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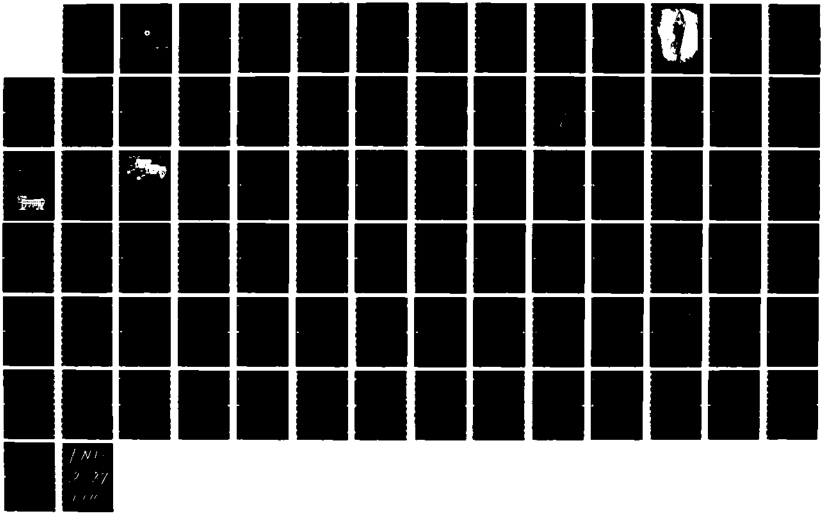

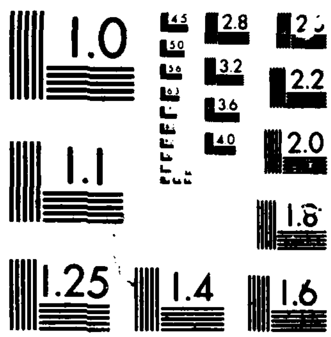
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Report No. CG-D-25-86

AD-A175 760

UNITED STATES COAST GUARD

WPB HYBRID CONCEPT FEASIBILITY DESIGN

FINAL REPORT

APRIL 1986

Prepared for:

U.S. Department of Transportation
United States Coast Guard
Office of Research and Development
Washington, D.C. 20593

87 1 05 062

NOTICE

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
CG-D-25-86		

4. Title and Subtitle	5. Report Date
UNITED STATES COAST GUARD WPB HYBRID CONCEPT FEASIBILITY DESIGN	APRIL 1986
	6. Performing Organization Code
7. Author(s)	8. Performing Organization Report No.
Kevin Kinports, John R. Meyer	
9. Performing Organization Name and Address	10. Work Unit No. (TRAIS)
David W. Taylor Naval Ship R&D Center Code 1233 Bethesda, Maryland 20084-5000	11. Contract or Grant No. DTCG23-85-F-20030
12. Sponsoring Agency Name and Address	13. Type of Report and Period Covered Final Report
UNITED STATES COAST GUARD(G-DMT/54) 2100 2nd Street SW WASHINGTON,D.C. 20593-0001	14. Sponsoring Agency Code U. S. Coast Guard

15. Supplementary Notes

16. Abstract

A WPB hybrid concept (WPB-HYB) feasibility design to meet specific U. S. Coast Guard requirements was developed. This report contains the technical details and conceptual drawings of the WPB-HYB design. Included are a description of the physical characteristics,a weight breakdown, engineering and operational characteristics. This 35-knot hybrid hydrofoil concept, at a full load weight of 185 L.tons, satisfies the 5-day USCG mission requirement at a 28-knot foilborne cruise speed for 24 hours and a 12-knot hullborne speed for 96 hours with a total distance traveled of 1824 n.miles. The ship's crew consists of 2 officers, 2 CPOs and 12 enlisted personnel. The WPB-HYB mission load of 15.0 L.tons includes 2.5 L.tons of armament. A comparison of this design is made with the current 95' WPB, the SEUS WPB and the USCG hybrid concept demonstrator.

17. Key Words	18. Distribution Statement
HYDROFOILS, HYBRID CRAFT, PATROL BOAT, SHIP POWERING, SHIPMOTIONS, HYSWAS, SHIP STABILITY	This document is available to the Public through the National Technical Information Service, Springfield, VA 22161

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
NOT CLASSIFIED	NOT CLASSIFIED	85	

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ABSTRACT

A WPB hybrid hydrofoil concept (WPB-HYB) feasibility design to meet specific U.S. Coast Guard requirements was developed. This report contains the technical details and conceptual drawings of the WPB-HYB design. Included are a description of the physical characteristics, a weight breakdown, engineering and operational characteristics. This 35-knot hybrid hydrofoil concept at a full load weight of 185 long tons satisfies the 5-day USCG mission requirement at a 28-knot foilborne cruise speed for 24 hours and a 12-knot hullborne speed for 96 hours with a total distance traveled of 1824 n. miles. The ship's crew of 16 consists of 2 officers, 2 CPOs, and 12 enlisted. The WPB-HYB mission load of 15.0 long tons includes 2.5 long tons of armament. A comparison of this design is made with the current 95' WPB, the SEUS WPB, and the USCG hybrid concept demonstrator.*

ADMINISTRATIVE INFORMATION

The WPB hybrid hydrofoil concept feasibility design described in this report was developed for the U.S. Coast Guard (MIPR DTCG23-85-F-20030, Work Unit 1-1233-508) by the David Taylor Naval Ship Research & Development Center. The purpose of the study is to provide hybrid hydrofoil concept design information which satisfies the requirements stated by the USCG in the Military Interdepartmental Purchase Request (MIPR). The USCG sponsor is LT Wayne Lundy.

INTRODUCTION

A hybrid hydrofoil concept demonstrator design was previously explored for the U.S. Coast Guard and reported in Reference 1. In that study a feasibility analysis, applying a physically well-defined buoyancy/fuel (B/F) tank and hydrofoil system to a specific craft, an existing USCG 95-foot WPB, was performed. The purpose of the modification was to enhance the craft's mission capabilities in terms of speed, range/endurance, and motions in a seaway.

It was concluded that the hybrid hydrofoil concept demonstrator is technically feasible, has merit, and provides considerable improvement over that of the WPB, particularly in speed, range, and motions. The 181.3 ton demonstrator design is all steel, has 2 Pielstick diesel engines, and carries 38.1 tons of usable fuel in addition to a mission load of 15 tons. Full maximum speed is estimated to be 34.0 knots, maximum foilborne endurance is 53 hours at 22.5 knots, and maximum range is about 1,310 n. miles at 27.5 knots. Hullborne range at 12.5 knots was estimated to be 2,590 n. miles. There is adequate fuel (with a 10% reserve) to carry out a 5-day mission of 24 hours at 30 knots, plus 96 hours at 13 knots for a total range of 1,968 n. miles.

A recommendation was made to investigate a new hybrid design in which the upper hull would accommodate a larger crew and improve intact stability, overall structural efficiency, and the machinery room layout. This report describes the follow-on hybrid hydrofoil design, which incorporates these improvements and satisfies the U.S. Coast Guard WPB replacement requirements stated in Table 1.

*All tons are long tons.

TABLE 1. WPB REQUIREMENTS

1. *Endurance* — Approximately 5 days endurance is required. The crew, fuel and payload associated with 5 days endurance are addressed separately below.

2. *Speed* — A propulsion system is desired that will provide both hot pursuit speed and fuel economy when patrolling. An economical patrol speed around 10 kts with a maximum continuous speed greater than 20 kts are considered minimum requirements.

3. *Range* — A minimum range of 1440 nm is desired based on the following combination:

   10 kts (minimum) for 96 hrs
   20 kts (minimum) for 24 hrs

4. *Seakeeping* — Minimal motion underway and DIW are important to reducing crew fatigue and improving operations (boat launch/recovery, surveillance, navigation, etc.). Proven systems for reducing motions are desired.

5. *Crew* — The mission of the WPB in combination with the size of the WPB dictate a crew of 16 as follows:

   2 Officers
   2 CPO's
   12 Enlisted
   16 TOTAL

   In addition two (2) spare bunks shall be provided.

6. *Payload*

Crew & Effects	3.0 L. tons
Provisions	2.5 L. tons
Water	4.5 L. tons
TOTAL	10.0 L. tons

7. *Boat/Launch/Retrieval Capability* — 5.4M RHI with 70 hp O/B and powered davit. The capability to launch the boat from either side of the ship is preferred

8. *Towing* — Towing bit and towing arrangement adequate to tow a 500 ton vessel.

9. *Armament* — 1-25mm gun with 2000 rounds
   2-50 caliber machine guns with 1000 rounds.

10. *Damage Control* — 2 compartment damage stability.

11. *Miscellaneous* — Anchoring and refueling-at-sea capability must be provided.

PHYSICAL CHARACTERISTICS

GENERAL DESCRIPTION

The WPB hybrid hydrofoil concept (WPB-HYB) described in this report is a combination of a planing craft upper hull connected to a lower slender hull through a full-length single strut. The lower hull contains a foil system which provides dynamic lift at speeds above 20 kts. The foil system is also used in the hullborne mode to control motions and improve ride quality. The lower hull, strut and foil system are essentially the same as that of the demonstrator hybrid [1].

The WPB-HYB is illustrated in Figure 1, and key characteristics are given in Table 2. Depicted here are major dimensions, weights, speed, range, endurance, propulsion systems and foil strut information. The ship is further illustrated in Figures 2 and 3 in terms of inboard profile and deck plans.

In the foilborne mode, the WPB-HYB is powered by two, 3000 hp SEMT-Pielstick diesel engines driving aft into a combining bevel gear box then vertically to a bevel gear box located in the lower hull. Output of this box is transferred to a single propeller on the stern of the lower hull via a horizontal shaft. In the hullborne case, two, 110 hp, diesel engines provide power to two propeller stern drives for low-speed harbor and docking operations. The WPB-HYB utilizes one of the foilborne propulsion diesel engines for high speed hullborne operations up to 20 knots. Two 100-kW, diesel-driven, electric generators provide 60 Hz electrical power.

The foil system is an airplane type with a large foil just aft of amidships carrying approximately 75% of the load and a smaller foil in the tail section of the lower hull. The foils are mounted directly to the lower hull. The WPB-HYB main and aft foils have a foil loading of 860 psf in the full load condition. Dimensions and other physical characteristics are given in Figure 4.

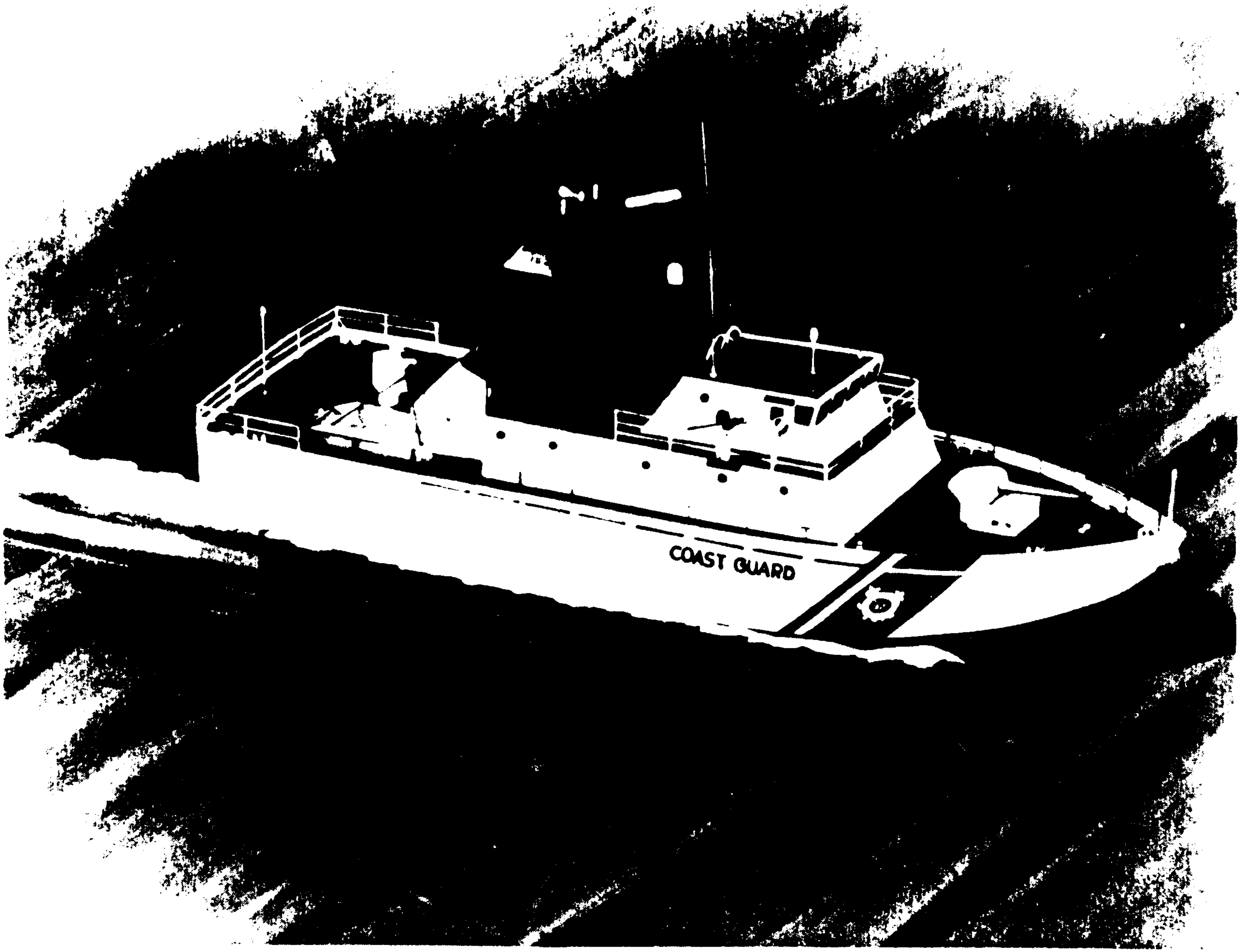


Fig. 1. WPB-Hybrid Concept Rendering

TABLE 2. WPB-HYB HYBRID HYDROFOIL PHYSICAL CHARACTERISTICS

SIZE:	
LOA	106.0 feet
LBP	100.0 feet
Beam (at deck)	26.0 feet
Beam (at waterline)	24.4 feet
Max Span (over foils)	30.0 feet
Draft, Hullborne	13.3 feet
Draft, Foilborne	7.5 feet
Depth at Midships	11.0 feet
Hull Volume	21,590 cubic feet
Deck House Volume	6,310 cubic feet
Total Volume	27,900 cubic feet
Material	Welded Al upper hull; Steel strut/tank
Lightship Weight	127.8 Tons
Full Load Weight	184.4 Tons
SPEED:	
Foilborne Design	34 knots
Takeoff	20 knots
Hullborne Design	12 knots
RANGE:	
Foilborne at 28 kts	1380 nautical miles (nm)
Hullborne at 12 kts	2382 nautical miles (nm)
ENDURANCE:	
Five-Day Mission	12 knots for 96 hours, and 28 knots for 24 hours, for total of 120 hours and 1824 nm
PROPULSION:	
Foilborne	2 Pielstick 12PA4200-VGDS diesels 1 fixed pitch propeller
Hullborne	2 Volvo-Penta, 100 hp diesel stern drives
Electric Prime Mover	Diesel, 2-100 KW generators
Foilborne hp Required	5900 hp at 34 kts
Takeoff hp Required	4500 hp at 20 kts
Takeoff Thrust Margin	~40%
Hullborne hp Required	930 hp at 12 kts
FOILS:	
Foil Concept	Airplane: 75% main, 25% aft
Strut/Foil Material	HY-130 with coating

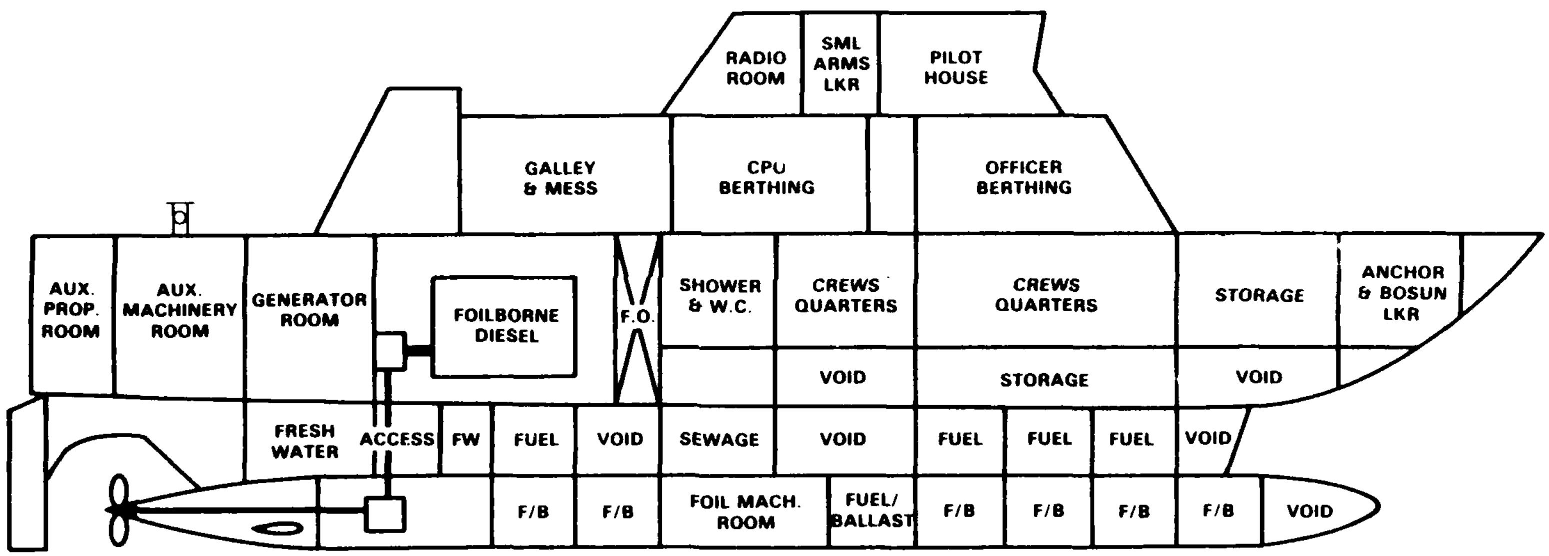


Fig. 2. WPB-HYB Inboard Profile

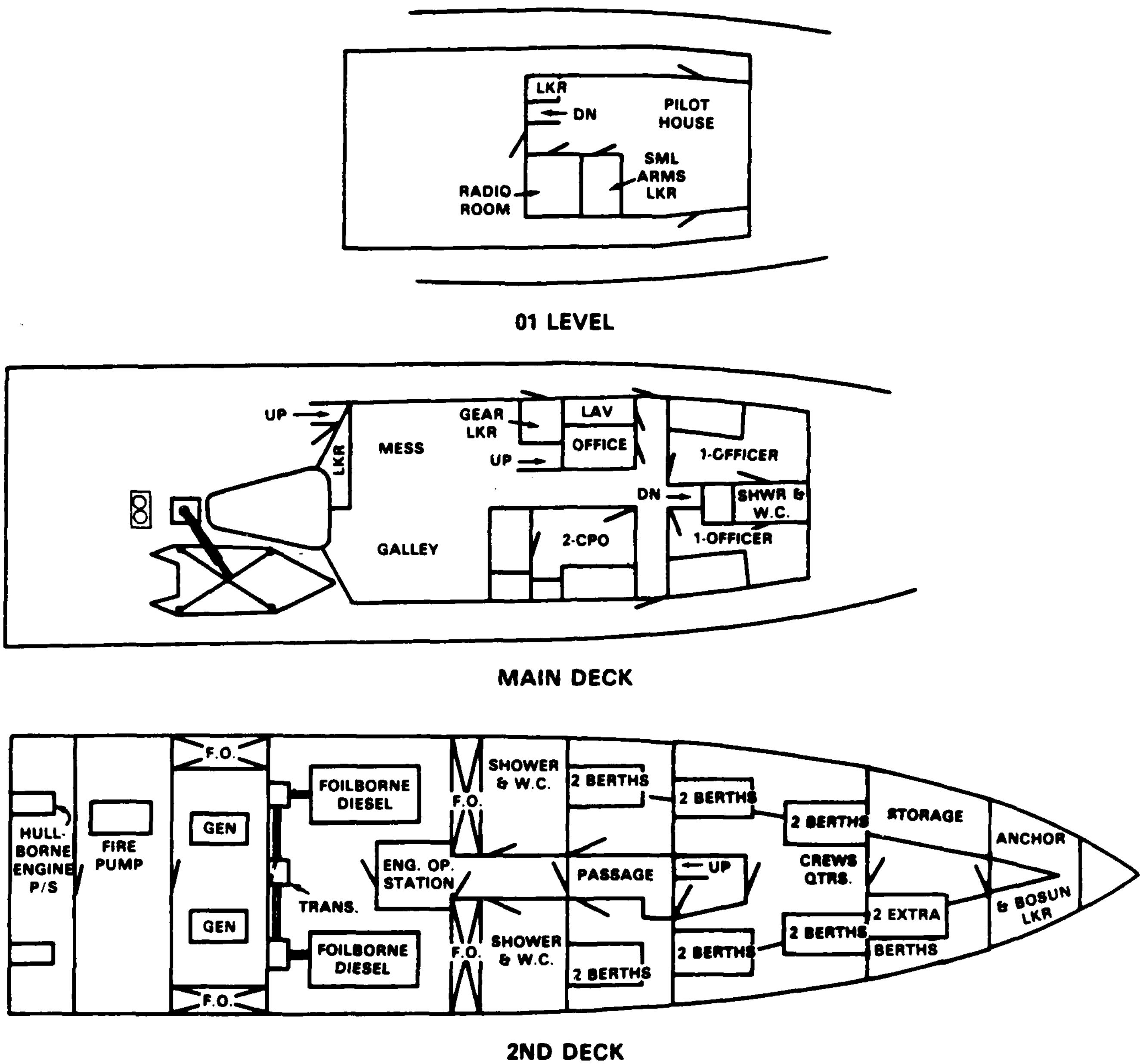
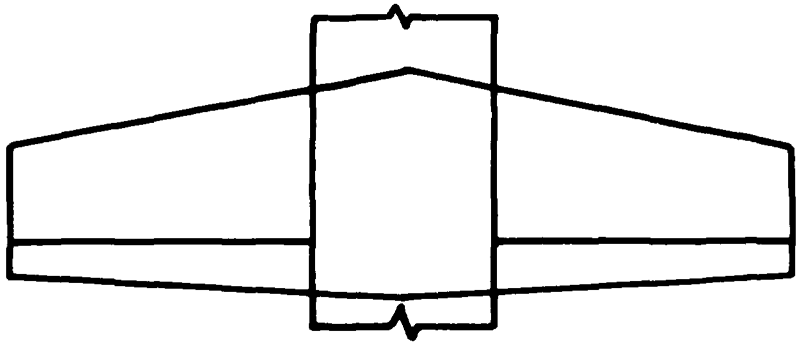


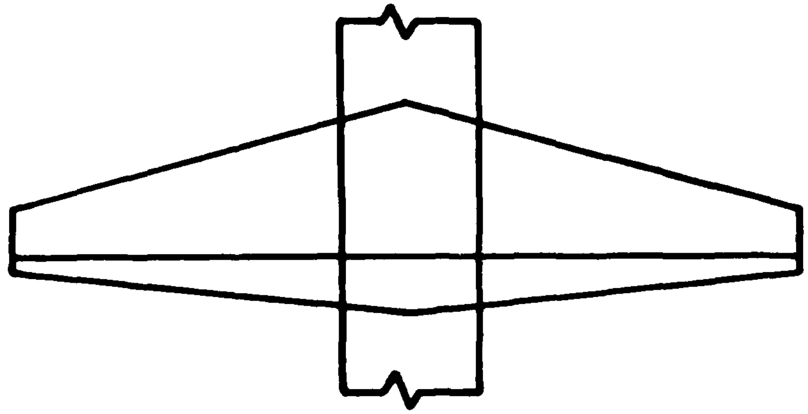
Fig. 3. WPB-HYB Deck Plans

FORWARD FOIL



SPAN, b	30 ft
ROOT CHORD, C_r	9 ft
CHORD AT POD, C_{pod}	8.06 ft
TIP CHORD, C_t	5 ft
AREA, S	210 ft^2
EXPOSED AREA, S′	150.27 ft^2
C/4 SWEEP	7.59°
L.E. SWEEP	11.31°
HINGE LINE SWEEP	0
MEAN GEOMETRIC CHORD, C_{avg}	7 ft
MEAN AERODYNAMIC CHORD,	7.19 ft
ASPECT RATIO, A	4.28
TAPER RATIO, λ	.55
POD STATION, η_{pod}	.23
DIHEDRAL, Γ	− 10°
POD WIDTH	7 ft

AFT FOIL



SPAN, b	19 ft
ROOT CHORD, C_r	5 ft
CHORD AT POD, C_{pod}	4.37 ft
TIP CHORD, C_t	1.5 ft
AREA, S	61.75 ft^2
EXPOSED AREA, S′	45.81 ft^2
C/4 SWEEP	8.06°
L.E. SWEEP	13.16°
HINGE LINE SWEEP	0
POD WIDTH	3.4 ft
AVERAGE CHORD, C_{avg}	3.2 ft
MEAN AERODYNAMIC CHORD	3.56 ft
ASPECT RATIO, A	5.84
TAPER RATIO, λ	.3
POD STATION, η_{pod}	.179
DIHEDRAL, Γ	− 10°

NOTE: POD LINES ASSUMED FOR FOIL CHARACTERISTICS: THIS FOIL IS MOUNTED ON POD AFTERBODY

Fig. 4. WPB-HYB Foil Characteristics

WEIGHT BREAKDOWN

The WPB-HYB weight breakdown is shown in Table 3. Weight information for the lower hull, strut, and foil is obtained from Reference 1. The Advanced Ship System Evaluation Tool (ASSET) is used to assist in the design of the upper hull. Certain exceptions to ASSET weight algorithms are taken since the USCG directed that SWBS Group 400, Command and Surveillance, be standardized at 2.0 tons. Also SWBS Group 700 (Armament) is standardized at 2.5 tons which included 25mm and 50 caliber ammunition. Additionally, potable water is set at 4.5 tons, crew and effects at 3.0 tons, and stores at 2.5 tons. Total useful mission load is therefore 15.0 tons (including armament).

The WPB-HYB lightship weight is 128.4 tons, including a 10% margin (as required by the USCG).

TABLE 3. WPB-HYB WEIGHT BREAKDOWN

SWBS	Group	Weight (long tons)	
100	Hull Structure		55.7
200	Propulsion Plant		22.5
	FB Components	21.5	
	HB Components	1.0	
300	Electric Plant		6.5
400	Command & Surveillance		2.0
500	Auxiliary Systems		17.5
	Systems (less 567)	10.1	
	Foil Assemblies (567)	7.4	
600	Outfit & Furnishings		10.0
700	Armament		2.5
M00	Margins (10%)		11.7
	LIGHTSHIP		128.4
F00	Full Loads		56.6
F10	Crew & Effects	3.0	
F30	Provisions	2.5	
F42	Fuel (95% usable)	42.2	
	Ballast	3.8	
F46	Lube Oil	0.5	
F50	Fresh Water	4.6	
	FULL LOAD WEIGHT		185.0
	FB Foil/Strut/Tank Buoyancy — at Foilborne Waterline		80.0
	FULL LOAD DYNAMIC LIFT		105.0

ENGINEERING CHARACTERISTICS

HULL

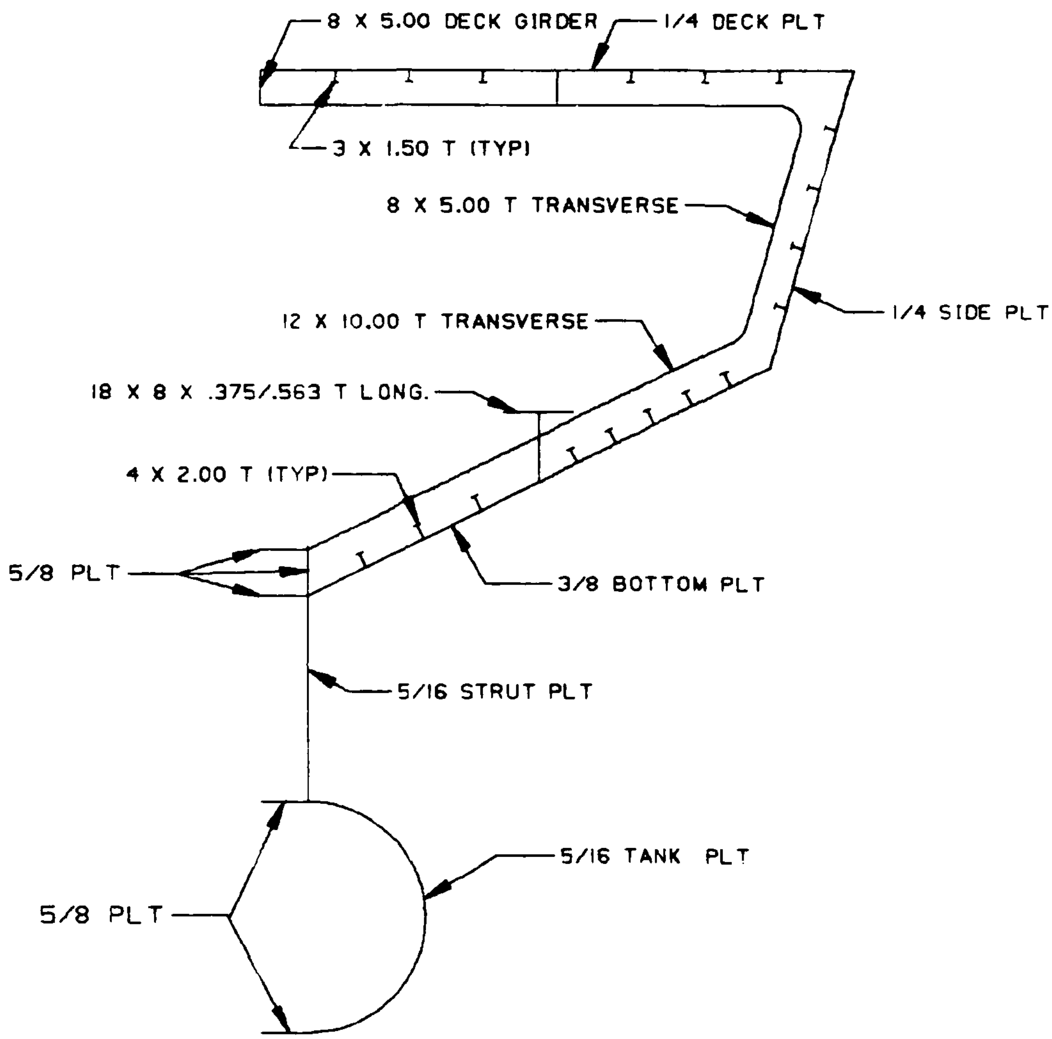
Hull lines are developed from a double chine, 110′ planning hull. The lines are altered to increase buoyancy forward for stability and hydrostatic considerations. The added buoyancy forward allowed the longitudinal center of buoyancy (LCB), longitudinal center of gravity (LCG), and Center of Lift to coincide. The double chine is reduced to a single chine to simplify construction for producibility and to increase the lower waterplane areas for improved intact stability. This hull form has a shallow deadrise of 12 degrees aft with the single, hard chine. After several iterations of this design to meet the payload, space and mission requirements, the final hull length between perpendiculars is 100 feet, the overall length is 106 feet, the maximum beam at the hullborne waterline is 24.4 feet and the maximum beam at the deck is 26.0 feet.

The hull structural design is based on the selection of welded, 5456 aluminum for the upper hull and superstructure material. The loads used for designing the upper hull bottom, sides, and main deck are wave impact pressures. The magnitude of this pressure is determined by the ship's speed, hull geometry, trim and design wave height. Watertight bulkheads are designed to withstand flooding pressures, and the internal deck is designed for nominal working loads.

The lower buoyancy/fuel tank and strut are welded, steel assemblies. The tank size and structure are taken directly from Reference 1. Derivation of the scantlings is reproduced in Appendix A for information. A typical midship section is shown in Figure 5.

The construction of this hull with a combination of materials will be similar to the U.S. Navy's SSP KAIMALINO, a SWATH research vessel with an aluminum upper hull, steel struts and steel lower hulls. The primary structural joint between the steel and the aluminum would be made using DATACLAD, Dupont's explosion-bonded steel and aluminum plate. Reference 2 states that this material has "performed flawlessly . . . with no signs of structural failure and only superficial surface corrosion in areas where the paint has been chipped".

NOTE: ALL DIMENSIONS IN INCHES



NOTE: HULL MATERIALS - ALUMINUM ABOVE HULL/STRUT INTERSECTION
HSLA STEEL BELOW

Fig. 5. WPB-HYB Typical Midship Section

DRAG AND POWERING

Drag and powering predictions are made by combining information from ASSET and Reference 1. ASSET is used to obtain the hullborne drag of the upper hull. This drag prediction is based on planing hull data. To the upper hull drag, the parasitic drag of the lower hull and foils is added. This drag is computed from the drag equations of Reference 1.

The parasitic drag combines the form drag from the foils, strut, and tank; an interference drag between the hulls; air drag for the upper hull; and spray drag for the upper hull. A ten percent margin is added to account for hull fouling.

It is felt that this drag prediction is conservative as the upper hull drag for a slightly deeper draft is used. Additionally the lower hull and foil drag from Reference 1 is derived for a fully wetted strut. This combination leads to a conservative hullborne drag prediction. The hullborne drag curve is shown in Figure 6.

Due to the use of the same strut, tank and foil system as discussed in Reference 1, the foilborne drag and powering predictions from that source are used directly. Foilborne drag calculations are presented in Appendix B for information. Again, this drag prediction is conservative since the drag curves assume a fully wetted strut. Foilborne drag curves are shown in Figure 7.

Because the drag curves of Figure 7 assume a fully wetted strut, they can be considered conservative in sea states with a significant wave height of one meter or less. Incremental drag increase with higher sea states is due to intermittent hull spray and wave action on the buoyancy/fuel tank, neither of which is easily analyzed.

Powering predictions are shown in Figure 8. Due to free flooding of the buoyancy/fuel tank, the full load and light ship displacements will vary by less than 4 tons. Consequently, powering predictions for only the full load displacement are calculated. A take-off thrust margin of approximately 40%, at a take-off speed of 18 to 20 knots, is more than adequate compared to the 25% margin used for most conventional hydrofoils.

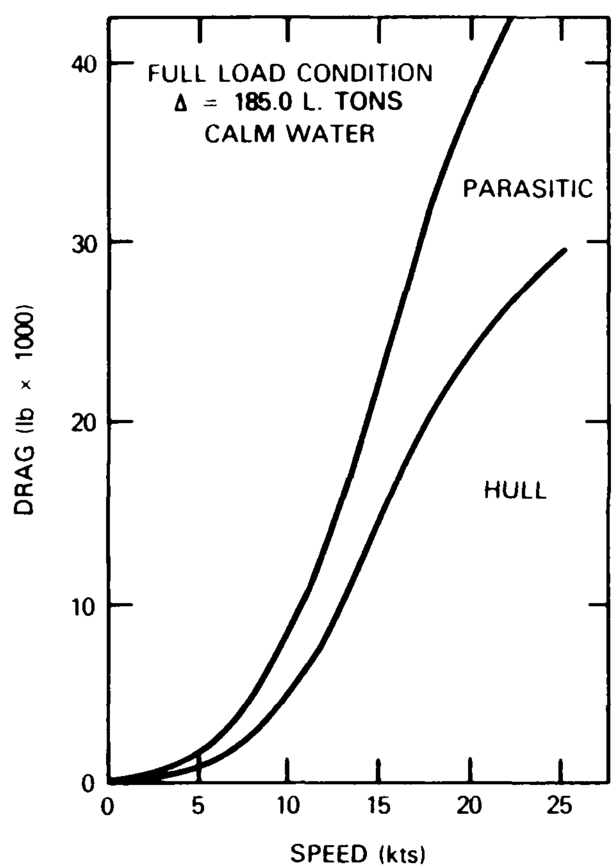


Fig. 6. WPB-HYB
Hullborne Drag vs. Speed

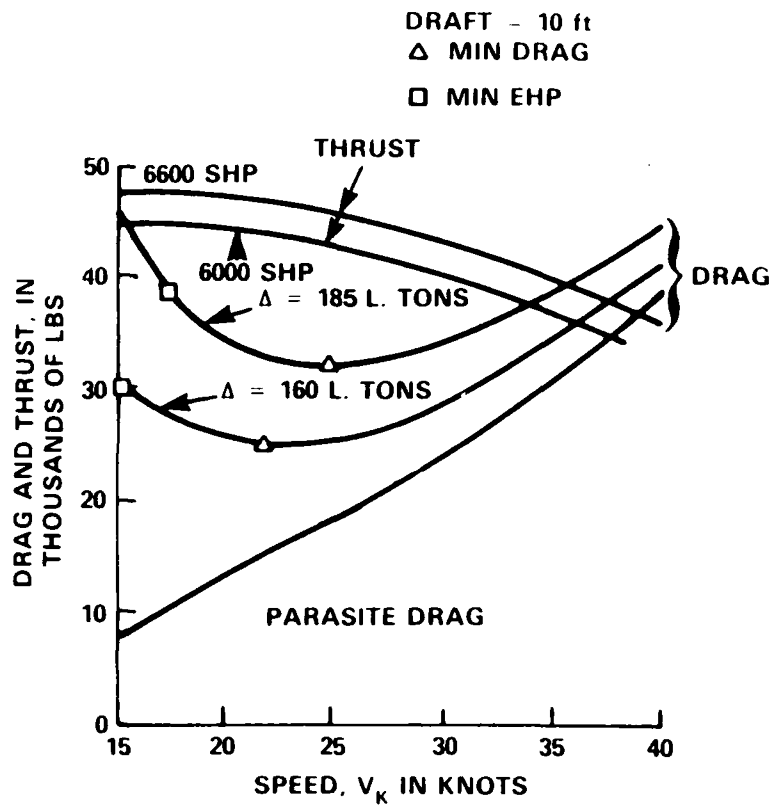


Fig. 7. WPB-HYB Foilborne Drag

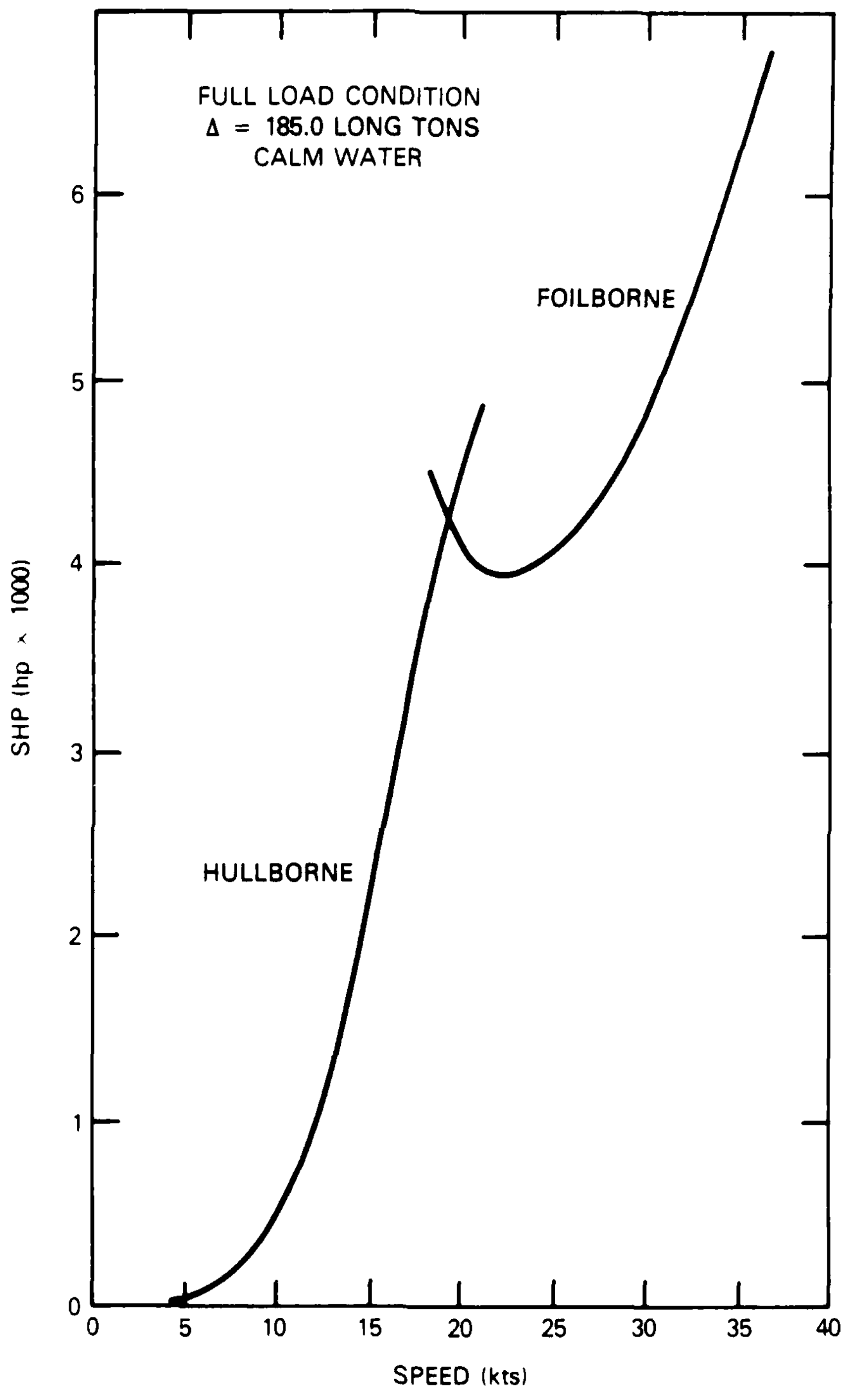


Fig. 8. WPB-HYB Power Required

PROPULSION

After a preliminary overview of various options, the decision was made to use diesel prime movers and mechanical transmissions. Due to space and weight constraints, the selection of candidate engines was limited. Four engines with the required power ratings are the SEMT-Pielstick 12PA4200VGDS, the Paxman Valenta 16 CM, and the MTU 16V538TB82/92. A comparison of these engines is given in Table 4.

TABLE 4.
CANDIDATE ENGINE COMPARISON

Engine	MTU 16V538TB82	MTU 16V538TB92	Pielstick 12PA4200VGDS	Paxman Valenta 16 CM
HP Cont (hp/rpm)	2930/1710	3365/1790	2960/1500	3350/1500
HP Int (hp/rpm)	3190/1760	3710/1850	3250/1550	3650/1550
L (in.)	124.4	124.4	117.0	128.1
W (in.)	64.6	64.6	57.1	57.5
H (in.)	90.7	90.7	84.8	97.5
Dry Wgt. (LT)	6.6	6.6	6.9	8.3
SFC (lb/HP-hr)	0.382	0.394	0.373	0.381

The Pielstick engine is favored due to the slightly smaller overall dimensions and better fuel consumption. However, any of the candidate engines would meet the minimum horsepower requirements with a 25% take-off margin (i.e., 2700 hp/engine). The take-off margin, top speed and endurance would vary slightly with the engine chosen. The calculations for range and endurance are based on the SEMT-Pielstick engine data.

The transmission proposed is an adaptation of the proven Grumman design for the FLAGSTAFF (PGH-1) and refined for use on the Israeli hydrofoil SHIMRIT. Since the overall shaft speed reduction is only 1.5:1, it is recommended that the total reduction be taken up in the lower bevel gear box in order to minimize the weight of the three upper hull gear boxes and associated shafting.

The arrangement of the major components is shown in Figure 9. Clutches are located on each diesel engine shafting so that dual or single engine operation can be accomplished. The lower bevel gear box is contained in a dedicated watertight enclosure that insures a double protection against salt water corrosion. The propeller shaft is fitted with sleeve bearings and a shaft seal at the aft end. Since the propeller is fixed pitch, it is attached to the shaft in a conventional manner.

The main propulsion system characteristics are shown in Figures 10 through 13 and include specific fuel consumption, propulsive efficiency, fuel flow (long tons per hour) and fuel consumption (nm per long ton). All are plotted versus ship speed. Additionally, the performance parameters and full details for the SEMT-Pielstick 12PA4200VGDS are shown in Figure 14.

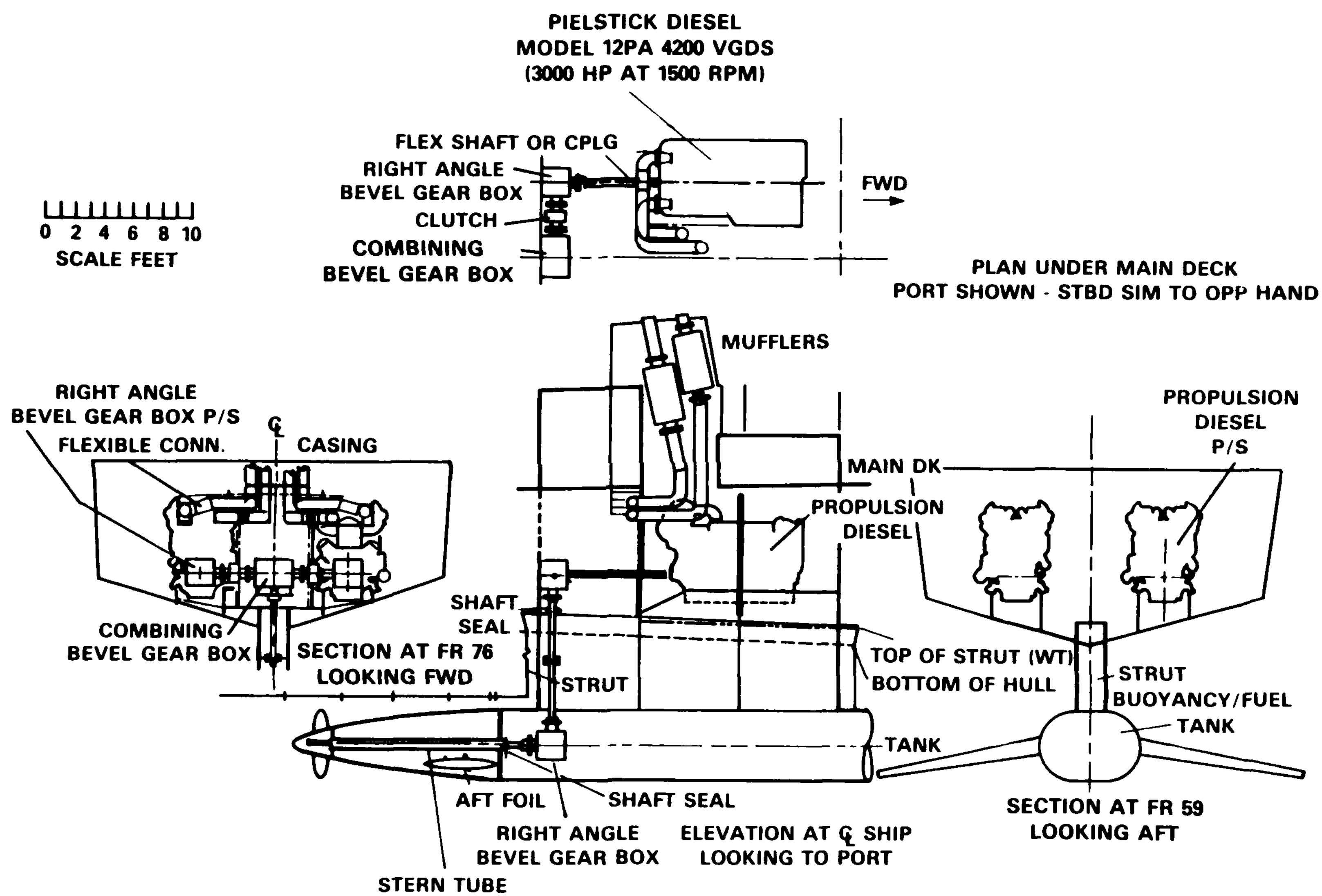


Figure 9 - WPB-HYB Machinery Arrangement

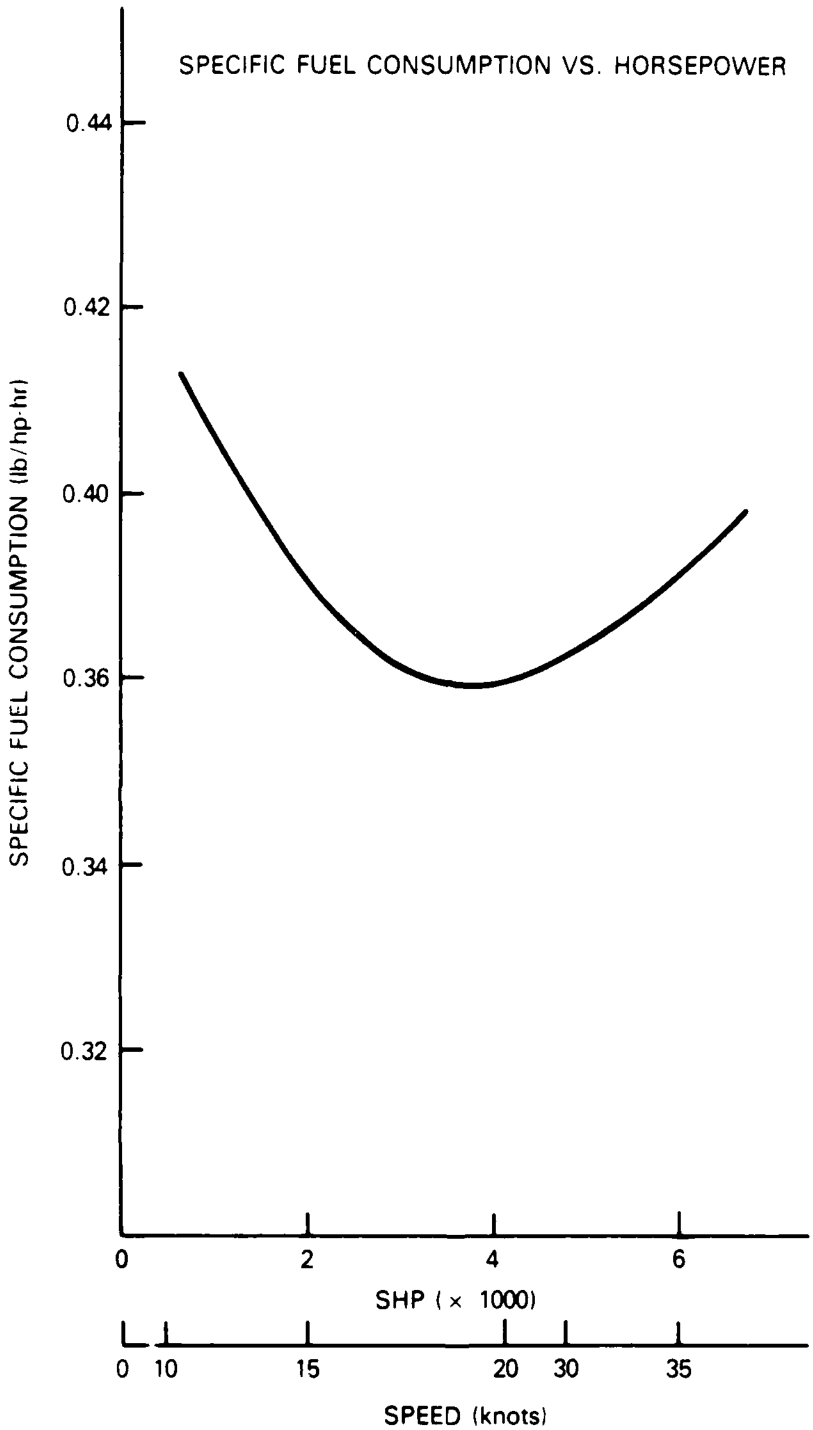


Fig. 10. WPB-HYB Foilborne Powerplant Characteristics

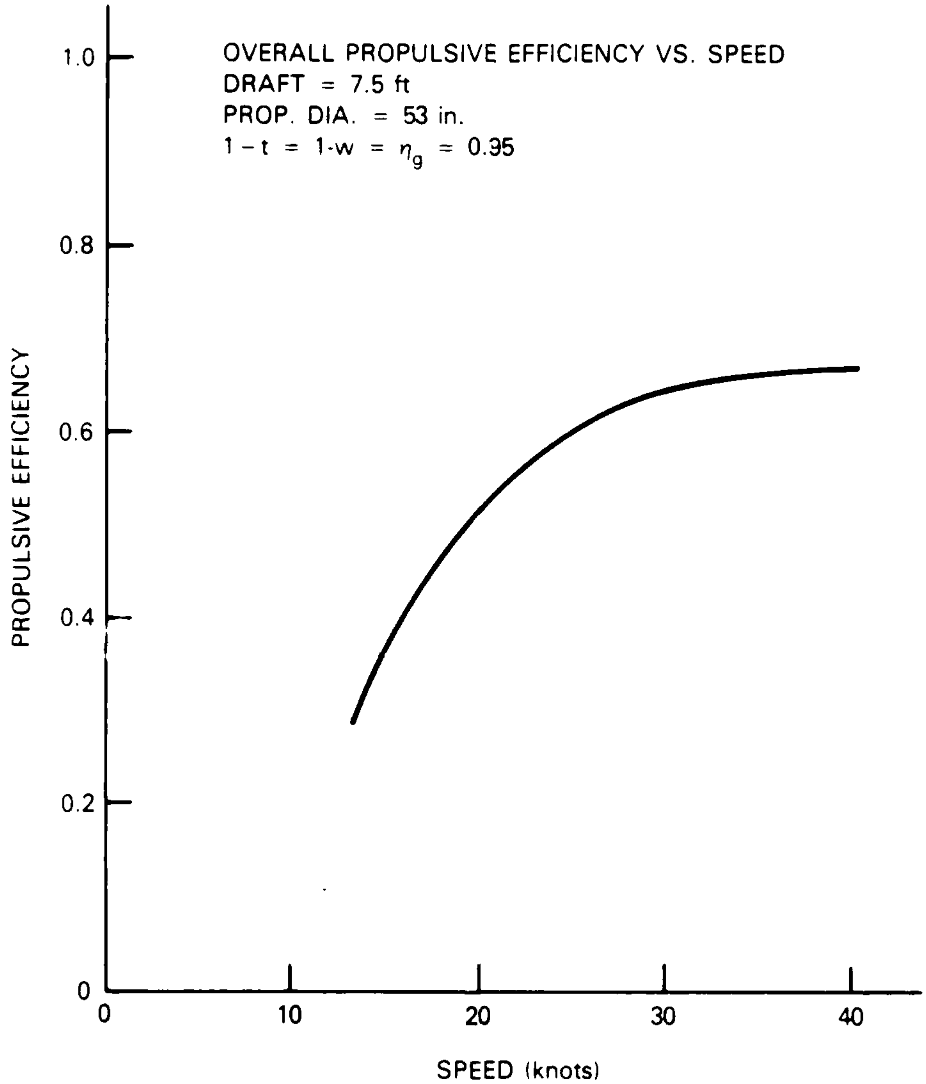


Fig. 11. WPB-HYB Foilborne Propulsive Efficiency

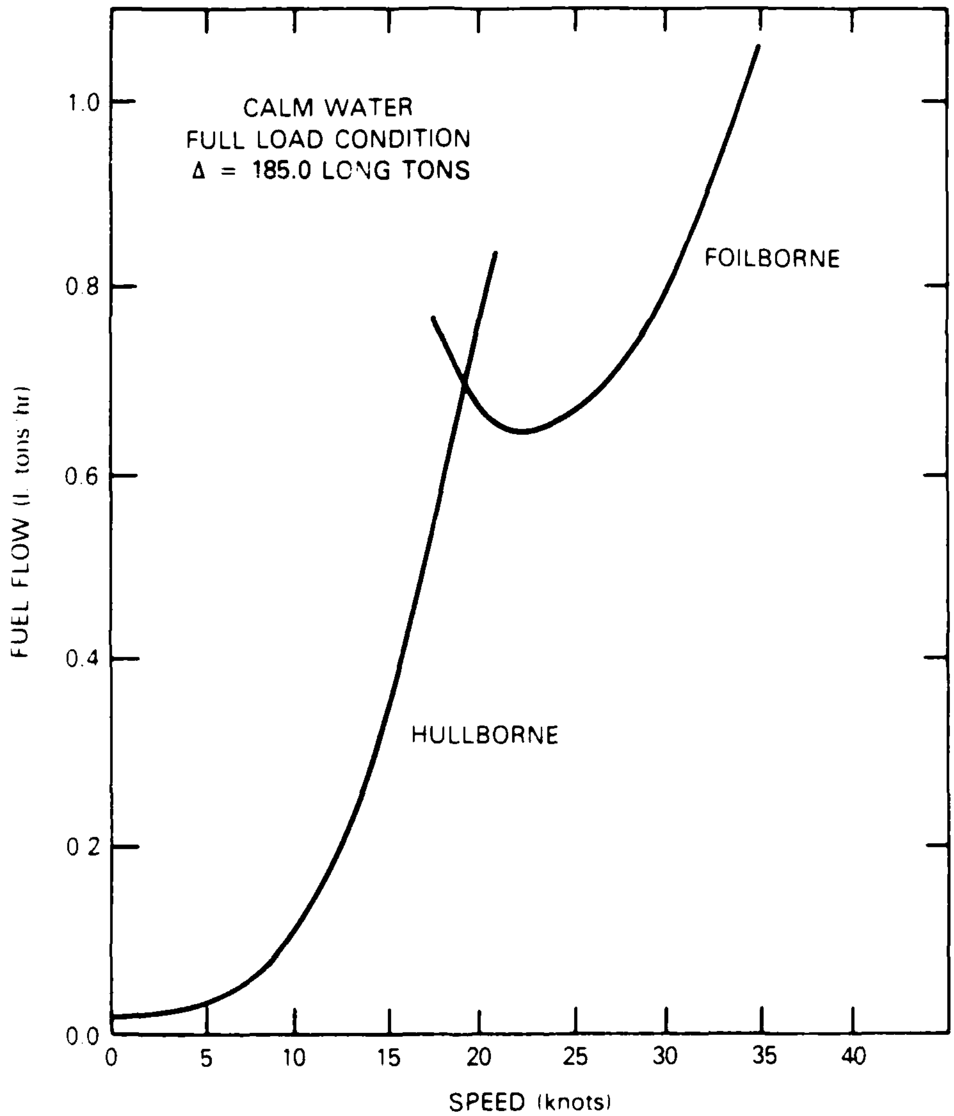


Fig. 12. WPB-HYB Fuel Flow

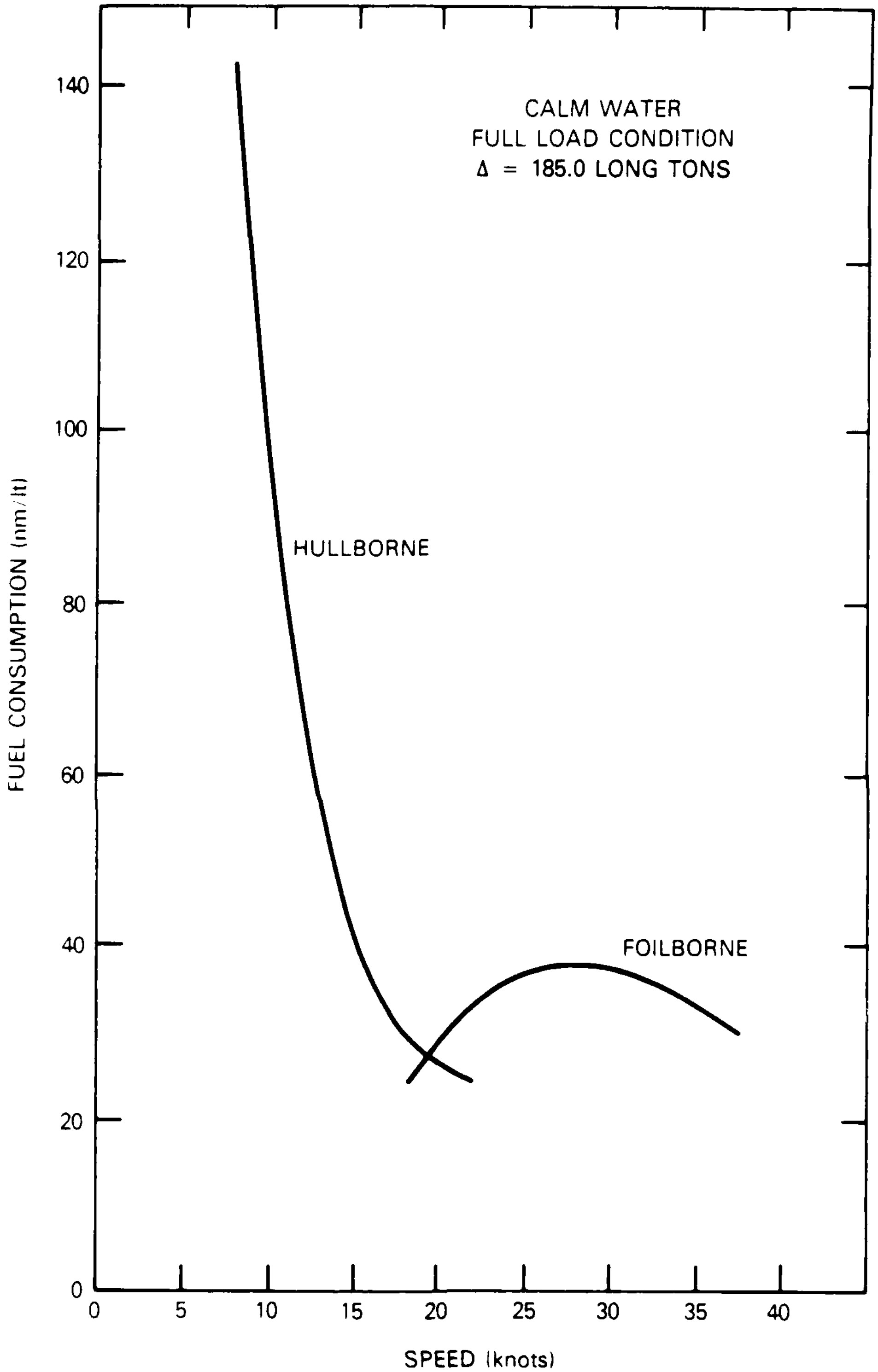
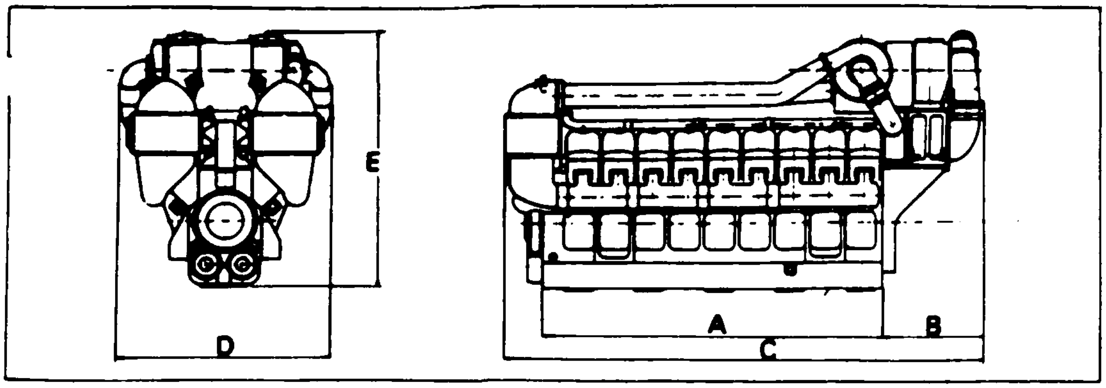


Fig. 13. WPB-HYB Fuel Consumption

Encombrement/Overall size



Dimensions moteur mm Engine Dimensions mm	A	B	C	D	E	Poids (kg) Weight (kg)
8 cyl.	1 405	850	2.578	1.576	2.225	5.100
12 cyl.	2.005	645	2.973	1.450	2.155	7.000
16 cyl.	2.605	850	3.795	1.850	2.225	9.120
18 cyl.	2.905	850	4.095	1.850	2.225	10.020

Performances

puissance minimum continue (72 h)	puissance maxi continue	puissance intermittente	puissance de pointe
minimum continuous rating (72 h)	maxi. continuous rating	intermittent rating	sprint rating
à 450 tr/mn 6.9 ch/cyl ou 5.1 kW/cyl. at 450 r.p.m. 6.9 HP/cyl or 5.1 kW/cyl	à 1500 tr/mn 250 ch/cyl. ou 184 kW/cyl. at 1500 r.p.m. 250 HP/cyl. or 184 kW/cyl.	à 1550 tr/mn 275 ch/cyl. ou 202 kW/cyl. at 1550 r.p.m. 275 HP/cyl. or 202 kW/cyl.	à 1595 tr/mn 300 ch/cyl. ou 221 kW/cyl. at 1595 r.p.m. 300 HP/cyl. or 221 kW/cyl.

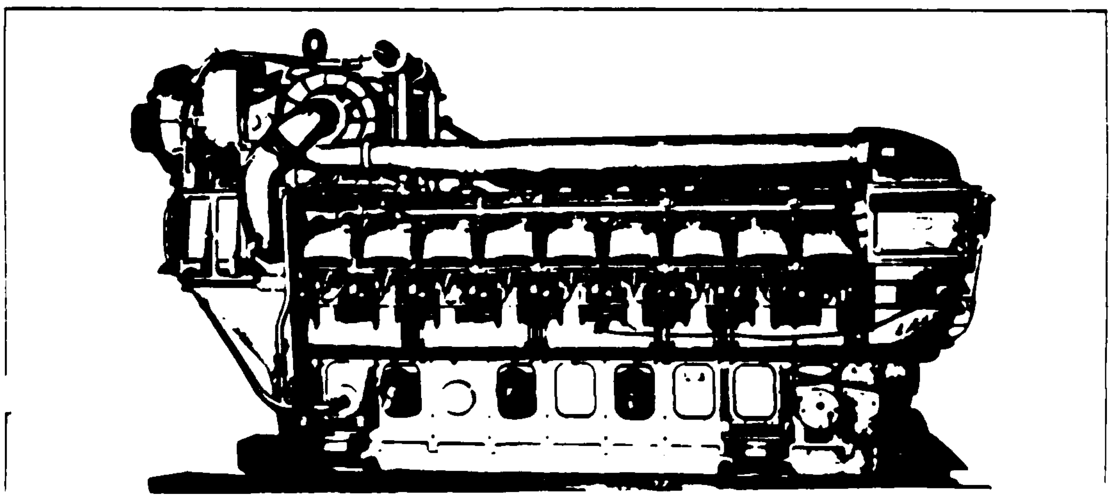


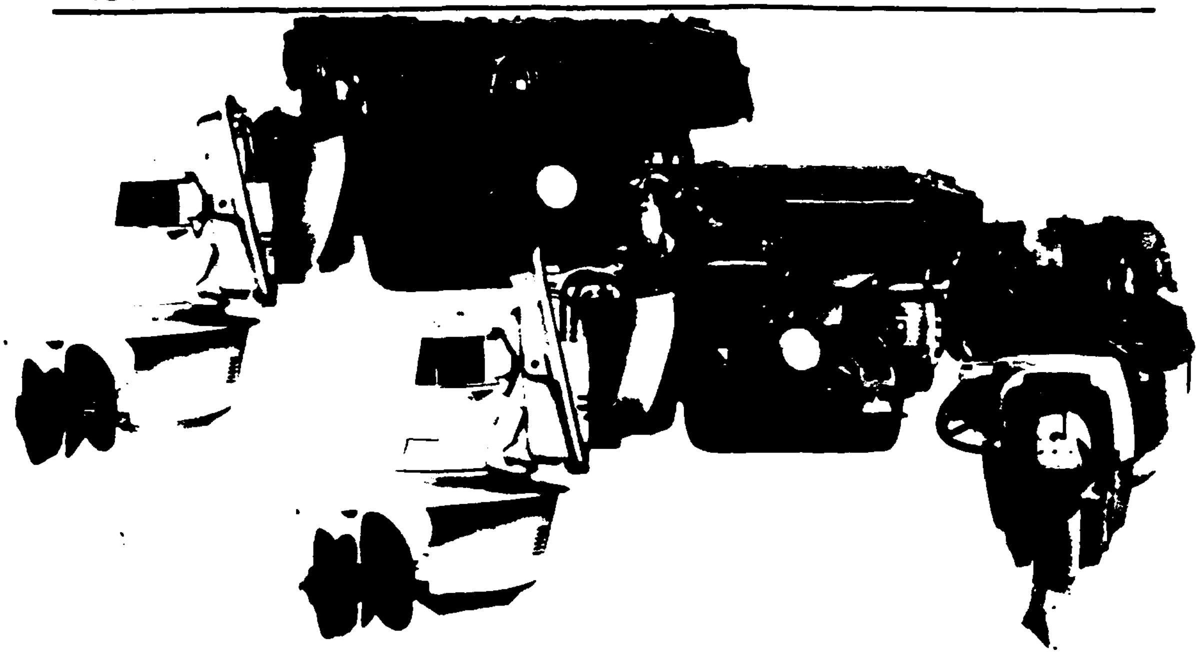
Fig. 14. WPB-HYB Main Powerplant Characteristics

The main propulsion system is used for hullborne speeds greater than 7 knots and for foilborne operations. However, there is an auxiliary propulsion system to provide: (1) take home power, (2) a low speed, high endurance loitering capability, and (3) manuevering capability for harbors, confined waters and docking. This propulsion system consists of two Volvo-Penta inboard diesel engines, 110 hp each, that are located in the aft-most compartment. Each engine drives a retractable, rotatable stern drive with a fixed pitch propeller. These engines provide a high degree of maneuverability at low speeds. They also eliminate the need for a reversing gear on the main propulsion engines. The stern drives are retractable to minimize drag and to avoid damage while in the foilborne mode. The performance parameters for this system are shown in Figure 15.

VOLVO PENTA OF AMERICA
PRODUCT BULLETIN

AQAD30A/DP
AQAD40B/DP

DUOPROP®



Engine Data

Engine Model/Transmission	AQAD30A/DP	AQAD40B/DP
Type of Operation	Four stroke marine diesel engine with swirl combustion chamber design	
Flywheel Output at 3600 rpm	[illegible] hp (81 kw)	165 hp (121 kw)
Number of Cylinders	4 in-line	6 in-line
Displacement	146	220
Operating Range/Max	[illegible]/3600	
Fuel Type	Diesel	
Bore/Stroke Inches	[illegible] 62/3.54	
Compression Ratio	[illegible]	
Valves	Overhead	

	AQAD30A/DP	AQAD40B/DP
Gear Type	DUOPROP	
Gear Ratio	2.30:1	1.95:1
Weight With DUOPROP	941 lbs	1162 lbs
Fresh Water Cooled	Standard	
Turbocharger	Standard	
Aftercooled	Standard	
Power Tilt	Standard	
Power Trim	Standard	
Power Steering	Available	Standard

Two engines with high output to weight ratios designed for marine applications and turbocharging.

Cast iron engine block and cylinder head, oil cooled pistons, thermostatically controlled fresh water cooling systems, five main bearing crankshaft on 30 series and seven main bearing crankshaft on the 40 series, and wet replaceable cylinder liners. A marine 12 volt electrical system and an alternator with a charging output of 14 volts 50 Amps.

These turbocharged, aftercooled dieselis are combined with the revolutionary Duoprop drive system which feature matched contra-rotating propellers that deliver more efficient power. This DP package is a true performer. Duoprop delivers up to 10-15% greater thrust than a conventional single propeller drive. Duoprop provides improved steering capabilities, faster boat planing, increased maneuverability and better fuel economy. The Duoprop is now combined with the newly engineered 290 transom shield kit offering power trim as standard equipment. This shield provides precision alignment and a custom fitted rubber gasket to insure a permanent transom seal. A built-in digital power trim indicator monitors trim angles and settings eliminating the guesswork when setting trim.

VOLVO PENTA

duoprop

Flywheel output [illegible]

Fig. 15. WPB-HYB Auxiliary Powerplant Characteristics

INTACT STABILITY

The addition of a buoyancy/fuel tank to a conventional hull produces two effects that relate to the safety of the ship under high beam wind loading. The first is independent of the net weight or buoyancy of the fuel/ballast tank, and is an increase in the ship's heeling moment, for a given wind, due to a lower center of lateral resistance for the underwater appendage. The second effect is related to the tank's net weight, with positive buoyancy detracting from the ship's righting moment at any heel angle and negative buoyancy providing an improvement.

The intact stability calculations were conducted using the U.S. Navy's SHCP (Ship Hull Characteristics Program) computer program for a range of displacements and vertical centers of gravity covering anticipated operating conditions for the ship. These plots provided a "map" of stability for a variety of loading conditions. The result is Figure 16. This figure shows the WPB-HYB's maximum allowable vertical center of gravity versus displacement. A point on the "70 kt beam wind" curve would meet the minimum intact stability requirements with a seventy knot beam wind. A second curve is shown to indicate the allowable kg for a more moderate beam wind. Detailed calculations are given in Appendix C.

The criteria applied to this design is as outlined in the U.S. Navy's Design Data Sheet 079-1, "Stability and Buoyancy of U.S. Naval Surface Ships". The criteria used is the "six-tenths" righting arm rule exclusively, and does not include the area criteria used for conventional ships to account for roll energy. The reason is that the WPB-HYB with the buoyancy/fuel tank will have roll characteristics that do not relate to a conventional hull; i.e., the amount of roll damping will be very high. Therefore, the conventional roll energy approach does not appear to be valid. Stability analysis based on righting arms alone is considered adequate.

A summary of the factors related to the hydrostatic analysis is shown in Table 5 for the full load and minimum operating conditions. Since the fuel in the tank is replaced by saltwater as fuel is removed, the minimum operating condition displacement does not change, to a great extent, from the full load displacement. In addition, the stability actually increases with the lighter fuel being replaced by saltwater very low in the ship. Consequently, only the full load operating condition is shown in the stability plots.

The minimum operating condition assumes that all of the fuel, stores and water in the tank and strut have been used, and that the fuel in the buoyancy/fuel tank has been replaced with salt water. It is also assumed that the upper hull fuel tanks; i.e., service tanks, are still full of fuel. A 10% margin has been added to the vertical center of gravity.

Plots of intact stability and cross curves of stability are shown in Figures 17 and 18. Clearly, for a 70 knot beam wind, the intact stability criteria is satisfied. Detailed stability information is included in Appendix C.

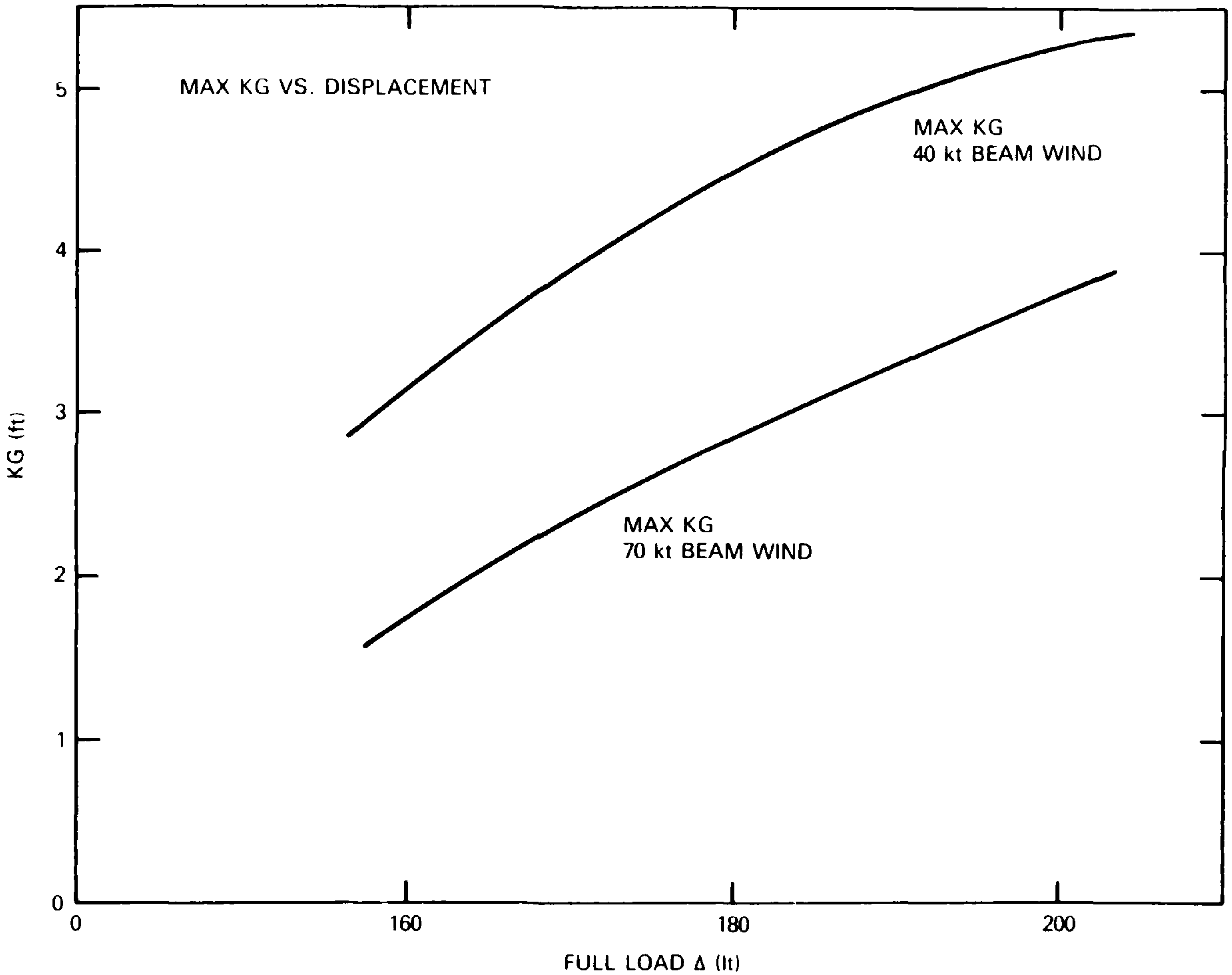


Fig. 16. WPB-HYB Maximum Allowable KG

TABLE 5.
WPB-HYB HYDROSTATIC ANALYSIS SUMMARY

	Full Load	Min. Op.
Displacement (tons)	185.0	181.5
Draft Foilborne (feet)	7.0	7.0
Draft Hullborne (feet)	13.3	13.2
Max Beam @ HB WL (feet)	24.4	24.4
Vertical Center of Gravity-KG (feet)	2.26	2.05
Limiting KG (feet)	3.05	2.90
Vertical Center of Buoyancy-KB (feet)	−1.13	−1.26
BM_T (feet)	9.22	9.14
GM = KB + BM − KG	5.83	5.83
Longitudinal Center of Buoyancy (feet aft of amidships)	−7.4	−7.2
Longitudinal Center of Gravity (feet aft of amidships)	−6.8	−6.6
Moment to Trim 1"	20.3	19.9
Trim (+ By the Bow) (ft)/(deg)	+0.61"/0.35°	+0.61"/0.35°
Longitudinal Center of Flotation (feet aft of amidships)	−14.5	−14.8

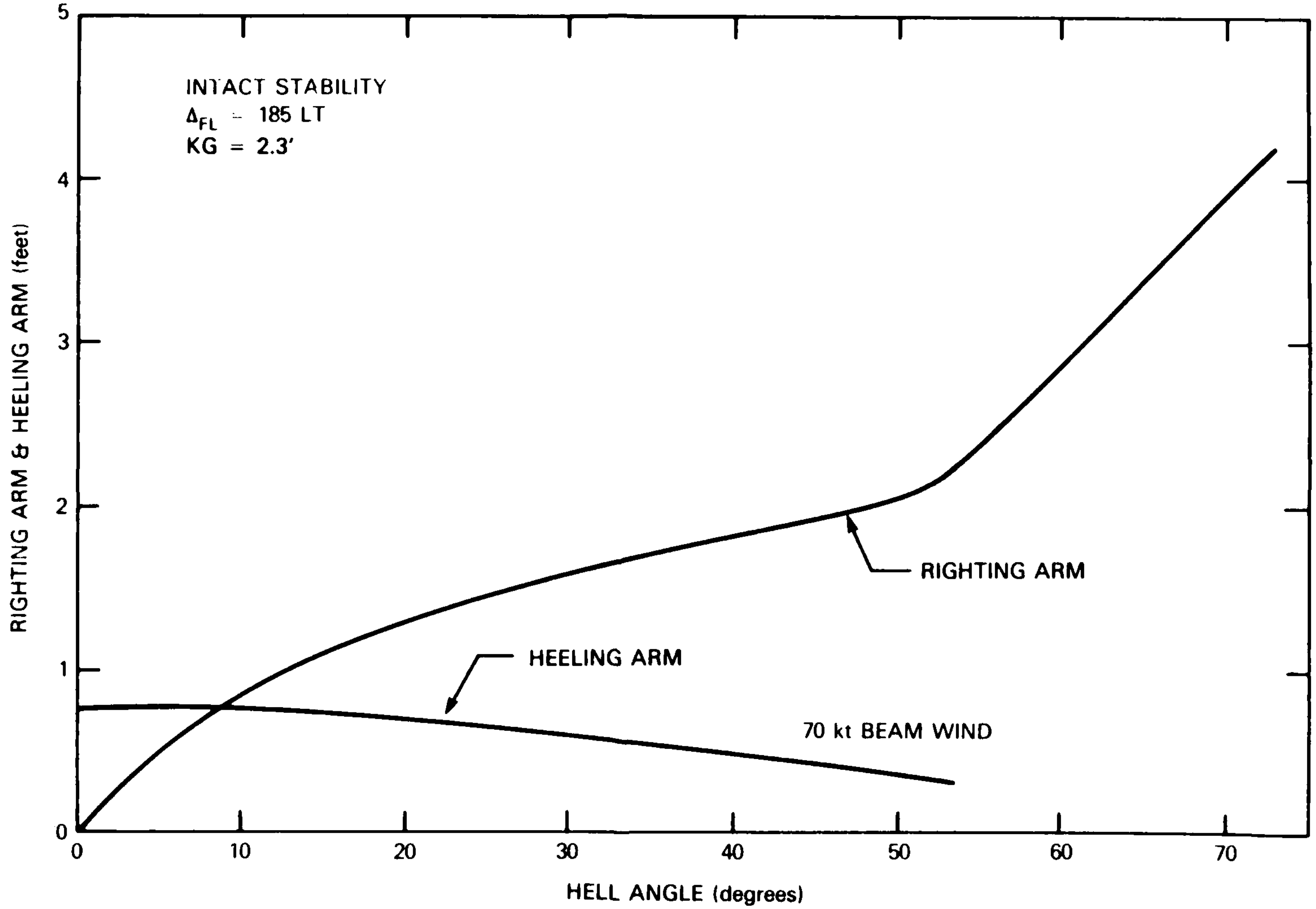


Fig. 17. WPB-HYB Intact Stability Characteristics

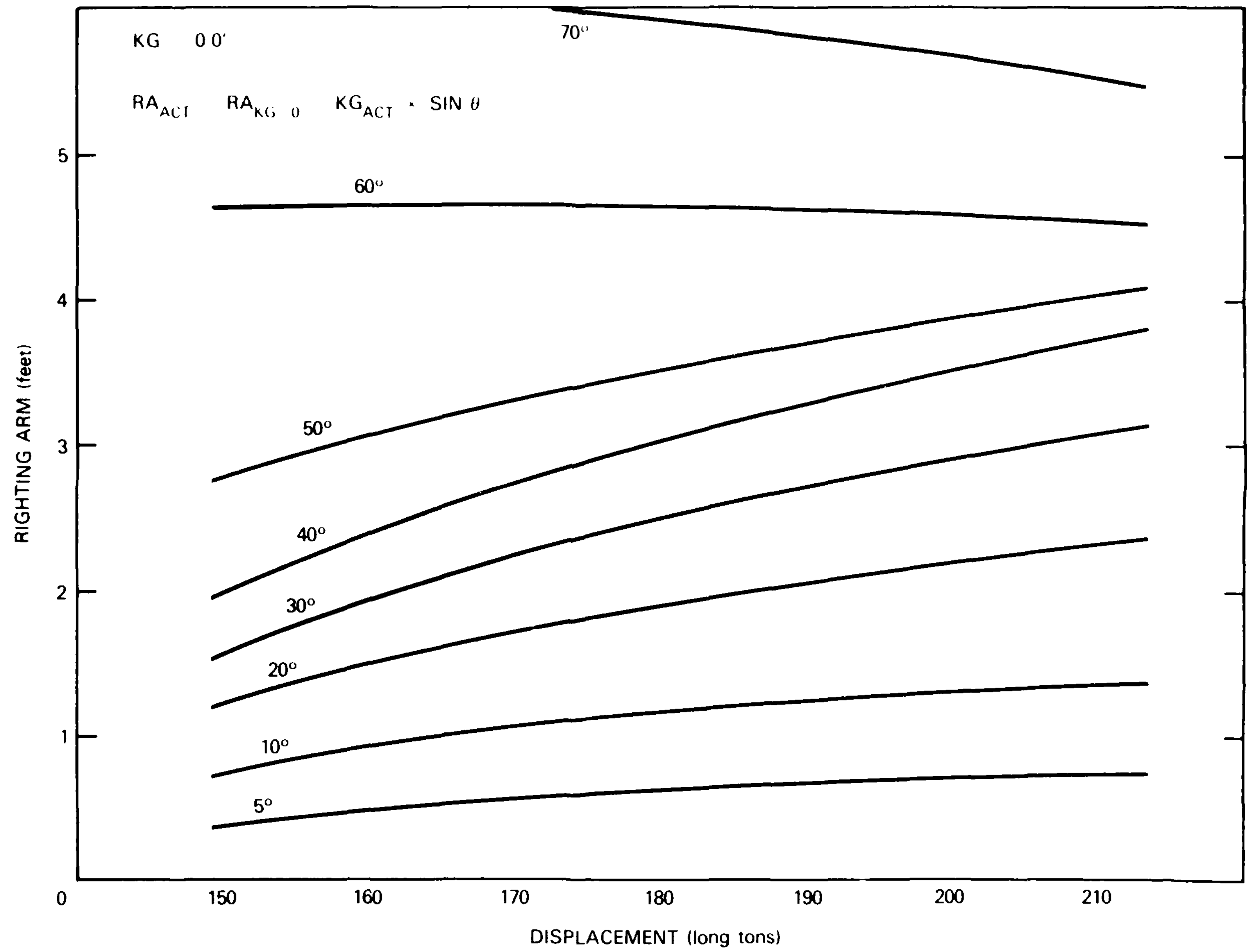


Fig. 18. WPB-HYB Cross Curves of Stability

DAMAGED STABILITY

Locations for the watertight bulkheads are based on the floodable length curve shown in Figure 19. Floodable length calculations are performed on the ship in the full load condition which is the governing case. The margin line was taken to be three inches below and parallel to the sheer line. The criteria imposed is that the ship survive the flooding of any two adjacent compartments, with no specified length of damage. The floodable length curve shows that the applicable standard is met.

An investigation of the craft's damaged stability is also performed for the ship's full load condition. A two compartment damage condition is imposed and a wind velocity of 40 knots is assumed. The results are shown in Figure 20. This graph shows only the worst case, damage at Frame 85. All combinations of damage were considered but are omitted for clarity.

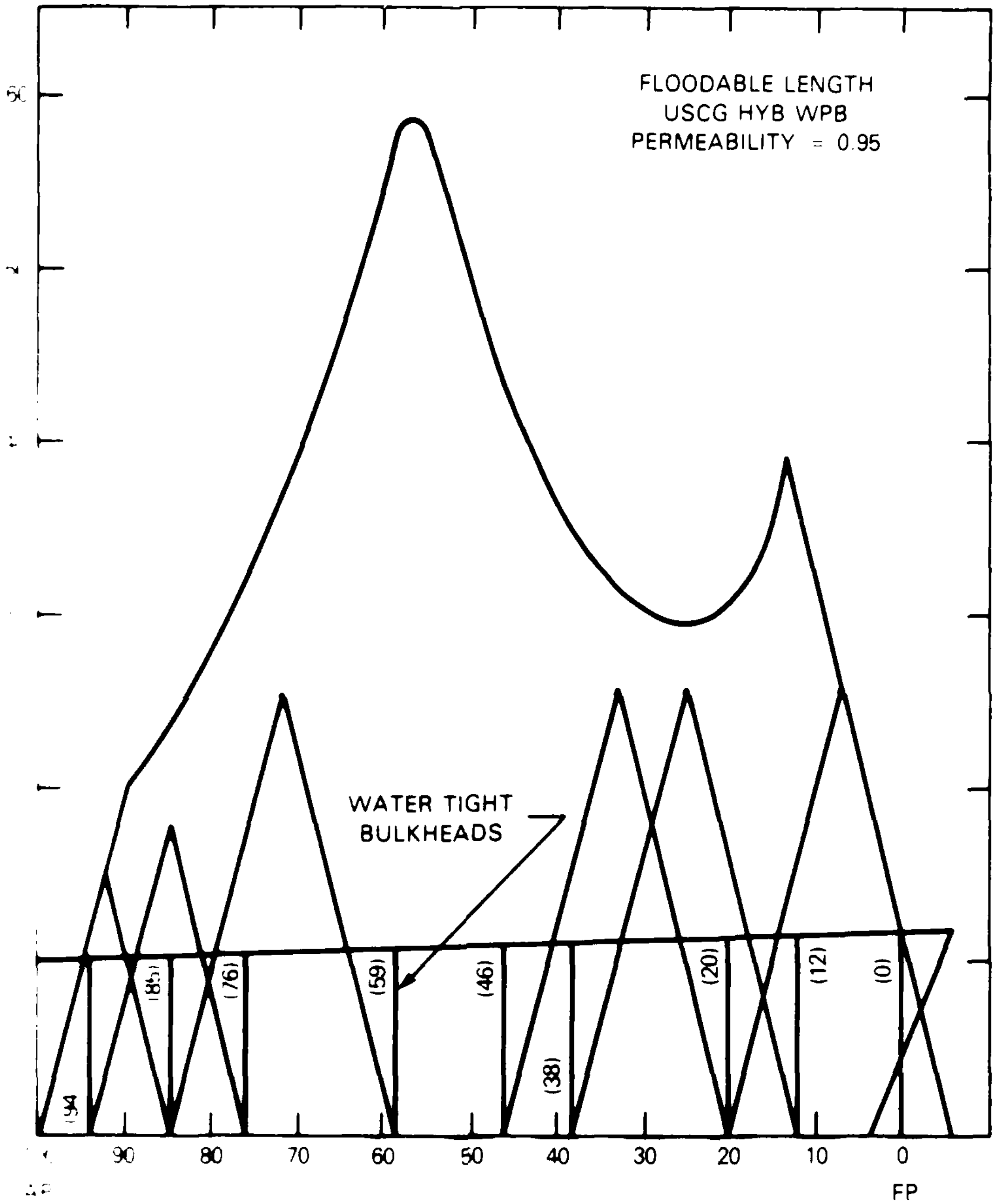


Fig. 19. WPB-HYB Floodable Length Curve

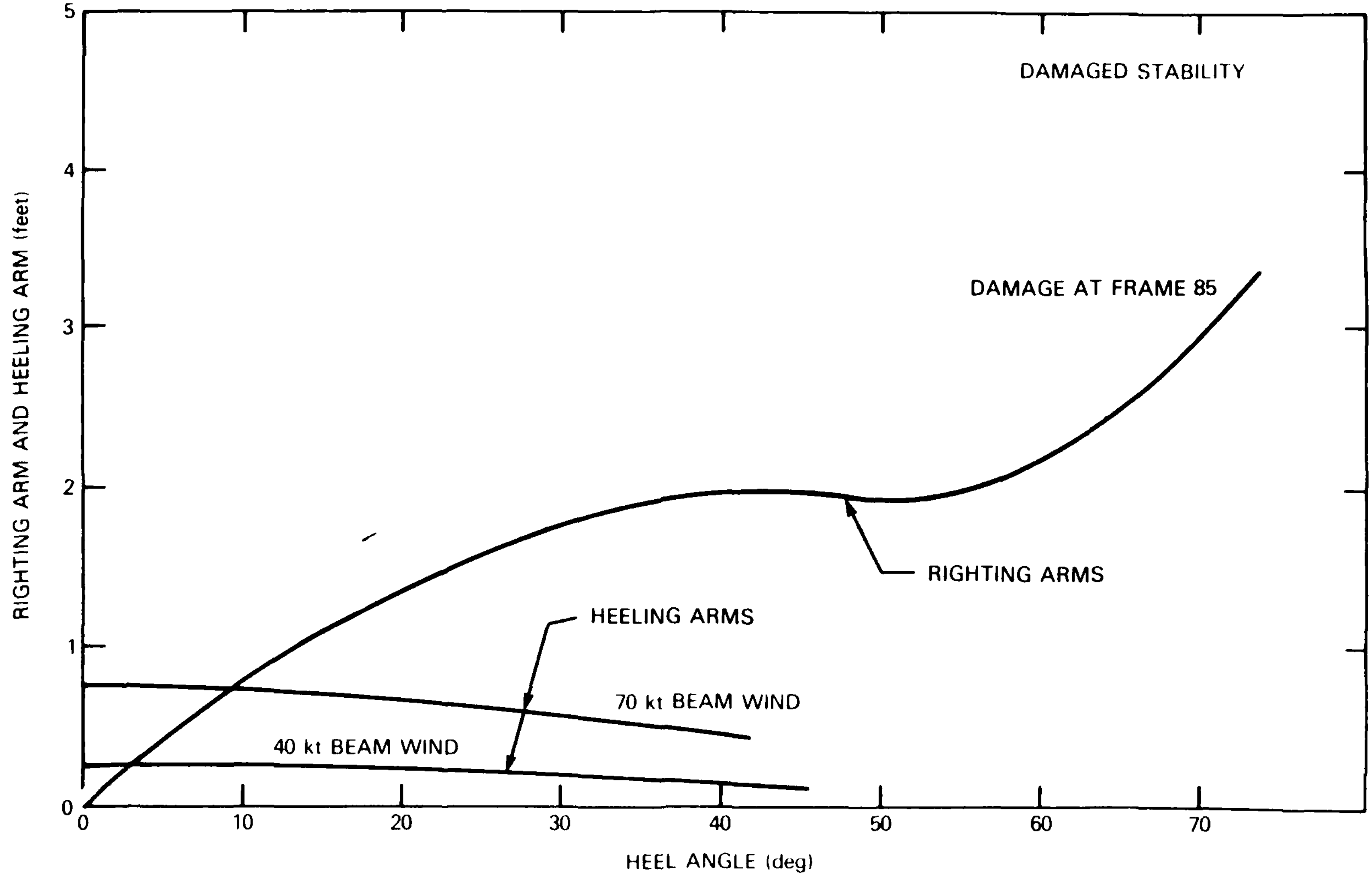


Fig. 20. WPB-HYB Damaged Stability

OPERATIONAL CHARACTERISTICS

RANGE AND ENDURANCE

Range and endurance versus speed characteristics of the ship are shown in Figures 21 and 22. Calculations were based on the full load condition. The available volume for the fuel load is taken to be 90% of the volume in the fuel/ballast cells, with 10% reserved for structure and unremoveable salt water ballast. Useable fuel is calculated as 95% of the fuel load, and 10% of this amount is considered as reserve. The total available fuel load is 36.1 long tons. Of this total, 23.7 tons is located in the B/F tank, 2.9 tons in the strut and 9.5 tons in the upper hull.

Calculations result in a hullborne range of 2382 nautical miles (nm) at 12 knots which translates into an endurance of 199 hours. In the foilborne mode, the range is 1377 nm at 30 knots which translates into an endurance of 49.2 hours. These calculations include an auxiliary fuel rate of 33 lb/hr.

For the five day mission, a hullborne speed of 12 knots, for 96 hours, and a foilborne speed of 28 knots, for 24 hours, requires a total of 35.1 long tons of fuel. The fuel available, subtracting the 10% reserve, is greater by approximately 1 ton. At these speeds, the total distance covered is 1824 nm in five days. This mixed mode of operating the WPB-HYB increases the ship's range and endurance in the 10 to 30 knot speed range. Several mixed mode examples are shown in Table 6. The increase in range and endurance, using a mixed mode operation, is shown by the dashed line in Figures 21 and 22.

TABLE 6.
MIXED MODE OPERATION

	Ship Speed (fb/hb, knots)	Fuel Usage (hr/lt)	Endurance (hours)	Range (nm)	Avg. Speed (knots)
A.	28	1.362	24	672	15.1
	12	5.5	+ 101.6	+ 1220	
			125.6	1892	
B.	30	1.253	24	720	12.6
	10	9.44	+ 160	+ 1600	
			184	2320	
C.	22	1.544	36	792	12.7
	10	9.44	+ 121.7	+ 1212	
			157.7	2002	

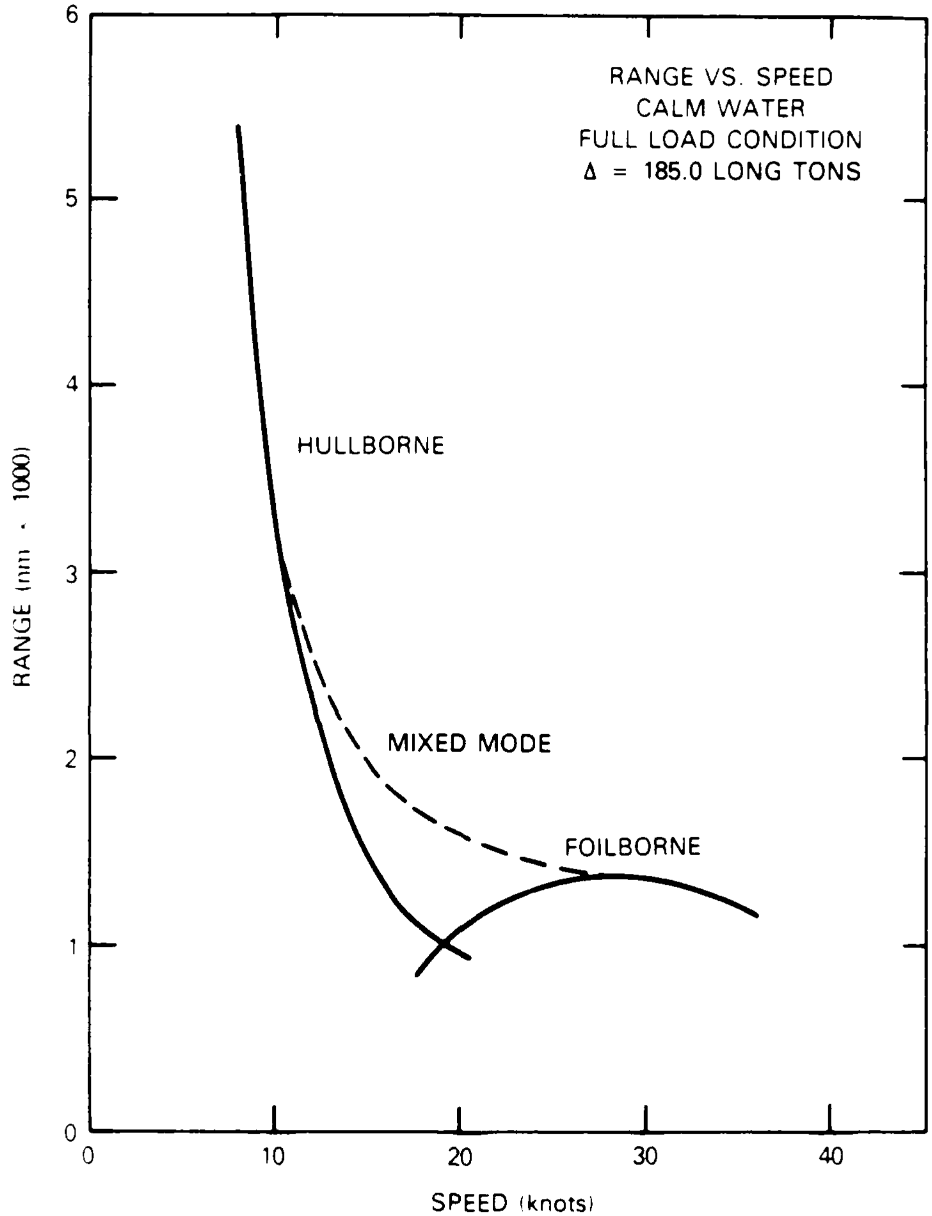


Fig. 21. WPB-HYB Range Characteristics

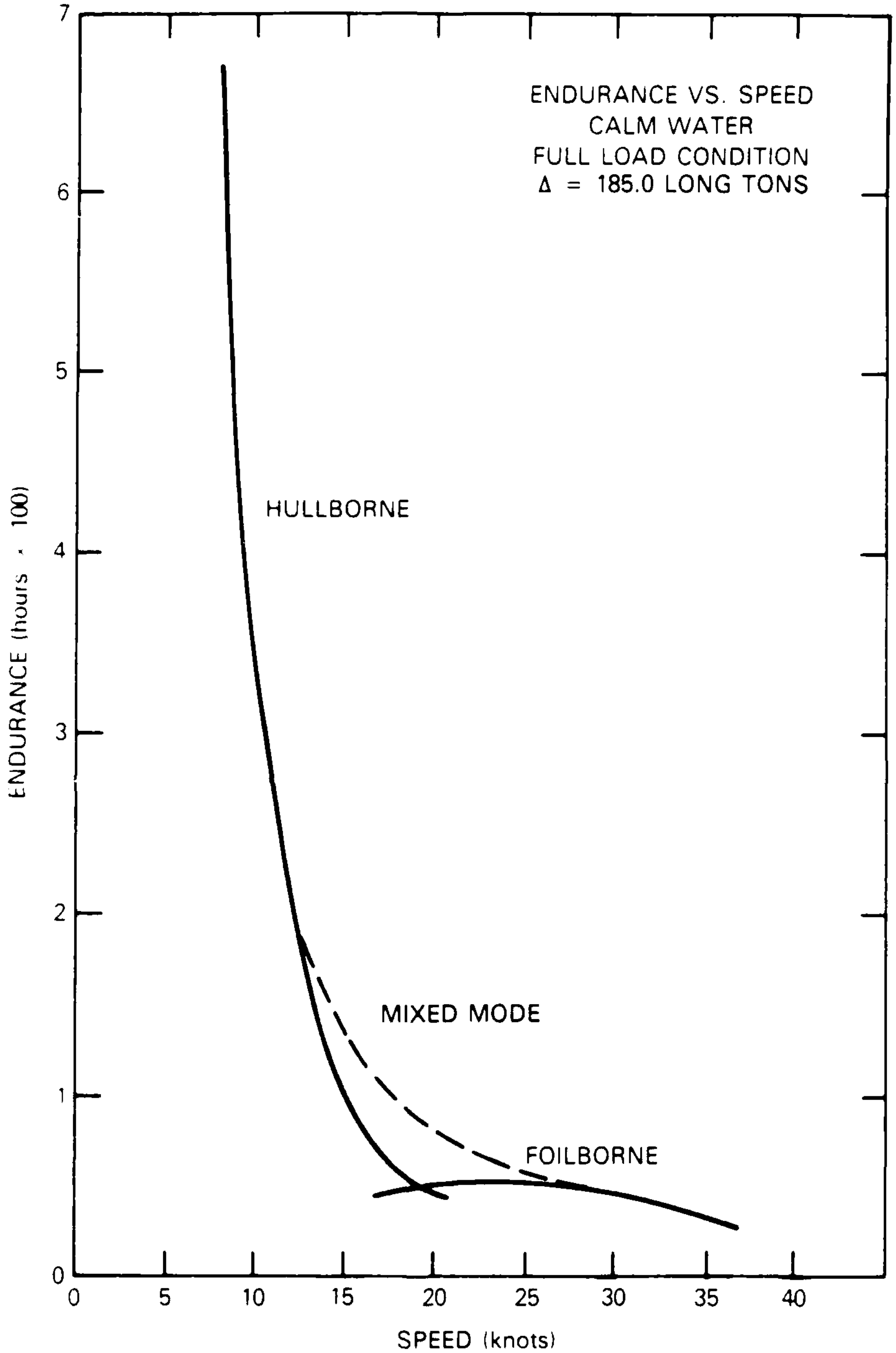


Fig. 22. WPB-HYB Endurance Characteristics

MANEUVERABILITY

Turning Performance

Foilborne turning performance has not been rigorously analyzed for the particular hybrid configuration described in this report because it is beyond the scope and funding of this study. However, there are certain observations that can be made that relate to this characteristic. Hydrofoils are well known for their high turn-rate capability since they bank to turn with the control system designed to produce a coordinated turn. Rates of 6° to 8° per sec at 40 knots or more are normal for conventional hydrofoils with fully submerged foil systems. The addition of a large buoyancy/fuel tank to a fully submerged foil system is predicted, from reference 3 computer simulation of the Extended Performance Hydrofoil (EPH) PCH-1 Feasibility Demonstrator, to degrade turning characteristics approximately 25%. However, it should be noted that during model tests of the EPH configuration (see Reference 4) that full-scale foilborne turn rates of up to 8° per second were accomplished. This implies that no degradation in turn rate of EPH may be experienced. The use of a long central strut in place of the four separate relatively short chord struts of the EPH model introduces an element of unknown into the picture, and is expected to add directional stability (reduce achievable turn rates). The use of a large rudder in the current hybrid design tends to follow the lessons learned from the EPH model and provides a reasonable assurance that turn-rates of 4 to 6 degrees per second at 35 knots may be achieved.

Hullborne Maneuverability

The issue of hullborne maneuvering is centered on the capability of the hybrid ship, discussed in this report, to safely maneuver in a harbor in the presence of other vessels or objects, and dock under reasonable conditions of wind and current. The combination of a large rudder and rotatable stern drives is expected to assure safe harbor operations, docking, and undocking *without any particular problems*. Additional hullborne maneuverability is possible if a bow thruster is installed. The latter may be necessary on this hybrid design in view of the increased lateral plane area due to the strut and tank, and effects of current on the additional area. At low hullborne speeds, the WPB-HYB will not be as maneuverable as the current WPB.

The main foil overhang, about 2 ft beyond the main hull, can be accommodated by the use of camels and/or a foil guard added to the hull over the main foil location. A foil guard is currently used on HIGHPOINT (PCH-1) R&D hydrofoil and has been satisfactory in over 20 years of operations. The PHM hydrofoils utilize a floating platform between the ship and pier to accommodate an aft foil overhang of about 9 ft.

TOWING

The requirement exists to tow a 500-ton disabled ship at 5 knots. The estimated power required for WPB-HYB at 5 knots is about 80 shp. Since the power available from the auxiliary propulsion diesels is 220 shp, the power available for towing is 140 hp. This is equivalent to a thrust available of about 6,200 lbs at 5 knots assuming a propulsive efficiency of 65%. The drag of a 500-ton ship at 5 knots is estimated at approximately 5,000 lbs. Therefore, the WPB-HYB has the towing capability required. If more thrust is needed, towing can easily be accomplished using one of the main propulsion diesels.

MOTIONS

As in the case of Maneuverability, funding for this feasibility study did not permit a rigorous treatment of motions prediction for the Hybrid Concept described in this report. An understanding of motions to be expected of this hybrid design may be derived from a long history of hydrofoil experience and model tests of EPH as documented in Reference 4. For example, Figure 23 shows a comparison of HIGHPOINT (PCH-1) trials and simulation data compared with EPH model tests. The PCH-1 vertical acceleration data are for the pilot house location, whereas model data is for bow and center of gravity locations. One can see that EPH "pilot house" data would fall above, but close to, PCH-1 data indicating only a small degradation in vertical motions due to an addition of a buoyancy/fuel tank.

Additional relative vertical acceleration measures are shown in Figure 24. Here, data for the c.g. location are plotted for a 95′ WPB, Bell-Halter SES, RHS-160, JETFOIL, and EPH model tests. A band indicating anticipated motions of the USCG Hybrid Concept described in this report is also shown as a probable estimate.

Figure 25 depicts pictorially the relative position of an existing 95′ WPB and the hybrid design in a 10-foot high wave system (comparable to significant wave height of mid Sea State 5). It can readily be appreciated from this representation that although the upper hull of the hybrid form will be impacted by wave tops, the motions therefrom are likely to be similar to the 95′ WPB in a much smaller wave system. Further evidence of this trend can be derived from the fact that during certain EPH test model runs, the upper hull ran closer to the water surface than programmed. These were first considered "bad" runs, but subsequent review of video tapes and movies indicated that the motions did not appear visually to be any greater than on "good" runs when the keel rode higher above the mean water surface. This visual observation is further verified by the data in Table 7 and augmented by a video tape of EPH model test runs 248, 249, 250, and others.

It is therefore projected that motions, both hullborne and foilborne, of the hybrid design will be greatly improved over the current WPB and allow high speed operations between 30 and 35 knots in rough water up thru mid Sea State 5. Ride quality and associated crew performance will likewise be significantly enhanced.

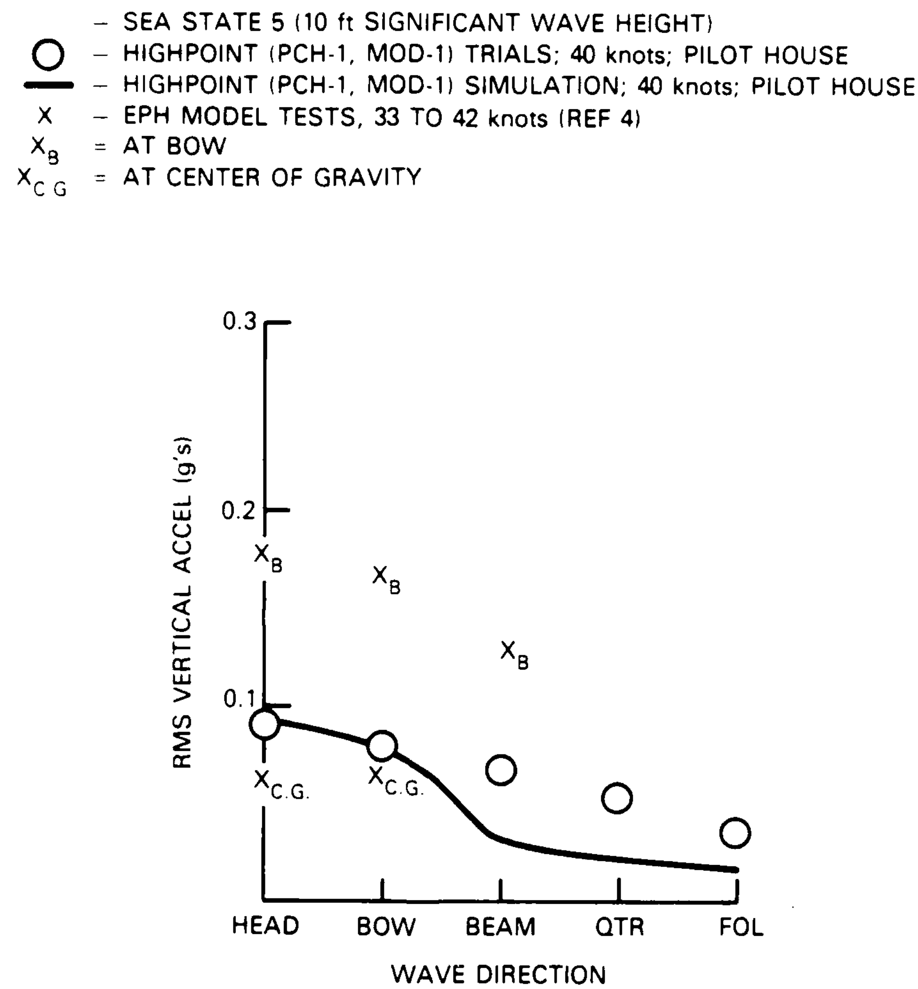


Fig. 23. Comparison of PCH-1 and EPH Vertical Motions

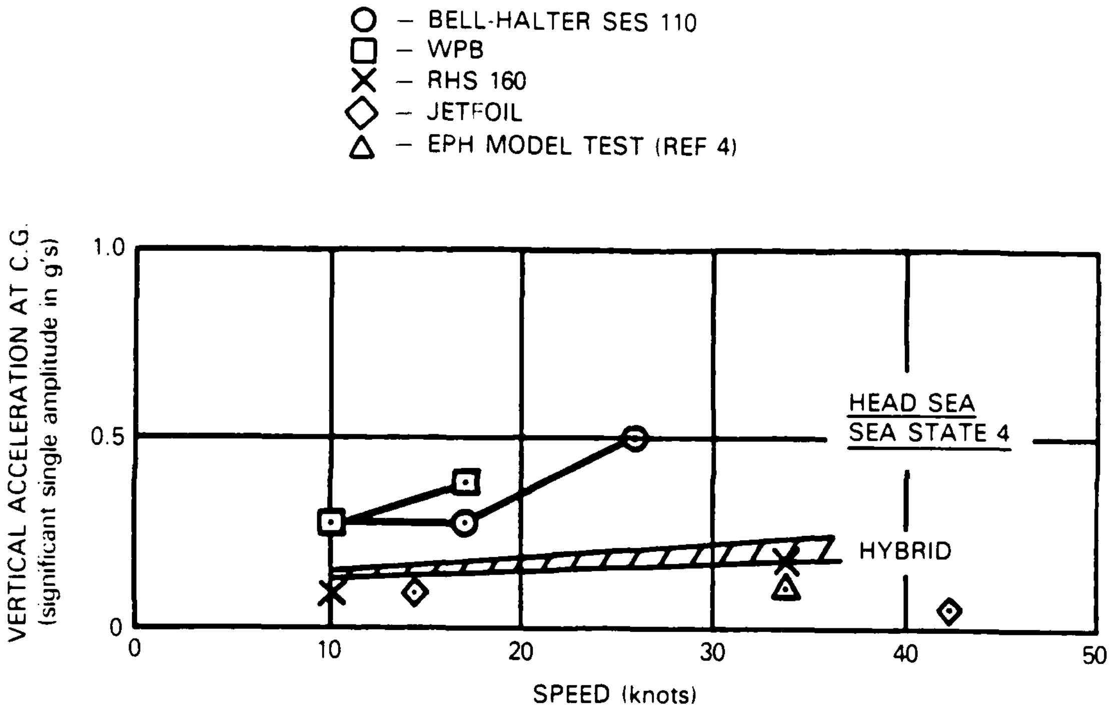


Fig. 24. Vertical Acceleration Comparison

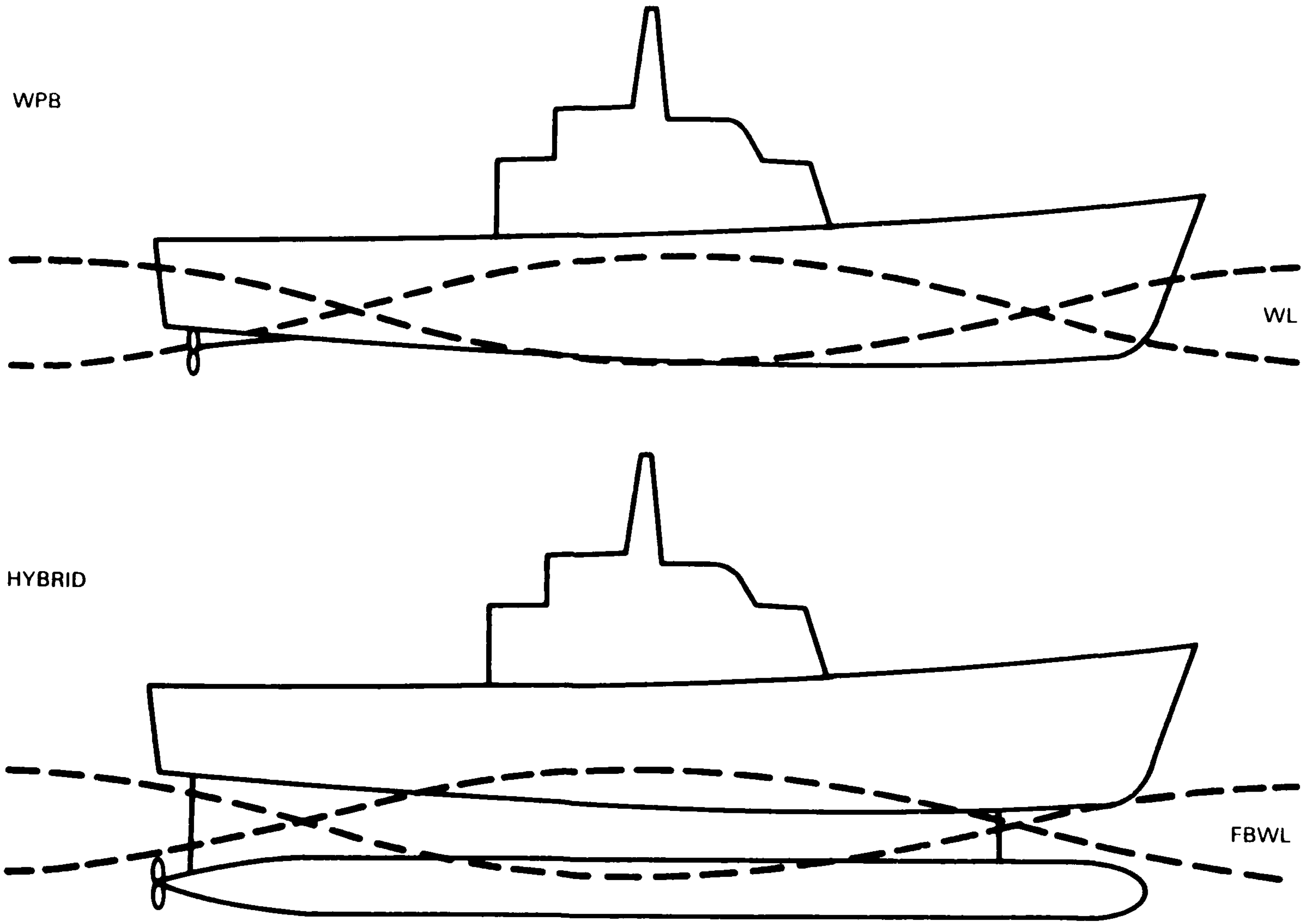


Fig. 25. Comparison of WPB & Hybrid in 10 ft Waves

TABLE 7.
COMPARISON OF EPH RUNS (FULL SCALE VALUES)*

Speed:	33.5 kts
Wave Condition:	Regular
Wave Height:	8.3 ft
Wave Length:	150 ft
Heading:	180°
Maneuver:	Zig-Zag

Run No.	Flying Height	Transfer Functions			rms Values		
		Pitch Amplitude (Amplitude / Wave Slope)	Heave Acceleration (Amplitude / Wave amp × ωe^2) (c.g.)	Bow Acceleration (Amplitude / Wave amp × ωe^2)	Pitch (rms) Degrees	Heave Accel. at c.g. (rms g's)	Bow Accel. (rms g's)
248	High	0.0957	0.105	0.26	0.733	0.067	0 19
249	Low	0.0569	0.0323	0.116	0.645	0.041	0 13
		0.0789	0.0433	0 156	0.645	0.041	0.13
250	High	0.0484	0.0422	0.122	0.670	0.065	0 19
		0.0600	0.0603	0.18	0.574	0.065	0.19

*From Reference 4.

BOAT LAUNCH AND RETRIEVAL

Boat launch and retrieval is essential to the WPB mission. This ship is provided with a 5.4m Rigid Hull Inflatable boat and a small telescoping crane located on the fantail. This arrangement permits the boat to be launched and recovered from either side.

The relatively high GM (5.8 ft at full load) tends to reduce roll amplitudes but increase roll acceleration. However, this acceleration is countered by the tendency of the foils to dampen roll accelerations. The result is relatively low roll angles and low roll accelerations. The foils act in a similar manner to minimize pitch and heave. The WPB-HYB should have excellent boat launch and retrieval capability even at very low hullborne speeds.

COMPARISONS

Table 8 shows how the current WPB-HYB compares with the earlier hybrid design, the 95' WPB class and the SEUS WPB class. Although the hybrid designs are heavier, they clearly out-perform the planing hull WPB's in speed, range at high speed, and motions.

The current hybrid design is larger and slightly heavier than the concept demonstrator. The increase in volume is due to the larger crew size, two spare bunks and a more spacious machinery arrangement. The decrease in range with a slight increase in fuel load is due to a simpler fuel compensating system. This system instantly replaces fuel used with sea water. Consequently, as fuel is burned, the ship displacement does not decrease. A more complicated, air pressurized fuel and ballast management system, as outlined in Reference 1, could be installed to increase the WPB-HYB's range and endurance approximately 30%.

With the addition of the strut, tank and foil system, the navigational draft of the hybrid designs is greater than the planing hull WPBs. However, a USCG survey of WPB homeports indicates that a 14 foot draft would allow the WPB-HYB to utilize 75% of the existing ports.

TABLE 8.
USCG WPB COMPARISON

Item	95′ WPB Class	SEUS WPB	Hybrid Concept Demonstrator	Hybrid WPB
Displacement; L. tons	105.0	161.0	181.0	185.0
Draft; ft	6.3	7.3	14	13.3
LOA; ft	95	110	95	106
LBP; ft	90	105	90	100
Max. Beam; ft	20 at Deck	21 at Deck	30 Across Foils[(1)]	30 Across foils[(2)]
Max. Cont. Power; hp	2400	5760	5920	5920
Fuel Load; L. tons	9	30.6	38	40.1
Crew	14	15	14	16[(3)]
Hull Material[(4)]	Steel	Steel with Al Deck	Steel	Al (Upper Hull) Steel (Lower Hull & Strut)
Max. Speed, kts (full load)	21	29.7	34	34
Range; n. miles (calm water)	3000 at 9 kts 460 at 21 kts	2640 at 13.1 kts 1058 at 26 kts	4180 at 10 kts 2600 at 12.5 kts 1660 at 25 kts	3410 at 10 kts 2380 at 12 kts 1380 at 28 kts
Endurance; hrs (calm water)	333 at 9 kts 22 at 21 kts	201 at 13.1 kts 40.7 at 26 kts	208 at 12.5 kts 66 at 25 kts	198 at 12 kts 52 at 26 kts
5-Day Mission (calm water)		24 hrs at 26 kts 96 hrs at 13.1 kts 1882 n. miles	24 hrs at 30 kts 96 hrs at 13 kts 1968 n. miles	24 hrs at 28 kts 96 hrs at 12.2 kts 1843 n. miles
Motions - Single Amplitude Significant Vertical Acceleration in g's at c.g.	0.43 at 25 kts in SS-3 0.85 at 25 kts in SS-5	0.33 at 25 kts in SS-3 0.78 at 25 kts in SS-5	0.2 at 30 kts in SS-4 (Estimated)	0.2 at 30 kts in SS-4 (Estimated)

Notes: (1) 5 ft foil overhang.
(2) 2 ft foil overhang.
(3) Plus 2 spare bunks.
(4) All ships have Aluminum deckhouse.

CONCLUSIONS

The following conclusions can be drawn from the foregoing work:

1. The hybrid WPB, with a 34 knot foilborne speed and a full load displacement of 185 long tons, satisfies all of the U.S. Coast Guard WPB requirements. The main propulsion system consists of two, SEMT-Pielstick 12PA4200VGDS diesel engines driving a single, fixed pitch propeller, 4.4 feet in diameter, by means of mechanical transmission. The mechanical transmission uses three, right angle, bevel gear boxes and a combining gear box. The engines can be used in either single or tandem operation. The auxiliary propulsion plant, used for station loitering and low speed maneuvering, consists of two, 110 hp diesel engines powering retractable, rotatable stern drives with fixed pitch propellers.

2. The hybrid has sufficient fuel, with a 10% reserve, to operate for 96 hours at 12 knots and 24 hours at 28 knots with a total distance traveled of 1824 nautical miles.

3. Draft of the WPB-HYB has been held less than 14 ft. This meets the goal of being able to homeport in 75% of the U.S. Coast Guard WPB ports.

4. Intact and damaged stability calculations demonstrate that stability criteria are satisfied.

5. Comparison with a current WPB 95 footer and SEUS WPB shows that WPB-HYB has performance advantages in terms of speed, range at high speed and motions in a seaway.

6. The design is technically feasible and utilizes subsystems, components and construction methods and materials that are state-of-the-art.

REFERENCES

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3. Russ, J.E., "Simulated Motions and Loads of an Extended Performance Hydrofoil (EPH) in Calm Water and in Waves," David Taylor Naval Ship R&D Center, Report No. SPD-1000-01, July 1983.

4. Gersten, A., "Motions and Tank Loads in Waves for an Extended Performance Hydrofoil with a Submerged Bouyancy/Fuel Tank," David Taylor Naval Ship R&D Center, Report No. SPD-0942-01, May 1980.

APPENDIX A

USCG WPB HYBRID HYDROFOIL CONCEPT

STRUCTURAL ANALYSIS

NOTE: This material is reproduced directly from Reference 1.

DESIGN NO.	SUBJECT			WBS
M174	USCG HYBRID CONCEPT - TANK SCANTLINGS			
ANALYST		CHECKER	ANALYSIS DATE	PAGE NO.
EEH			5/9/84	A-1

TANK SCANTLINGS

THIN SHORT TUBE - EXTERNAL PRESSURE   ROARK 4 ED PG 354 CASE 31

HEAD = 14'-0" = 6.22 psi   F.S: 5

p' ELASTIC BUCKLING UNIT PRESSURE = 5 × 6.22 = 31.1 psi

$$p' = 0.807 \frac{Et^2}{lr} \sqrt[4]{\left(\frac{1}{1-\nu^2}\right)^3 \frac{t^2}{r^2}} : .807 \frac{(30\times10^6)\,t^2}{(14\times12)(30)} \sqrt[4]{\left(\frac{1}{1-.27^2}\right)^3 \frac{t^2}{30^2}}$$

$$31.1 = 4804 t^2 \sqrt[4]{1.25 \frac{t^2}{900}} = 927.41 t^{\frac{5}{2}}$$

$$t = \left(\frac{31.1}{927.41}\right)^{\frac{2}{5}}$$

$t = .257"$ USE .313" PLT

CHECK FOR INTERNAL PRESSURE   ROARK pg 298 CASE 1

FUELING PRESSURE = 40 psi − 6.22 = 33.78 × 2 = 67.56 psi (F.S)

S_1 (MERIDIONAL MEMBRANE STRESS) $= \frac{PR}{2t}$

$$S_1 = \frac{67.5 \times 29.843}{2 \times .313} = 3218 \text{ psi}$$

S_2 (HOOP WALL STRESS) $= \frac{PR}{t}$

$S_2 = 3218 \times 2 = 6436$ psi

DESIGN NO.	SUBJECT			WBS
M174	USCG HYBRID CONCEPT - TANK SCANTLINGS			
ANALYST		CHECKER	ANALYSIS DATE	PAGE NO.
BEH			5/4/84	A-2

TANK SCANTLINGS (CONT'D)

INTERNAL BURSTING PRESSURE $P_w = 2 S_w \frac{b-a}{b+a}$

ASSUME USING HY80 $f_{tw} = 104{,}600$ psi

$$P_w = 2 \times 104{,}600 \frac{30 - 29.687}{30 + 29.687}$$

$P_w = 1097$ psi

FLAT TOP & BOTTOM ROARK Pg 225 CASE 36

$S_{MAX} = \beta \frac{wb^2}{t^2}$ $\frac{a}{b} = \frac{168}{24} = \eta = \infty$ $\beta = .750$

$$t^2 = \frac{\beta w b^2}{S_{MAX}} = \frac{.750 \times 33.78 \times \overline{24}^2}{55000 \ (\text{HY80 } f_{t_{ALLOW}})} = .265$$

$t = .515''$ USE $.625''$

DESIGN NO.	SUBJECT		WBS
M174	USCG HYBRID CONCEPT - TANK SCANTLINGS		

ANALYST	CHECKER	ANALYSIS DATE	PAGE NO.
BZH		5/4/84	A-3

TANK SCANTLINGS (CONT'D)

INTERNAL BURSTING PRESSURE $P_w = 2 S_w \frac{b-a}{b+a}$

ASSUME USING HY80 $f_{tw} = 104{,}600$ psi

$$P_w = 2 \times 104{,}600 \ \frac{30 - 29.687}{30 + 29.687}$$

P_w: 1097 psi

FLAT TOP & BOTTOM   ROARK Pg 225 CASE 36

$$S_{max} = \beta \frac{wb^2}{t^2} \qquad \frac{a}{b} = \frac{168}{24} : 7 = \infty \qquad \beta = .750$$

$$t^2 = \frac{\beta w b^2}{S_{max}} = \frac{.750 \times 33.78 \times \overline{24}^2}{55000 \ (\text{HY80 } f_{t\,allow})} = .265$$

$t = .515"$ USE $.625"$

DESIGN NO.	SUBJECT		WBS
M174	USCG HYBRID CONCEPT - TANK SCANTLINGS		
ANALYST	CHECKER	ANALYSIS DATE	PAGE NO.
EEH		5/4/84	A-4

TANK BULKHEADS

ROARK PG 216 CASE 6

CONSIDER AS UNSTIFFENED FLAT PLT. -
ASSUME CIRCULAR PLT- 60" DIA - UNIFORM LOAD.

HY80 $S_{MAX} = 55{,}000$

S_{MAX} (RADIAL) $= \frac{3W}{4\pi t^2}$ $\qquad t^2 = \frac{3W}{4\pi S_{MAX}}$ $\qquad W = \pi r^2 \times 1.5\ (F.S) \times 40$

$$t^2 = \frac{3(40 \times 4262)}{4\pi \times 100{,}000} = 0.407$$

$t = .638$ (USE HY100 TO YIELD STRESS) USE .625"

S_{MAX} (TANGENTIAL) $= \frac{3W}{4\pi m t^2}$ $\qquad t^2 = \frac{3W}{4\pi m S_{MAX}}$

$$t^2 = \frac{3(40 \times 4262)}{(4\pi)(\frac{1}{.27})(100{,}000)} = .270$$

$t = .520$ - USE .625"

BULKHEADS BETWEEN CELLS -

UNIFORM PRESSURE BOTH SIDES - MAKE .313"

DESIGN NO.	SUBJECT			WBS
M174	USCG HYBRID CONCEPT - TANK SCANTLINGS			
ANALYST		CHECKER	ANALYSIS DATE	PAGE NO.
EEH			5/4/84	A-5

END BULKHEADS FOR VENTED FUEL TANK AFT.

HEAD = 24'-0"

P (FUEL) = 8.68 psi

$$t^2 = \frac{3(8.68 \times 4262)}{4\pi \times 55000} = .161$$

t = .401   USE .500 HY80

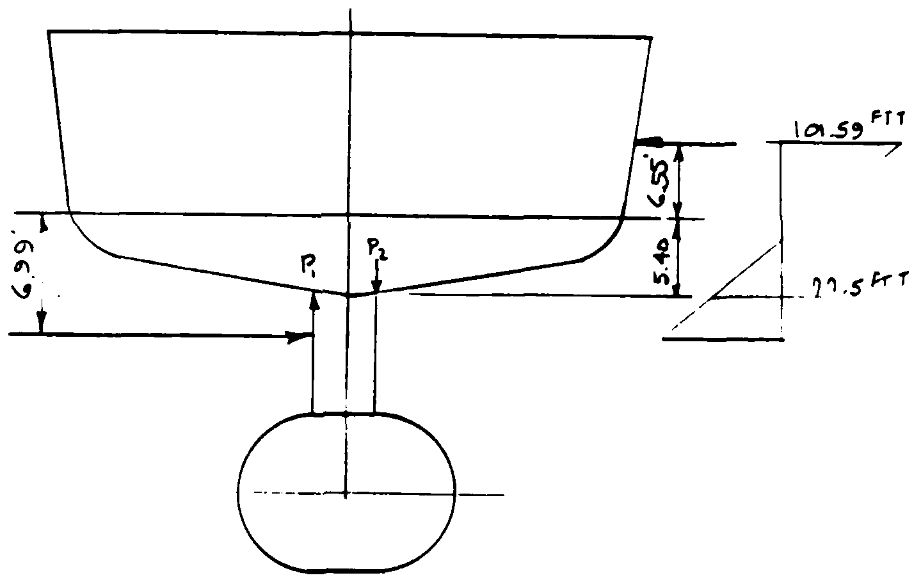
DESIGN NO.	SUBJECT		WBS
M174	USCG HYBRID CONCEPT- STRUT SCANTLINGS		
ANALYST	CHECKER	ANALYSIS DATE	PAGE NO.
EEH		5/4/84	A-6

ASSUME MAX SIDE LOAD MOMENT EQUAL TO 80 KNOT

WIND HEEL MOMENT = 101.59 ft tons

= 227,562 ft lbs /70 = 3251 ft lbs / ft of

STRUT ATTACHMENT LENGTH.



ASSUME STRUT SIDE RTS ACT AS COUPLE ON HULL

$$P_1 = P_2 = \frac{77.5 \times 2240}{2} = 86,800^{\#}/70 = 1240^{\#}\text{/FT STRUT LGTH}$$

DESIGN NO.	SUBJECT			WBS
M174	USCG HYBRID CONCEPT - STRUT SCANTLINGS			
ANALYST		CHECKER	ANALYSIS DATE	PAGE NO.
EEH			5/4/84	A-7

CRITICAL BUCKLING STRESS OF STRUT SIDE PLATES

ROARK PG 348 CASE 3

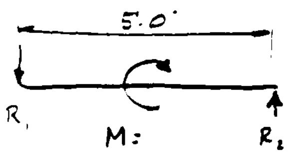
$$S' = K \frac{E}{1-\nu^2}\left(\frac{t}{b}\right)^2$$ - ASSUME PLTG = .313"

$$S' = 5.76 \frac{30\times10^6}{1-.27^2}\left(\frac{.313}{84}\right)^2$$

$S' = 2588$ psi $\qquad f_{cu} = \frac{1240\times7}{84\times.313} = 330$ psi

CHECK EXIST WEB FRAMES ROARK PG 108 CASE 20

SIMPLISTIC APPROACH - ENDS SUPPORTED AT STANCHIONS - INTERMEDIATE COUPLE DUE TO STRUT LOAD



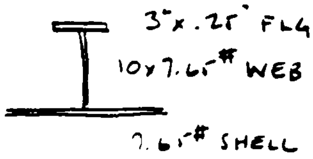
17,360 FT#

$R_1 = R_2 = \frac{17360}{5} = 3472$#

MAX $M = R_1 \times 30 + (17{,}360\times12) = 312{,}480$ "#

$S.M_{REQ'D} = \frac{312{,}480}{40{,}000} = 7.812$ IN^3 EXCLUSIVE OF EXIST LOADS

EXIST FRAME



$I = 62.09$ "^{4}

$SM = 10.95$ "^{3} > 7.812

DESIGN NO.	SUBJECT		WBS
M174	USCG HYBRID CONCEPT - STRUT SCANTLINGS		
ANALYST	CHECKER	ANALYSIS DATE	PAGE NO.
EEH		5/4/84	A-8

STRUT PLATING   DDS 1000-4

STIFFENER SPACING : 84/3 = 28"
WATER HEAD = 14' - 5' = 9'-0"

NO PERMANENT SET t = .25" - USE 5/16" HS

STIFFENERS

ASSUME SIMPLE SUPPORTS
H = 9'-0"
L = 4'-0"
S = 2.33'

$M = 49\, L^2 (2H - L) S$ "#

$M = (49)(4)^2 \left[(2 \times 9) - 4\right] 2.33$

$M = 25{,}574$ "#

$SM_{REQD} = \frac{25{,}574}{12{,}000} = 2.13\ \text{in}^3$

$2\frac{1}{2} \times 2\frac{1}{2} \times \frac{5}{16}$" INV L   SM = 2.21

APPENDIX B

USCG WPB HYBRID HYDROFOIL CONCEPT

FOILBORNE DRAG AND POWERING

NOTE: This material is reproduced directly from Reference 1.

Craft Drag Polar

Derivation of the Craft Drag Polar

The submerged parasite drags were estimated in the manner of reference 7 and 11 for comparison with the DTNSRDC supplied drag curve as shown on Figure 4.2.1-1. The estimated spray and air drags were then added to the DTNSRDC drag curve to obtain the total parasite drag curve.

The calculated parasite drag coefficients are fit to a quadratic in 1/q on Figure 4.2.1-2 and the result is compared with the drag calculations on Figure 4.2.1-1. For a craft foil loading of:

$$\frac{L}{S} = \frac{2240 \times 76.2}{271.75} = 628.11 \qquad 4.2.1\text{-}1$$

the resulting parasite drag polar is:

$$C_{D_p} = .02497 + 29.114 \frac{1}{q} - 10821 \left(\frac{1}{q}\right)^2 \qquad 4.2.1\text{-}2$$

$$= .02497 + \frac{29.114}{628.11} C_L - \frac{10821}{(628.11)^2} C_L^2$$

$$= .02497 + .046352 \ C_L - .027428 \ C_L^2$$

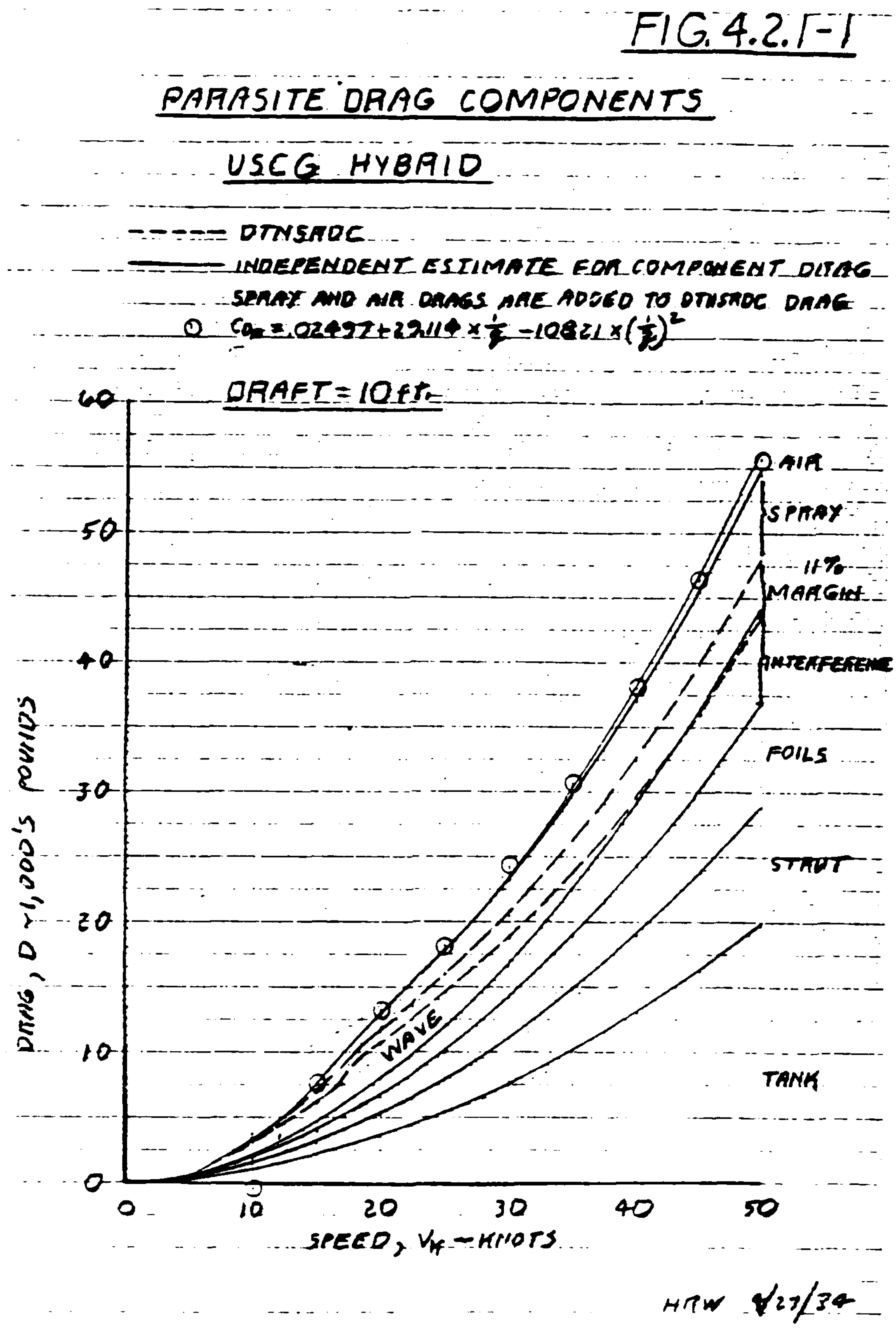


Figure 4.2.1-1. PARASITE DRAG COMPONENTS USCG HYBRID

FIG. 4.2.1-2

PARASITE DRAG CURVE FIT

DRAFT = 10 ft.

$$C_{D_P} = .02497 + 29.114 \times \frac{1}{q} - 10,721 \times \left(\frac{1}{q}\right)^2$$

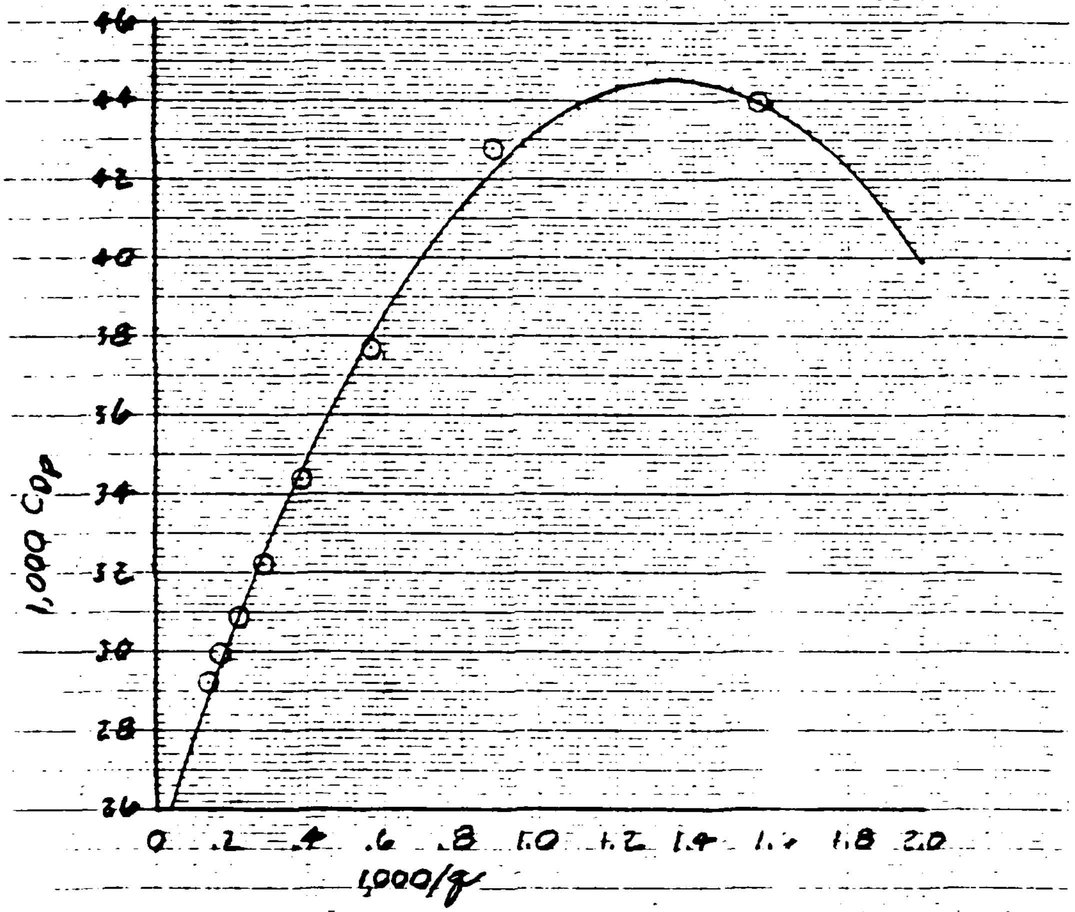


Figure 4.2.1-2. PARASITE DRAG CURVE FIT DRAFT = 10 FT.

By the methods of reference 11 the induced and surface image drag coefficients are:

$$C_{D_i} = .088647\ C_L^2 \qquad 4.2.1\text{-}3$$

$$C_{D_{SURF}} = .016624\ C_L^2 \qquad 4.2.1\text{-}4$$

where a $\pi A\ C_{D_i}/C_L^2$ of 1.25 was arbitrarily employed for the aft foil in the absence of a circulation distribution analysis.

For design lift coefficients set equal to the foil lift coefficient at 35 knots the wake drag coefficient becomes:

$$C_{D_{WAKE}} = .026091 \left[\frac{(\ell_2/\ell)^2}{S_1/S} + \frac{(\ell_1/\ell)^2}{S_2/S}\right] (C_L - C_{L_{35}})^2 \qquad 4.2.1\text{-}5$$

$$= .026091 \times 1.0003\ (C_L - .18062)^2$$

$$= .026099\ (C_L - .18062)^2$$

The coefficient should be .0035471 for speeds higher than 35 knots but the difference is negligible for the speed range of interest here.

The wave drag coefficients calculated by the methods of reference 11 are fitted to a quadratic in craft lift coefficient on Figure 4.2.1-3 with the result:

$$C_{D_{WAVE}}/\sigma_i = .0013105 - .019255\ C_L + .086962\ C_L^2 \qquad 4.2.1\text{-}6$$

for $L = 76.2$ LT

FIG. 4.2.1-3

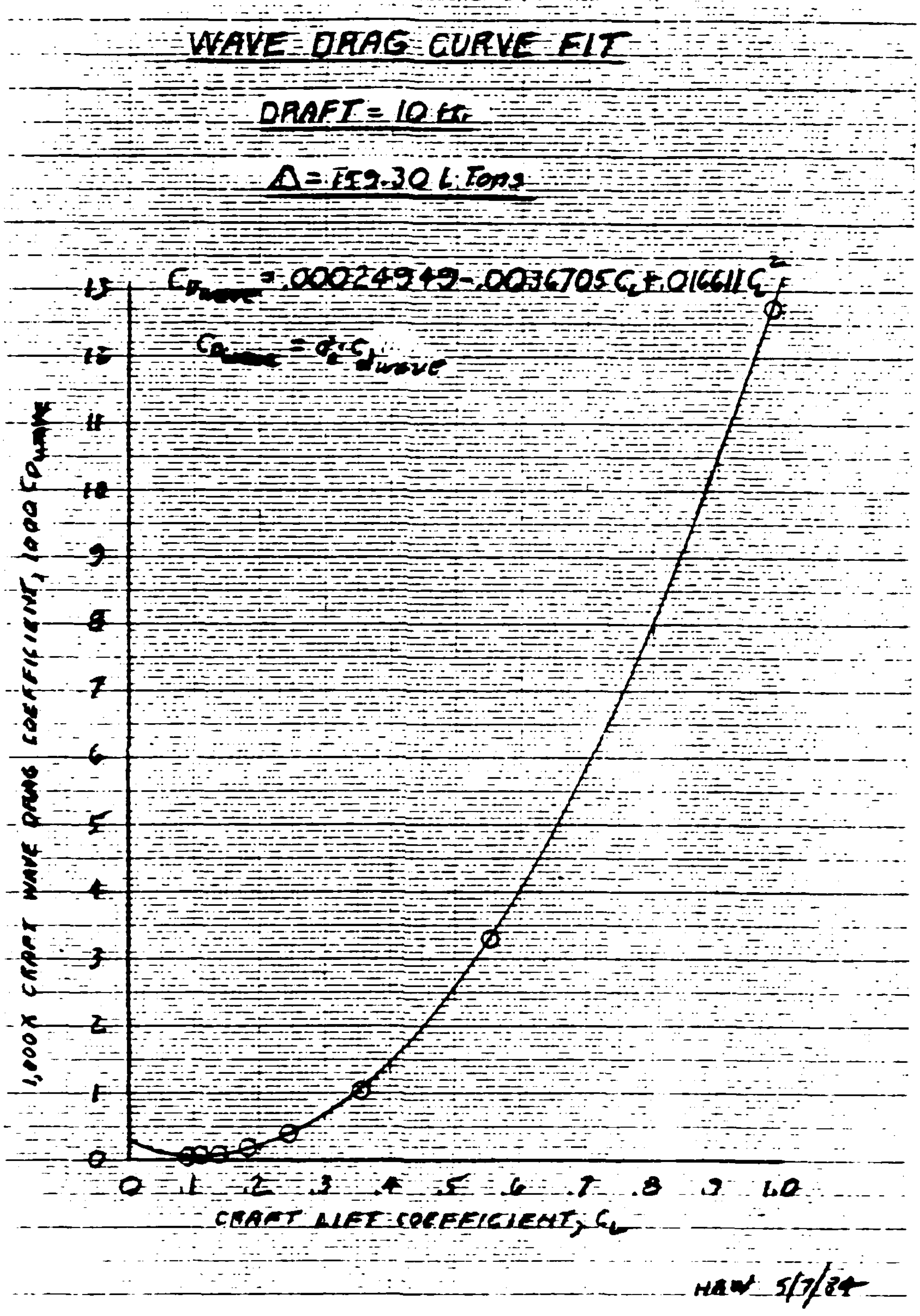


Figure 4.2.1-3. WAVE DRAG CURVE FIT

From Equations 4.2.1-3 through 4.2.1-6 the total lift drag coefficient is:

$$C_{D_i} = .088647\ C_L^2 \qquad 4.2.1\text{-}7$$

$$C_{D_{WAKE}} = .00085144 - .009428\ C_L + .026099\ C_L^2$$

$$C_{D_{SURF}} = .016624\ C_L^2$$

$$C_{D_{WAVE}} = .00024949 - .0036705\ C_L + .016611\ C_L^2$$

$$C_{D_L} = .001109 - .013098\ C_L + .14798\ C_L^2$$

and with Equation 4.2.1-2 the total drag coefficient becomes:

$$C_{D_p} = .02497 + .046352\ C_L - .027428\ C_L^2 \qquad 4.2.1\text{-}8$$

$$C_{D_L} = .0011009 - .013098\ C_L + .14798\ C_L^2$$

$$C_D = .026071 + .033253\ C_L + .12055\ C_L^2$$

The calculated lift drags are compared with the total lift drag polar of Equation 4.2.1-7 on Figure 4.2.1-4. The total drag polar of Equation 4.2.1-8 is shown on Figure 4.2.1-5 and the corresponding drag curve for two displacements is shown on Figure 4.2.1-6. The drag curves of Figure 4.2.1-6 are presented as effective power required curves on Figure 4.2.1-7.

It should be noted that the drag calculations throughout this report were for a draft of 10 ft, i.e. for a fully wetted strut. Thus these performance results are conservative for the flight waterline.

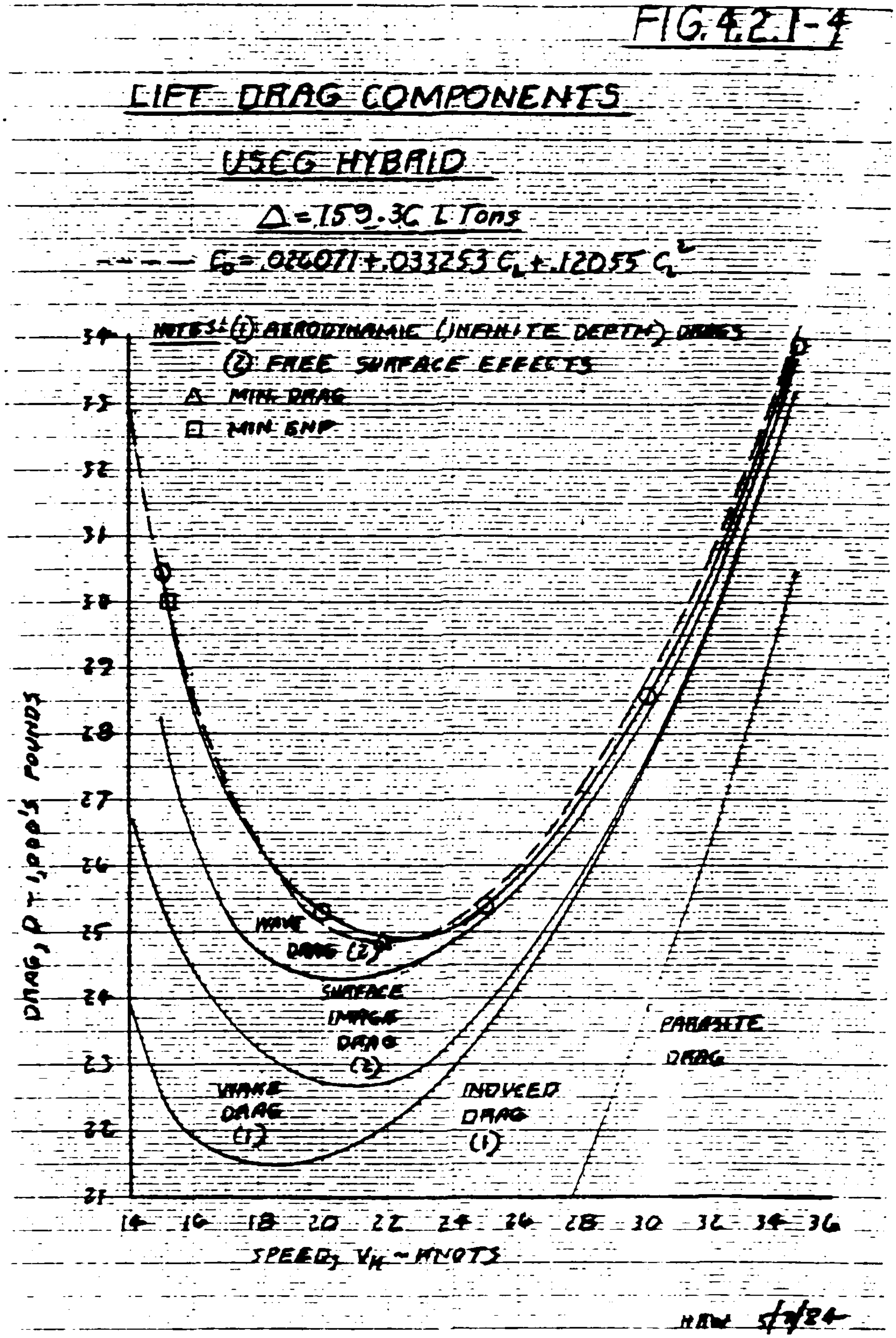


Figure 4.2.1-4. LIFT DRAG COMPONENTS USCG HYBRID

FIG 4.2.1-5

CRAFT DRAG POLAR

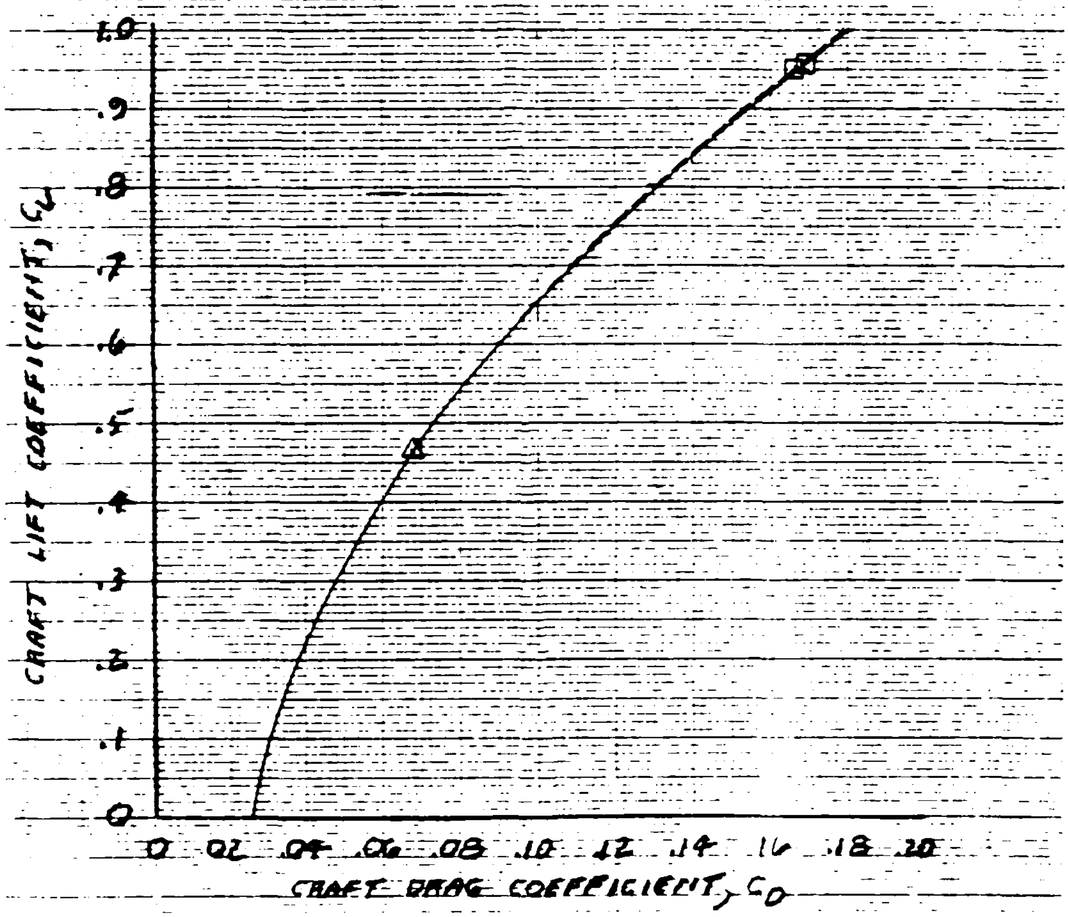
USCG HYBRID

DRAFT = 10 ft. Δ = 159.30 L Tons

$$C_D = .026071 + .033253\,C_L + .12055\,C_L^2$$

	C_L	VALUE	V_K		
$(L/D)_{max}$	.46504	6.8787	21.313	MIN. DRAG	Δ
$(C_L^{3/2}/C_D)_{max}$	.95513	5.5627	15.220	MIN. EHP	$\square$

Δ = 181.33 L Tons



HAW 5/8/84

Figure 4.2.1-5. CRAFT DRAG POLAR USCG HYBRID

APPENDIX C

USCG WPB HYBRID HYDROFOIL CONCEPT

INTACT STATIC STABILITY

APPENDIX C

INTACT STATIC STABILITY

1.0 General

The addition of the buoyancy/fuel (B/F) tank produces two effects that relate to the safety of the ship under a high beam wind. The first is independent of the net weight or buoyancy of the tank. It is an increase in the heeling moment, for a specific displacement, due to a lowering of the center of lateral resistance for the underwater hull. The second effect is related to the tank's net weight, with positive buoyancy detracting from the ship's righting moment at any heel angle and negative buoyancy providing an improvement.

From the standpoint of reducing the loading on the foil system, and consequently a reduction in the induced drag, it is desirable to have a positively buoyant B/F tank. However, this loading condition runs counter to the desire to carry maximum fuel in the tank and to provide adequate resistance to wind heel. This dilema is partially resolved by determining the limits on the tanks positive buoyancy for adequate intact stability in a 70 knot beam wind. The criteria applied to this design is the US Navy's Design Data Sheet DDS-079. From this design sheet, the "six-tenths" righting arm rule is used exclusively to evaluate stability. The analysis does not include the area criteria used for conventional ships to account for roll energy. The reason is that the WPB Hybrid with the B/F tank in place will have roll characteristics that do not relate to a conventional hull; i.e., the amount of roll damping would be high, and the dynamics would have little relation to a conventional ship.

1.1 Analysis

The intact stability calculations were conducted with the tank and strut considered part of the hull. The volume and center of buoyancy were independent of the tank's contents. The foils were input as appendages. Standard righting arm curves were generated with the US Navy's SHCP (Ship Hull Characteristics) program for a range of displacements and vertical centers of gravity that spanned the anticipated operating conditions for the ship. These plots provided a map of stability for a variety of loading conditions.

The second step was to determine the wind heeling arms for the assumed 70 knot beam wind. The ship, both above and below the waterline, was divided into polygons to determine the underwater center of lateral resistance and the centroid for the wind heeling arm. These calculations are shown in Table C-1 and Table C-2.

The heeling arms were then plotted against the the righting arms to produce the classic intact stability curves. These graphs are shown in Figures C-1 through C-6, corresponding to displacements of 150 to 200 tons. From these plots, it was possible to determine the highest permissible location for the vertical center of gravity, for each ship displacement, that met the six-tenths righting arm criterion. These curves are shown in Figures C-7 to C-11.

The extreme loading for the USCG WPB Hybrid was assumed to be the full load condition. Since the ship has automatic ballast compensation, the difference between the Full Load condition and the Minimum Operating condition is minimal. Even though there is a loss of 3.5 tons (this change represents less than 2% of the full load displacement) the vertical center of gravity actually lowers as the lighter fuel in the B/F tank is replaced with seawater.

Once the final vertical center of gravity and displacement are known, an easy assessment of the intact stability was made.

TABLE C-1

Center Of Lateral Resistance

	Area (sq ft)	Centroid (ft below BL)	Moment
Hull	266	1.5	399
Strut	330	-2.0	-660
Tank	418	-6.5	-2717
Total	1014	-2.9	-2978

TABLE C-2

Wind Heeling Arm

	Area (sq ft)	Centroid (ft abv BL)	Moment
Hull (Sta 0-5)	382	8.0	3056
(Sta 5-10)	330	7.7	2541
Superstructure	440	15.0	6600
Pilot House	168	23.0	3864
	1320	12.2	16061

Ref: US Navy Design Data Sheet DDS-079

Assume: Wind Speed = 70 knots for Intact Stability
40 knots for Damaged Stability

$$\text{Heeling Arm} = \frac{0.0035 \times V \times A \times L \times \cos O}{2240 \times \text{Displacement}}$$

where A = sail area in square feet
V = wind speed in knots
L = lever arm (wind heel arm + ctr. of lat. res.)
O = angle of heel

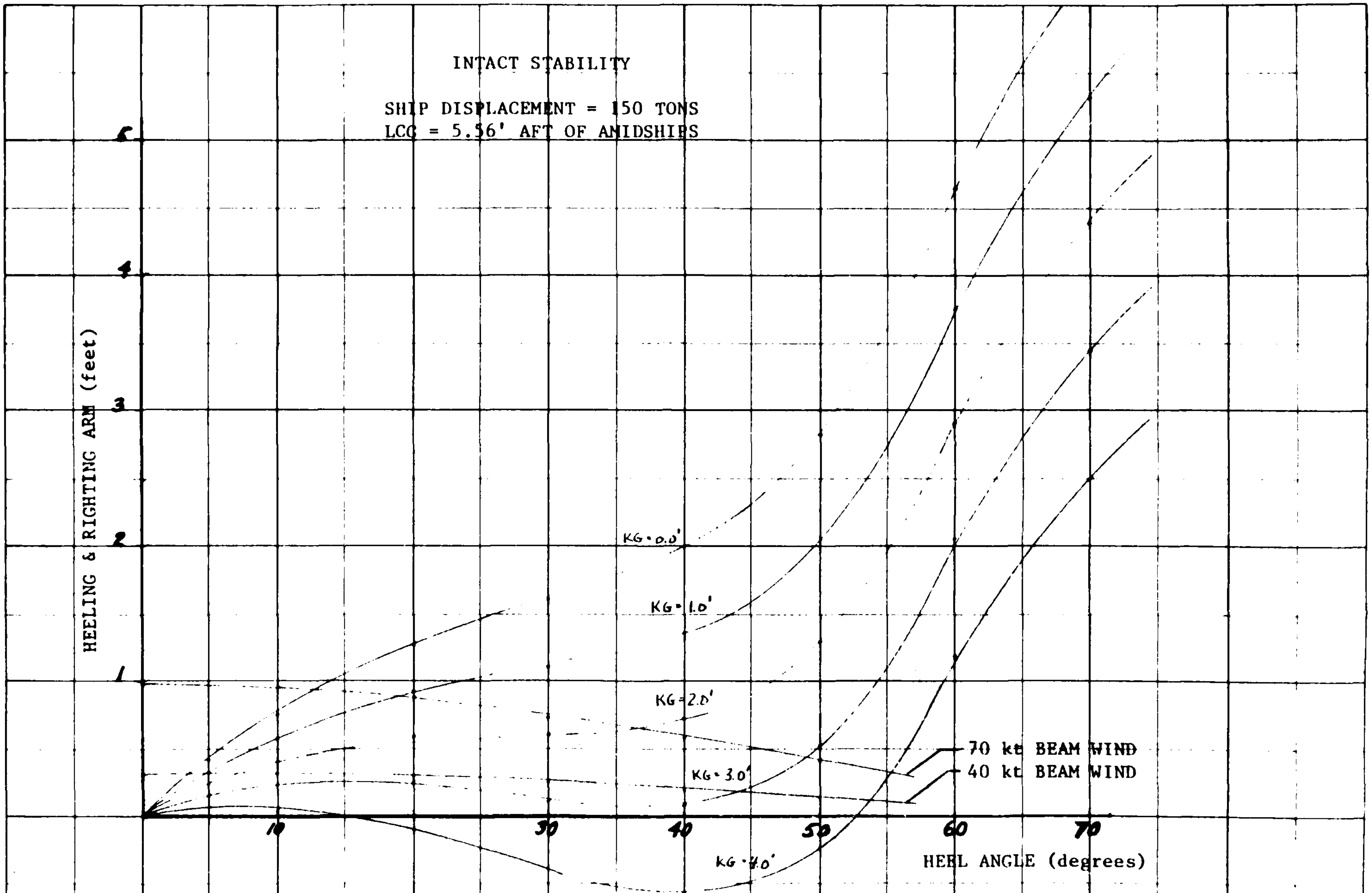

INTACT STABILITY
SHIP DISPLACEMENT = 150 TONS
LCG = 5.56' AFT OF AMIDSHIPS
HEELING & RIGHTING ARM (feet)
6
4
3
2
1
10
30
40
50
60
70
KG = 0.0'
KG = 1.0'
KG = 2.0'
KG = 3.0'
KG = 4.0'
70 kt BEAM WIND
40 kt BEAM WIND
HEEL ANGLE (degrees)

FIGURE C-1

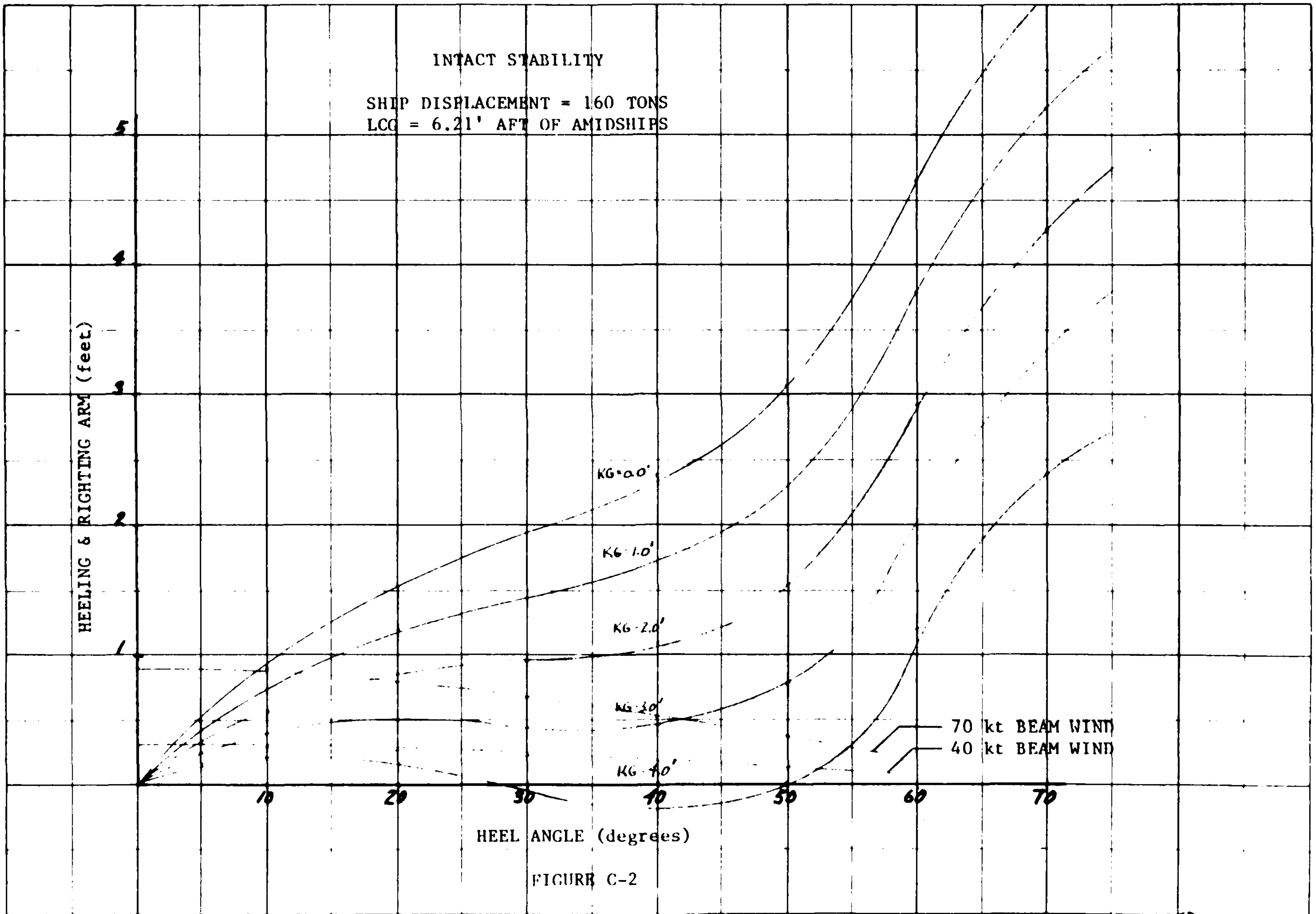

INTACT STABILITY
SHIP DISPLACEMENT = 160 TONS
LCG = 6.21' AFT OF AMIDSHIPS
HEELING & RIGHTING ARM (feet)
1
2
3
4
5
KG = 0.0'
KG 1.0'
KG 2.0'
KG 3.0'
KG 4.0'
70 kt BEAM WIND
40 kt BEAM WIND
10
20
30
40
50
60
70
HEEL ANGLE (degrees)

FIGURE C-2

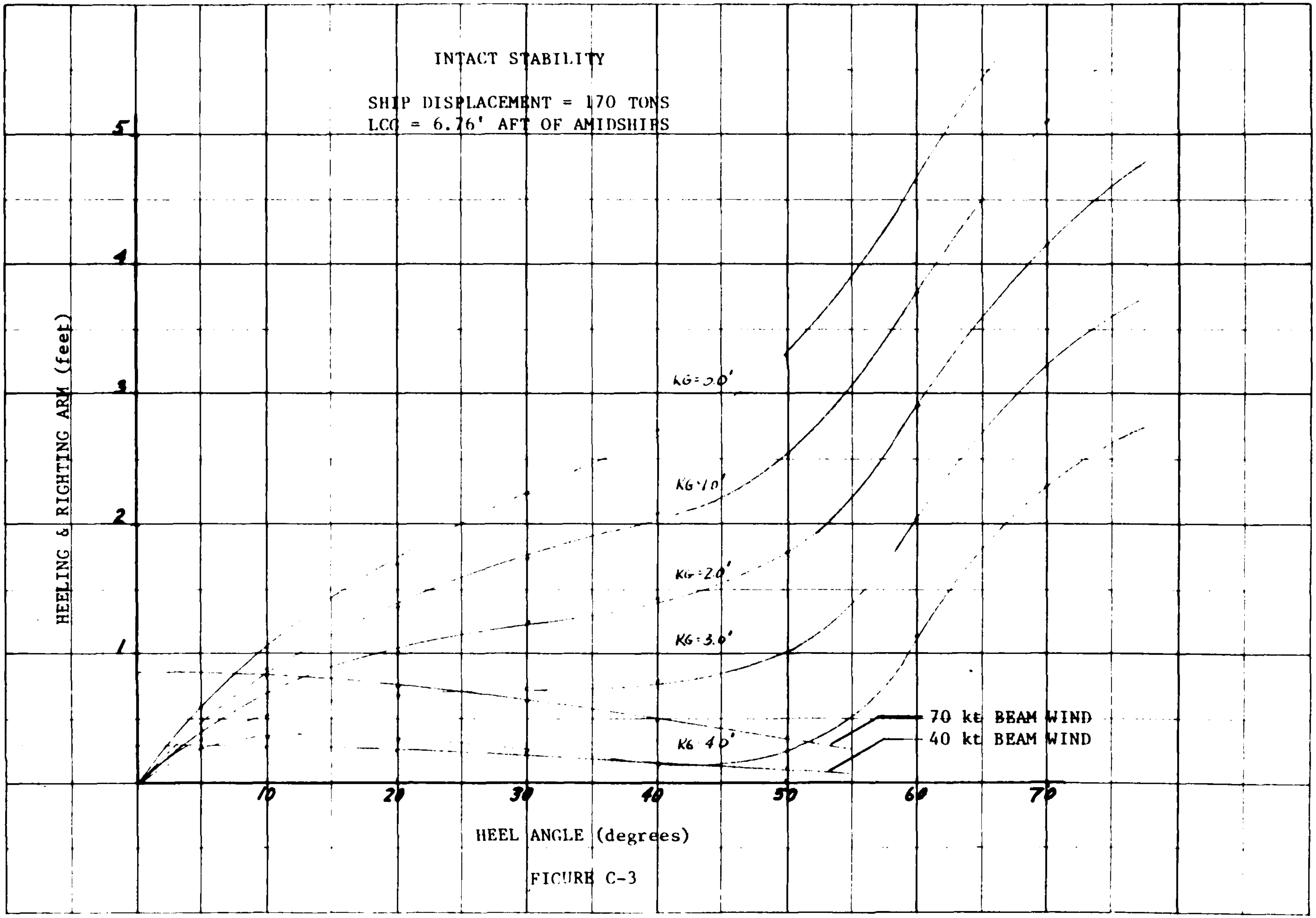

INTACT STABILITY
SHIP DISPLACEMENT = 170 TONS
LCG = 6.76' AFT OF AMIDSHIPS
HEELING & RIGHTING ARM (feet)
1
2
3
4
5
10
20
30
40
50
60
70
KG=0.0'
KG=1.0'
KG=2.0'
KG=3.0'
KG=4.0'
70 kt BEAM WIND
40 kt BEAM WIND
HEEL ANGLE (degrees)

FIGURE C-3

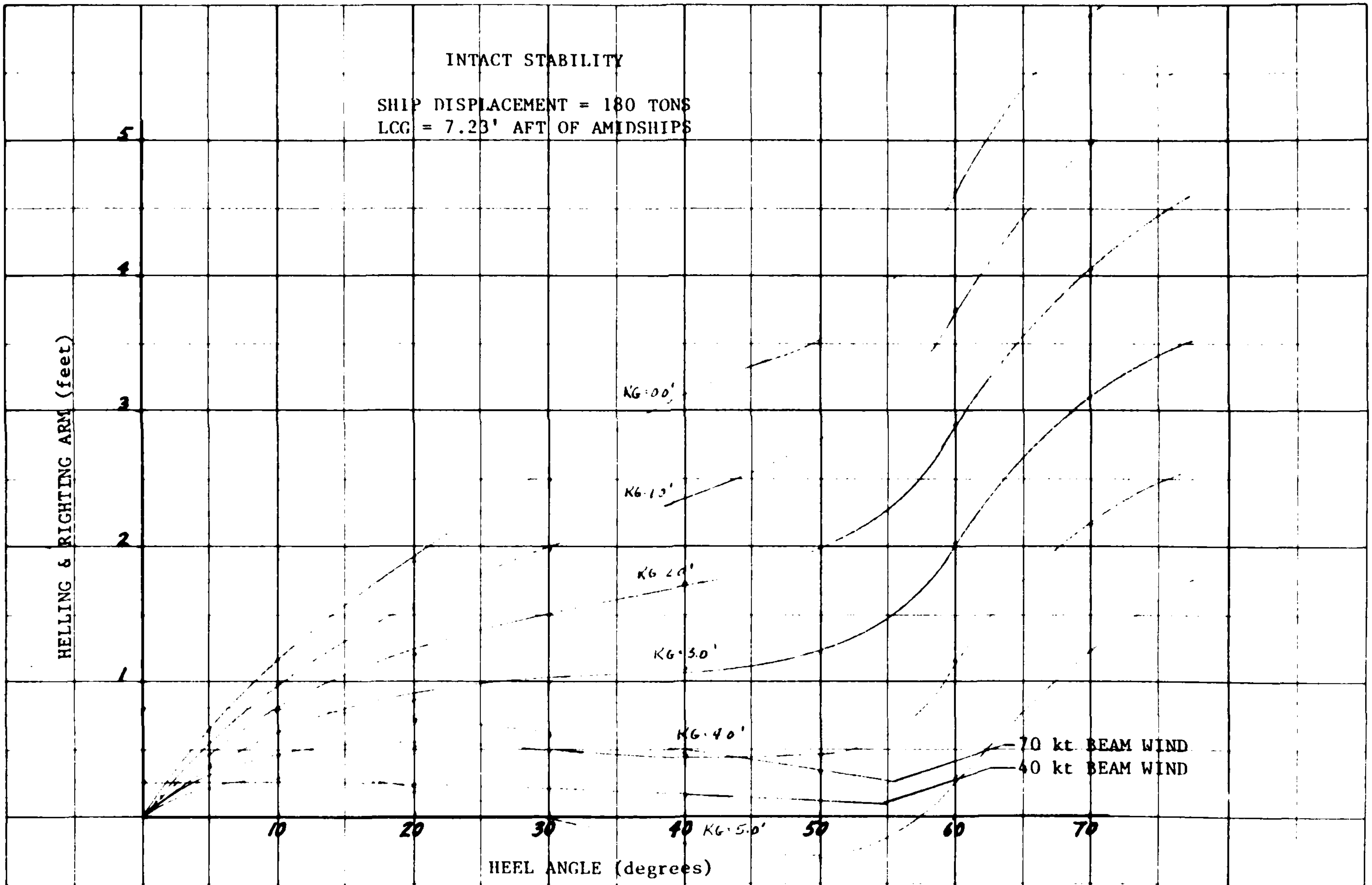

INTACT STABILITY
SHIP DISPLACEMENT = 180 TONS
LCG = 7.23' AFT OF AMIDSHIPS
HELLING & RIGHTING ARM (feet)
HEEL ANGLE (degrees)
1
2
3
4
5
10
20
30
40
50
60
70
KG·0.0'
KG·1.0'
KG·2.0'
KG·3.0'
KG·4.0'
KG·5.0'
70 kt BEAM WIND
40 kt BEAM WIND

FIGURE C-4

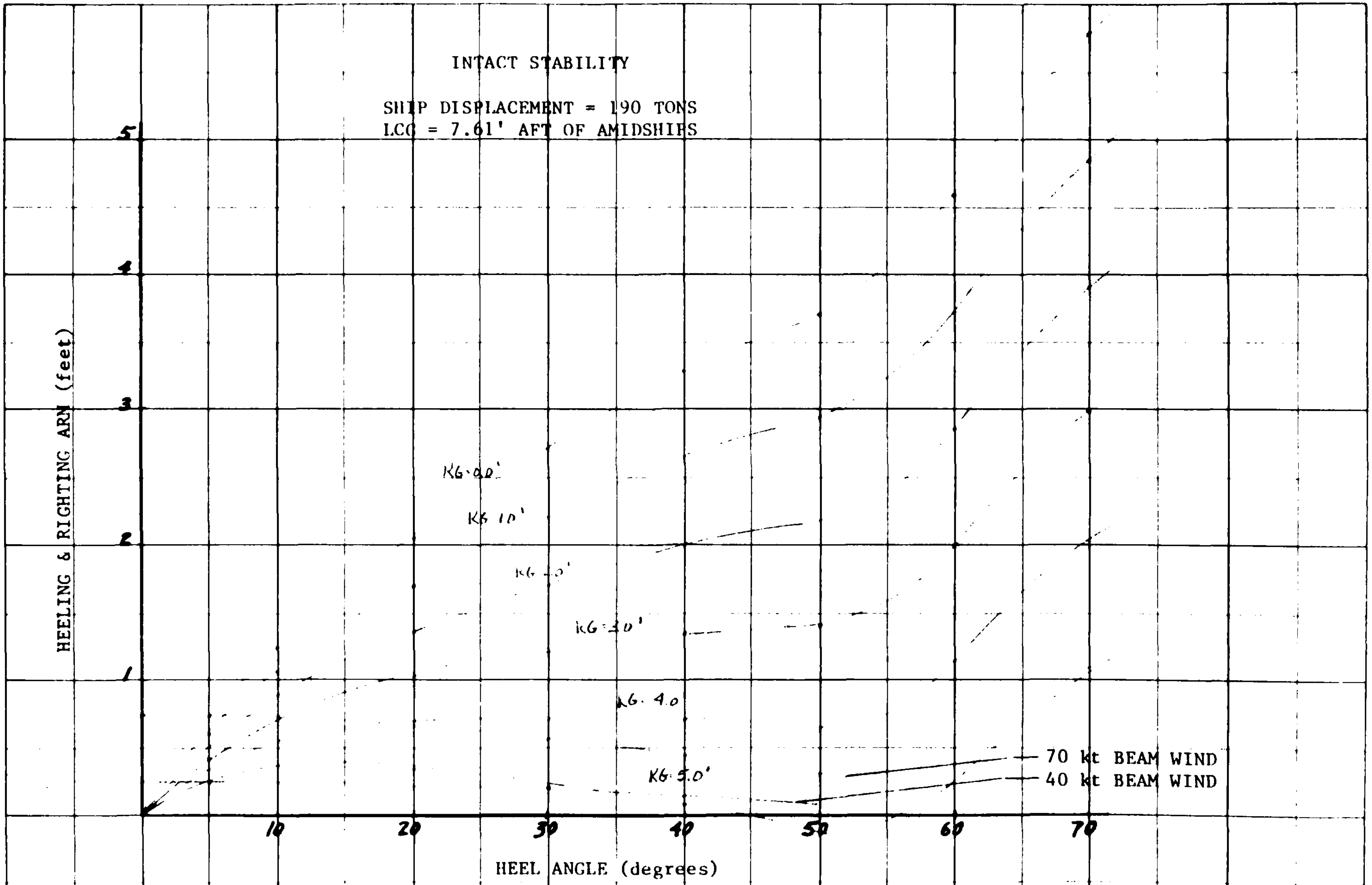

INTACT STABILITY
SHIP DISPLACEMENT = 190 TONS
LCG = 7.61' AFT OF AMIDSHIPS
HEELING & RIGHTING ARM (feet)
1
2
3
4
5
10
20
30
40
50
60
70
KG 0.0'
KG 3.0'
KG 4.0
KG 5.0'
70 kt BEAM WIND
40 kt BEAM WIND
HEEL ANGLE (degrees)

FIGURE C-5

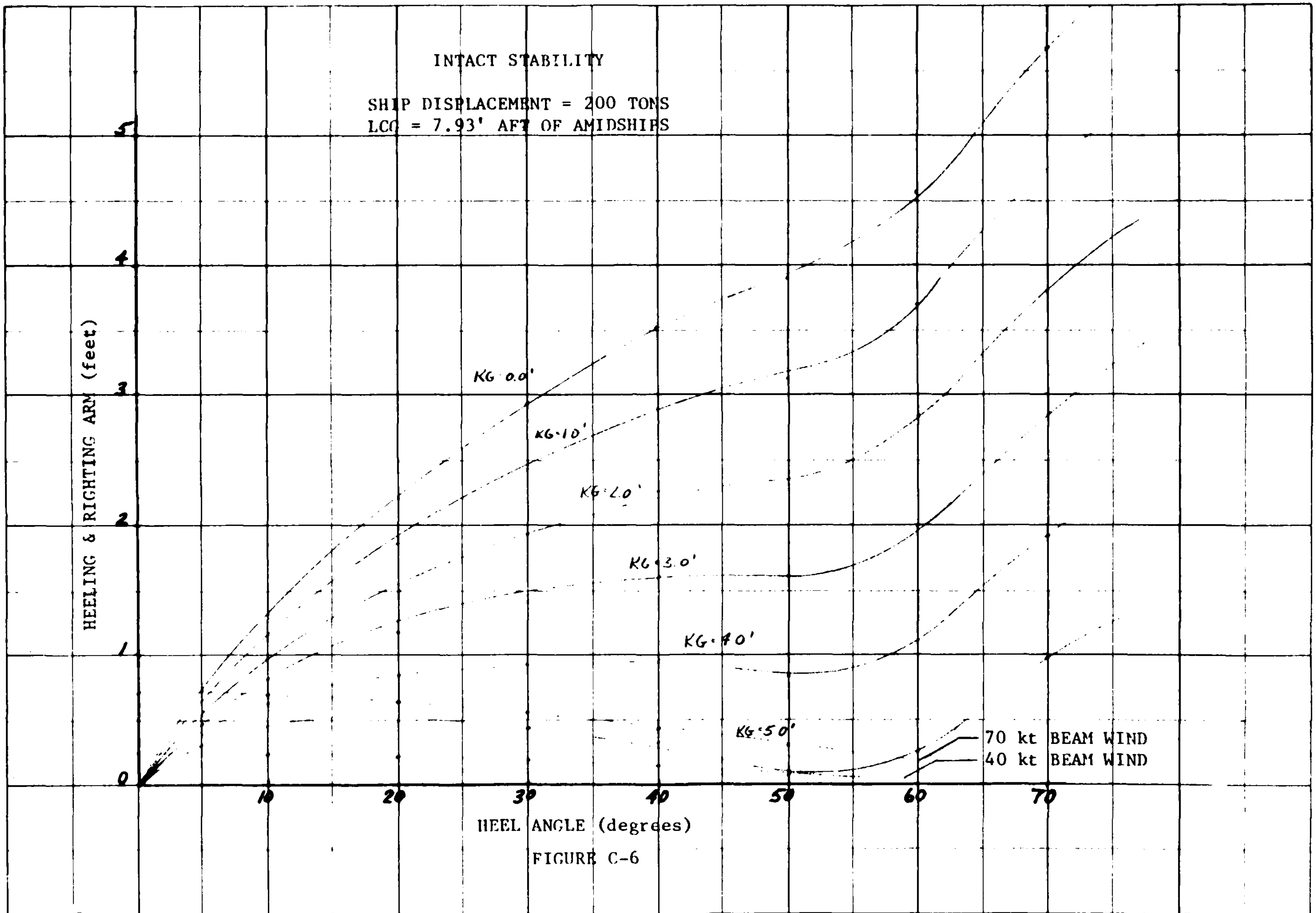

INTACT STABILITY
SHIP DISPLACEMENT = 200 TONS
LCG = 7.93' AFT OF AMIDSHIPS
HEELING & RIGHTING ARM (feet)
0
1
2
3
4
5
10
20
30
40
50
60
70
HEEL ANGLE (degrees)
KG 0.0'
KG 1.0'
KG 2.0'
KG 3.0'
KG 4.0'
KG 5.0'
70 kt BEAM WIND
40 kt BEAM WIND

FIGURE C-6

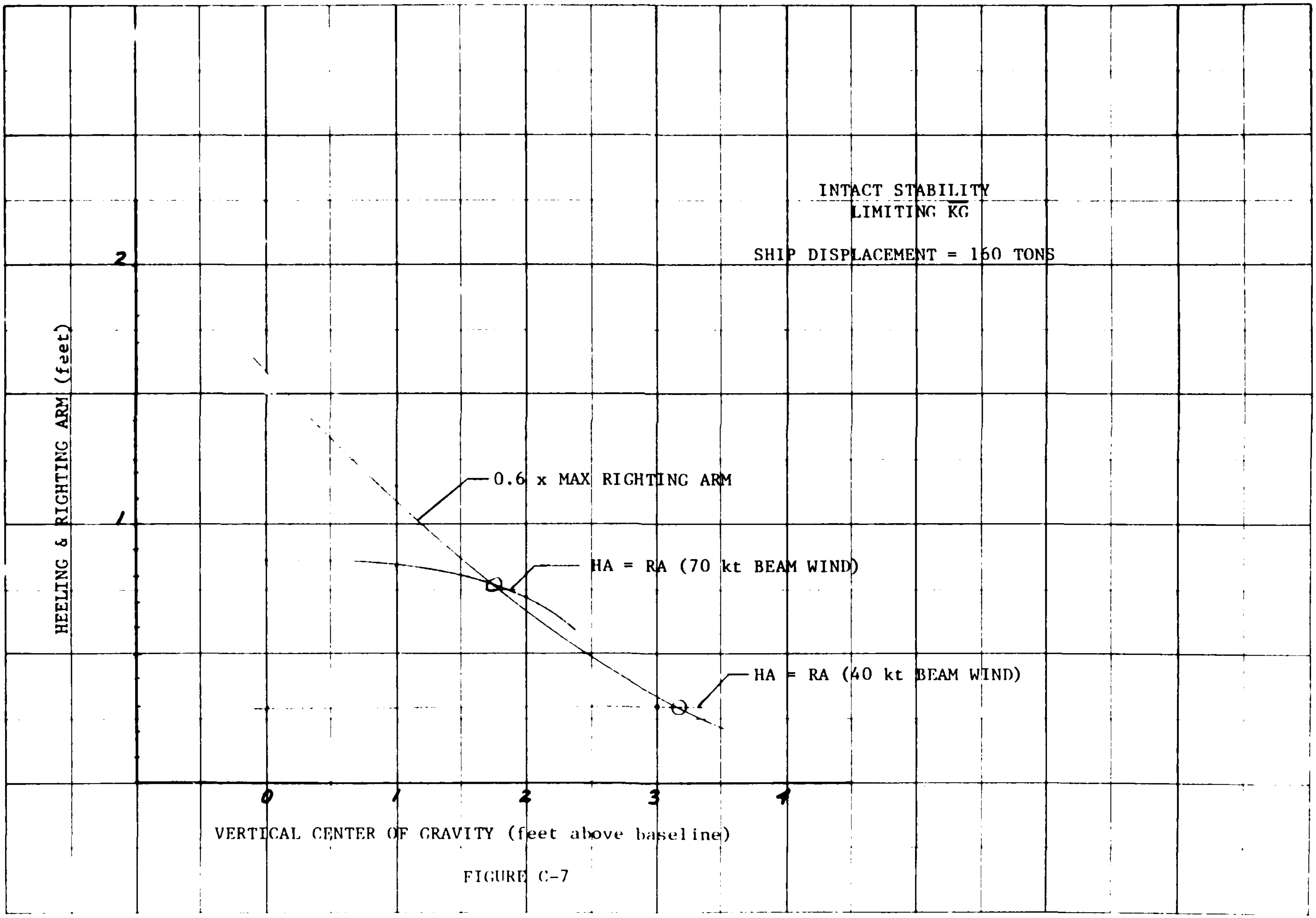

INTACT STABILITY
LIMITING $\overline{KG}$
SHIP DISPLACEMENT = 160 TONS
0.6 x MAX RIGHTING ARM
HA = RA (70 kt BEAM WIND)
HA = RA (40 kt BEAM WIND)
HEELING & RIGHTING ARM (feet)
VERTICAL CENTER OF GRAVITY (feet above baseline)
0
1
2
3
4

FIGURE C-7

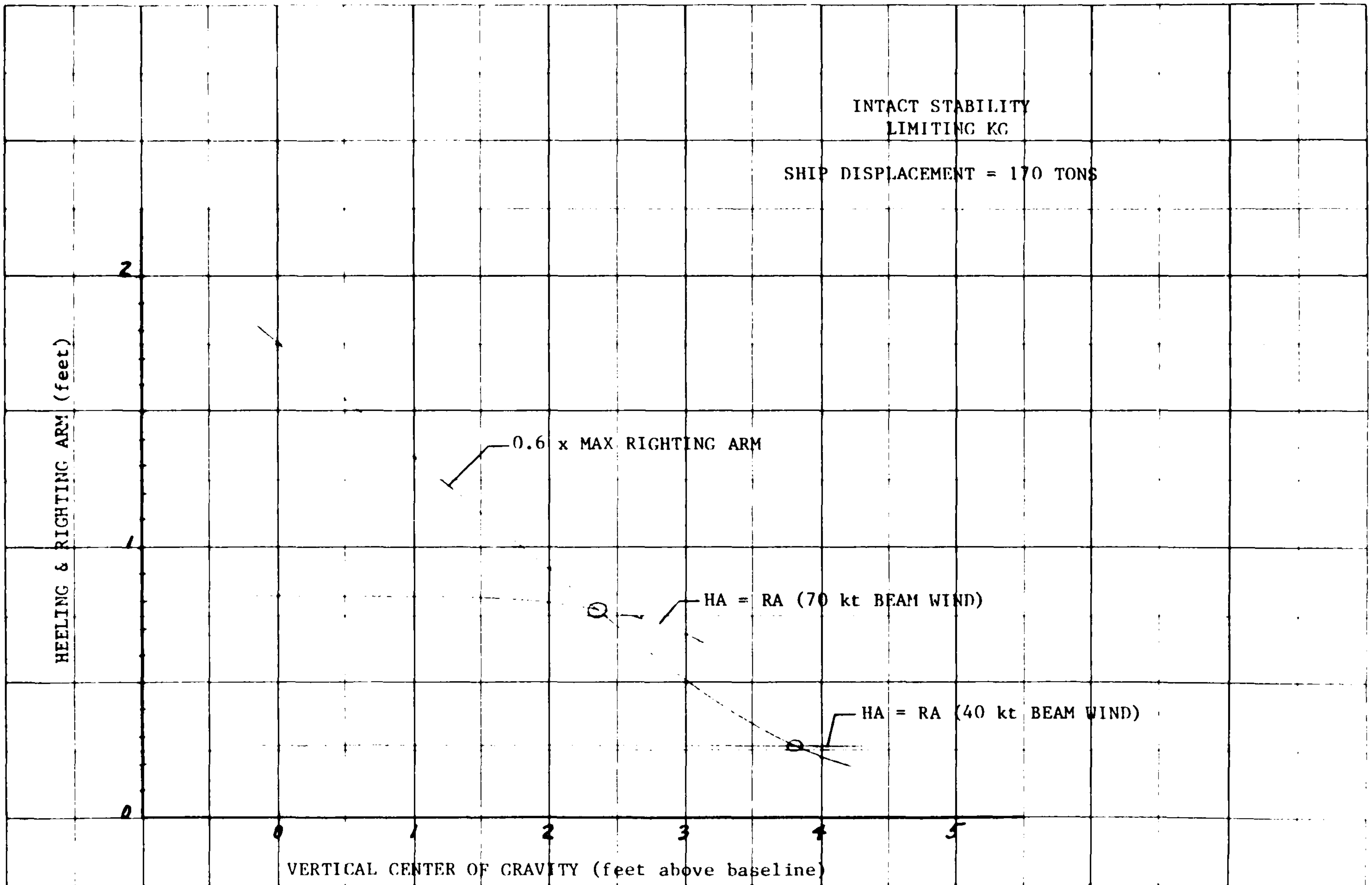

INTACT STABILITY
LIMITING KG
SHIP DISPLACEMENT = 170 TONS
0.6 x MAX RIGHTING ARM
HA = RA (70 kt BEAM WIND)
HA = RA (40 kt BEAM WIND)
HEELING & RIGHTING ARM (feet)
0
1
2
0
1
2
3
4
5
VERTICAL CENTER OF GRAVITY (feet above baseline)

FIGURE C-8

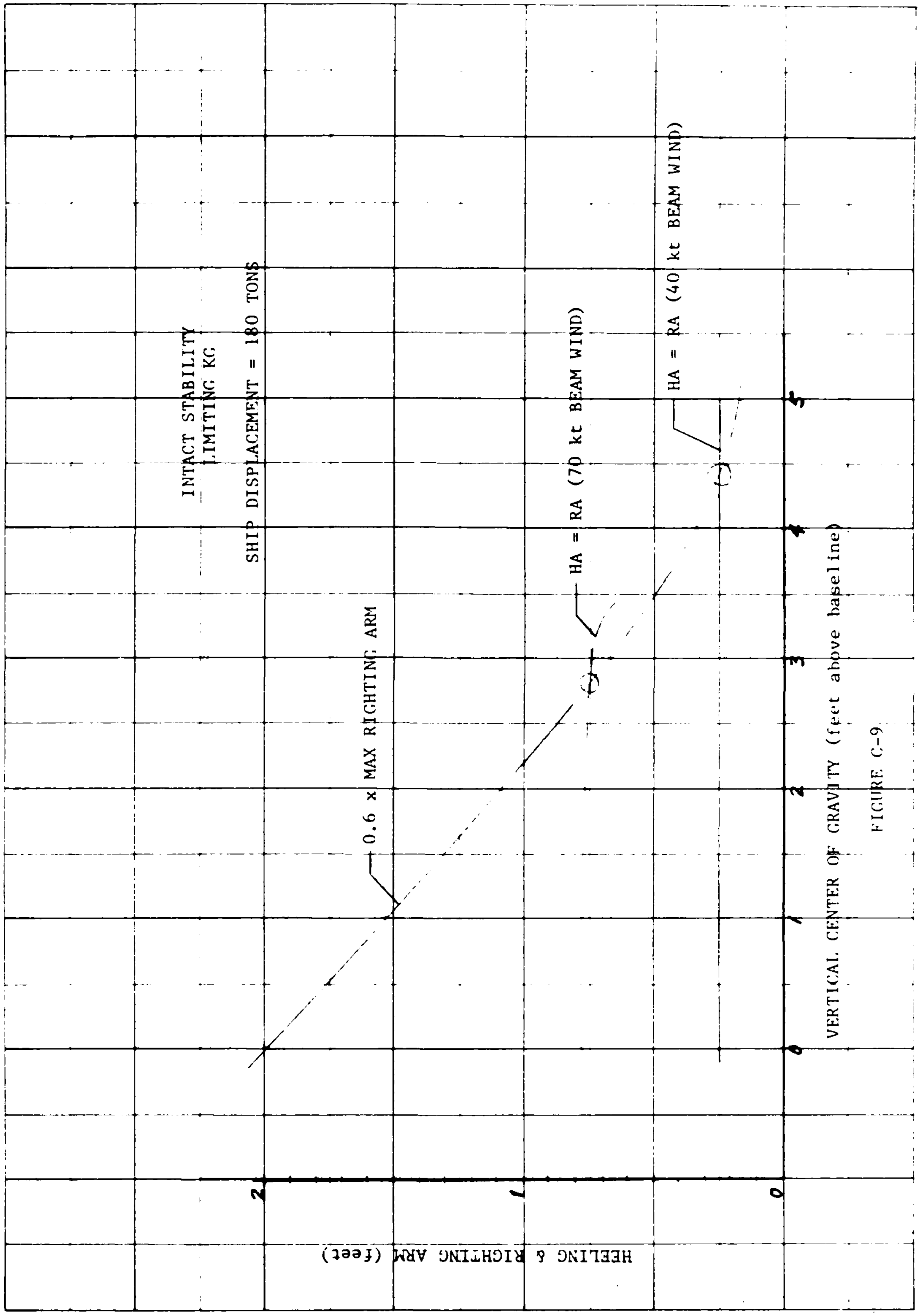

INTACT STABILITY
LIMITING KG
SHIP DISPLACEMENT = 180 TONS
0.6 x MAX RIGHTING ARM
HA = RA (70 kt BEAM WIND)
HA = RA (40 kt BEAM WIND)
HEELING & RIGHTING ARM (feet)
0
1
2
3
4
5
VERTICAL CENTER OF GRAVITY (feet above baseline)

FIGURE C-9

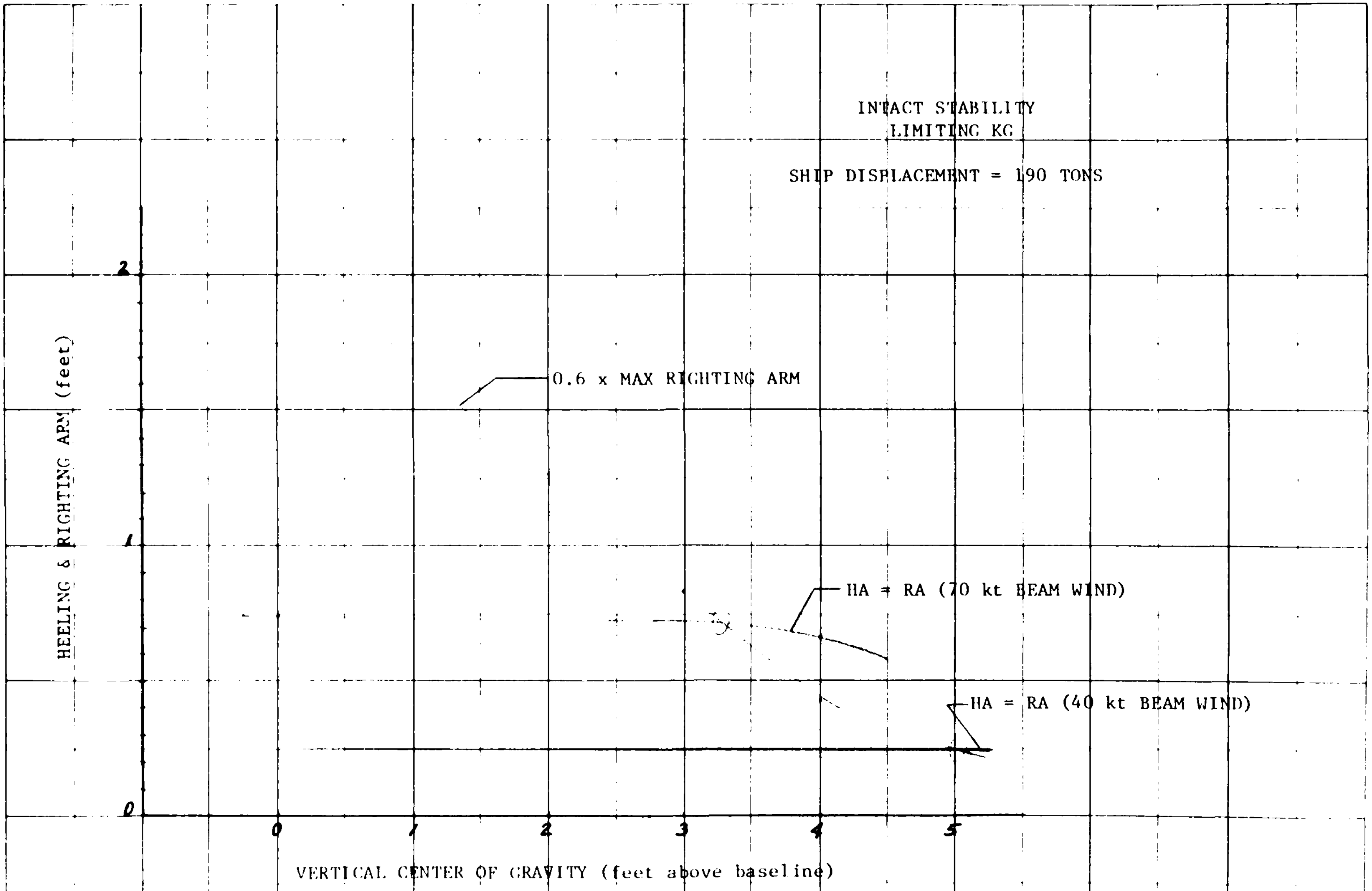

INTACT STABILITY
LIMITING KG
SHIP DISPLACEMENT = 190 TONS
0.6 x MAX RIGHTING ARM
HA = RA (70 kt BEAM WIND)
HA = RA (40 kt BEAM WIND)
HEELING & RIGHTING ARM (feet)
2
1
0
0
1
2
3
4
5
VERTICAL CENTER OF GRAVITY (feet above baseline)

FIGURE C-10

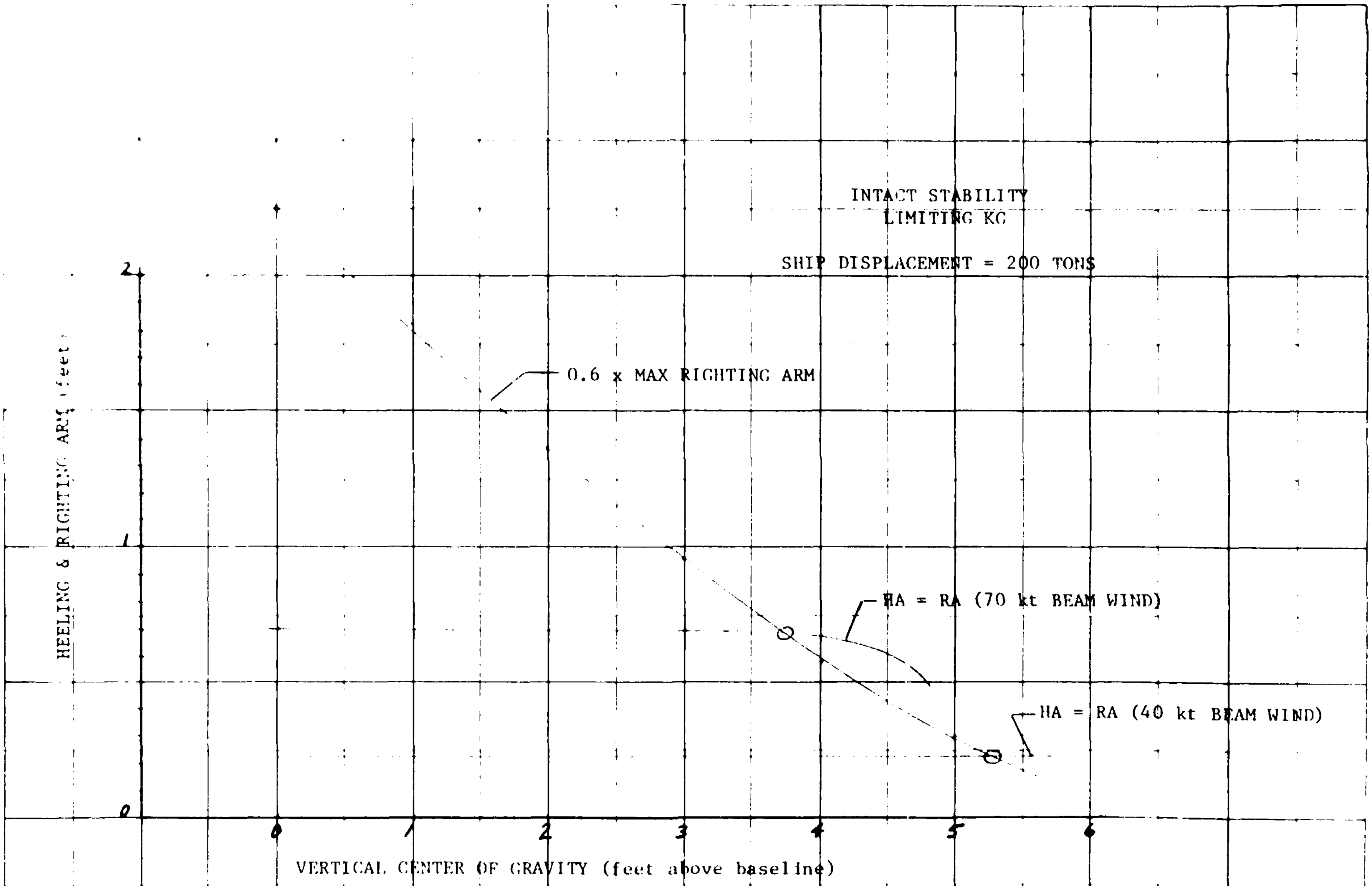

INTACT STABILITY
LIMITING KG
SHIP DISPLACEMENT = 200 TONS
0.6 x MAX RIGHTING ARM
HA = RA (70 kt BEAM WIND)
HA = RA (40 kt BEAM WIND)
HEELING & RIGHTING ARM (feet)
0
1
2
0
1
2
3
4
5
6
VERTICAL CENTER OF GRAVITY (feet above baseline)

FIGURE C-11

END

2-87

DTIC