavitating propellers, ventilated propellers, partially submerged propellers, and air propellers including ducted, contrarotating, and tandem air propellers.

Gersten, A., '"PREDICTION OF SEAKEEPING AND MANEUVERING CHARACTERISTICS OF HIGH PERFORMANCE CRAFT - A STATE OF THE ART SURVEY", NSRDC TN-SPD-255, Nov 1973, 10-U05783L

Gregory, D. L., "HULL-APPENDAGE-PROPULSOR INTERACTION FOR HIGH SPEED CRAFT", NSRDC TN-SPD-245, Feb 73, 10-U05780L

This bibliography on hull-appendage-propulsor interaction was compiled in support of the Coastal (Medium) Developmental Craft (CMDC) or Coastal Patrol Craft (CPC) design effort. It is divided into three sections: General material on scale effects and appendages, material applicable to planing craft, and information on all other related craft. A brief discussion of the content of each document is also included.

West, Eugene E., "THE EFFECT OF SURFACE PREPARATION AND REPAINTING PROCEDURES ON THE FRICTIONAL RESISTANCE OF OLD SHIP BOTTOM PLATES AS PREDICTED FROM NSRDC FRICTION PLANE MODEL 4125", NSRDC, Report 4084, May 1973

Cox, G. G., and Lofft, R. F., "STATE-GF-THE-ART FOR ROLL STABILIZERS", 14th International Towing Tank Conference, Report of Seakeeping Committee, Appendix 5, 1975

Little, R. C. et al, "THE DRAG REDUCTION PHENOMENON: OBSERVED CHARACTERISTICS, IMPROVED AGENTS, AND PROPOSED MECHANISMS", Naval Research Lab., NRL Report 7758, June 1974

This paper features primarily drag reduction research performed at the Naval Research Laboratory; it also attempts to cast this work into perspective against the general background of the work done in this area. The interplay of additive molecular properties, additive structure, and solvent medium is emphasized as an important factor in the drag reduction effect. Several drag reduction mechanisms are also proposed through the use of relatively simple well-defined flows that closely model the types of motion which appear to be associated with the turbulence bursting phenomenon. Specific topics discussed include surface effects, onset phenomena, concentration and molecular weight effects, polymer-solvent interactions, polymer shear stability, polymer structural effects, novel agents, and drag reduction mechanisms.

HYDRODYNAMICS

Beveridge, John L., "THRUST DEDUCTION IN CONTRAROTATING PROPELLERS", NSRDC, Ship Performance Department, Report 4332, Nov 74

A theoretical method is presented for calculating the steady propulsive interaction (thrust deduction) force in contrarotating propellers. Contrarotating propellers operating at off-design loading and spacing as well as the contribution of a rudder were investigated. The importance of the separate thrust deduction of the forward and aft propellers in analyzing the behavior of a CR propeller set was shown. Numerical results are given for a MARAD high-speed containership. Some principal findings for the subject ship are: (1) good agreement between theory and experiment with regard to the thrust deduction of a centerline rudder, (2) at equal thrust the forward and aft propellers produced 73 percent and 27 percent of the total thrust deduction, respectively, and (3) the total thrust deduction is reduced by unbalancing the propelling thrust with smaller thrust carried on the forward propeller.

Hadler, J. B., Hubble, E. N., Holling, H. D., "RESISTANCE.CHARACTERISTICS OF A SYSTEMATIC SERIES OF PLANING HULL FORMS - SERIES 65", Chesapeake Section, SNAME, May 74

This paper presents the results of resistance measurements made on Series 65. This series is composed of two groups of hard chine planing hulls with widely different planforms. Within each of the groups, the length-beam ratio and the deadrise are varied. The results are incorporated with those from Series 62 to form a comprehensive compilation of planing craft experimental data. The results are analyzed and compared with predictions from the equations for prismatic surfaces developed by Savitsky.

Giannotti, Dr. Julio, and Fuller, Nathan R., Jr., "SLAMMING OF HIGH PERFORMANCE MARINE VEHICLES", 11th Annual Symposium, Association of Senior Engineers

The increasing demand for high performance marine vehicles has resulted in the need for new design concepts. High operational speeds and unconventional hull geometries make the design process differ from those used for conventional displacement mono-hull ships.

One of the most critical areas encountered by the designer is the prediction of the magnitude and distribution of the impact pressure caused by slamming in calm water or in rough seas.

This report reviews some of the existing slamming theories and suggests possible ways of making them applicable to the design of high performance marine vehicles. Areas where more research is needed are indicated and possible methods for design are recommended.

Allan, Robert F., "SHALLOW DRAUGHT TOWBOATS IN THE CANADIAN NORTHLAND", 2nd International Tug Conference, Organized by Ship & Boat International

The paper describes shallow water navigation on the Mackenzie River System in Northern Canada, discusses development of tunnel-stern pushboats in relation to a trend to higher power, and introduces an improved ducted propulsion system which represents a dramatic improvement over conventional tunnel stern arrangements.

HYDRODYNAMICS

Falls, R. et al, "A COMPARISON OF CONTRAROTATING PROPELLERS WITH OTHER PROPULSION SYSTEMS", Society of Naval Architects and Marine Engineers, Chesapeake Section, Feb 71

Hubble, Nadine, "CORRELATION OF RESISTANCE TEST RESULTS FROM FIXED- AND FREE-TO-TRIM METHODS FOR A DYNAMIC-LIFT CRAFT (MODEL 4667)" NSRDC, Ship Performance Department, Report 3544, April 72

Customary methods are discussed for deterrnining the resistance characteristics in smooth water of hulls of planing and hydrofoil craft. Results are presented and compared for a hull, with possible application to either type of craft, which has been tested by both the fixed-trim method, generally used for hydrofoil craft, and the free-to-trim method, generally used for planing craft. Recommendations are made -for conducting future resistance tests of dynamic-lift craft, i.e., both planing and hydrofoil hulls, in the fixed trim mode as well as for converting the data to the form of free-to-trim test data to facilitate general design studies for both types of craft.

Tsakonas, S., Jacobs, W. R., Ali, M. R., "PROPELLER-DUCT INTERACTION DUE TO LOADING AND THICKNESS EFFECTS", Davidson Laboratory, Stevens Institute of Technology, R-1722, April 75

This study is a continuation of an earlier investigation dealing with the interaction of a propeller and its enshrouding nozzle when both are operating in a nonuniform inflow field. The present investigation complements the previous one by introducing thickness of both lifting surfaces and camber of the duct. Thus a complete analysis is available which takes into account the true geometry of the propeller and duct, including the propeller and duct thickness and duct camber distributions along with the camber and flow angle of the propeller and the conicity angle of the duct. A computer program adaptable to a high-speed digital computer has been developed which evaluates the steady and time-dependent pressure (loading) distributions on both lifting surfaces and the resulting hydrodynamic forces and moments generated by the propulsive device. Provision has also been made in the analysis and program to deal with a nonaxisymmetric nozzle and a tilted nozzle.

Mercier, John A., and Savitsky, Daniel, "RESISTANCE OF TRANSOM-STERN CRAFT IN THE PRE-PLANING REGIME", Davidson Laboratory, Stevens Institute of Technology, R-1667, June 73

An analytical procedure is presented for predicting the resistance of transom-stern hulls in the non-planing range -- specifically for volume Froude numbers less than 2.0. The predictive technique is established by a regression. analysis of the smooth-water resistance data of seven transom-stern hull series which included 118 separate hull forms.

The statistically-based correlation equation is a function of slenderness ratio, beam loading, entrance angle, ratio of transom area to maximum section area and volume Froude number. This equation can be used to estimate the low Froude number resistance of planing hull forms in the early stages of design.

HYDRODYNAMICS

Anon., "THE EFFECT OF A NOZZLE ON STEERING CHARACTERISTICS", 2nd International Tug Conference, Organized by Ship & Boat International

A method is presented for predicting how the steering characteristics of a ship are affected by fitting a fixed nozzle. The presence of a nozzle upstream appears to have a significant effect on the rudder forces. Full-scale manoeuvring trials carried out with two twin-screw tugs, one with open propellers and the other equipped with nozzles, confirm the predicted trends. It is concluded that propeller, nozzle and rudder should be designed in an integrated way to ensure that an optimum solution is obtained with regard to both propulsive and steering qualities.

Thew, C. , "APPLICATION OF KORT NOZZLES - STATE OF THE ART", 2nd International Tug Conference, Organized by Ship & Boat International

After many years of doubt and prejudice the Kort Nozzle has become accepted as standard for tugs. Its history, practical development and application are discussed.

Millward, A. , "THE EFFECT OF WEDGES ON THE PERFORMANCE CHARACTERISTICS OF TWO PLANING HULLS".

An investigation has been made into the effect of adding wedges or trim tabs to two models of the DTMB Series 62 planing hulls over a range of longitudinal centre of gravity positions and displacements to determine the optimum wedge configuration and the range of effectiveness of a wedge.

Measurements were also made to determine whether a wedge had an effect on the dynamic lift on the hull and hence whether there was a change in resistance other than that resulting from control of the trim angle.

Connolly, J. E., "ROLLING AND ITS STABILISATION BY ACTIVE FINS", The Royal Institution of Naval Architects, March 1968.

Specification of the most suitable roll stabiliser for any particular ship requires the ability to predict motion under operational conditions with confidence during the design stage, and for this purpose, theory is developed and compared with the results of trial measurements on two ships together with supporting measurements on a model. The theory is shown to provide a satisfactory basis for the prediction of rolling motion and for distinguishing cases where a passive device is adequate to fulfil the operational requirements without the additional cost and complication of an active system. Simple tables are presented to facilitate such predictions.

It is shown that the performance of active stabilisers in the two trials ships could be represented theoretically with reasonable accuracy; this result justified the development of simple design techniques for specifying the required size and characteristics of active stabilisers to restrain rolling within selected limits.

HYDRODYNAMICS

Peck, James G., and Kelley, Jerry R., "CAVITATION AND VENTILATION EXPERIMENTS OF FOUR CONTROLLABLE PITCH PROPELLERS FOR THE OPEN WATER RESEARCH VEHICLE, PROTEUS", NSRDC, Ship Performance Department Report, SPD-239-03, Aug 75

Cavitation performance of Four variable pitch propellers are evaluated and presented for comparison with PROTEUS (Propulsion Research and Open-Water Testing of Experimental Underwater Systems) open-water test results. All four variable pitch propeller models are members of a parametric series with common characteristics. Cavitation performance of the Newton-Rader propeller (4447) with the ventilation ring attached to the model pod are also presented with little or no difference in performance from data for the same conditions without the ventilation ring. Results of open-water characteristics of the Newton-Rader propeller are compared with the test results of June 1971. The data show good agreement for the design advance ratio and any differences in data agreement can be attributed to the use of the propeller over the period of time invdlved. Curves of the cavitation performance of two of the propellers under various conditions of ventilation are presented.

Cheng, Henry M., "A PROPOSED METHOD OF ANALYSIS FOR PROPULSIVE PERFORMANCE OF CONTRAROTATING PROPELLERS", NSRDC, Hydromechanics Laboratory, Technical Note No. 129, April 1969

Hecker, Richard, and McDonald, Neil A., "THE EFFECT OF AXIAL SPACING AND DIAMETER ON THE POWERING PERFORMANCE OF COUNTERROTATING PROPELLERS", David Taylor Model Basin, Hydromechanics Lab., Report 1342, Feb 60

An investigation of counterrotating (CR) propellers was conducted at the David Taylor Model Basin. For this investigation a series of counterrotating propellers was designed and tested in open water. Part of this series was used to investigate the effect of axial spacing on efficiency while another part was used to study the effect of the forward propeller diameter on efficiency. Two methods, one theoretical and one empirical, were used to predict the optimum forward diameter.

The results show that axial spacing has a negligible effect on efficiency as long as the propellers are operating at their design spacing. The effect of forward propeller diameter on efficiency is shown to be essentially the same as for single propellers. The results further indicate that either of the two methods used to determine the optimum forward diameter is adequate.

Due to limitations imposed by the test equipment the propellers were run at Reynolds numbers lower than usually considered acceptable. The experimental results, however, compare well with theory.

HYDRODYNAMICS

Coon, John H., "PROPELLER VORTEX CAVITATION INCEPTION STUDIES", David Taylor Model Basin, Hydromechanics Laboratory, Report 1724, S-R009-01 01, Mar 63

Chuang, Sheng-Lun, "DESIGN CRITERIA FOR HYDROFOIL HULL BOTTOM PLATING (A PRACTICAL APPLICATION OF RESEARCH ON SLAMMING)", NSRDC, Structures Department, Report 3509 (Revised), Aug 75

This report introduces a method for calculating pressure distributions on the hull bottom of a craft that is subjected to slamming loads at high cruising speed in waves. Design procedure and criteria for hydrofoil hull bottom plating and structure are included and examples given of their utilization in applications of the method. Various existing theories and methods on slamming are included in summary form for purposes of review and comparison.

Peck, J. G., and Kelley, J. R., "CAVITATION PERFORMANCE CHARACTERISTICS, OPEN-WATER CHARACTERISTICS OF PROPELLERS 4529, 4530, AND 4611, AND THE BLADE SECTION SHAPES OF PROPELLER 4611", NSRDC, Ship Performance Department, TM TM 15-75-23, Mar 75

Van Dyck, Robert L., and Mercier, John A., "SMOOTH- AND ROUGH-WATER TESTS OF THREE VERSIONS OF A 65-FT MK III. PATROL BOAT", Davidson Laboratory, Stevens Institute of Technology, LR-1704, Oct 73

Chuang, Sheng-Lun, Birmingham,. John T., Furio, Anthony J., Jr.) "EXPERIMENTAL INVESTIGATION OF CATAMARAN CROSS-STRUCTURE SLAMMING", NSRDC, Structures Dept, Report 4653, Sept 75

A model of a conventional catamaran was tested in regular head waves at the Naval Ship Research and Gevelopment Center to investigate the cross-structure slamming phenomenon. The severity of slamming was found to be determined principally by the relative motions resulting from the ship's pitch and heave and the relations of these motions with the impacting wave surface. The impact pressure prediction method that was developed on the basis of these findings gave results that agreed reasonably well with the data from model tests and full-scale trials on USNS HAYES (T-AGOR-16). Spatial averages of impact pressures obtained from the model and full-scale data provide pressure-area relations for use in determining load criteria for cross-structure bottom plate, panel, and grillage design. The effect of deformability of impact surfaces was also investigated and the results used to provide guidance in the development of load criteria for the structural design of the cross structure in the slamming area.

Heckcr, R., and Morgan, Wm. B., "SCALE EFFECT STUDIES ON PARTIALLY-SUBMERGED PROPELLER 4281", NSRDC, Hydromechanics Laboratory, 249-H-06, Dec 68

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Lindenmuth, William T., and Barr, Roderick A., "STUDY OF THE PERFORMANCE OF A PARTIALLY SUBMERGED PROPELLER", HYDRONAUTICS, Inc., Technical Report 760-1, July 1967

West, E. E., "POWERING PREDICTIONS FOR THE UNITED STATES COAST GUARD 140-FEET WYTM REPRESENTED BY MODEL 5336", NSRDC, SPD-223-16, April 1975

(U) This report presents powering predictions for a WYTM with stock propellers. This hull can attain a speed of 14.6 knots in smooth deep, fresh water. A slight increase should be attained with design propellers.

Hurwitz, Rae B., and West, E. E., "FLOW OBSERVATIONS AND AN ANALYSIS OF VELOCITY SURVEY DATA FOR A UNITED STATES COAST GUARD WYTM REPRESENTED BY MODEL 5336", NSRDC, SPD-223-15, May 1975

(U) A velocity survey experiment was conducted with a model representing a United States Coast Guard WYTM. Values of longitudinal and tangential velocity component ratios are included herein. A harmonic analysis of the circumferential distribution of the longitudinal and tangential velocity component ratios was performed. The results are presented herein and are considered valid. Experiments were conduced to determine flow patterns about under water portion of hull. Photographs show separation above propeller.

Nelka, John J., "FIELD-POINT PRESSURES IN THE VICINITY OF A SERIES OF SKEWED MARINE PROPELLERS WITH FORWARD RAKE", NSRDC, Report No. 485-H-03, Feb 73

Shields, C. E., "PERFORMANCE CHARACTERISTICS OF A DEEP VEE 32' HARBOR SECURITY PATROL BOAT (HSPB)", NAVSECNORDIV REPORT 6660-19, July 1975

Baitis, A. E., Cox, G. G., and Woolaver, D., "THE EVALUATION OF VOSPER ACTIVE FIN ROLL STABILIZERS", Third Ship Control Systems Symposium, Sept 72

Peck, James G., and Moore, Donald H., "INCLINED-SHAFT PROPELLER PERFORMANCE CHARACTERISTICS", NSRDC, Report 4127, April 74

Holling, Henry D., and Hubble, E. Nadine, "MODEL RESISTANCE DATA OF SERIES 65 HULL FORMS APPLICABLE TO HYDROFOILS AND PLANING CRAFT", NSRDC, Report 4121, May 74

Captive model resistance data are presented for a series of hull forms developed from existing AG(EH) lines as part of a hydrofoil craft research program. These hulls are also applicable to planing craft. Variations in length-to-beam, length-to-draft, and beam-to-draft ratios are represented for each of two basic configurations, one suitable for airplane-type hydrofoil support systems and the other for canard type. Resistance, trimming moment, effective longitudinal center of gravity, draft, wetted area, and wetted lengths are presented for various trim angles, loadings, and speeds in the hullborne and takeoff regimes.

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Bales, N. K., "COMPARATIVE SEAKEEPING CHARACTERISTICS OF TWO UNITED STATES COAST GUARD PATROL BOATS IN REGULAR WAVES", DTNSRDC, SPD-635-01, Sept 75, AD-A015 951/7WO

Moody, Charles G., "HYDRODYNAMIC CHARACTERISTICS OF'A CONTROL SURFACE", DTNSRDC, SPD-640-01, Sept 75, AD-A015 962/4WO

tlolster, J. L. et al, "WATERJET DUCT HYDRODYNAMICS TEST REPORT", August 1974, SRI

Hankley, D. W., "FULL SCALE PROPULSION CHARACTERISTICS OF TWO MARINE WATERJETS RATED AT 500 HP and 1050 HP", Jan 71, NAVSECNORDIV #6660-6

Blount, D. L. et al, "PROPELLER CHARACTERISTICS FORMAT FOR USE WITH HIGH SPEED CRAFT, July 75, NAVSECNORDIV

Van Den Bosch, Dr. J. J., "COMPARATIVE TESTS OF FOUR FAST MOTORBOAT MODELS IN CALM WATER AND IN IRREGULAR HEAD WAVES AND AN ATTEMPT TO OBTAIN FULL-SCALE CONFIRMATION", Netherlands Ship Research Center TNO, Shipbuilding Department, Leighwaterstraat 5, Delft., December 1974, Report No. 196 S

Does not present readily usable information for the practicing designer.

Buck, Jon; Kennell, Colen G.; Fuller, Nathan R., "PERFORMANCE CHARACTERISTICS OF HIGH PERFORMANCE AND ADVANCED MARINE (HIPAM) SURFACE VEHICLES", SNAME Chesapeake Section, 94 Oct 74

General overview of all high performance vehicle including planing hulls; their performance in terms of transpbrt efficiency and sea-state capability is compared with conventional ships.

Jones, Robert R., Allen, Raymond G., and Soule, Stephen B., "THE PREDICTION OF HULL-WAVE IMPACT LOADS ON HIGH PERFORMANCE MARINE VEHICLES - A COMPUTERIZED DESIGN TOOL (U) ", CONFIDENTIAL, Proceedings of the Second Ship Structure Workshop, Structures for High Performance Ships at NSRDC, Vol III, Feb 1973,

Presents a computer-aided design tool for the calculation of both local and overall structural loads.

HYDRODYNAMICS

Gray, Harry P., Allen, Raymond G., and Jones, Robert R., "PREDICTION OF THREE-DIMENSIONAL PRESSURE DISTRIBUTIONS ON V-SHAPED PRISMATIC WEDGES DURING IMPACT ON PLANING", NSRDC Report 3795, Feb 1972

A computer program has been developed which calculates the water-pressure distribution on V-bottom prismatic wedges during impact and planing. The method of computation is based on previously published semi-empirical procedures with several modifications that facilitate programming and result in close correlation to recently published experimental data.

The prismatic wedge may have any positive value of trim, deadrise angle, and wetted length. The pressure distribution for the entire hull or any given section of the hull may be calculated in specified increments by using the appropriate input data. Results obtained from the program are in reasonable agreement with certain published experimental planing data.

Jones, Robert R., and Allen, Raymond G., "A SEMIEMPIRICAL COMPUTERIZED METHOD FOR PREDICTING THREE-DIMENSIONAL HULL-WATER IMPACT PRESSURE DISTRIBUTIONS AND FORCES ON HIGH-PERFORMANCE HULLS," NSRDC Report 4005, Dec 1972

This report describes the development and usage of a semiempirical, quasi-static computerized method for calculating instantaneous three-dimensional water pressure distributions on high-speed marine vehicles. The method can simulate either planing or hull-wave impacts in three degrees of motion-pitch, heave, and surge. The analysis technique requires hull offsets, trochoidal wave parameters, and such initial condition information as the hull position, the vertical and horizontal velocity components, and the pitch rate. The method can be used to obtain results of varying complexity, including a description of normal pressures for all or selected portions of the hull, a normalized pressure versus impact area relationship, and horizontal and vertical impact forces. The results of its application to the analysis of the hull-wave impact of two model hull configurations are presented although the computer program developed for the method is not documented in this report.

This program, called IPPRES, is a large and complicated program. Because of its expense it should be used only in cases of unusual hull shapes where accurate predictions are required. For conventional planing hulls the Heller-Jasper theory is a reasonably accurate tool for generating load criteria for structural design and remains the most useful and dependable method available for preliminary design.

Gersten, Alvin, "MANEUVERING AND CONTROL OF PLANING CRAFT - A STATE-OF-THE-ART SURVEY AND RECOMMENDED RESEARCH PROGRAM", NSRDC Report TM 15-75-15, Dec 1974, 10-U0-5844M

Literature on planing craft has been examined to determine what methods are available for evaluating maneuvering and control qualities of small boats in the early design stages. It has been found that while ground has been broken with regard to experimental and theoretical prediction of stability derivatives and forces on high-speed rudders, much more systematic work must be done to provide adequate design tools. Assembly of computer simulations for maneuvering of planing craft has been severely neglected. A research program whose implementation should fill many gaps in existing technology is presented.

Gregory, D. L., and Dobay, G. F., "THE PERFORMANCE OF HIGH-SPEED RUDDERS IN A CAVITATING ENVIRONMENT," SNAME Spring Meeting, Lake Vuena Vista, Fla., April 1973

Mathis, P. B. and Gregory, D. L., "PROPELLER SLIPSTREAM PERFORMANCE OF FOUR HIGH-SPEED RUDDERS UNDER CAVITATING CONDITIONS", NSRDC Report 4361, May 1974, 10-U05617M

Altman, R. J., "RUDDERS FOR A 50-KNOT PLANING CRAFT", Hydronautics, HYDR-TR-509-1, July 1965, 10-U02605-M

Lasky, M. P., "AN INVESTIGATION OF APPENDAGE DRAG", NSRDC Rept. #3775, Circa 2/73

Remmers, K. D., McDonald, N. A., "OPEN-WATER AND CAVITATION PERFORMANCE OF PROPELLERS FOR A 325 HORSEPOWER MERCURY OUTDRIVE UNIT," NSRDC SPD T&E Rept #424-H-01, 5/71

Gregory, D. L., Hale, M. R., "PERFORMANCE CHARACTERISTICS OF A RIVER PATROL BOAT (PBR) WITH TWIN DISC WATERJETS", CONFIDENTIAL, NSRDC SPD T&E Rept C-400-H-03, 3/71

Savitsky, D., Numata, E., and Chiocco, M., "PRELIMINARY HYDRODYNAMIC MODEL TESTS OF SEVERAL LVA PLANING HULL CONCEPTS," Davidson Laboratory, Stevens Inst. of Technology, Hoboken, N. J., SIT-DL-75-1840, Oct 1975, 63 p., AD-A016 798/1WO

Kallis, J. A., "ROUGH WATER TRIALS ON THE NAVY BERTRAM BOAT FOR THE HARBOR BOAT EVALUATION PROGRAM, NSAP, No. K-6-72", NSRDC Evaluation Report No. 49-H-01, July 1972

Lueders, D., "MODEL TESTS OF TWO PLANING FORMS AND A ROUNDED BOTTOM FORM IN Aid IRREGULAR SEA," Davidson Laboratory Report No. 478-H-01, June 1972

Stahl, R. G., "THE RELATIVE PERFORMANCE OF AN AIR CUSHION PLANING HULL (ACPH) TO A CONVENTIONAL PLANING HULL (CPH) IN CALM WATERS AND IRREGULAR SEAS," NSRDC Evaluation Report No. 478-H-

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Hadler, J. B. and Hubble, E. N., "PREDICTION OF THE POWER PERFORMANCE OF THE SERIES 62 PLANING HULL," 1971, SNAME Transactions, Vol. 79

Clement, E. P., & Springston, G. B., & Moore, W. L., "HYDRODYNAMIC DESIGN PROCEDURE FOR A DYNAPLANE BOAT", NSRDC Rept #2871, 6/71

Fridsma, G., "A SYSTEMATIC STUDY OF THE ROUGH WATER PERFORMANCE OF PLANING BOATS (IRREGULAR WAVES - PART II)," SIT Davidson Lab Rept # SIT-DL-71-1495, 3/71

Savitsky, D., "SMALL CRAFT ENGINEERING - SMALL CRAFT BEHAVIOR IN A SEAWAY," University of Michigan, College of Engineering, Engineering Conferences

Karafiath, G., and Moore, W. L., LITERATURE SURVEY OF POWERING PERFORMANCE PREDICTION FOR HIGH-PERFORMANCE VEHICLES FOR APPLICATION TO A COASTAL (MEDIUM) DEVELOPMENTAL CRAFT", NSRDC TN-SPD-248, Feb 73, 10-U05781L

A literature survey is presented on available powering prediction techniques (including computer programs) for partially air supported planing craft, air cushion vehicles, partially hydrofoil supported planing craft, and partially hydrofoil supported catamarans in support of the design effort for the Coastal (Medium) Developmental Craft, or Coastal Patrol Craft (CPC).

Rood, E. P., and Dailey, N. L., "CATASTROPHIC HYDROELASTIC AND SIDE VENTILATION PHENOMENA ON HIGH-SPEED CRAFT APPENDAGES", NSRDC TN-SPD-252, 10-U05782L

There are three catastrophic phenomena associated with high speed craft appendages operating in a water medium. Two of the phenomena are hydroelastic; flutter and divergence; the third phenomena: side ventilation, is a two fluid interaction associated with struts and control surfaces. Each of these phenomena are described and the consequences of each are explained in this report.

HYDRODYNAMICS

Cumming, R. A., and Morgan, Wm. B., "PROPELLER DESIGN ASPECTS OF LARGE, HIGH-SPEED SHIPS", Symposium on "HIGH POWERED PROPULSION OF LARGE SHIPS", Session on: THE ROLE OF CAVITATION IN PROPELLER DESIGN, Netherlands Ship Model Basin, Wageningen, Dec 1974

The state-of-art of propeller design for large, high-speed ships is reviewed. Davitation effects on efficiency, vibration, and strength are emphasized since propeller designs for this type of ship are for the most part controlled by cavitation considerations. Trade-offs necessary in carrying out a propeller design are discussed along with the criteria required. The trade-offs and criteria are discussed more philosophically than definitive since they can only be discussed in general terms.

Savitsky, Daniel, and Brown, P. Ward, "PROCEDURES FOR HYDRODYNAMIC EVALUATION OF PLANING HULLS", Davidson Laboratory, Stevens Institute.of Technology, R-1859, November 1975

Recent Davidson Laboratory basic studies of planing hull hydrodynamics have produced a wealth of technology which is not generally available to the small boat design profession. Included are studies related to the pro-planing resistance of transom stern hulls; the effectiveness of trim control flaps; the effect of bottom warp on planing efficiency; the influence of re-entrant transom forms; and the seakeeping of planing hulls.

The present paper consolidates these results in a form suitable for design purposes and illustrates their application in predicting planing performance in smooth and rough water.

Anon., "ROTATABLE SHROUDS" and "GENERAL INFORMATION ON THRUSTERS", English translation of Russian Paper, Naval Intelligence Command Headquarters, 1969

Lutowski, Richard Norman, "A COMPUTER PROGRAM FOR VARIOUS ASPECTS OF PLANING CRAFT," Masters Thesis, Stevens Institute of Technology, 1973

A computerized procedure for the calculation of shaft horsepower of planing surfaces is presented. Taken into account are appendage, wind, and propeller-induced forces in addition to the forces commonly used to evaluate effective horsepower. To this central program are added subroutines for the estimation of porpoising stability and rough water performance. From a computer software standpoint, the program has the virtues of high execution speed and modest core requirement, making it suitable for design trade-off studies. It is intended that this program will not merely supplement, but will replace, existing EHP prediction programs for most design applications. Thus, it is hoped that a useful tool has been added to the computer-aided design inventory of the small boat naval architect.

HYDRODYNAMICS

Blount, D. L., and Fox, D. L., "SMALL CRAFT POWER PREDICTION", Western Gulf Section, SNAME, 14 February 1975

A valid performance prediction technique for small craft is an invaluable tool not only for the Naval Architect, but also for the operators and builders. This presentation describes the methodology for making speed-power predictions for hard chine craft on the types found in the offshore, military, and recreational applications. The distinct advantage of this method is that existing technical data have been organized into a logical approach, and areas of limited data have been overcome by the presentation of engineering factors based on model tests and full scale trials of specific hull forms. This speed-power prediction method accounts for hull proportions, loading, appendage configuration, propeller characteristics (including cavitation), and resistance augmentation due to rough water.

Albrecht, K. and Suhrbier, K. R., "INVESTIGATION OF THE FLUCTUATING BLADE FORCES OF A CAVITATING PROPELLER IN OBLIQUE FLOW", International Shipbuilding Progress, Vol. 22, April 1975, No. 248

Layne, Douglas E., "RUDDER FORCE AND MOMENT MEASUREMENTS ON A 1/4-SCALE SES 100 RUDDER", NSRDC, Report 4118, Nov 73

Gregory, D. L., "FORCE AND MOMENT CHARACTERISTICS OF SIX HIGH-SPEED RUDDERS FOR USE ON HIGH-PERFORMANCE CRAFT", NSRDC, Report 4150, Nov 73

Gregory, D. L., and Dobay, G. F., "THE PERFORMANCE OF HIGH-SPEED RUDDERS IN A CAVITATING ENVIRONMENT", Presented at Lake Buena Vista, Florida, SNAME, April 73

Force and moment coefficients for six high-speed craft rudders are presented. These experimental results indicate that the rudder section shape has little effect on the maximum lift coefficient, although the drag and rudder stock torque are influenced by the section shape. Lift, drag, and rudder stock torque are all significantly affected by variations in the cavitation number.

Details of the six rudder designs are presented and the relative merit of the designs is discussed. Recommendations for further investigation of high-performance craft rudders are included.

Peck, J. G., and Moore, D. H., "INCLINED-SHAFT 4-BLADED PROPELLER PERFORMANCE CHARACTERISTICS", Presented at Lake Buena Vista, Florida; SNAME, April 1973

Most small naval craft utilize commercially available propellers on inclined shafts as thrusters. Information on the forces generated by inclined shaft propellers is scarce. In order to help the designer of small craft, an experimental program was undertaken to evaluate commercially available propeller performance when inclined to the oncoming flow. A series of four, 4-bladed, commercial propellers with pitch ratios, P/D, of 0.8, 1.0, 1.2, and

1.4 were characterized over a range of shaft angles, cavitation numbers and advance coefficients. Besides the usual shaftline thrust and torque, horizontal and vertical side forces were also measured. The results of these experiments support the previous assumption that a propeller on an inclined shaft may produce more forward thrust than the same propeller on a horizontal shaft. This paper contains propeller characteristic curves and lift; and side-force data which are directly applicable in the design of high-performance small craft.

Peck, James G., "TUNNEL HULL CAVITATION AND PROPELLER INDUCED PRESSURE INVESTIGATION", NSRDC, SPD-597-01, Nov 1974

Cavitation performance of two propellers at different hull clearance-to-diameter ratios in a tunnel hull model are presented, as well as the propeller-induced pressures measured in the tunnel wall. Cavitation performance of the two propellers in uniform flow is also included. The propellers operating in the tunnel hull were found to be more efficient than in uniform flow. Predominate features of the induced pressure measurements were the blade-frequency harmonics. There was no evidence of flow separation on the tunnel hull model at 'simulated ship speeds of 45 knots.

Blount, Donald L., and Carinder, Jude E., "PROPELLER CHARACTERISTIC FORMAT FOR USE WITH HIGH SPEED CRAFT", NAVSECNORDIV REPORT 6660-18, July 1975

Kress, Robert F., "HIGH-SPEED PROPELLER DESIGN", Presented at Lake Buena Vista, Florida, SNAME, April 1973

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Cox, G. G., "STATE-OF-THE-ART FOR SUBCAVITATING PROPELLER DESIGN METHODS", 12th ITTC, Rome, Italy, Sept. 1969

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Hecker, R., "EXPERIMENTAL PERFORMANCE OF A PARTIALLY SUBMERGED PROPELLER IN INCLINED FLOW", SNAME Spring Meeting 1973

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Hecker, R., and Hendrican, A., "OPEN WATER TEST RESULTS AND DESIGN DIAGRAM EXTENSIONS FOR PROPELLERS OF TROOST SERIES B 7.85", March 1971, NSRDC T&E Report SPD-419-H-01

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Vosper Thornycroft, "PROPELLER DESIGN FOR USN CPIC", June 1973, Vosper Thornycroft Report No. HY/139

Moore, W. L., "DESIGN COMPUTER PROGRAMS FOR SUPERCAVITATING PROPELLERS", NSRDC Ship Performance Dept., Tech Note 236

Scherer, J. O., and Bohn, J. C., "PARTIALLY SUBMERGED SUPERCAVITATING PROPELLERS PARAMETRIC ANALYSIS AND DESIGN OF A FAMILY OF NINE MODEL PROPELLERS", Dec 1973, Hydronautics, Inc. Tech Report 7307-l

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Sabit, A. S., "REGRESSION ANALYSIS OF THE RESISTANCE RESULTS OF THE BSRA SERIES", International Shipbuilding Progress, Vol. 18, No. 197, 1971

Hires, Richard I., "RECREATIONAL CRAFT PERFORMANCE STUDY --PITCH AND HEAVE RESPONSE OF THREE PLANING CRAFT AT ZERO SPEED IN FOLLOWING SEAS", Davidson Laboratory, Stevens Institute of Technology Report 1850, September 1975

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Hobbs, Robert W., "HYDRODYNAMIC SURFACE SELECTION FOR OPTIMUM PERFORMANCE IN PLANING BOAT POWER SELECTION", R. W. Hobbs Report 7006, Coral Gables, Florida, October -1972

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Payne, Peter R., "SUPERCRITICAL PLANING HULLS", AIAA Paper No. 74-333 AIAA/ SNAME Advanced Marine Vehicles Conference, San Diego, California, February 25-27, 1974

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Mercier, John A. and Furino, Peter, "SMOOTH AND ROUGH-WATER TESTS OF A 65-FT. MK111 PATROL BOAT", Davidson Laboratory, Stevens Institute of Technology LR-1666, May 1973

HYDRODYNAMICS

Bailey, D., "PERFORMANCE FREDICTION--FAST CRAFT", National Physical Laboratory Report Ship 181, October 1974, also RINA, Small Craft Group, London, Nov 1974

Fast craft discussed here are those which operate in a Froude number range of 0.3 - 1.5 (V/ L 1.0 - 5.0) and which can be of displacement or planing hull type. The faster derivatives of the latter such as the racing boat are considered to be outside the scope of the present paper.

Predicting the performance of fast craft at an early design stage will demand reliable estimates of the power requirements for a given calm water speed as well as some idea of the handling characteristics of the proposed design. This paperppresents data, largely developed from model experiments, and methods of prediction are given together with the effect on performance of varying such parameters as waterline beam and longitudinal centre of buoyancy. Devices such as spray rails and transom wedges used in refining a particular design are discussed, and manoeuvring and seakeeping aspects considered.

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Ogilvie, Francis T., "FLUTTER-LIKE OSCILLATIONS OF A PLANING PLATE", University of Michigan Report No. 146, July 1973

Mercier, John A., "REPORT OF BUILDER'S TESTS AND TRIALS FOR 1/3-SCALE MANNED MODEL OF SKI-CAT HIGH SPEED CATAMARAN" (U) CONFIDENTIAL, Davidson Laboratory, Stevens Institute of Technology Report 1695, August 1973

Kroeger, N. Bernard, Jr., and Cummings, Damon E., "SUBCAVITATING PROPELLER DESIGN FOR MAXIMUM PROPELLER EFFICIENCY OR MINIMUM FUEL USE", Marine Technology, SNAME, April 1974

An optimization procedure is described for the design of a subcavitating propeller for given service conditions. Strength and cavitation criteria are included. Diameter, rpm, chord lengths, pitch distribution, camber distribution and thickness distribution are developed for the optimum performance. The optimum propeller is defined as that using the minimum power at a given ship speed. If power plant characteristics are known, the propeller may be designed for minimum fuel rate at a given ship speed. Characteristics of the propeller at other than design conditions may be derived.

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Two ferro-cement planing hull riverine craft (one waterjet/diesel and one outboard propelled) capable of speeds of 25 knots were constructed. Built by service personnel in Viet Nam and attaining performance sufficient for combat operations. The results clearly indicate that F-C design and construction techniques exist for high performance boat applications not previously considered feasible.

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Mahone, R. M., Wolk, H. L., "FINAL REPORT ON THE DEVELOPMENT OF A SLAM-MITIGATING SYSTEM FOR CREW USE, EVALUATION DURING SEA TRIALS ABOARD ON OSPREY-CLASS PTF", Distribution limited to U. S. Government, NSRDC Report 4008, Jan 1972

A proposed slam isolation pedestal was tested during sea trials on an Osprey-Class PTF in 6 to 10 ft head seas at maximum speed. Adapted to the standard Navy crew seat in the combat information center (CIC), the slam isolation pedestal reduced the average deck acceleration of 1.25 g to a value of 0.42 g at the seat foundation.

The g-loads measured at the bridge and CIC as a result of craft slamming were found to have a normal distribution, and the time interval between successive slams followed an exponential decaying curve.

Distribution limited to U. S. Government agencies only; Test and Evaluation Info., 27 September 1972. Other requests for this document must be referred to NAVSHIPRANDCEN Code 17

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Anon., "DESIGN PRACTICES FOR SILENCING DIESEL POWERED SMALL BOATS", NSRDC, NAVSEA 0902-038-1010,

Hagelin, Karl O., "AIRBORNE-NOISE REDUCTION OF A 36-FOOT LANDING CRAFT PERSONNEL (LARGE) MARK IV", NSRDC, Report PAS-75-25, July 1975

High airborne-noise levels of a 36-foot Landing Craft Personnel (Large) Mark IV were reduced by the installation of exhaust silencers and acoustical treatment in the engine compartment and cabin. Instructions for the installation of the modifications for inclusion in a boat alteration to be implemented by Naval Sea Systems Command are included.

Wolk, H. L., and Tauber, J. F., M.D., "MAN'S PERFORMANCE DEGRADATION DURING SIMULATED SMALL BOAT SLAMMING", NSRDC, Report 4234, Jan 1974

A research program has been developed and preliminary data obtained on man's performance in a repetitive slamming environment such as would be encountered in a high-performance craft traversing rough seas.

HABITABILITY & SAFETY

The Naval Ship Research and Development-Center (NSRDC) slam simulator was used to test human volunteers in two series of laboratory-controlled studies that simulated ship slamming. The results indicate (1) that man's performance is degraded in a slamming environment (2) that.the subjective reactions of the volunteers do not reflect their performance scores (3) that the test data are highly reproducible, and (4) that only minor muscular skeletal discomforts occurred during the test sessions. The report includes background material on man's known tolerance to single impacts and vibration.

Lewis, David P., and Snuggs, John F., "AIRBORNE NOISE CONTROL AS APPLIED TO HIGH PERFORMANCE CRAFT", 11th Annual Symposium of the Association of Senior Engineers, Feb 1974

This paper familiarizes the reader with the basic concepts of airborne noise control and demonstrates their application during ship design and construction to produce airborne noise acceptable ships. In view of the special size and weight constraints which exist for high performance craft, major emphasis is placed on the efficiency of the alternative noise control methods. A simplified noise prediction technique for use by non-acoustically trained engineers is presented. Although not sufficiently detailed for a thorough noise analysis, the method provided can be useful in conducting trade-off analyses, and in verifying the results of more detailed efforts. The limitations of theoretical noise studies, including the effects of airborne and structural flanking paths, are discussed with emphasis on the special case of high performance craft.

Sweger, George A., "WHAT HAVE YOU DONE FOR THE FLEET SAILOR'S LIFE TODAY?" 11TH Annual Symposium of the Association of Senior Engineers, March 1974

This paper presents a picture of the U. S. Navy's personnel life-saving equipment program, how it is tailored to the requirements of emergencies inherent with fleet operations and how it helps to increase survival and recovery of seamen.

The discussion primarily deals with individual equipments that have been developed under the broad category of lifesaving systems, used to protect, escape or survive various threats to human life aboard ship. Sections of the paper are devoted to a brief look at historical development, what's presently in the fleet or coming soon, and some ideas for the future.

The author also briefly presents his opinions on the Navy's shortcomings in the lifesaving area and proposes a total systems approach to replace the present piecemeal approach of today.

Spiegel, Robert Frederick, "ENVIRONMENTAL MEDIA DESIGN - 2 YEARS LATER", 11th Annual Symposium of the Association of Senior Engineers

This paper reports the findings of a questionnaire survey devised to ascertain the effect of aesthetic audio-visual experiences on the mood and feeling state of personnel during an average work-day.

The survey was conducted at the Naval Ship Engineering Center of military and civilian, male and female, technical and clerical staff.

The results of the survey reveal that such experiences can, indeed, have a profound effect upon the mood and feeling state of individuals in the mainstream of life.

Douglas, B. E., and Kenchington, H. S., "MECHANICAL IMPEDANCE TECHNIQUES IN SMALL BOAT DESIGN", NSRDC

This paper is concerned with the use of mechanical impedance technology to isolate and diagnose the structural cause of airborne noise problems on small boats. A normal mode interpretation is given to analog mechanical impedance and structural radiation factor spectra in order to (1) identify hull and decking resonances, (2) examine noise transmission path strengths and (3) differentiate between radiating structural modes and the normal acoustic modes of the room. These techniques were applied to solve an airborne noise problem on a 36-foot naval landing craft.

Thomson, Donald, "EVALUATION OF AN ACOUSTIC HOOD TECHNIQUE FOR DIAGNOSING SOURCES OF NOISE ABOARD SMALL BOATS", NSRDC, Report PAS-75-41, Oct 75

A specially designed acoustic hood fabricated of lightweight aluminum was installed over a diesel engine in a 28-foot boat and evaluated as a means of diagnosing sources of noise. The hood was not considered practical because low-frequency airborne noise was amplified owing to double-wall resonance effects.

Bender, E., and Collins, A., "EFFECTS OF VIBRATION ON HUMAN PERFORMANCE: A LITERATURE REVIEW", NSRDC Report 1767, 15 Feb 1969

Reed, F. Everett, "ACCEPTABLE LEVELS OF VIBRATION ON SHIPS", Marine Technology, SNAME, April 1973

The Draft International Standard ISO/DIS 2631 "Guide for the Evaluation of Human Exposure to Whole-Body Vibration" provides an excellent base for setting acceptable levels of vibration on ships. A standard for evaluating vibration levels has been needed for some time.and the new standard not only provides a sound foundation for evaluating vibration, but also permits the vibration levels to be rated numerically as percentages of the established standard of fatigue-decreased proficiency. The standard is related to frequency, direction of motion, and the time exposure at the different locations in the ship. "Safe exposure limits" and "reduced comfort limits" are defined in terms of percentages of this same fatigue-decreased proficiency level.

NOTE: Since the preparation of this paper, the Draft International Standard has been adopted as a standard not only of the International Standards Organization but also of the American National Standards Institute.

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Dyer, Thomas R. , and Lundgaard, Eertel, "NOISE CONTROL ON DIESEL TUGS", Marine Technology, SNAME, October 1973

The paper briefly gives basic acoustic definitions and explains the fundamental concepts used in noise control. The mechanics of noise generation and the various methods used in noise suppression are explained. The silencing program employed on two sister tugs, Edith Lovejoy and Anne Carlander, is described in detail. The acoustic treatment of the tugs is not identical and the resulting noise level differences are discussed. Alternative acoustic approaches are described and evaluated. The paper is illustrated with graphs and tables of noise levels, and shows typical vessel arrangements and acoustic treatment details. A short bibliography is included.

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