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ADVANCED NAVAL VEHICLES CONCEPTS EVALUATION (ANVCE) FINAL REPORT

70-KNOT LARGE HYDROFOIL FEASIBILITY STUDY

Prepared by

GRUMMAN AEROSPACE CORPORATION

1 March 1977

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(WHEN ATTACHED)

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PROPRIETARY
to Grumman Aerospace Corporation

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PREFACE

(U) The conceptual design described in this report was developed by Grumman Aerospace Corporation in fulfillment of Technical Instructions issued on 20 August 1976 by the Hydrofoil Program Office, Code 115, of the David W. Taylor Naval Ship Research and Development Center (DWTNSRDC) at Carderock, Maryland. The principal objective of both the Technical Instructions and the resulting design (designated M165) was to assess the impact on large hydrofoil ships, similar to the postulated Hydrofoil Ocean Combatant (HOC), of incorporating a 70-kt dash speed capability into a normal cruise speed requirement of approximately 50 kt.

(U) The major portion of the engineering development of Design Ml65 was funded through Contract N00600-76-C-0246, administered by the Hydrofoil Program Office of DWTNSRDC. Basic lift system hydrodynamic characteristics were provided by the Hydrofoil Program Office based upon earlier preliminary developments undertaken at DWTNSRDC and elsewhere on high-speed hydrofoil sections. The reference HOC design utilized for comparison with Design Ml65 is a variant of Grumman Design M154D developed earlier under corporate funding, in anticipation of a Navy-funded HOC development program.

(U) The Technical Instructions which initiated the conceptual design of Design Ml65 were issued as an adjunct to the Advanced Naval Vehicles Concepts Evaluation (ANVCE) Study; therefore, this report has been formatted in general accord with Working Paper WPO05, Point Design Description, issued by the ANVCE Project Office (OP96V).

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ILLUSTRATIONS

ILLUSTRATIONS (Continued)

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Section 1

INTRODUCTION

(U) Major emphasis in the development of hydrofoils for the U.S. Navy in recent years has concentrated on developments within the subcavitating regime, generally defined as speeds less than approximately 50 to 52 kt. Although the potential for higher speeds has been recognized for some time, and was explored in detail by Grumman Aircraft Engineering (now Grumman Aerospace) as early as 1961 under auspices of the U. S. Maritime Administration (Ref. 1); it has been generally thought that the higher takeoff speeds and probable midrange inefficiencies (40 to 50 knots) of pure supercavitating foils tend to minimize their effectiveness for military platforms. Thus, U. S. Navy development of supercavitating foil systems for realistic military applications has been limited since the early 1960s.

(U) Recent high-speed foil system developments sponsored by the David W. Taylor Naval Ship Research and Development Center (DWTNSRDC) have resulted in a foil concept which has the potential of extending the speed regime of subcavitating hydrofoils to the supercavitating regime up to 70 kt with little sacrifice of efficiency at subcavitating speeds.

(U) Before proceeding with further development of this new high-speed foil system, it was deemed appropriate to assess the impact on a military hydrofoil ship of incorporating a 70-kt dash speed capability with a 40-to-50-kt normal cruise speed requirement. The most currently postulated next-generation hydrofoil ship, the Hydrofoil Ocean Combatant (HOC) was selected as the reference ship for this assessment. Accordingly, Technical Instructions were issued to Grumman Aerospace by the Hydrofoil Program Office, Code 115, DWTNSRDC to proceed with this assessment. This report describes the Grumman-developed conceptual design, M165, and compares it with a variant of a previously developed HOC design, M154D-2. Performance estimates of both ‘designs are provided and qualitative assessments of the technical risk developing the high-speed capabilities of Design Ml65 are made relative to current subcavitating large hydrofoil ship technology.

(U) Since the foil section data provided with the Technical Instructions from DWTNSRDC represents only one aspect ratio (5.0), performance estimates of foil configurations with aspect ratios more suitable for the ship size under consideration must be based on engineering judgernent. Although, the resultant conceptual design of Ml65 can be considered speculative, it does represent the application of the best engineering judgement based on the available data as to the probable size and performance of a 70-kt HOC.

(U) Based on early studies, a supercavitating condition on a foil was found to be the most desirable mode for high-speed operation. Later experiments run on supercavitating foils revealed three major findings which directed the Design Ml65 foil to operate in the superventilated mode. The major findings of these experiments were:

- If a supercavitating foil is run in waves at cavitating speeds within 1/4 chord of the water surface, sooner or later it encounters a large disturbance which springs the cavity open to the atmosphere. The foil is then in a supervsntilated condition
- Once the superventilated condition is generated, the ventilated condition is maintained to depths of submergence lower than 1-1/2 to 2 chords, even though the speed may be reduced to that which originally formed the cavity on the foil
- On one experimental run at a foil submergence of one chord, the cavity on the foil (in a supercavitated condition) erupted to the atmosphere as soon as a significant disturbance was encountered. This phenomeon occurred in a superventilated mode and was accompanied by abrupt changes in force.

This force variation in changing from supercavitating to superventilating may be detrimental to control of the craft. If this proves to be the case, the system can only be designed for one flow regime. Since Design Ml65 will operate in random seas (therefore encountering significant disturbances) it is safe to conclude that the foil will eventually ventilate.

Section 2

VEHICLE DESCRIPTION

(C) Grumman Design Ml65 is a 1,350 metric ton hydrofoil ocean combatant designed to accommodate a mix of state-of-the-art combat system elements currently under development. Maximum continuous speed foilborne is in excess of 50 kt, but by employing various flow transition devices on the struts and foils, a 70-kt burst speed capability has been incorporated into the design. Ranges at design conditions are 1,850 n mi at 40 kt foilborne, and 4000 n mi at 12 kt hullborne, foils extended; both with normal hotel and shipboard service loads. An increased hullborne range capability is provided with a separate hullborne cruising and maneuvering propulsion system.

(U) Accommodations are available for a crew of 86 persons including 9 officers, 9 CPOs and 68 enlisted men.

(U) The principal characteristics of Design Ml65 are described in Subsection 2.1 and 2.2, with detail subsystem descriptions provided in Subsection 2.3. Profile, general arrangement, and major equipment arrangement drawings are presented in the following figures:

Fig. No.	
2-1	Outboard Profile and Front View
2-2	Inboard Profile, General Arrangement
2-3	Main Deck, 01 and 02 Levels - General Arrangement
2-4	Second Deck, First Platform and Hold-General Arrangement
2-5	Propulsion Machinery and Foil System Arrangement
2-6	Transcavitating Pod Arrangement

2.1 PRINCIPAL CHARACTERISTICS

2.2.1 Mission

(C) Like the Hydrofoil Ocean Combatant (HOC), the specific tasks of the Ml65 would include protection of naval forces and shipping, offshore resource protection, and barrier operations. The vehicle also has the capability for performing surveillance and reconnaissance operations, sea launched ballistic missile defense; inshore warfare; and, with modification, mine warfare and operational logistic support.

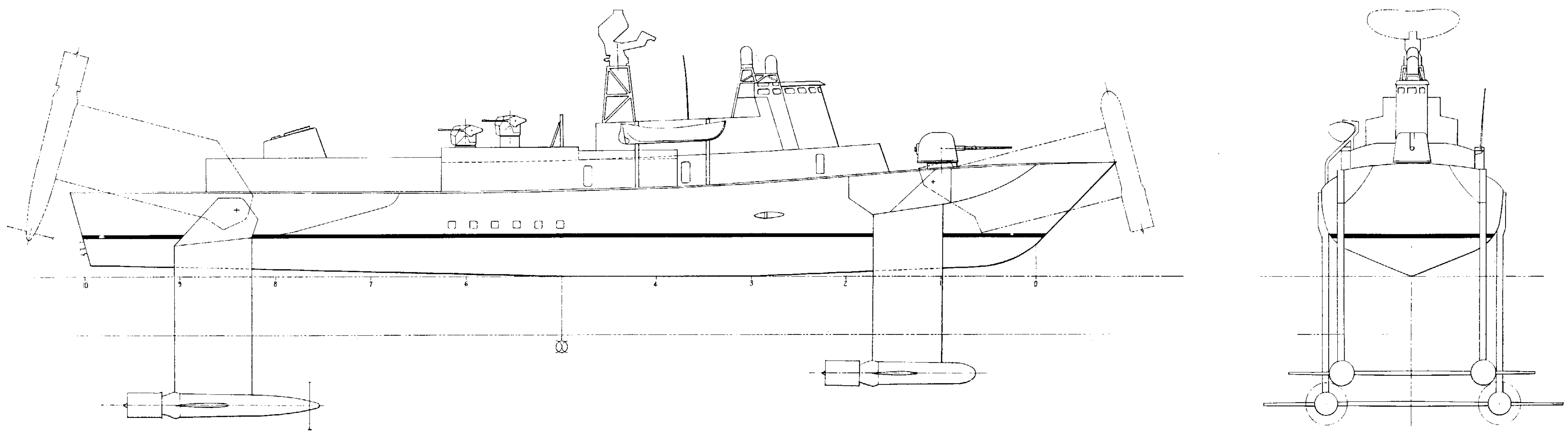

Fig. 2-1 Outboard Profile and Front View

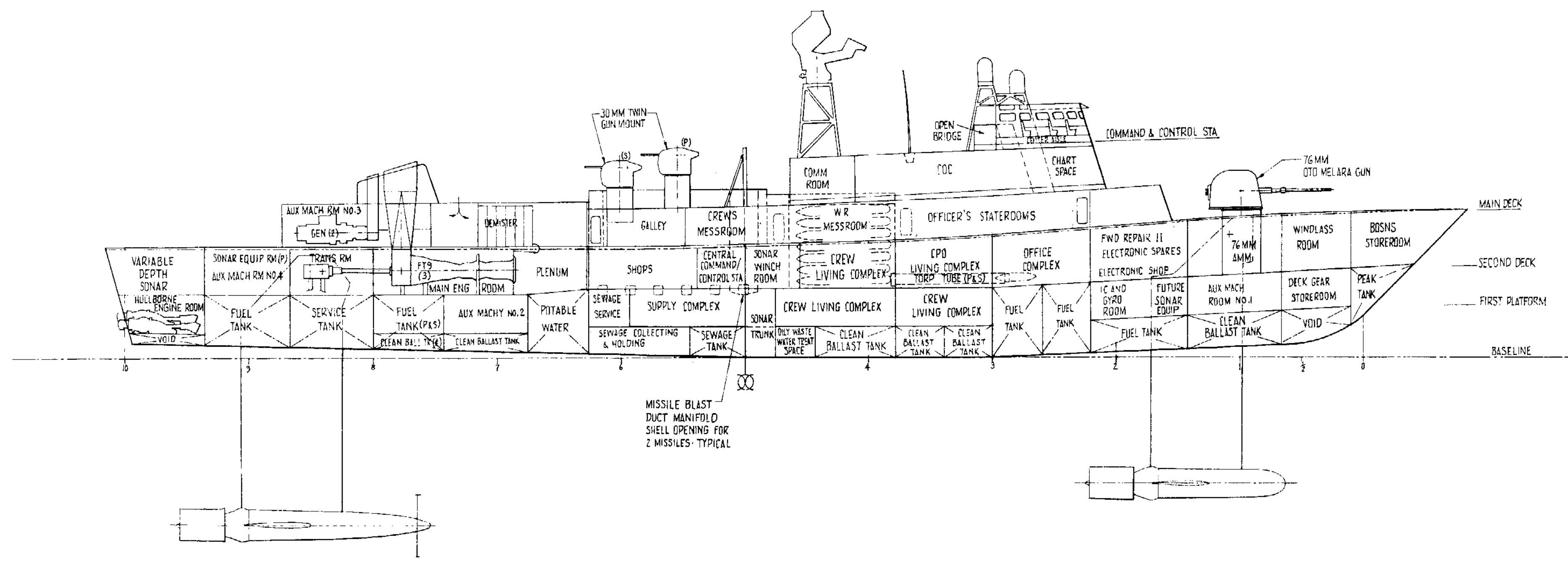

Fig. 2-2 Inboard Profile, General Arrangement

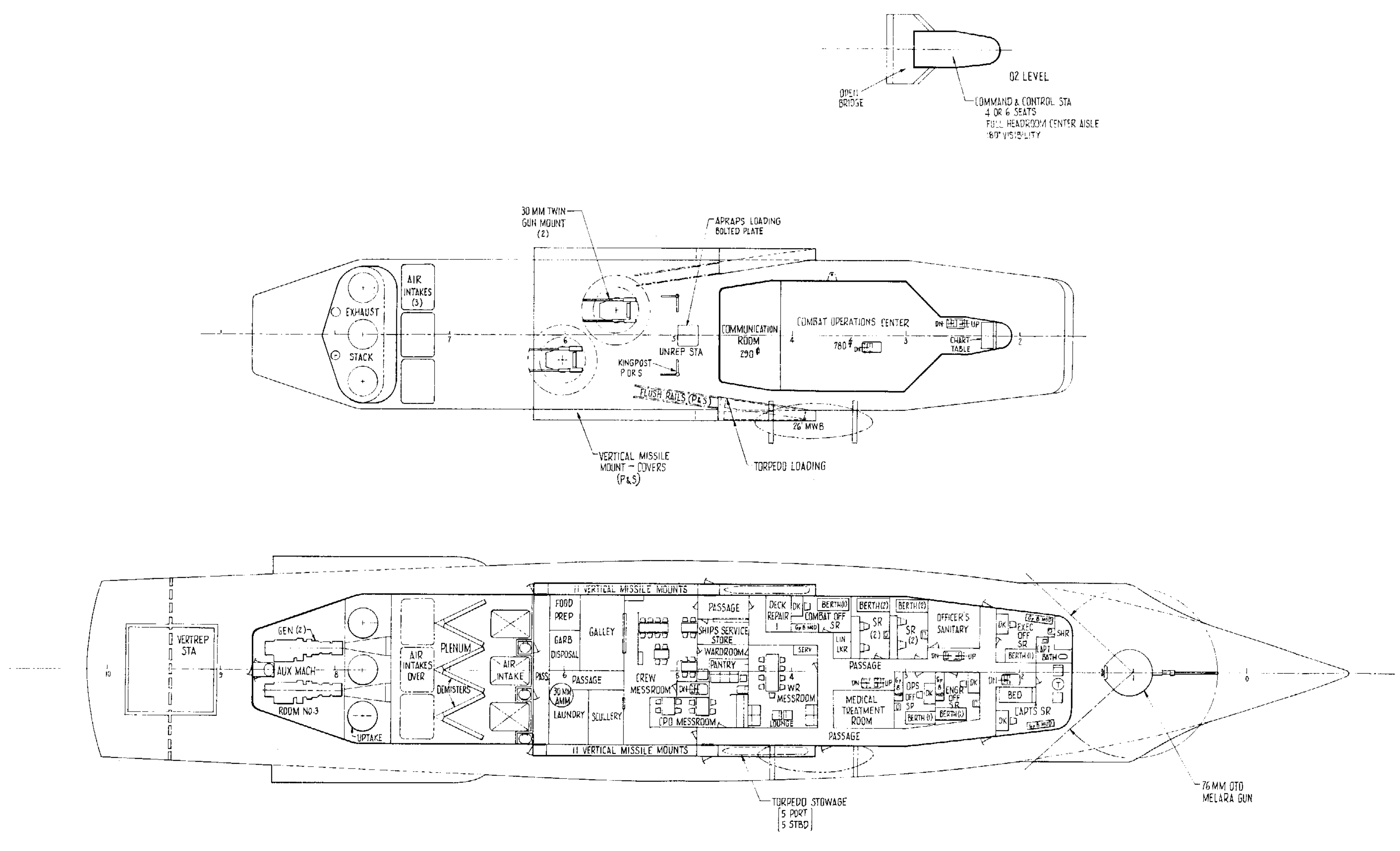

Fig. 2-3 Main Deck, 01 and 02 Levels, General Arrangement

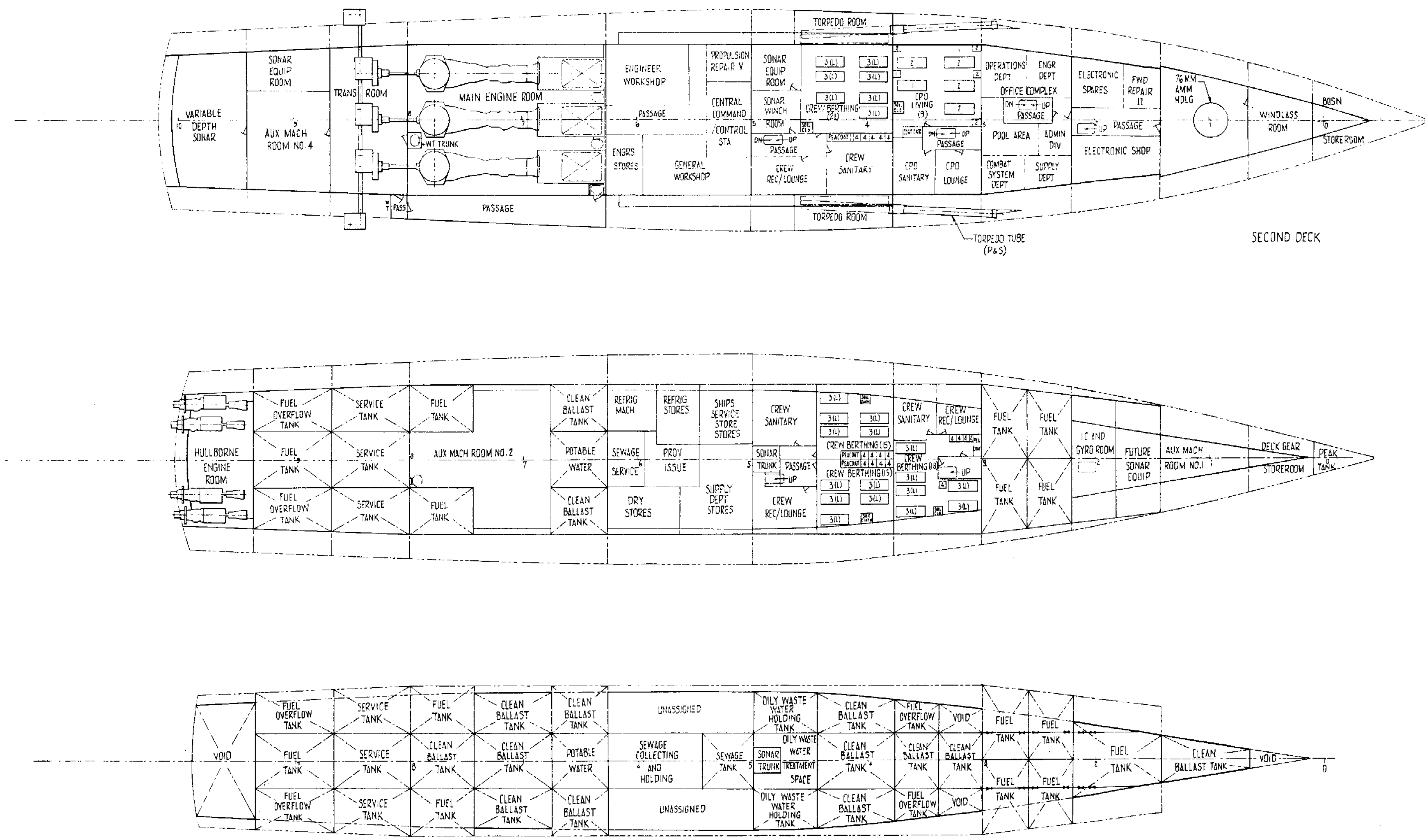

Fig. 2-4 Second Deck, First Platform and Hold, General Arrangement

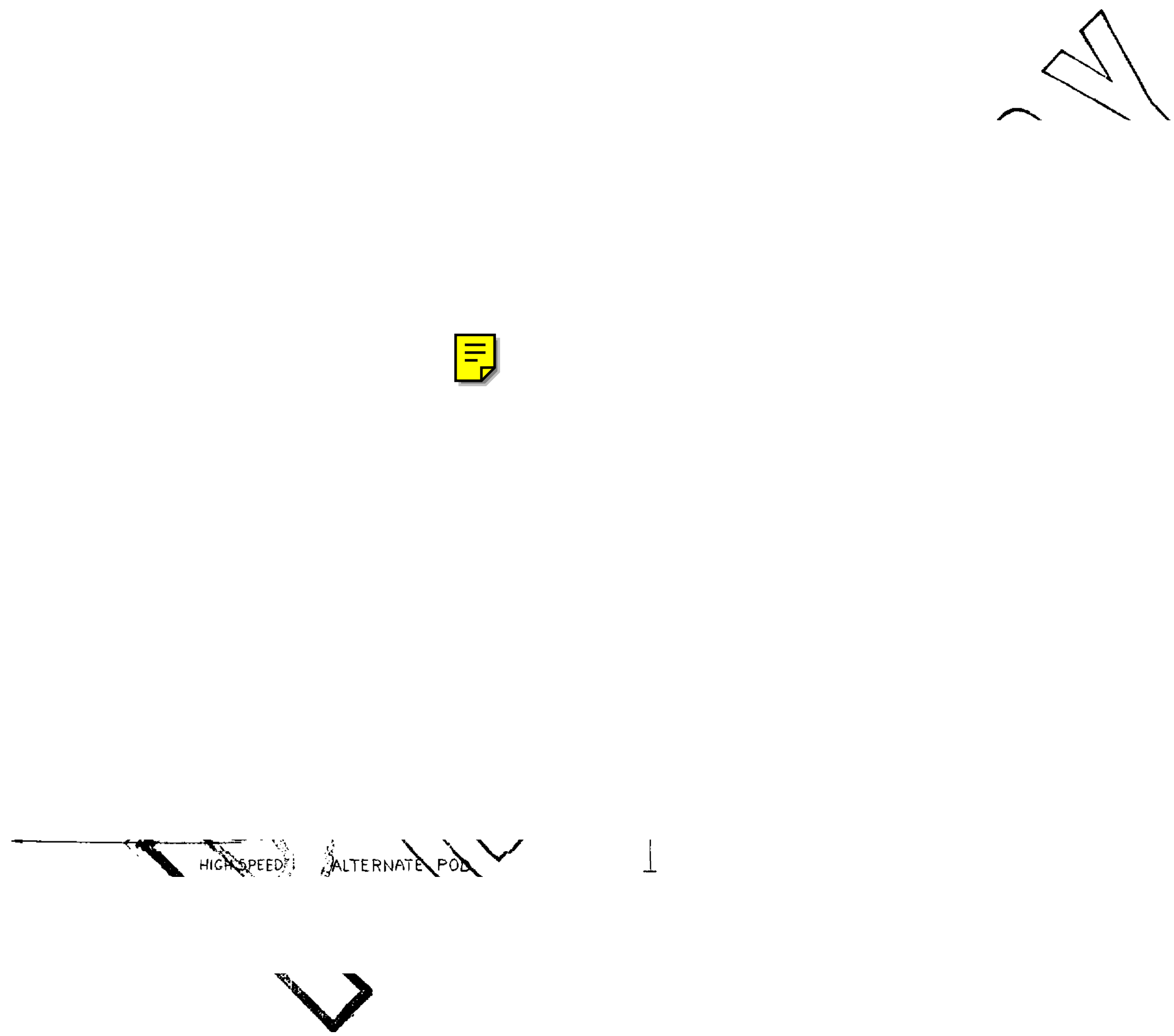

Fig. 2-6 Transcavitating Pod Arrangement

2.1.2 Characteristics

DIMENSIONS (U)

	feet	meters
Length Overall - Foils Retracted	296.5	90.37
- Foils Extended	271.5	82.75
Beam Overall - Foils Retracted	77.5	23.62
- Foils Extended	77.5	23.62
Operational Draft - Foils Retracted	10.17	3.10
- Foils Extended (Hullborne)	49.36	15.04
Draft (Nominal) Foilborne	24.0	7.32
Length Between Perpendiculars (Hull)	247.0	75.29
Maximum Beam (Hull)	47.50	14.48
Radar Height		
SPS-49 Foilborne	65	19.81
Hullborne	50	15.24
AWG-9 Foilborne	60	18.29
Hullborne	45.0	13.72

HULL GEOMETRY (U)

(U) The hullform used for Design Ml65 was derived by systematic scaling of the lines of Grumman's proprietary Ml54 parent hydrofoil hull. Hull length, beam, and depth were reduced by appropriate scale factors to derive a slightly smaller bull appropriate to the design requirements. The resulting Ml65 hull particulars are as follows:

	feet	meters
Length Overall	261.20	79.61
Length Between Perpendiculars	247.00	75.29
Maximum Beam	47.50	14.48
Hull depth to sheer, amidships	21.92	6.68

Later analysis indicated that, due to the greater weight and volume of the 70-kt foil system, as compared to a 50-kt design, the assumed hullform should be modified to provide adequate stability for open ocean operation, as discussed in Subsection 2.2.6.

POWERPLANTS (U)

Main Propulsion	three Pratt and Whitney FT-9 gas turbines rated at 37,000 SHP continuous, 43600 SHP (Takeoff)
Hullborne Propulsion	four Jacuzzi 14YJ water pumps rated at 215 SHP continuous at 2550 RPM
Electric Service	two Lycoming TF35 gas turbines rated at 2800 SHP continuous at 1500 RPM

SYSTEMS (U)

Accommodations	9 Officers, 9 CPOs, 68 Enlisted men
Fuel (Propulsion)	360 metric tons in 11 storage tanks plus four overflow tanks of approx 65 metric tons
(Growth)	Tank space and weight available for additional fuel.
Electrical	Two 1050 kw, 60-Hz generators Two 90 kw, 400-Hz generators
Hydraulic	Four Abex AP27V Hydraulic pumps rated at 8.83 $\frac{\text{liters}}{\text{sec}}$ @ 20.68 mpa + six 500 hp pumps (unspecified)
Steering	
Foilborne	Two hydraulically actuated (steerable) forward struts
Hullborne - 8 to 35 kt.	Two hydraulically actuated (steerable) forward struts
Hullborne - 0 to 8 kt	Four Jacuzzi 14YJ water jets

WEIGHTS (U)	metric tons
Full Load Displacement	1350.00
Lightship Weight	886.30
Fuel (Propulsion & Ship Service)	360.00
Other Loads	103.70

2.1.3 General Arrangement

(U) Design Ml65 hull arrangement consists of continuous Main and Second Decks, and a partial lower Platform Deck. The Hold is subdivided into 12 major watertight subdivisions.

(U) The principal propulsion units are located aft of amidships and consist of three main foilborne FT-9 propulsion gas turbines driving two propellers through a dual-mesh, right-angle-geared transmission system. A separate low speed (0 - 8 kt) hullborne propulsion system consisting of four Jacuzzi 14YJ water jet pumps located at the transom on the First Platform, driven by four hydraulic motors is used for foils-up maneuvering. The hydraulic motors are driven by pumps located on the ship service Lycoming TF-35 gas turbines located aft in the Deck House. Maneuvering at low speeds is accomplished by equipping the jet pumps with steering and reversing gates. Propulsion machinery is arranged to facilitate overhaul and maintenance considerations.

(U) Crew accommodations for 86 officers and enlisted personnel are located amidships in areas where hullborne and foilborne motions are at a minimum.

(U) Lift system retraction is forward for the bow strut/foil array and aft for the stern strut/foil array. The aft array is retracted by rotating the struts aft. The strut retraction axis is located on the centerline of the transmission for shafting disconnects. The retraction mechanism for the forward array is similar to the aft system with the exception of the actuator size.

2.1.4 Combat System Arrangement

(C) The combat system is arranged to provide adequate arcs of fire/launch for weapons and to provide director or target track coverage required to support Weapon Control. All surveillance sensors are located to provide the necessary detection range and arcs of coverage for tracking targets.

(C) The major combat system components are the vertically launched, standard (MR) missiles located along both sides of the hull inboard amidships, and the 76 mm Oto Melara gun located forward on the Main Deck. The amidships location of the APRAPS sonar deployment was selected to minimize motion of the acoustic unit and cable during launch. The variable depth sonar, or alternatively linear and towed sonar arrays, are deployed through the transom with additional space available near the forward strut/foil array for future sonar requirements.

(U) The Combat Operations Center and the Communication Room are located on the 01 Level. The Command and Control Station is located on the 02 Level with seating for four or six with full headroom at the center aisle and 180-degree visibility. Radar antenna locations were selected to provide adequate height above the waterline to meet the technical or the range-to-horizon performance requirements.

2.2 VEHICLE PERFORMANCE

2.2.1 Strut-Foil-Pod Performance

(U) Foilborne performance predictions for Design M165 are based upon data received from DWTNSRDC for a high-speed mixed-foil configuration (Ref. 2). The strut-foil system was designed and tested during a 3 year program (designated TAP) initiated by NAVMAT to determine the feasibility of developing a strut-foil system for high-speed operation of hydrofoil craft that would perform satisfactorily at takeoff and at moderate speeds. Although this strut-foil concept is in its early stage of development, the L/D ratios have been demonstrated from tests run to date. Figures 2-7 through 2-9 and Tables 2-l through 2-3 contain all of the strut-foil characteristics supplied by DWTNSRDC. Since no data was received for rough water conditions, all performance characteristics given herein are for smooth water. Furthermore, since no allowances were made for propulsion/actuation pods, the L/D ratios in Fig. 2-8 and 2-9 were modified to better represent the performance of the strut/pod/foil configuration employed in Design M165. These modifications to the foilborne L/D ratios include the added drag of the four pods that house actuation devices and transmission machinery and the additional drag associated with lengthening the aft struts by 2.44 m.

(U) Hullborne drag data was derived partially on the basis of smooth-water model tests of Grumman hull design Ml54 run at Davidson Laboratory and reported in Ref. 3. Appropriate scaling and interpolation techniques were used to account for hull variations and displacement. Due to the efficiency of hull design M154, maximum hullborne performance is obtained with minimum drag on the foils (foil trim set for zero dynamic lift). This condition is maintained across the hullborne, foils down speed range (8 to 35 kt).

(U) Figures 2-8 and 2-9 and Tables 2-l through 2-3 present the foil-strut characteristics for both incidence and flap control as supplied by DWTNSRDC. It is anticipated that both flap and incidence control will be required. Incidence will be limited to 0 to 4 deg, and flaps would be used as primary control in the subcavitating and partially cavitating regimes. For the supercavitating regime, incidence control and tabs ($C_{L_{TAB}}$ = .0035/deg up to 15 deg) will be used for control.

BASED ON SUBCAVITATING AREA FOR BOTH INCIDENCE CONTROL AND FLAP CONTROL

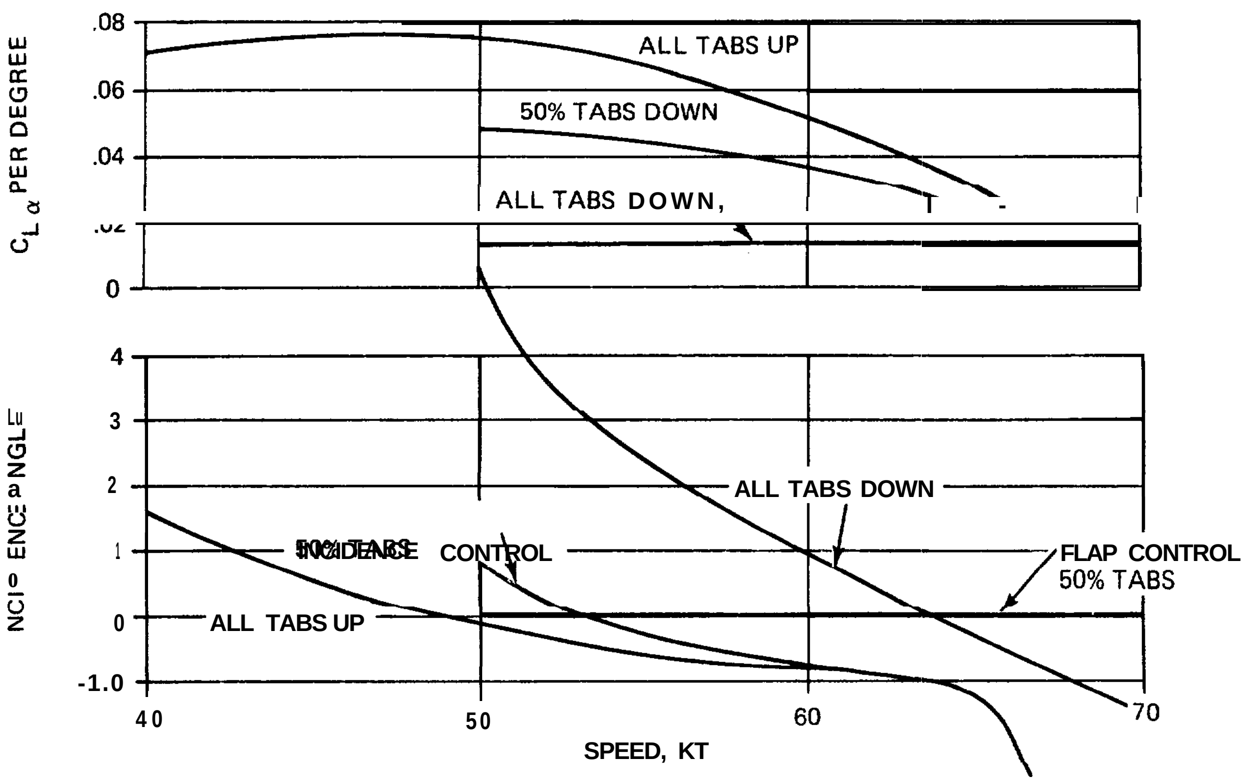

Fig. 2-7 Strut and Foil Characteristics (Part 1 of 2)

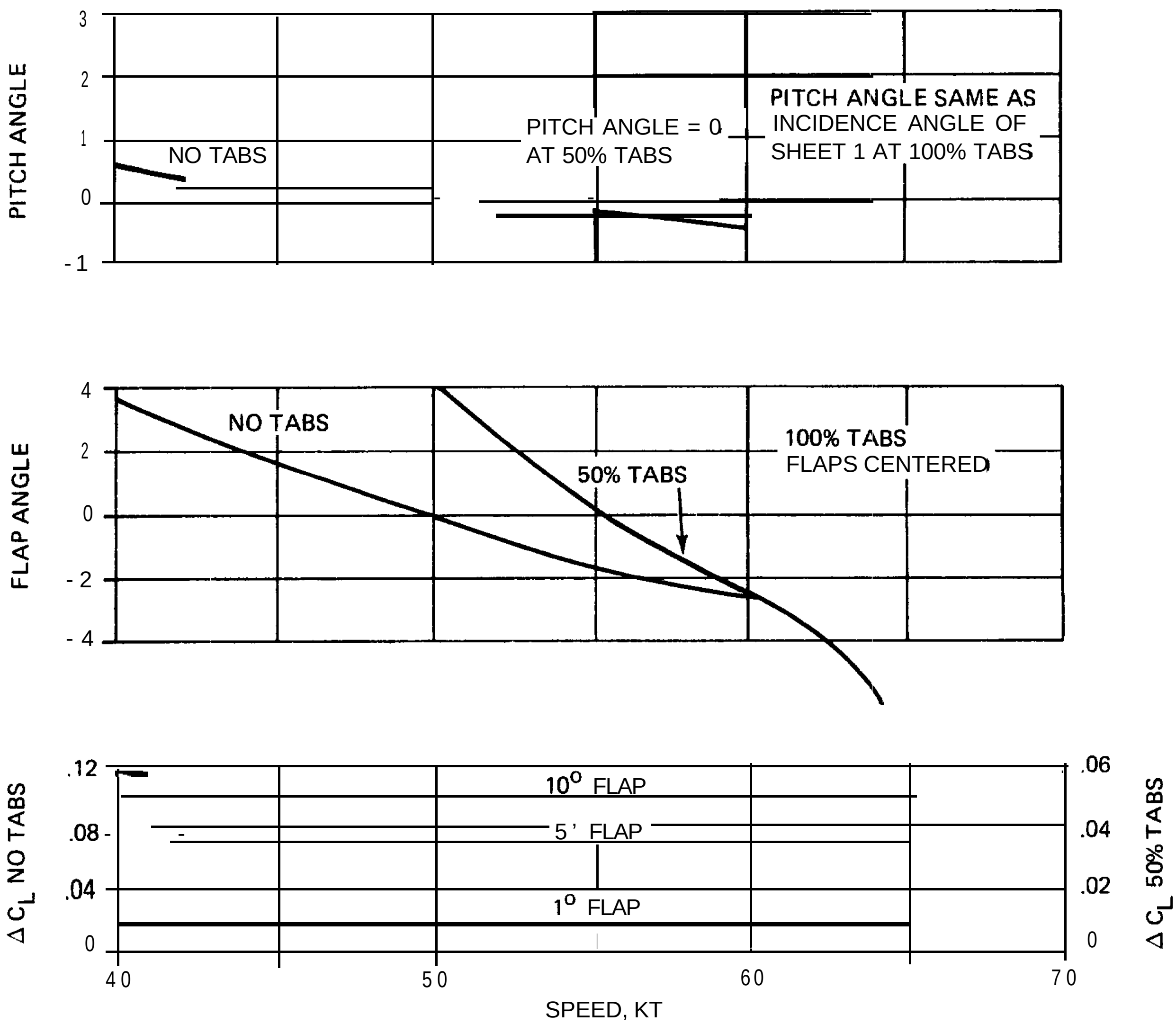

Fig. 2-7 Strut and Foil Characteristics (Part 2 of 2)

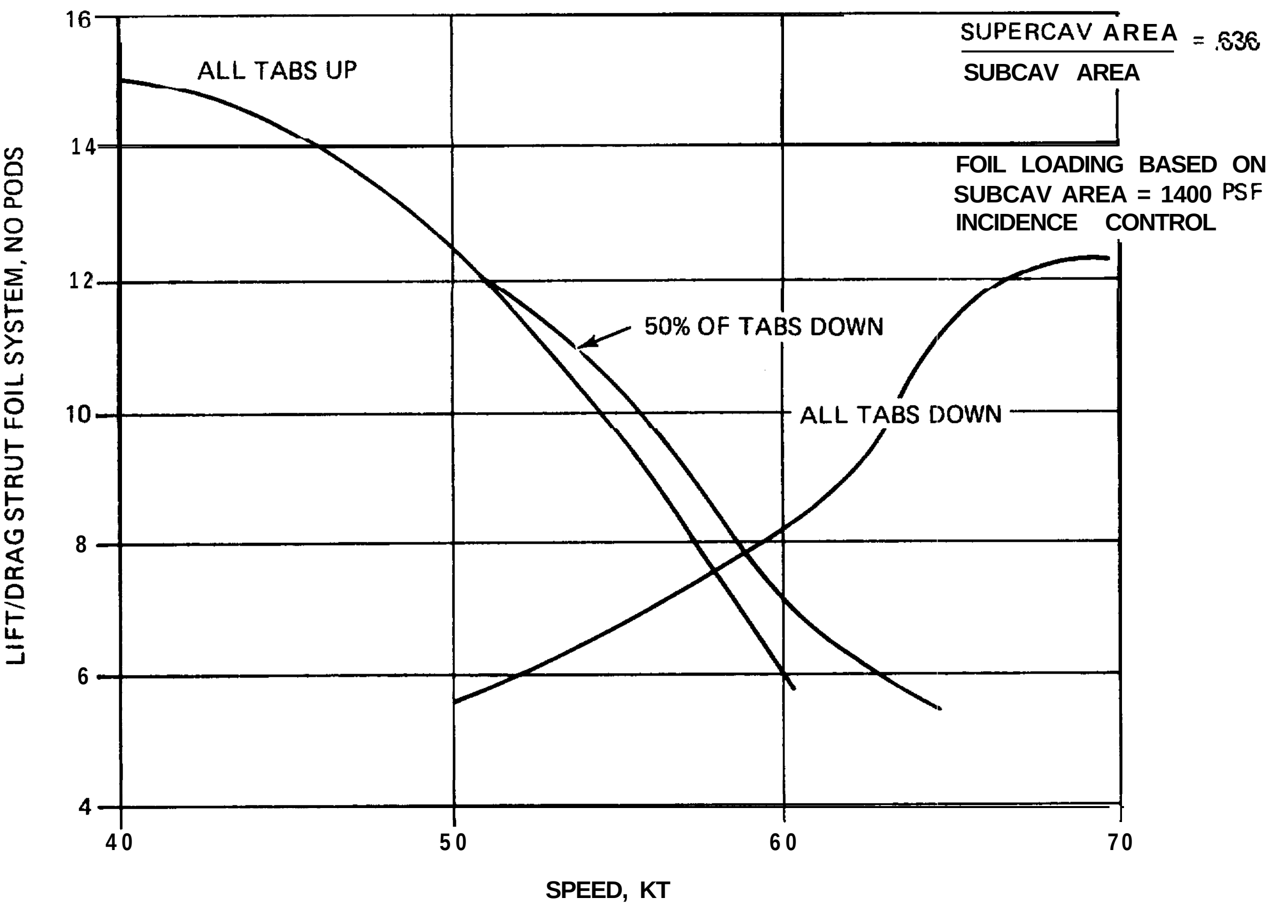

Fig. 2-8 Strut and Foil L/D, Incidence Control

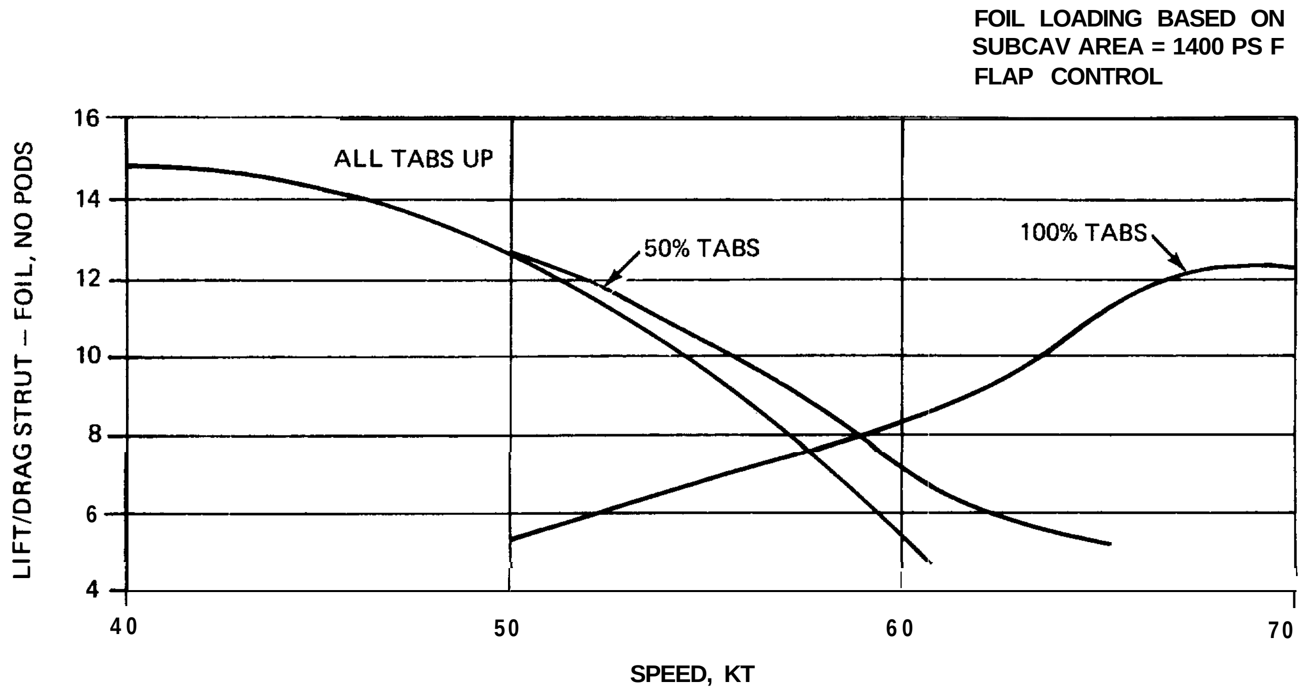

Fig. 2-9 Strut and Foil L/D, Flap Control

Table 2-1 Mixed Foil Characteristics

$C_L = A + C_{L_\alpha} \alpha + C_{L_\delta} \delta$

α = incidence angle of subcavitating section

δ = flap angle

Use C_{L_a} from Fig. 2-7 (Sheet 1)

$C_{L_\delta} \delta$ from Fig. 2-7 (Sheet 2), for incidence control $C_{L_\delta} = 0$

Find A below.

SHIP SPEED, KT	SUPERCAV AREA / SUBCAV AREA	A: ALL TABS UP	A: 50% TABS DOWN	A: ALL TABS DOWN
50	.636	–	–	–
50	.636	–	.152	.108
55	.636	–	.150	.105
60	.636	–	.148	.101
65	.636	–	.148	,101
70	.636		–	.101

Table 2-2 High-Speed Lift-to-Drag Ratios of Strut/Foil Configuration (Incidence Control)

Speed	% Tabs Opened	Angle of Attack(1)		Lift Coefficient(2)			Lift-to-Drag Ratio(3)			Cl, (Des.)	
		Sub	Super	Sub	Super	Total	Sub	Super	Net	Sub	Super
50	0	0	–	.196	0	.196	12.6		12.6	.0735	.013
	50	0.78	2.28	.126	.070			9.1	11.0		
	100	–	6.77	0	.196			5.7	5.7		
55	0	–.52	–	.162	0	.162	9.7	–	9.7	.065	
	50	.04	1.54	.099	.063			10.5	10.0		
	100	–	4.38	0	.162			6.8	6.8		
60	0	–.90		.136	0	.136	5.5	–	5.5	.050	
	50	–.71	0.89	.080	.056			12.2	7.11		
	100	–	2.69	0	.136			8.2	8.2		
65	50	–.202	–.52	.068	.047	.115	3.5	12.1	4.93	.030	
	100	–	1.07	0	.115			12.0	12.0		
70	100	–	0	0	.100	.100		12.3	12.3		

(1) Angle of Attack Supercavitated is 1.5° higher than subcavitated.

(2) C_L =%Sub $[0.196 + C_{1_\alpha}\,\alpha]$ + % Sup $[A + .013\,(\alpha + 1.5)]$ A from Table 2.2.1-1

(3)

$$\frac{D}{L}\,\text{Net} = \frac{\frac{C_{L\,sup}}{(L/D)sub} + \frac{C_{L\,sup}}{(L/D)sup}}{C_{L_{Total}}}$$

UNCLASSIFIED

UNCLASSIFIED

Table 2-3 High-Speed Lift-to-Drag Ratios of Strut/Foil Configuration (Flap Control)

Speed Kt	% Tabs	Angle of Attack		δ_F	Lift Coefficient			Lift to Drag Ratio			$C_{L\alpha}$	
		Sub	Super		Sub	Super	Total	Sub	Super	Net	Sub	Super
50	0	0	–	0	.196	–	.196	12.6	–	12.6	.0735	.013
	50	0	1.50	4.5	.132	.064			12.0	12.4		
	100	–	6.77	Center	–	.196			5.7	5.7		
55	0	–.2	–	–1.3	.162	–	.162	9.7	–	9.7	.065	
	50	0	1.50	0.4	.100	.062			12.0	10.5		
	100	–	4.38	Center	–	.162			6.8	6.8		
60	0	–.5	–	–2.2	.136	–	.136	5.5	–	5.5	.050	
	50	0	1.50	–2.7	.076	.060			12.0	7.2		
	100	–	2.69	Center	–	.136			8.2	8.2		
65	50	0	1.50	–10.5	.055	.060	.115	3.5	12.0	5.6	.030	
	100	–	1.07	Center	–	.115			12.0	12.0		
70	100		0	Center	–	.100	–	–	12.3	12.3	–	

UNCLASSIFIED

(U) Figure 2-8 is the L/D ratio of the foil-strut system with no pods, for the incidence control system. The area ratio of supercavitating to subcavitating regimes is .636 and the foil loading based on the subcavitating wetted area is 1400 psf (167,032 pa).

(U) Figure 2-9 is the L/D ratio of the foil-strut system with no plods, for the flap control system. The foil loading and wetted area ratios are the same as the incidence control system.

2.2.2 Thrust, Drag, and Power

L/D VS SPEED

(U) Figure 2-10 presents the L/D ratio of the foil-strut-pod system of Design M165. It is assumed that the flaps, tabs and incidence systems can be scheduled in such a way that the L/D ratio is comprised of the maximum value at a given speed of either system in Fig. 2-8 and 2-9. The L/D ratios in Fig. 2-10 have been modified1 to account for the pods and the extended strut length on the aft struts.

(U) Figure 2-11 presents the L/D ratios of the Design Ml65 hull,, Full and half-fuel-weight displacement L/Ds are presented as a function of ship speed. These L/D ratios include the strut-foil-pod drags associated with zero lift on the foils.

D/W VS SPEED

(U) Figure 2-12 is a plot of drag to weight (total displacement) vs speed, which is the inverse of the craft L/D ratio. These ratios are presented for the full load displacement and the half-fuel-load displacement of Design M165.

THRUST AND DRAG VS SPEED

(U) Figure 2-13 is a plot of thrust and drag versus speed for the design full load and half-fuel-load displacements. An estimated hydraulic control power extraction of 3000 hp has been incorporated into the thrust curves and the drags are based on the net hydrodynamic lift of 1270.5 metric tons.

THRUST/WEIGHT VS SPEED

(U) Available foilborne propeller thrust to weight ratios (T/W) are shown in Fig. 2-14 for a 26" C day at maximum intermittent and continuous engine power settings. Thrust to weight at intermittent engine power is shown for three engines operating and represents T/W characteristics for maximum acceleration. For continuous engine power operation, the T/W characteristics are shown for two engines operating and represents T/W values during normal cruise operation.

[redacted]

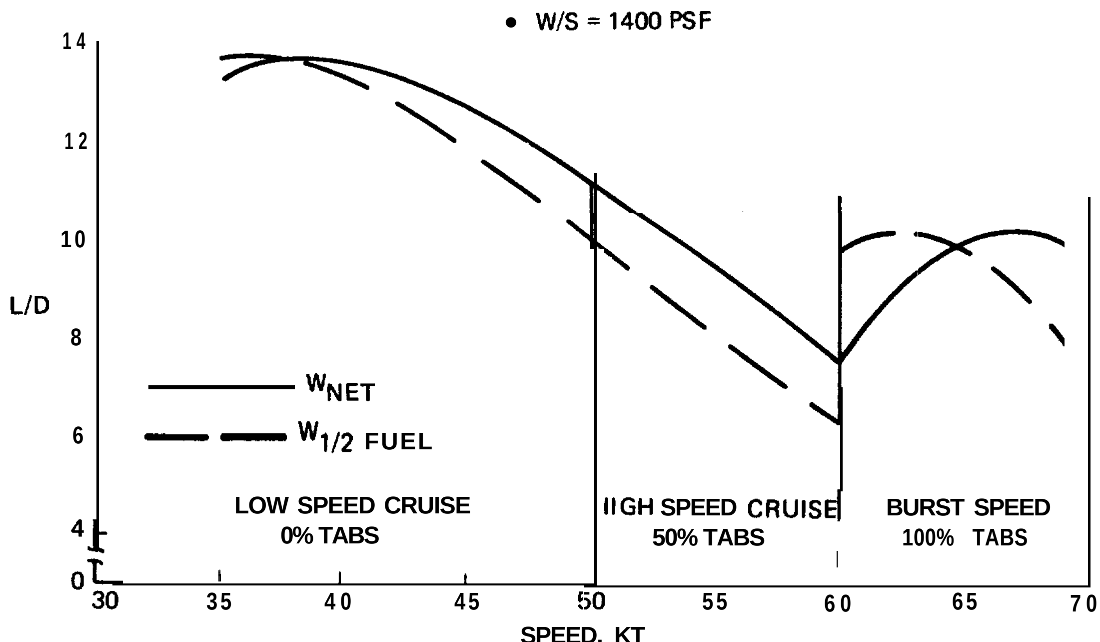

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Fig. 2-10 Dynamic L/D, Foilborne (U)

[redacted]

[redacted]

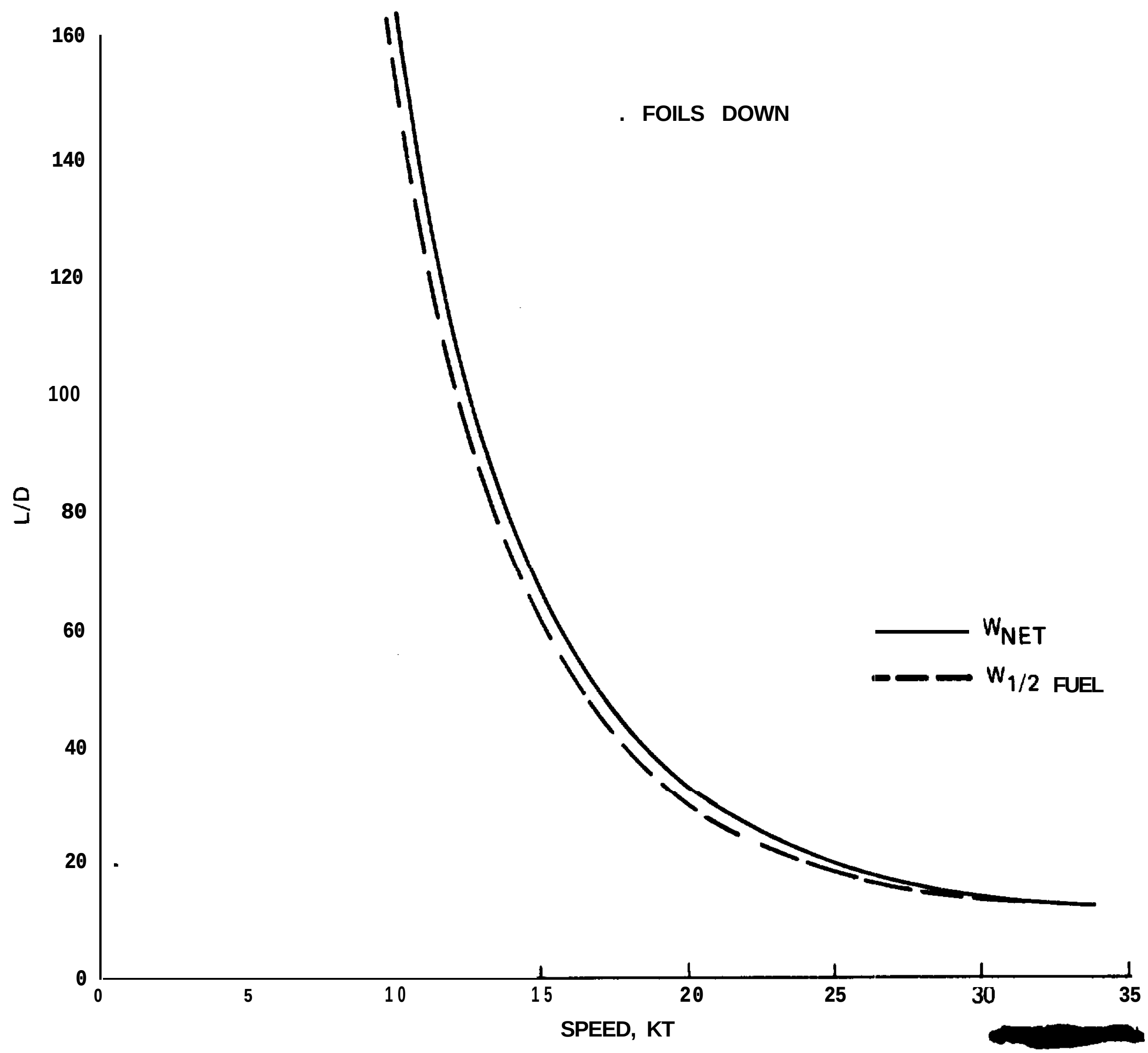

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Fig. 2-11 Dynamic L/D, Hullborne (U)

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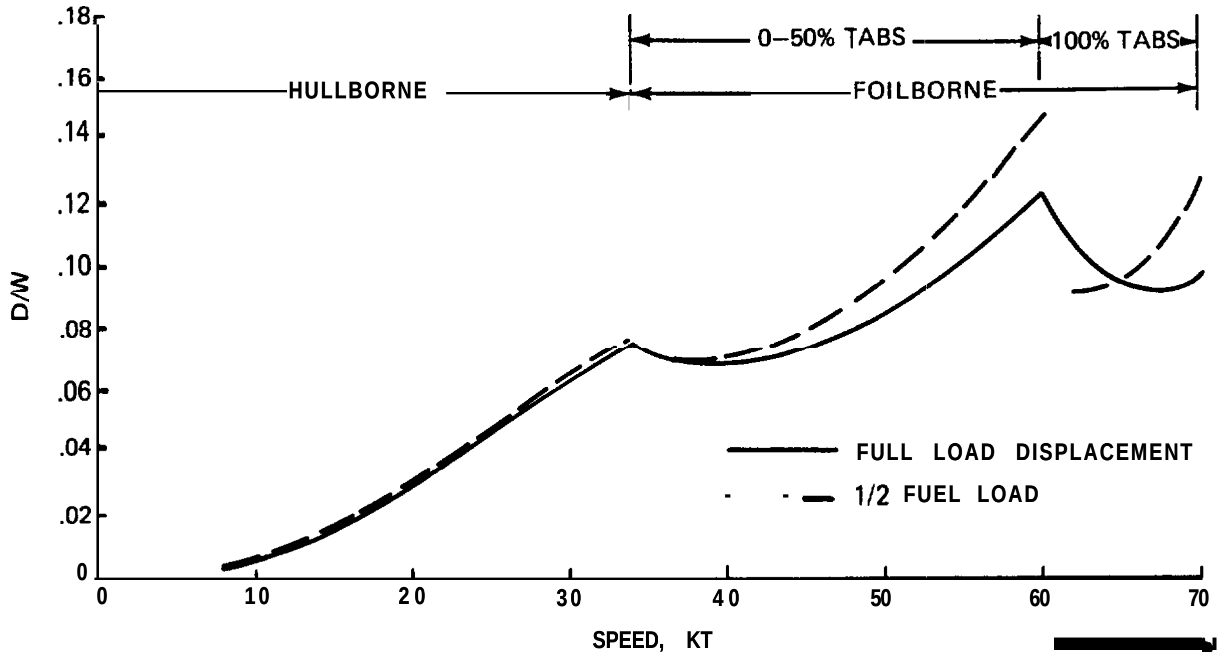

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Fig. 2-12 Drag/Weight vs Speed (U)

[redacted]

[redacted]

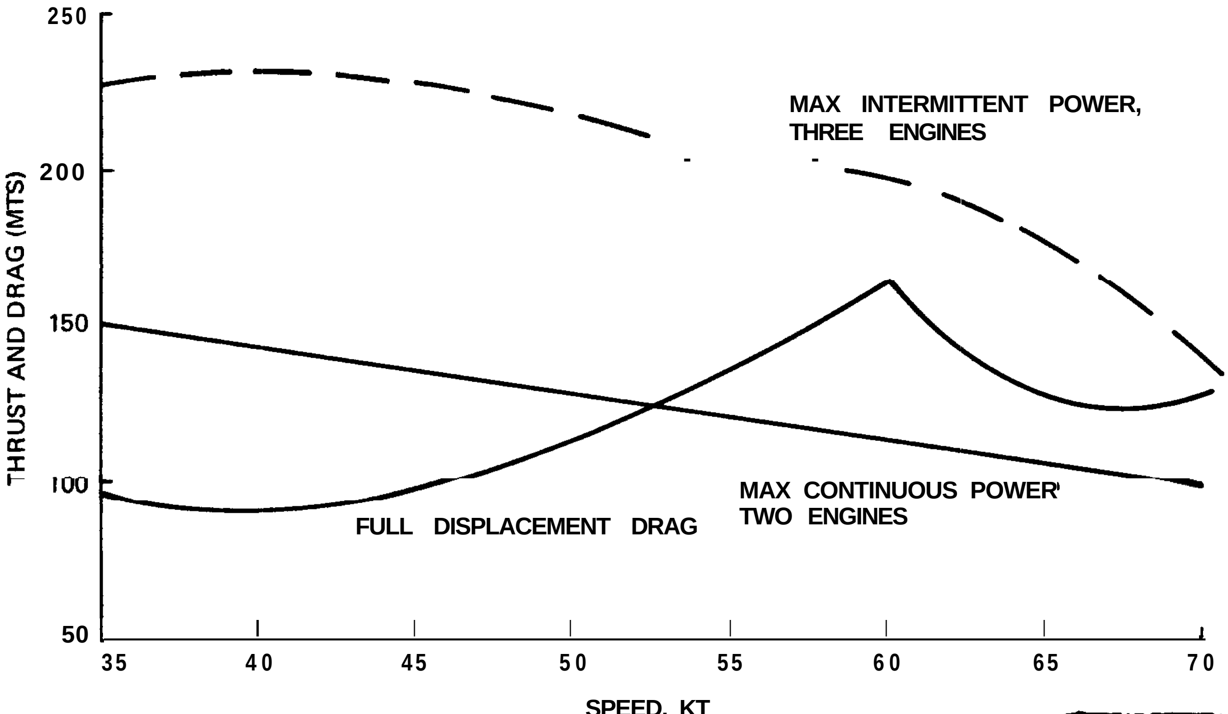

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Fig. 2-13 Thrust and Drag vs Speed (U)

[redacted]

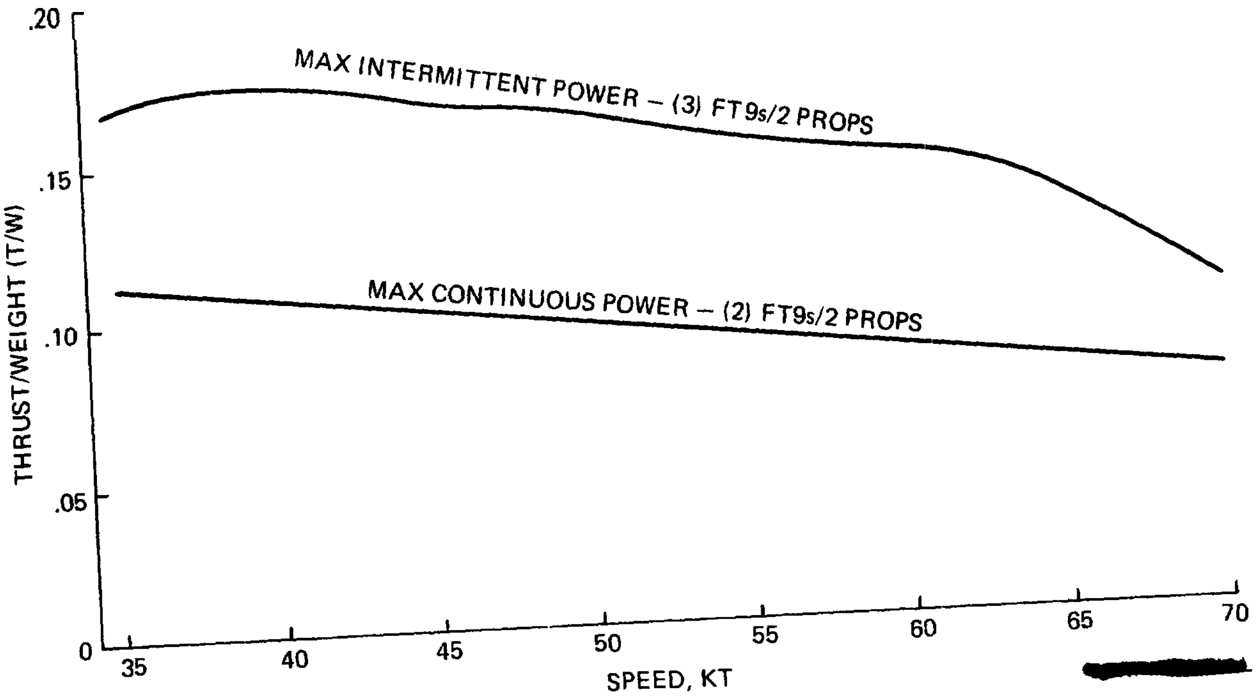

Fig. 2-14 Thrust/Weight vs Speed (U)

(U) Propeller characteristics used to generate the data in Fig. 2-14 are based on extrapolated data for the Newton-Rader propeller at a P/D of 2.06. No attempt has been made to define the propeller pitch schedule for the constant engine power setting modes of operation.

POWER VS SPEED

(U) Steady state (thrust=drag) power requirements per engine across the operating ship speed range are shown in Fig. 2-15. Three operational bands are shown:

Hullborne: O-8 kt with waterjets and one TF35 engine.

Hullborne: 8-35 kt with two foilborne propellers and one FT9 engine.

Foilborne: 35-70 kt with two foilborne propellers with one, two and three FT9 engines operating.

(U) The 8-kt hullborne waterjet limit is due to the hydraulic motor power limit. The lower hullborne speed limit with propellers operating is based on the FT9 engine idle power of 1000 SHP. With the variable pitch propellers, slower speeds can be achieved, but the engine power remains constant at 1000 SHP. Three engine powering options are shown for the foilborne mode which for a given ship speed are equivalent to the total power required by the ship. Matched foilborne SFC characteristics vary, however, depending on the number of engines operating as shown in Fig. 2- 17.

PROPULSIVE EFFICIENCY

(U) Steady state (thrust-drag) overall propulsive efficiencies are shown in Fig. 2-16 for half fuel load operation, for the indicated propeller and engine operating conditions. These efficiencies incorporate a hydraulic power extraction of 3000 hp in the foilborne mode. Propeller pitch for these conditions was optimized for minimum engine power resulting in nominal propeller pitch ratios as indicated on the figure. Further refinement of the pitch schedule will be based on minimum fuel flow. The engine powers corresponding to these efficiencies are used in the range estimates (see Subsection 2.2.4). It can be seen that in the foilborne mode overall propulsive efficiency is constant and independent of the number of engines operating. The propeller/engine matched characteristics, however, vary as shown in Subsection 2.3.2.

SPECIFIC FUEL CONSUMPTION VS SPEED

(U) Engine SFC characteristics across the ship operating range are shown in Fig. 2-17 for the indicated engines. These SFC values correspond to the engine power requirements

[redacted]

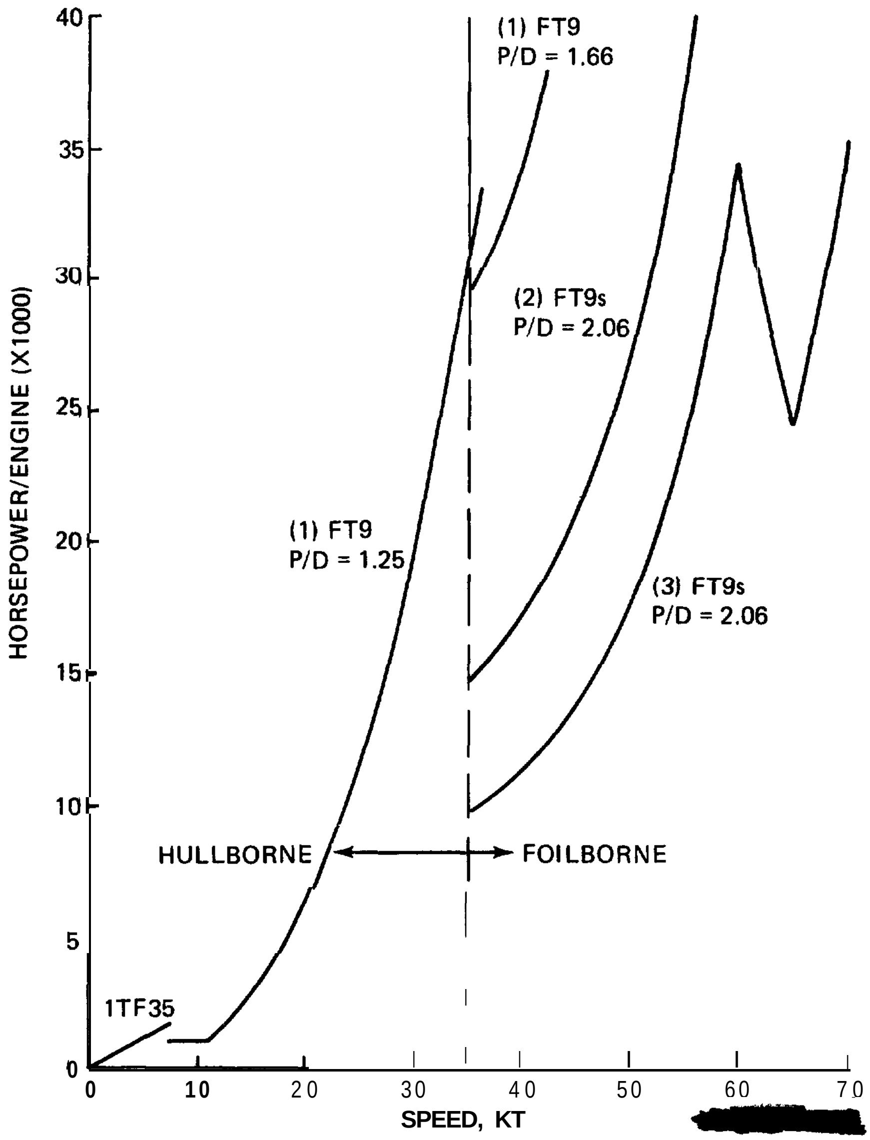

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Fig. 2-15 Horsepower/Engine vs Ship Speed (U)

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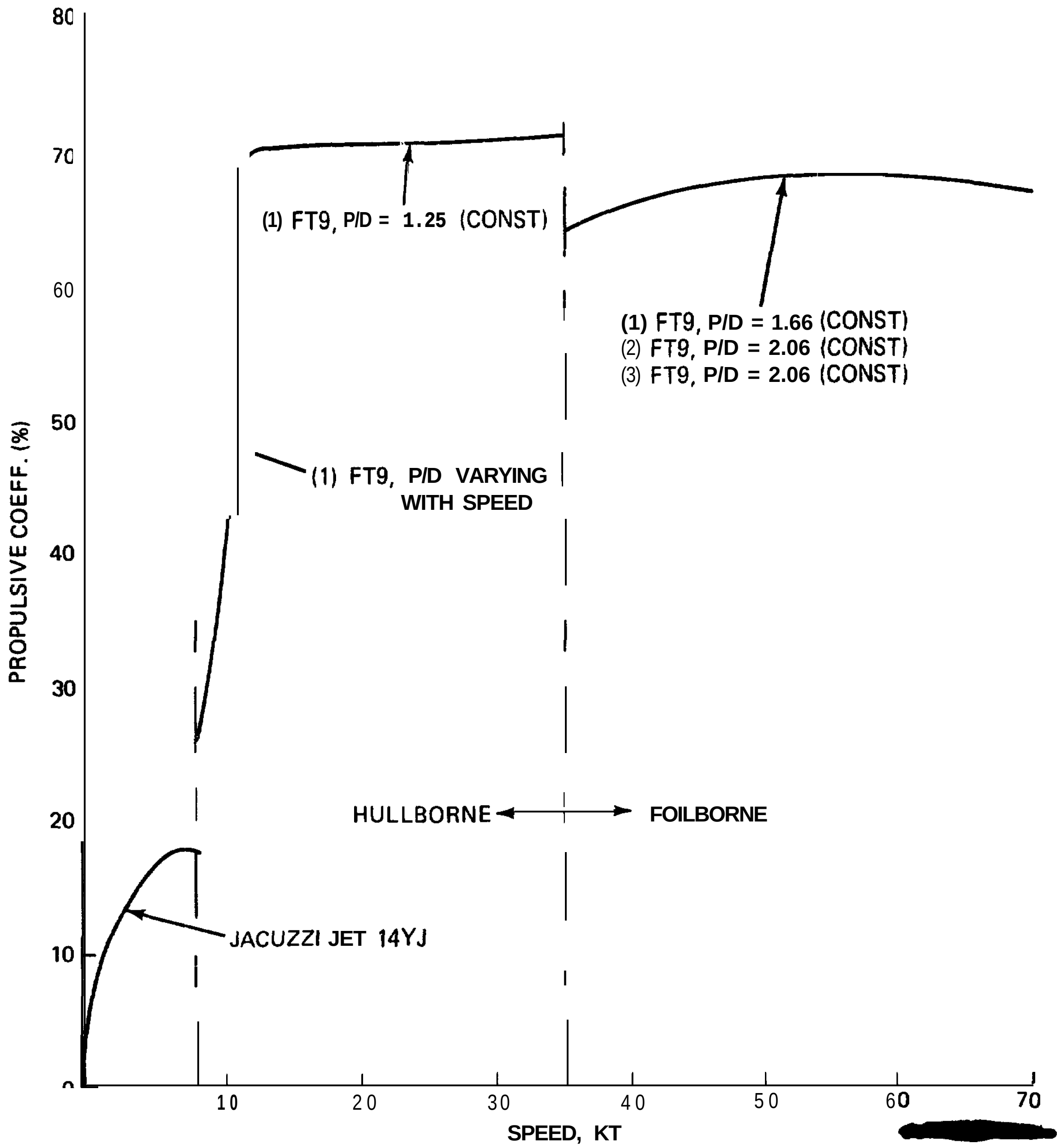

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Fig. 2-16 Propulsion Coefficient vs Ship Speed (U)

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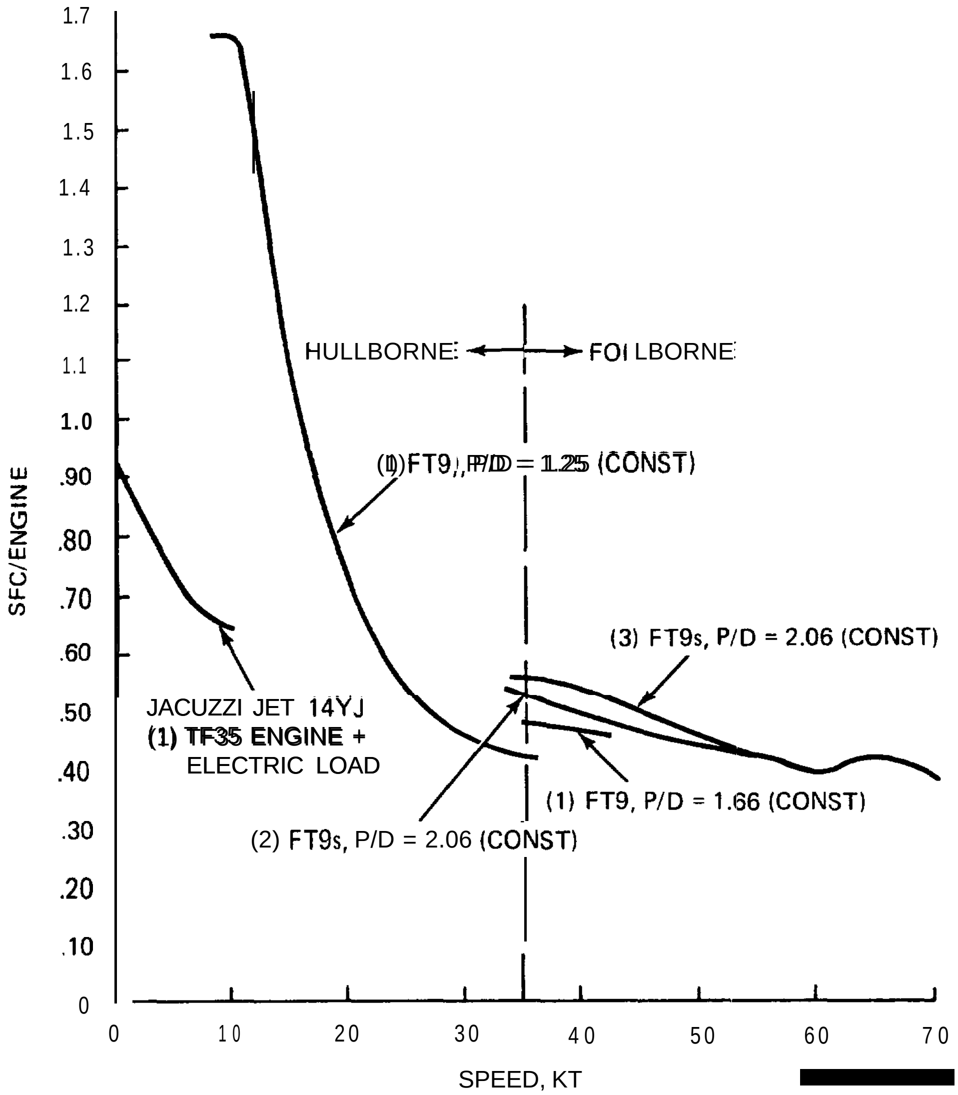


Fig. 2-17 SFC vs Ship Speed (U)

[redacted]

shown in Fig. 2-15. The variation in SFC with the number of engines operating is evident. Also shown is the rapid increase in SFC in the hullborne mode as the FT9 engine approaches idle power. The SFC values include the effect of the appropriate power extractions in the various modes of operation.

TRANSPORT EFFICIENCY VS SPEED

(U) Figure 2-18 is a plot of transport efficiency versus speed for smooth water conditions. Transport efficiency is defined as the ratio of work done by the vehicle (weight x speed) to the total propulsion power expended. Since the foilborne total horsepower is independent of the number of engines, the transport efficiency foilborne is also independent of the number of engines.

SPEED LIMITATIONS

(U) Hullborne, the hydrofoil behaves like any displacement hull in a rough sea. The speed is affected by an increase in resistance due to direct wave action and indirect effects of waves associated with ship motions (pitching, heaving, etc.) and a reduced propulsive efficiency caused by increased propeller loading, reduced hull efficiency and propeller racing.

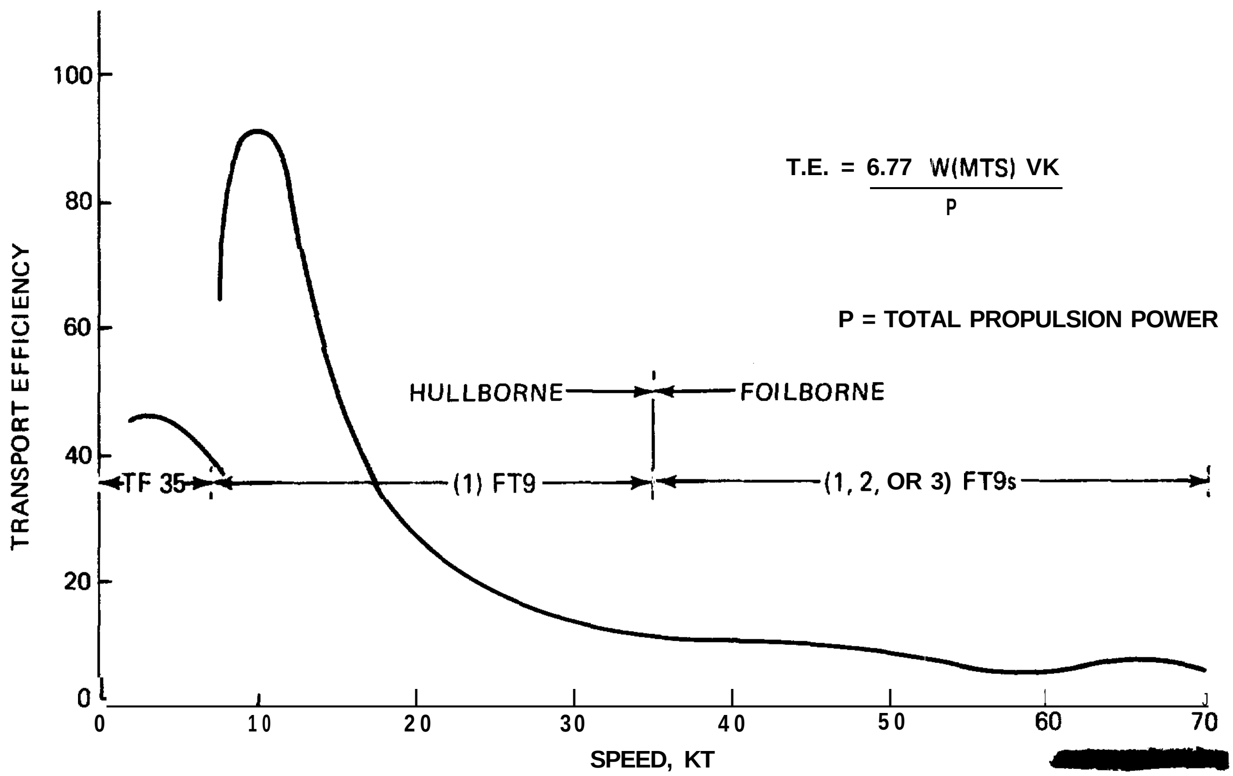
(U) Foilborne, the foil submergence must be varied to assure that both hull impacting and broaching are reduced to a minimum. As the sea state increases the foil submergence must increase, in order to decrease the broaching probability, thereby increasing the drag, In order to maintain a stable platform in these rough seas, the control system requires additional power extraction from the main engines which decreases the thrust available. These two phenomena combine to reduce the top speed of the vehicle as a function of sea state.

2.2.3 Maneuvering

FOILBORNE

(U) Turning characteristics of Design Ml65 were not predicted due to financial and time constraints. Some general comments on foilborne maneuvering can be made based on previous experimental work performed at DWTNSRDC on a 200-ton, 80-kt hydrofoil craft reported in Ref. 4 and 5. These investigations produced estimates of the hydrodynamic yaw angles on struts attached to high-speed hydrofoil craft performing coordinated turns. These estimated angles were then compared with predicted angles for sudden strut side ventilation to determine limitations to the craft maneuverability. The results of these investigations can be generalized to relate to Design Ml65 as follows:

[redacted]



[redacted]

Fig. 2-18 Transport Efficiency vs Speed, Smooth Water (U)

[redacted]

- Reducing the speed tightens the turning circle
- Lowering the speed greatly increases the turning rate
- The structural design for a high-speed hydrofoil craft depends on the hydrodynamic load due to turns in sea ways. As a result, the craft structural design will determine its mission capability as opposed to the desired result that mission requirements determine structural requirements
- Sudden strut side ventilation will not in principle severely limit maneuverability for coordinated turns, providing the struts have no error in their alignment to the flow at manufacture and providing such phenomena as breaking waves are ignored.

(U) Incorporating the forward steerable struts into Design Ml65 should enhance the turning performance as compared to a fixed strut with a rudder. The steerable struts reduce the yaw angles experienced in a turn thereby reducing the probability of strut side ventilation on the forward and aft struts.

(U) A series of tests on the pseudo-blunt based strut fitted with the TAP-2 supercavitating foil were performed at the Lockheed Underwater Missile Facility (LUMF) for simulated full-scale craft speeds of 50 to 80 kt with the results published in Ref. 6. With the foil operating at a one-chord submergence, the ventilation angle measured on the TAP-2 pseudoblunt-based strut at 70 kt was approximately 4.5 to 5 deg for the foils in the ventilated condition.

(U) Tests seem to indicate that improvements can be made in maneuverability and control of a high speed hydrofoil craft by employing the pseudo-blu.nt basedstrut. These improvements, however , increase the drag (as compared to a parabolic strut), thereby requiring a careful tradeoff between craft maneuverability and control to select a strut profile that can minimize the drag penalty and retain sufficient air passage to ventilate the foil cavity.

HULLBORNE

(U) Hullborne maneuvering from 0 to 8 kt is performed by steering and reversing gates incorporated in the Jacuzzi pump nozzles. From 8 to 35 kt the steerable struts will be used for maneuvering. No peculiar problems are anticipated in hullborne maneuvering that are not appropriate to a vehicle of this size. Beyond hullborne speeds of 8 kt the 15.04 m operational draft (foils) extended may produce problems in shallow waters.

2.2.4 Range and Endurance

(C) Specific ranges (n mi/(mt of fuel)) as a function of speed with and without the ship service load are presented in Fig. 2-19 and 2-20. The average ship service load of 0.35 mt/hr is based on the NAVSEC 61553 estimate for the electric demand under cruise conditions for a large hydrofoil (see Ref. 7). The specific range values are for 1/2 fuel load, steady state (thrust=drag) operation. Propeller pitch was selected for maximum efficiency (minimum power) at each speed and operating condition as described previously in Subsection 2.2.2.

(C) The range and endurance for Design Ml65 are presented in Fig. 2-21 and 2-23 for no ship service load and in Fig. 2-22 and 2-24 for the 0.35 mt/hr service load. The hullborne regime has been divided into two separate operating regions (O-8 kt, 8-35 kt). The reason for this division is that the minimum speed of the ship with one FT9 idling is approximately 8 kt. For speeds less than 8 kt, the vehicle is propelled by four Jacuzzi waterjets, thereby creating two hullborne operating conditions.

(U) The foils down analysis assumed that no hydrodynamic lift was produced by the foil system, since at all hullborne speeds the hull was found more efficient than the foils. The added drag of the foils was then reduced to the $C_{D_{min}}$ of the strut/foil system.

(U) The foilborne range was calculated using the half fuel weight condition with a conservative gear efficiency of 95% and the appropriate horsepower extraction required to control the vehicle in the various sea state environments.

2.2.5 Weight and Center-of-Gravity Summary

(U) The weight summary for Design Ml65 is presented in Table 2-4. The weight analysis is based primarily on the Grumman Design Ml54 and algorithms presented in the Design M163, 2400-ton Point Design. The algorithms used in determining the Auxiliary Systems (less 567) and Outfit and Furnishings weights can be found in Appendices C and D respectively, of the Design Ml63 report (Ref. 8). Detail weight breakdowns are to be found for each WHS Group in the appropriate portions of Subsection 2.3 of this report.

(U) In the development of a hydrofoil ship design, as in the case of most marine vehicle designs, careful center-of-gravity accounting is necessary to achieve balanced realistic configurations. The availability of such information is felt vital to the assessment of the feasibility of any particular design. Towards this purpose the composite weight and center-of-gravity data for Design Ml65 is presented in Table 2-5.

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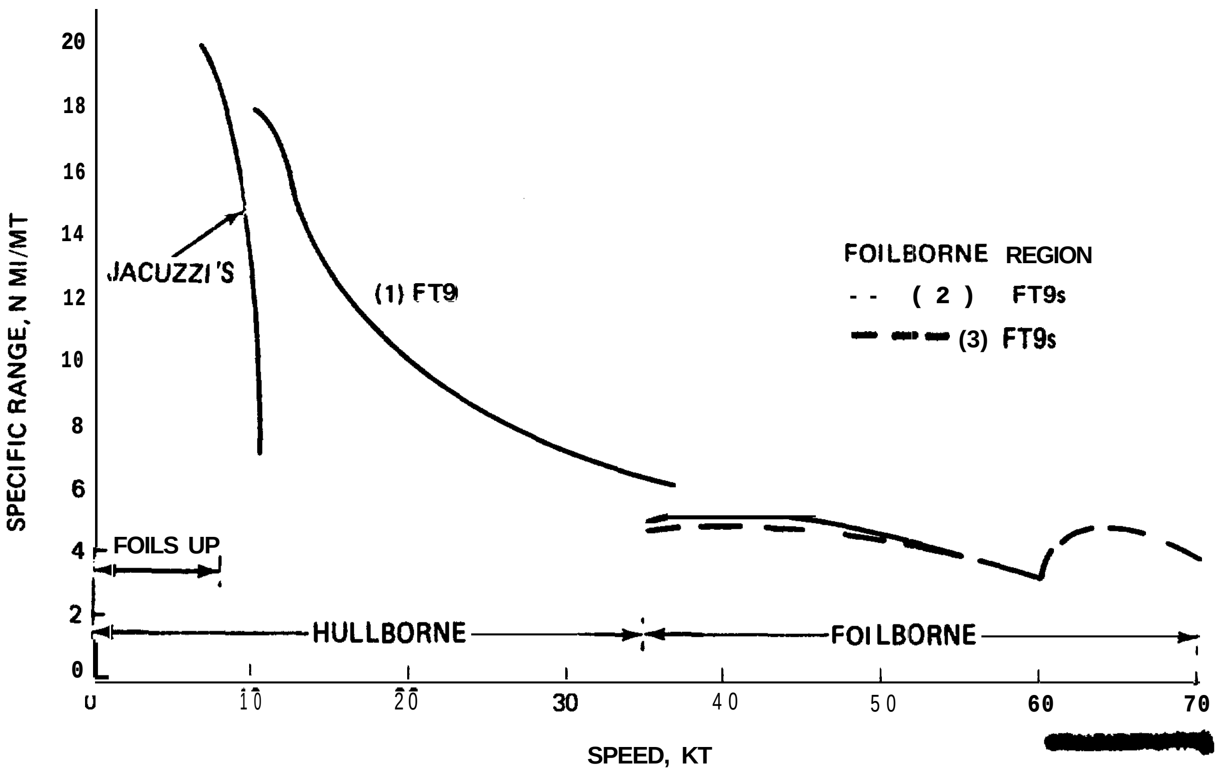

Fig. 2-19 Specific Range vs Speed, No Ship Service Load (U)

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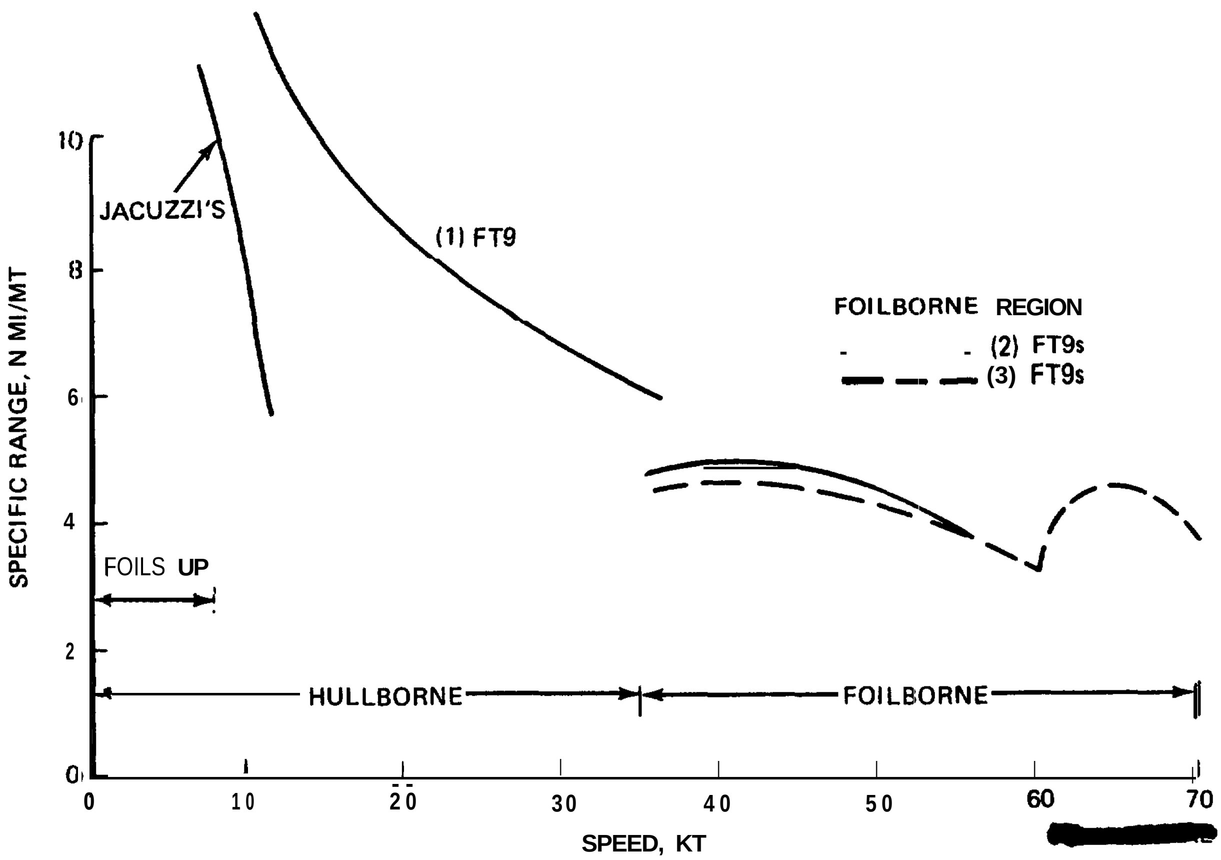

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Fig. 2-20 Specific Range vs Speed, Ship Service Load = .35 Mt/Hr (U)

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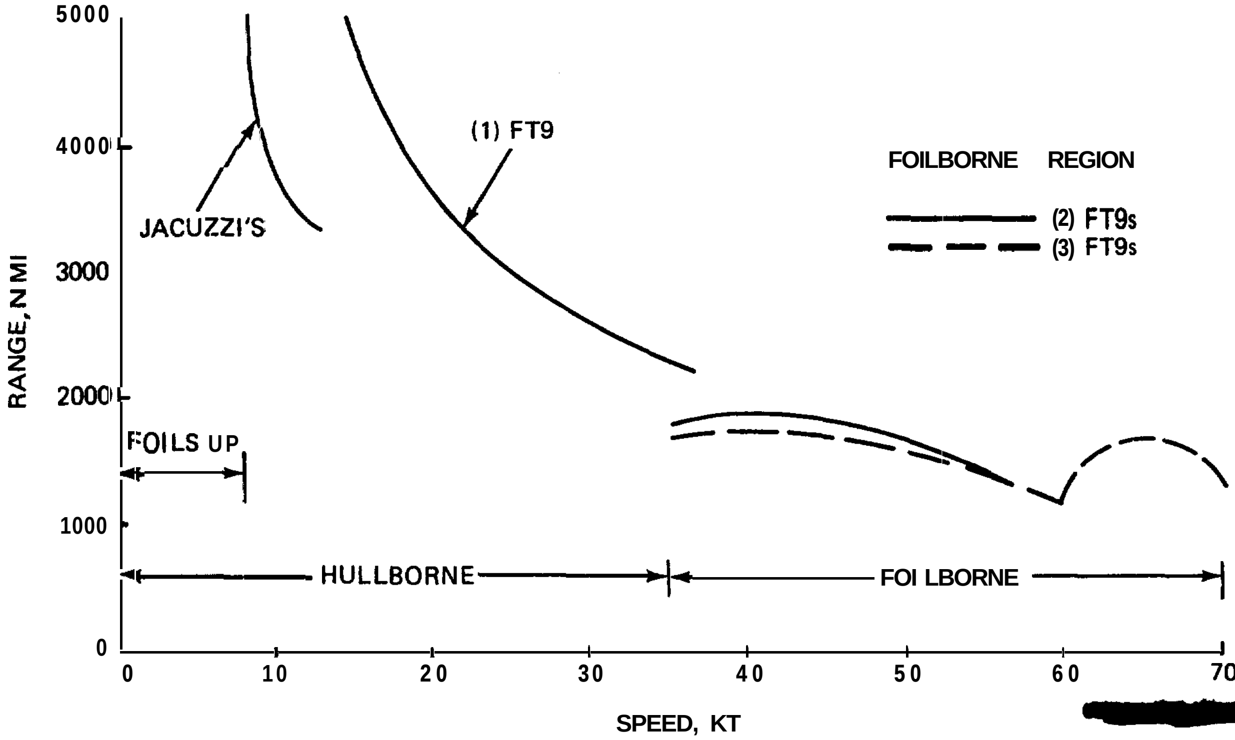

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Fig. 2-21 Range vs Speed, No Ship Service Load (U)

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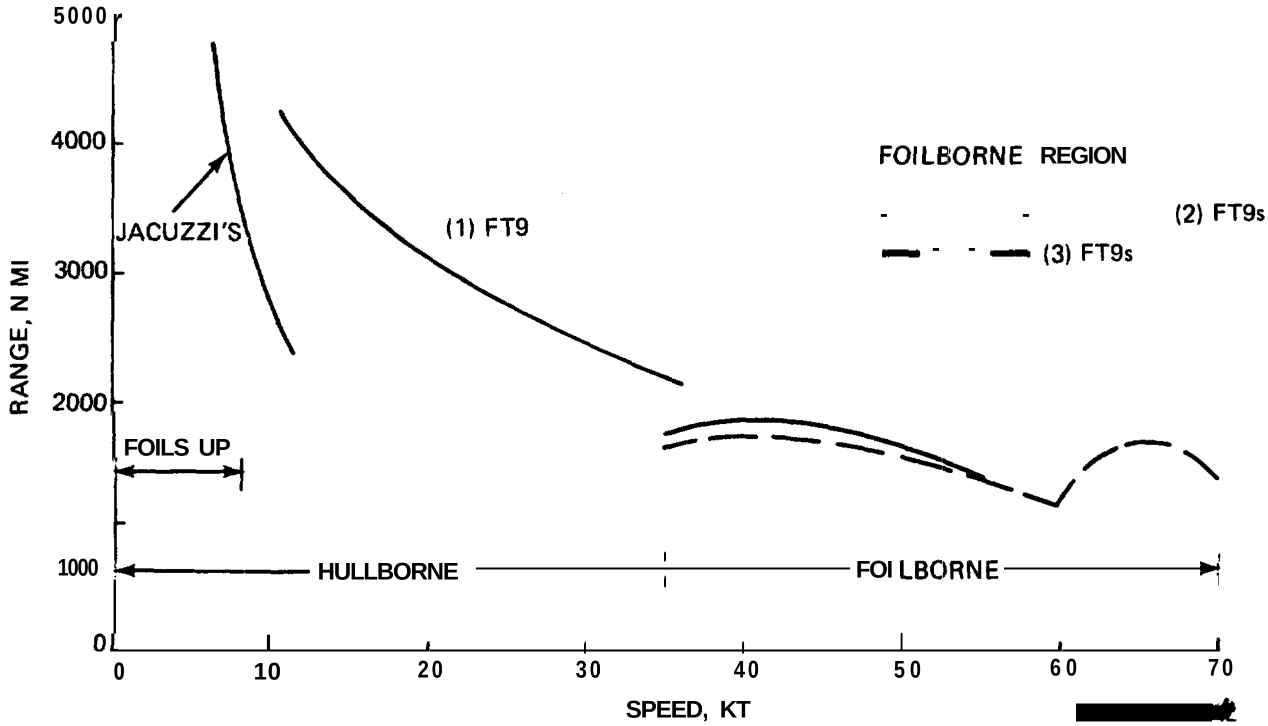

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Fig. 2-22 Range vs Speed, Ship Service Load = .35 Mt/Hr (U)

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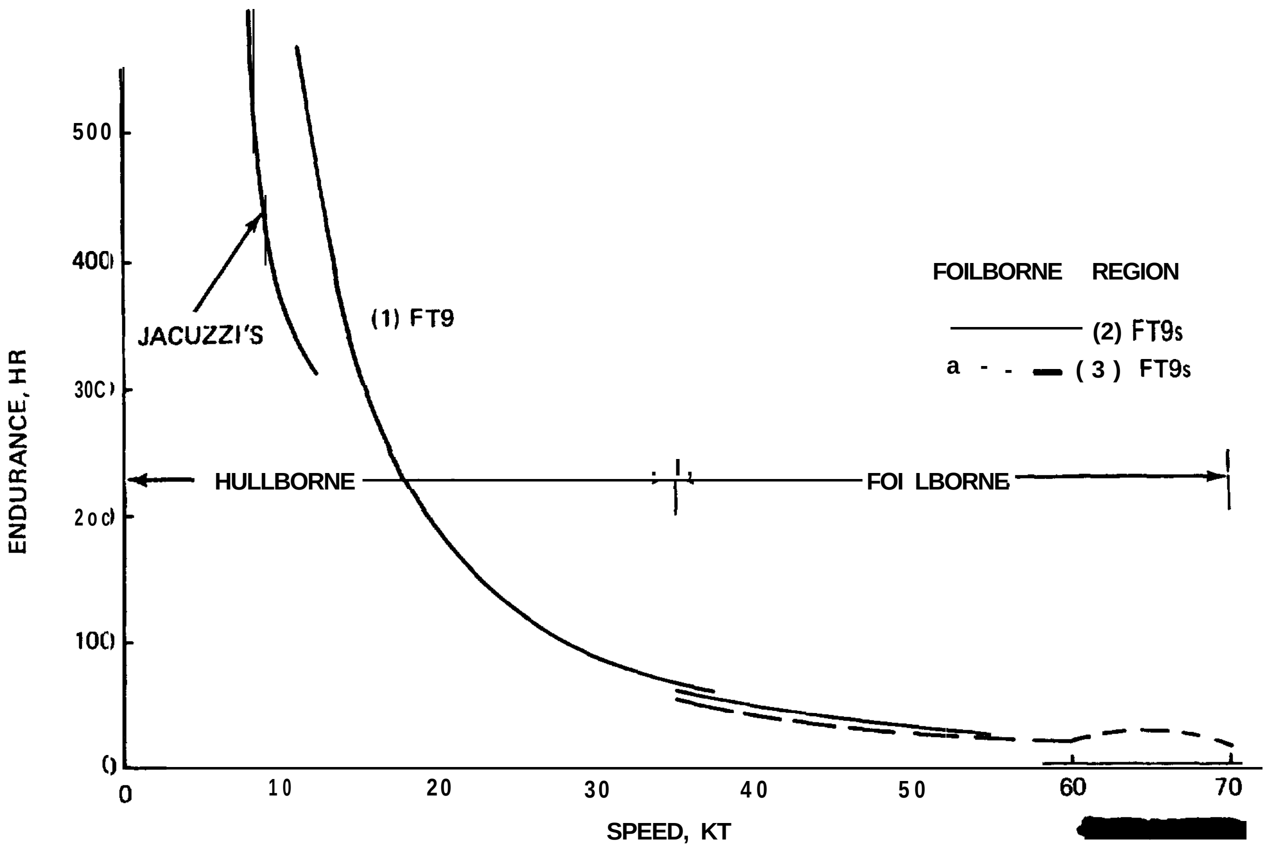

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Fig. 2-23 Endurance vs Speed, No Ship Service Load (U)

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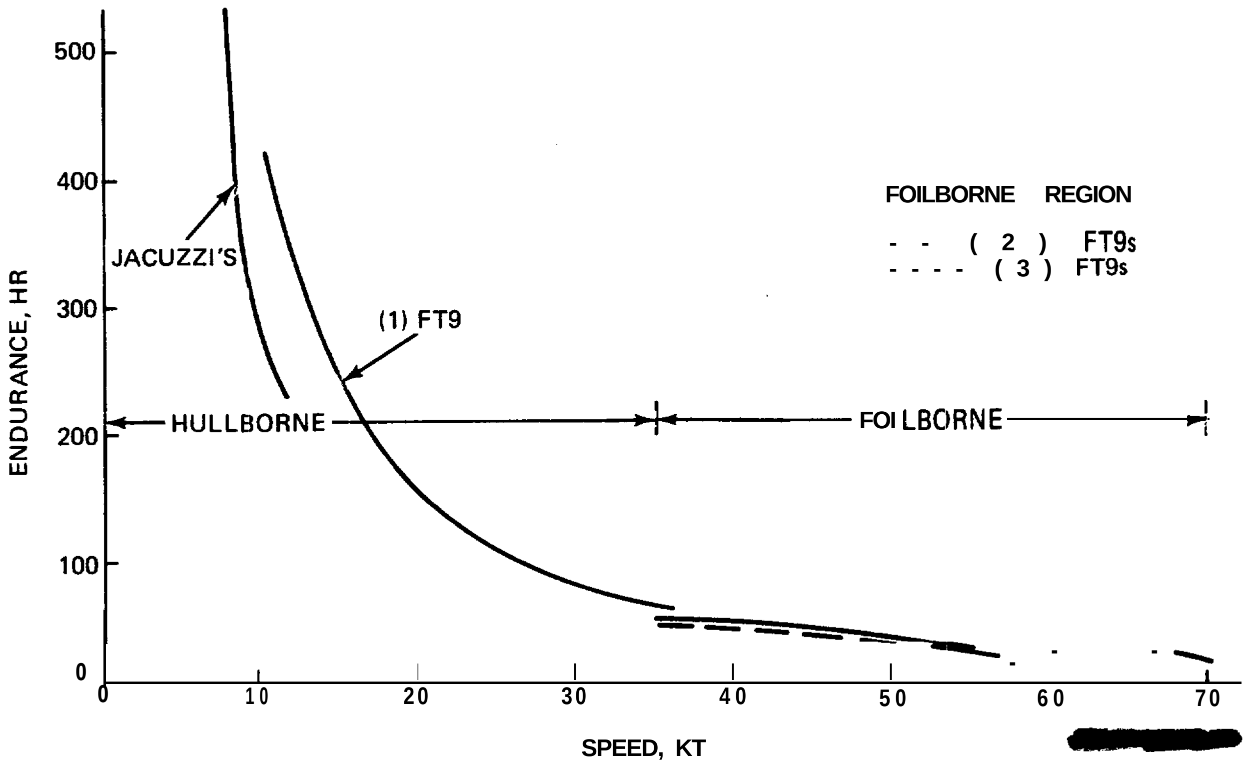

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Fig. 2-24 Endurance vs Speed. Ship Service Load = .35 Mt/Hr (U)

Table 24 Design MI65 Weight Analysis Summary Based on Current Technology

Item	Weight, metric tons	Remarks
100 Hull Structure	228.3	MI83 Ratio = $\frac{1350.0}{2400.0}$ = .5625
200 Propulsion	101.3	
300 Electric Plant	46.7	
400 Comm & Control	24.4	
500 Aux Systems (less 567)	100.4	*Wt = 10.96 + .0293 $\overline{(CN)}$ +.168 (N)
567.1/7 Struts	68.3	
567.2 Pods	24.8	
567.3 Foils	59.1	
567.4 Controls	12.0	
567.5 Retraction	18.1	
567 Total	(1 82.31	
600 Outfit & Furnishings	63.0	*Wt = .0125 $\overline{(CN)}$ + .36 (N)
700 Armament	24.3	
Margin (1 5%)	115.6	
Light Ship Condition	886.3	
Loads		
10 Ships Force	10.1	86 Men
20 Ordnance	61.6	
30 Stores	14.5	86 Men
40 Fuel	360.0	
50 Liquids	14.8	86 Men
Unassigned Payload	2.7	
Full Load Condition	1350.0	

*Formulas Developed for M163 $\overline{(CN)}$ = 2560; (N) = 86

Table 2-5 Weight Breakdown and Center-of-Gravity Summary (Sheet 1 of 2)

ESTIMATE Of WEIGHT FOR SHIPS
SNIP III LIGHT CONDITION
NAVSHIPS 929176 (REV, j-61, (Formerly NAVSHIPS 4616A-4) SHEET 1 U.S.S. M-165

PAGE ____
DATE

GROUP	DESCRIPTION	WEIGHT (Tons) Metric	CENTER OF GRAVITY ABOVE BASE	MOMENTS	REFERRED TO FRAME NO. FWD	MOMENTS	AFT	MOMENTS	REFERRED TO PORT	MOMENTS	ST'BD	MOMENTS
1	HULL STRUCTURE	228.3	14.3	3264.7			127.4	29085.4				
2	PROPULSION	101.3	10.2	1033.3			196.2	19875.1				
3	ELECTRIC PLANT	46.7	9.2	429.6			185.3	8653.5				
4	COMMUNICATION AND CONTROL	24.4	25.9	632.0			117.8	2874.3				
5	AUXILIARY SYSTEMS	100.4	19.1	1917.6			119.4	11987.8				
6	OUTFIT AND FURNISHINGS	63.0	19.0	1197.0			124.5	7843.5				
7	ARMAMENT	24.3	24.5	595.4			118.9	2889.3				
	Hydrofoil Lift System	182.3	-3.4	-619.8			120.8	22021.8				
	Margin	115.6	11.0	1271.6			136.5	15779.4				
	SHIP IN LIGHT CONDITION	886.3	11.0	9721.4			136.5	121010.3		FOILS EXTENDED		
	BASE ABOVE/BELOW BOTTOM OF KEEL - FEET			4656.8				1355.0				
	CENTER OF GRAVITY ABOVE BOTTOM OF KEEL - FEET	886.3	16.2	14378.2			138.1	122365.3		FOILS RETRACTED		

CONDITION A - LIGHT CONDITION

Ship complete, ready for service in every respect, including permanent ballast (solid and liquid), and liquids in machinery at operating levels, without any items of variable load, and without airplanes. This condition shall represent the ship under wartime conditions, with ultimate armament and boat allowance aboard.

DRAFT CORRESPONDING TO ABOVE DISPLACEMENT AT CENTER OF FLOTATION ____ FEET

TRANSVERSE METACENTER ABOVE BOTTOM OF KEEL AT ABOVE MEAN DRAFT ____ FEET

C.G. ABOVE BOTTOM OF KEEL ____ FEET | GM ____ FEET

MOMENT TO ALTER TRIM 1 INCH ____ FT. TONS

C.B. OF SHIP ON EVEN KEEL AT ABOVE DRAFT FORWARD/AFT OF REFERENCE FRAME ____ FEET

C.G. FORWARD/AFT OF REFERENCE FRAME ____ FEET

TRIMMING LEVER FORWARD/AFT ____ FEET

TRIM = $\frac{\text{DISP'T (tons)} \times \text{TRIMMING LEVER (ft.)}}{\text{MOMENT TO ALTER TRIM 1 IN. (ft. tons)} \times 12}$ = ____ = ____ FEET BY HEAD/STERN

DIFF. IN DRAFT BETWEEN L.C.F. AND MIDSHIPS = $\frac{\text{TRIM} \times \text{CG OF WP AFT OF MP (ft.)}}{\text{L.B.P. (ft.)}}$ = ____ = ____ FEET INCREASE/DECREASE

LIST = $\frac{\text{HEELING MOMENT (ft. tons)}}{.01745 \times \text{DISP'T (tons)} \times \text{GM}}$ = ____ DEGREES PORT/STARBOARD

DRAFTS ABOVE BOTTOM OF KEEL AT PERPENDICULARS: FORWARD ____ FEET, AFT ____ FEET, MEAN ____ FEET

COMPUTING BY | COMPUTING CHECKED

Table 2-5 Weight Breakdown and Center-of-Gravity Summary (Sheet 2 of 2)

ESTIMATE OF WEIGHT FOR SHIPS
SHIP IN FULL LOAD CONDITION
NAVSHIPS 9291/6 (REV. 3-67) SHEET 4

U.S.S. M-165

PAGE ____
DATE

DESCRIPTION	WEIGHT (Tons) Metric	CENTER OF GRAVITY ABOVE BASE	MOMENTS	REFERRED TO FRAME NO. FWD	MOMENTS	AFT	MOMENTS	REFERRED TO PORT	MOMENTS	STBD	MOMENTS
SHIP IN LIGHT CONDITION	886.3	11.0	9721.4			136.5	121010.3				
LOADS (FROM PAGE ___)	461.0	9.7	4471.7			142.9	65896.2				
Unassigned Payload	2.7	18.0	48.6			123.5	333.5				
SHIP IN FULL LOAD CONDITION	1350.0	10.5	14241.7			138.7	187240.0		FOILS EXTENDED		
BASE ABOVE/BELOW BOTTOM OF KEEL - FEET			4656.8				1355.0				
CENTER OF GRAVITY ABOVE BOTTOM OF KEEL - FEET	1350.0	14.0	18898.5			139.7	188595.0		FOILS RETRACTED		

CONDITION D-FULL LOAD CONDITION.-Ship complete, ready for service in every respect, with liquids in machinery at operating levels; authorized complement of officers, men, and their effects; full allowances of ammunition; full complement of airplanes (fully loaded); full supply of provisions and stores for the period specified in the design characteristics; fuel oil in amount necessary to meet endurance requirements; all other liquids in tanks, to full capacity.

For cargo and tender type vessels, the ammunition, stores, fresh water, and fuel, referred to above, are for the ship's own use; cargo, and supplies other than for ship's own use, shall be included in the amounts normally carried, or to the full capacity of the spaces assigned. Cargo shall be limited, if necessary, to avoid exceeding the limiting draft.

DRAFT CORRESPONDING TO ABOVE DISPLACEMENT AT CENTER OF FLOTATION ____ FEET

TRANSVERSE METACENTER ABOVE BOTTOM OF KEEL AT ABOVE MEAN DRAFT ____

C.G. ABOVE BOTTOM OF KEEL ____

GM, NO CORRECTION FOR FREE SURFACE. ____ FEET (CORRECTION = ____ feet), GM, CORRECTED FOR FREE SURFACE. ____

MOMENT TO ALTER TRIM 1 INCH ____ FT.

C.B. OF SHIP ON EVEN KEEL AT ABOVE DRAFT FORWARD/AFT OF REFERENCE FRAME ____

C.G. FORWARD/AFT OF REFERENCE FRAME ____

TRAINING LEVER FORWARD/AFT ____ FEET

TRIM = $\frac{\text{DISP'T (tons)} \times \text{TRIMMING LEVER (ft.)}}{\text{MOMENT TO ALTER TRIM 1 IN. (ft. tons)} \times 12}$ = ____ = ____ FEET BY HEAD/STERN

DIFF. IN DRAFT BETWEEN L.C.F. AND MIDSHIPS = $\frac{\text{TRIM} \times \text{CG OF WP AFT OF MP (ft.)}}{\text{L.B.P. (ft.)}}$ = ____ = ____ FEET INCREASE/DECREASE

LIST = $\frac{\text{HEELING MOMENT (ft. tons)}}{.01745 \times \text{DISP'T (tons)} \times \text{GM}}$ = ____ = ____ DEGREES PORT/STARBOARD

DRAFTS ABOVE BOTTOM OF KEEL AT PERPENDICULARS: FORWARD ____ FEET, AFT ____ FEET, MEAN ____ FEET

COMPUTING BY ____ COMPUTING CHECKED ____

B-28801

(U) Design Ml65 contains a Design and Builders Margin on Lightship Weight of 15%. Intact stability as reported in Subsection 2.2.5 assumes a 15% margin on the vertical center of gravity. An unassigned payload of 2.7 metric tons is also identified in Table 2-4.

2.2.6 Static Stability

(U) Three loading conditions were considered for the investigation of intact stability for Design M165. These were the Full Load and Lightship conditions from the weight reports, and a Burned Out condition in which only the usable fuel weight of 360 mt was subtracted from the Full Load condition. The Burned Out condition is intended to approximate the minimum operating condition for a hydrofoil.

(U) Surprisingly, the Burned Out foils extended condition was found to be the worst-case condition in which the vehicle would normally be expected to operate. Typically, the Burned Out foils retracted condition governs stability considerations. Righting arm curves for this condition are presented in Fig. 2-25. The associated heeling arms, due to a 100-kt beam wind were scaled from Ml63 data, reported in Ref. 8.

(U) As can be seen, the stability of the vehible in the Burned Out condition, as well as the other investigated conditions, is inadequate for open ocean operation, when the criteria from Ref. 9 is applied. This resulted from the hullform derivation being based on foil system characteristics similar to that of a 50-kt hydrofoil design. Later in the design process, it was found that the 70-kt foil system would have much greater weight and volume, relative to the ship size, than had originally been predicted. This substantially lowered the VCB with the foils down and raised the VCG with the foils retracted. The increase in the magnitude of the righting arms as the foil system is retracted is evidence of this unusual condition brought about by the large foil system.

(U) The stability of the vehicle could be improved by flooding of unoccupied volumes in the foil arrays, however, this would adversely effect the foilborne performance of the vehicle and is not recommended. Alteration of the hullform to provide the necessary stability could be accomplished by decreasing the length-to-beam ratio, $\frac{LBP}{B}$. The resulting decrease in hull efficiency must be considered as necessary to the 70-kt design unless a smaller, lighter weight foil system can be provided.

2.2.7 Ride Quality

FOILBORNE

(U) Since the mixed foil system employed in Ml65 is designed to operate in a fully wetted condition or at most only partially cavitated around the leading edge at speeds

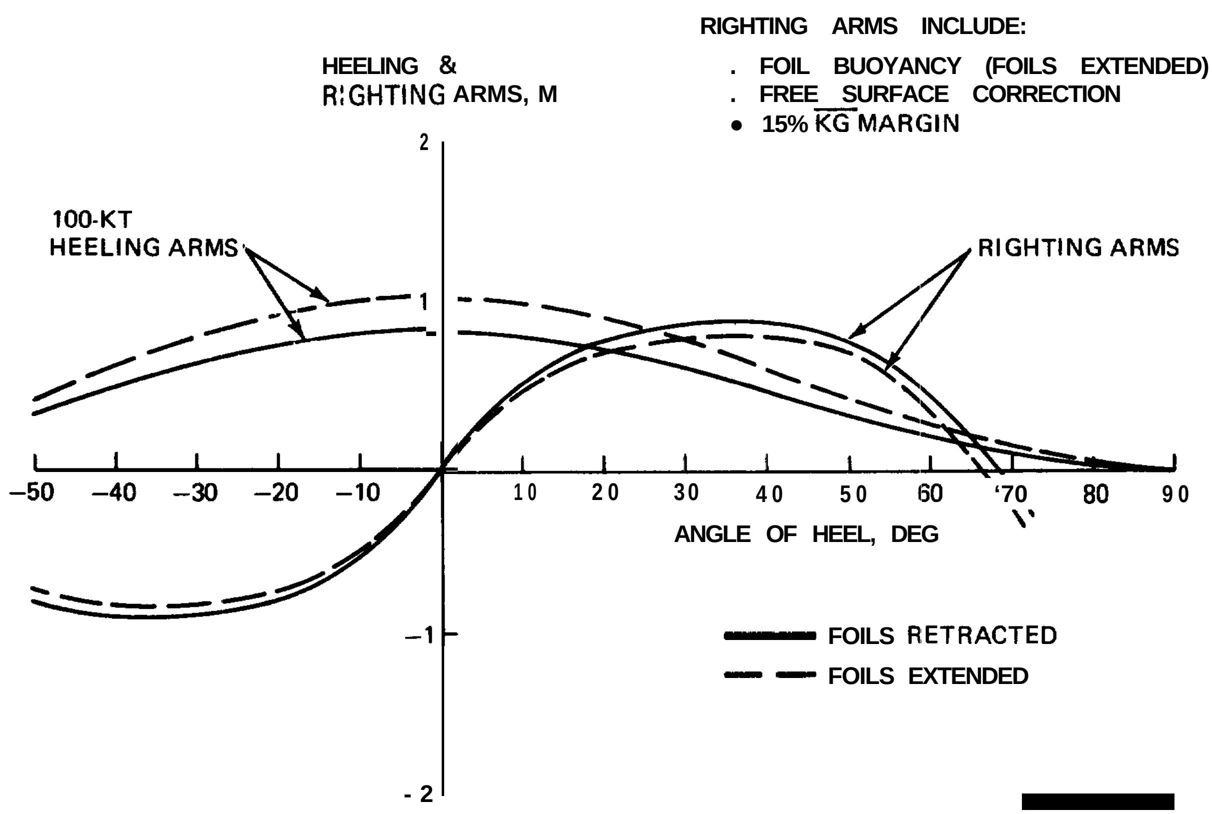

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Fig. 2-25. Intact Stability, Burned Out Condition (U) below 50 kt, the hydrodynamic efficiency of the strut/foil system is expected to be compatible to existing subcavitating hydrofoils. Once the supercavitated/superventilated condition is reached, however, it is difficult to predict the ride quality without extensive prototype testing of the vehicle.

(U) The ride quality at high speeds is directly related to cavity stability on the foils and the struts. The cavity stability of a supercavitating foil depends significantly on the cavity cavitation number (σ_C). Maintaining a constant cavitation number by ventilating the cavity, stabilizes the cavity, and the ride qualities of the vehicle are expected to be acceptable. If, however, the strut chokes (blocking the air path from the free surface), an unpredictable lift force on the foil will cause the craft to either crash or broach.

(U) Lateral stability and control at high speeds are derived from the pseudoblunt-based struts on Design M165. However, the struts may suddenly experience side ventilation when the craft is operating at high speeds in a seaway or performing high-speed turning maneuvers. This ventilation phenomena causes a significant change in the forces on the struts. The capability to maintain the craft in a steady turn or on a straight course in waves will be greatly degraded or restricted due to the strut side ventilation.

(U) It is assumed that existing autopilot designs such as HUDAP will be capable of handling the changes in lift-curve slope associated wtih the different modes of operation on the foil system. Therefore, assuming that strut choking and side ventilation can be avoided, the ride quality of Design Ml65 will be within acceptable limits.

HULLBORNE

(U) The intact stability analysis indicates that due to the increased foil weight and volume, the length to beam ratio ($\frac{LBP}{B}$) of Design Ml65 must be decreased by approximately 25% from the length to beam ratio which is required for an adequately stable 50-kt design. The effect of this change would generally be to deteriorate the hullborne ride quality. Due to the spectral nature of the motions problem, additional analysis of the hull motions analytically or through model tests, would be required to define the effect of this change in hull form for specific sea conditions.

2.3 SHIP SUBSYSTEM DESCRIPTION

(U) Detail descriptions of the major systems in Design Ml65 are contained in the following subsections. Weight breakdowns for the individual systems are presented at the end of each subsection.

2.3. 1 Hull Structure

(U) The hull structure weight, as a percentage of the Full Load displacement, was derived from recent work done on a 2400-ton hydrofoil design, and was directly applied to the 1350-ton Design M165. This procedure resulted in a structural weight allowance which was commensurate with existing weight trends for 50-kt hydrofoils. No attempt was made to assess the effect of 70-kt hydrodynamic impact loads on the hull structure weight. The added structural weight due to the relatively higher longitudinal bending loads encountered in the 2400-ton design would, however, tend to compensate for the increase in hull structural weight due to increased lateral loads on the shell panels. The hull structural arrangement is considered to be similar to that of other Grumman large hydrofoil designs. A conventional double bottom structure consisting of plate girders and floors is employed. Longitudinal bulkheads are used to share the longitudinal bending loads normally carried by the side shell alone.

GROUP 100 WEIGHTS

The calculated group 100 weights are presented in Table 2-6.

Table 2-6 Hull Structure Weight Breakdown

100 HULL STRUCTURAL COMPONENTS	WEIGHT METRIC TONS	WEIGHT %
110 SHELL &SUPPORTING STRUCTURE	67.4	29.5
120 HULL STRUCTURAL BULKHEADS	28.5	12.5
130 HULL DECKS	44.8	19.6
140 HULL PLATFORMS & FLATS	9.4	4.1
150 DECK HOUSE STRUCTURE	31 .o	13.6
160 SPECIAL STRCUTURES	16.4	7.2
170 MASTS, KINGPOSTS, &SERVICE PLATFORMS	1.8	0.8
180 FOUNDATIONS	26.9	11.8
190 SPECIAL PURPOSE SYSTEMS	2.1	0.9
TOTAL	228.3	100

2.3.2 Propulsion System

FOILBORNE SYSTEM

(U) The foilborne propulsion system consists of three (3) Pratt and Whitney FT9 engines driving two Newton-Rader A3/71 supercavitating propellers by means of a right-angle dual-mesh mechanical transmission system. The propellers have variable pitch with the pitch to diameter ratio ranging from 1. 05 to 2.06.

(U) The foilborne struts are retractable. The aft foilborne struts are retracted by rotating the struts aft. The retraction axis is coincident with the input shaft axis of the shoulder gearboxes, thereby eliminating the need for disconnect clutches for strut retraction.

FOILBORNE ENGINE

(U) The FT9 engine design characteristics are summarized in Table 2-7.

Table 2-7 FT9 Foilborne Engine Characteristics

TURBINE INLET TEMP	1350°F
AIR FLOW	270 LB/SEC
DRY WEIGHT	21,300 LB
COMPRESSION RATIO	24.0
SFC @MAXIMUM POWER, 4000 RPM, 26°C	0.38 LB/HP HR
MAXIMUM POWER (26°C, S.L., 4 IN. AND 6 IN. LOSSES)	43600 HP
NO. OF COMPRESSOR STAGES	6 LP/1 1 HP
NO. OF TURBINE STAGES	1 LP/2 HP/2 POWER
NO. OF COMBUSTORS	N.A.
COMBUSTOR TYPE	CAN ANNULAR
LENGTH	314.0 INCHES
DIAMETER	105 IN. W. X 99 IN LG.

(U) Engine power characteristics are shown in Fig 2-26, 2-27, and 2-28 for a 26°C ambient day with 4-in. and 6-in. inlet and exhaust duct losses for three engines, two engines, and one engine operating, respectively.

(U) Indicated on the maps are the transmission torque limits and the propeller match points for smooth water, 1/2 fuel weight, steady state (thrust=drag) operakion, for one, two, and three engines driving two foilborne propellers, respectively. Three engines are needed for

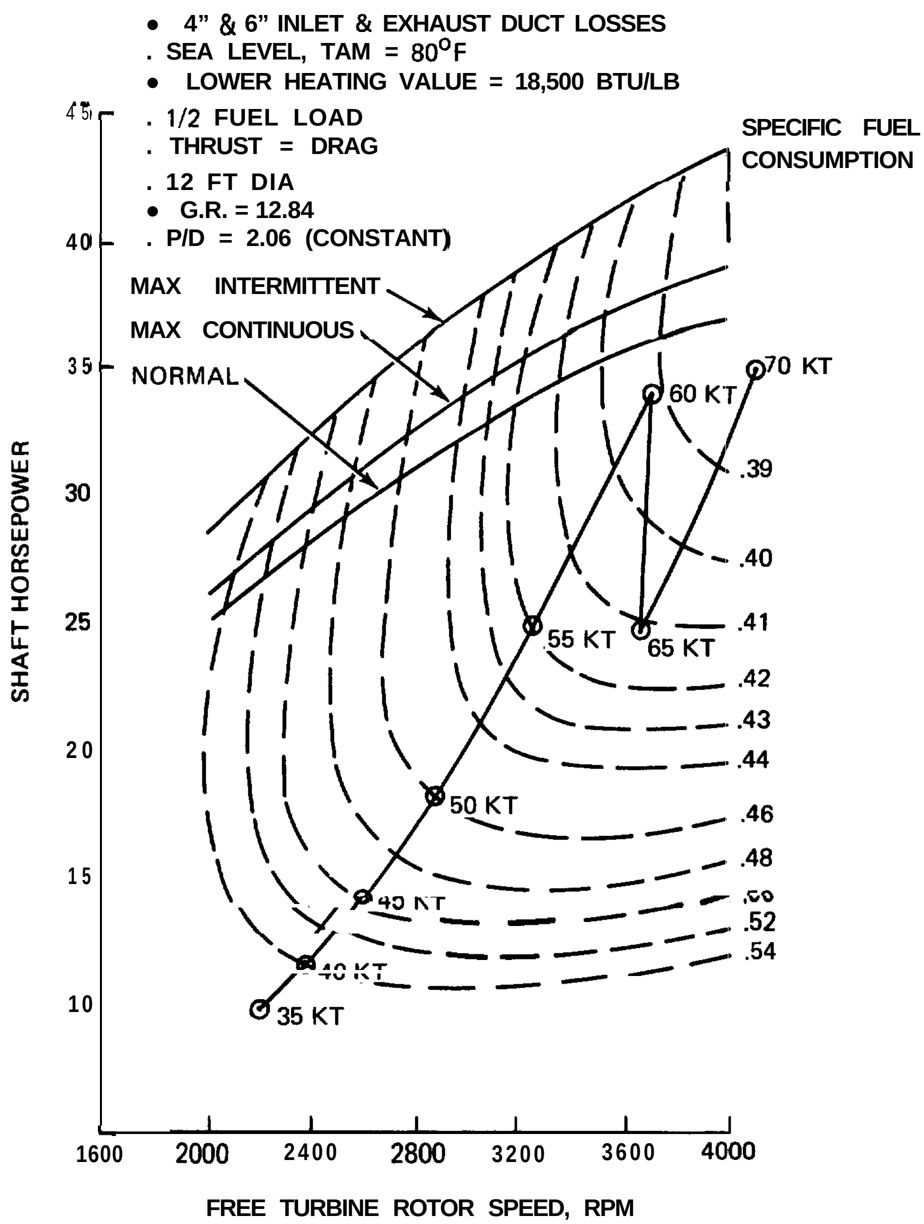


Fig. 2-26 **FT9** Estimated Performance Characteristics, Foilborne, Three **Engines** and Two **Propellers**

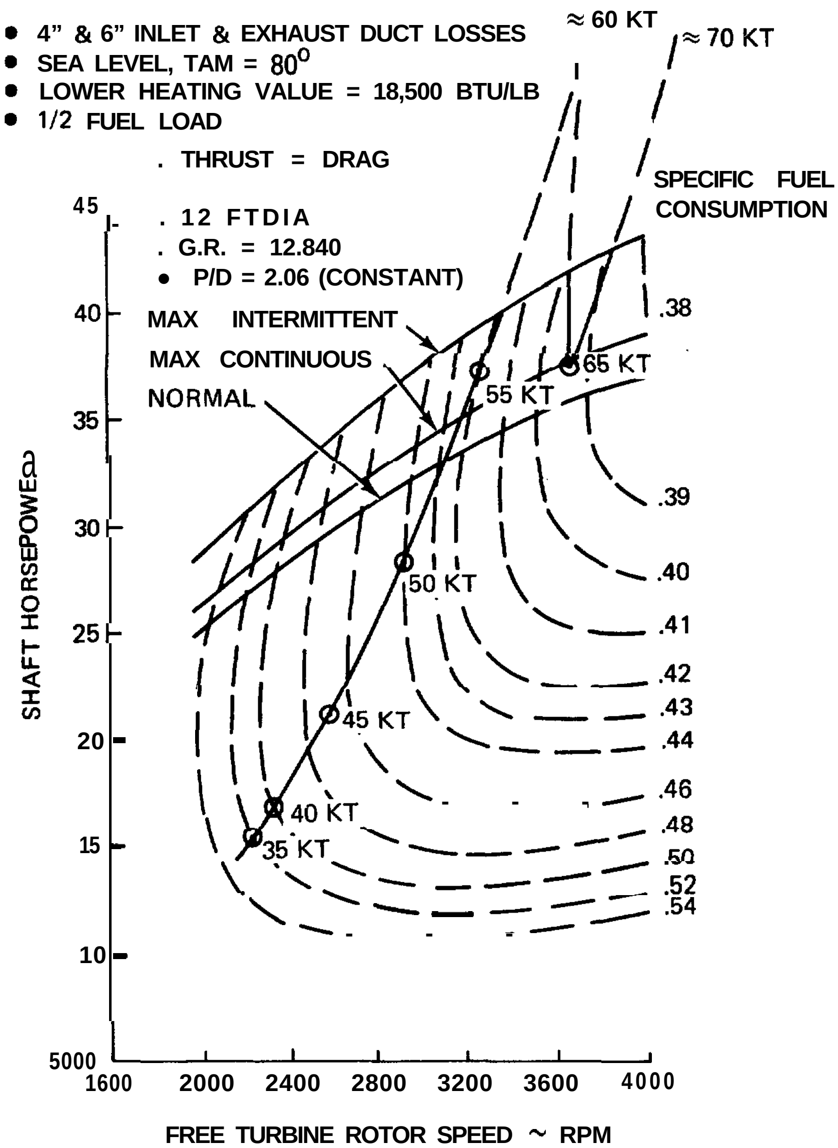


Fig. 2-27 FT9 Estimated Performance Characteristics, Foilborne, Two Engines and Two Propellers

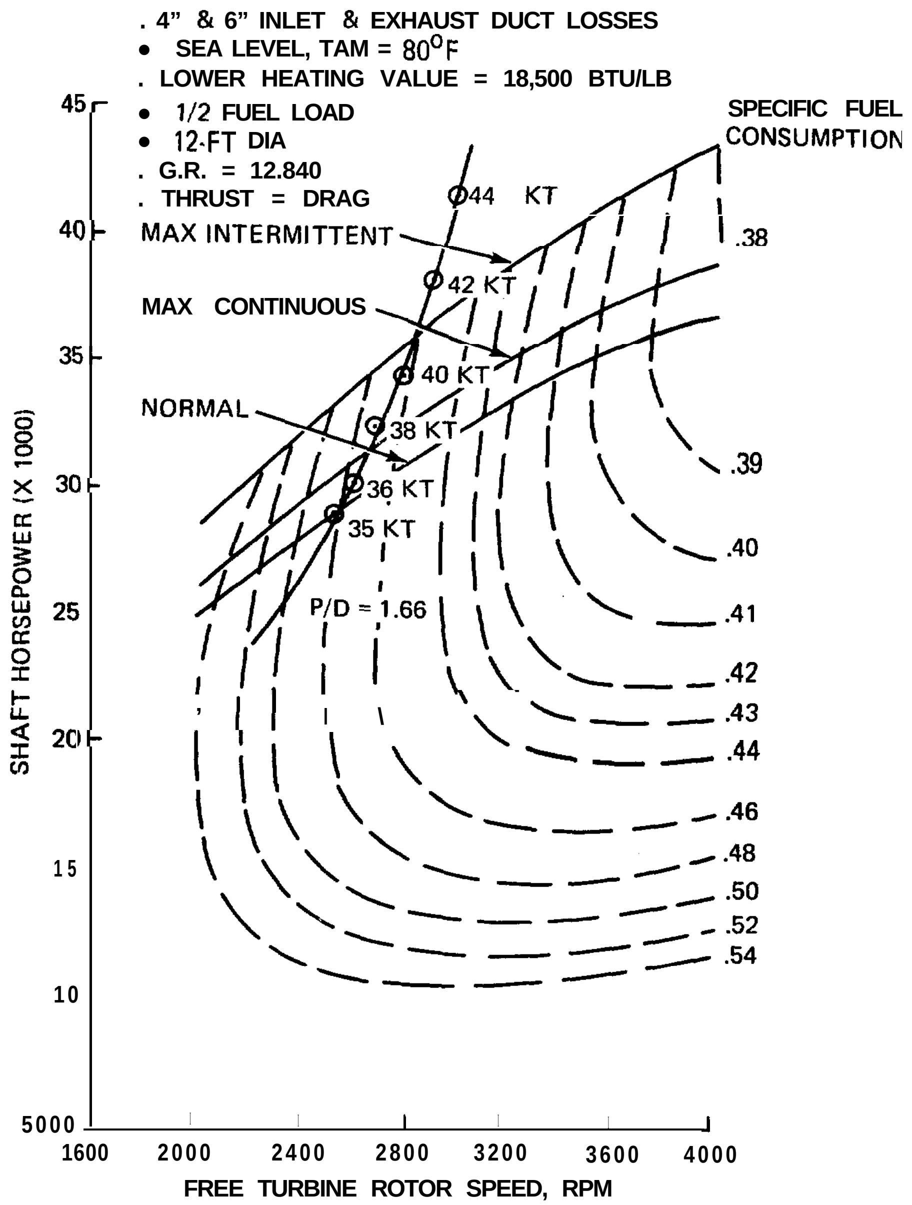


Fig. 2-28 FT9 Estimated Performance Characteristics, Foilborne One Engine and Two Propellers

acceleration through the 60-kt secondary drag hump and for the 70-kt burst capability. Foil-borne cruise can be accomplished for the most part with only two engines while hullborne operation with foils down is achieved with one engine driving the two foilborne propellers.

FOILBORNE PROPELLERS

(U) The foilborne propeller characteristics are summarized in Table 2-8.

Table 2-8 Foilborne Propeller Characteristics

DESIGN	NEWTON RADER A3/71
TYPE	SUPERCAVITATING/VARIABLE PITCH
INSTALLATION	TRACTOR
DIAMETER	3.66 m
NO. OF BLADES	3
BLADE AREA RATIO	.71
PITCH RATIO	VARIABLE FROM 1.05 TO 2.06

(U) Performance of a variable pitch Newton-Rader propeller was estimated by obtaining the performance of a 3.66 m diameter propeller for the four fixed-pitch ratios tested by the designers, i.e., 1.05, 1.25, 1.66, and 2.06. Actual design of a variable pitch hub and blade root section are not available at the present time and require developmental testing.

HULLBORNE SYSTEM

(U) Design Ml65 utilizes a separate non-interconnected low speed propulsion system for hullborne maneuvering. This system consists of four (4) Trimot A6V-225 constant pressure/ variable displacement hydraulic motors driving four (4) Jacuzzi 14YJ waterjets. Steering and reversing gates are incorporated in the pump nozzles, for hulllborne maneuvering up to 8 kt. Power is supplied to the Trimot A6V-225 hydraulic motors via Abex model no. AP27V series hydraulic pumps installed on the ship services gas turbine engine gear boxes. The hydraulically driven water pumps are not designed for lengthy hullborne operations, but were selected to eliminate the drag of hullborne propellers during takeoff and to eliminate the need for separate displacement engines and transmission components. 'The motor power, rpm, and capacity characteristics are shown in Fig. 2-29, with the Jacuzzi 14YJ waterjet load

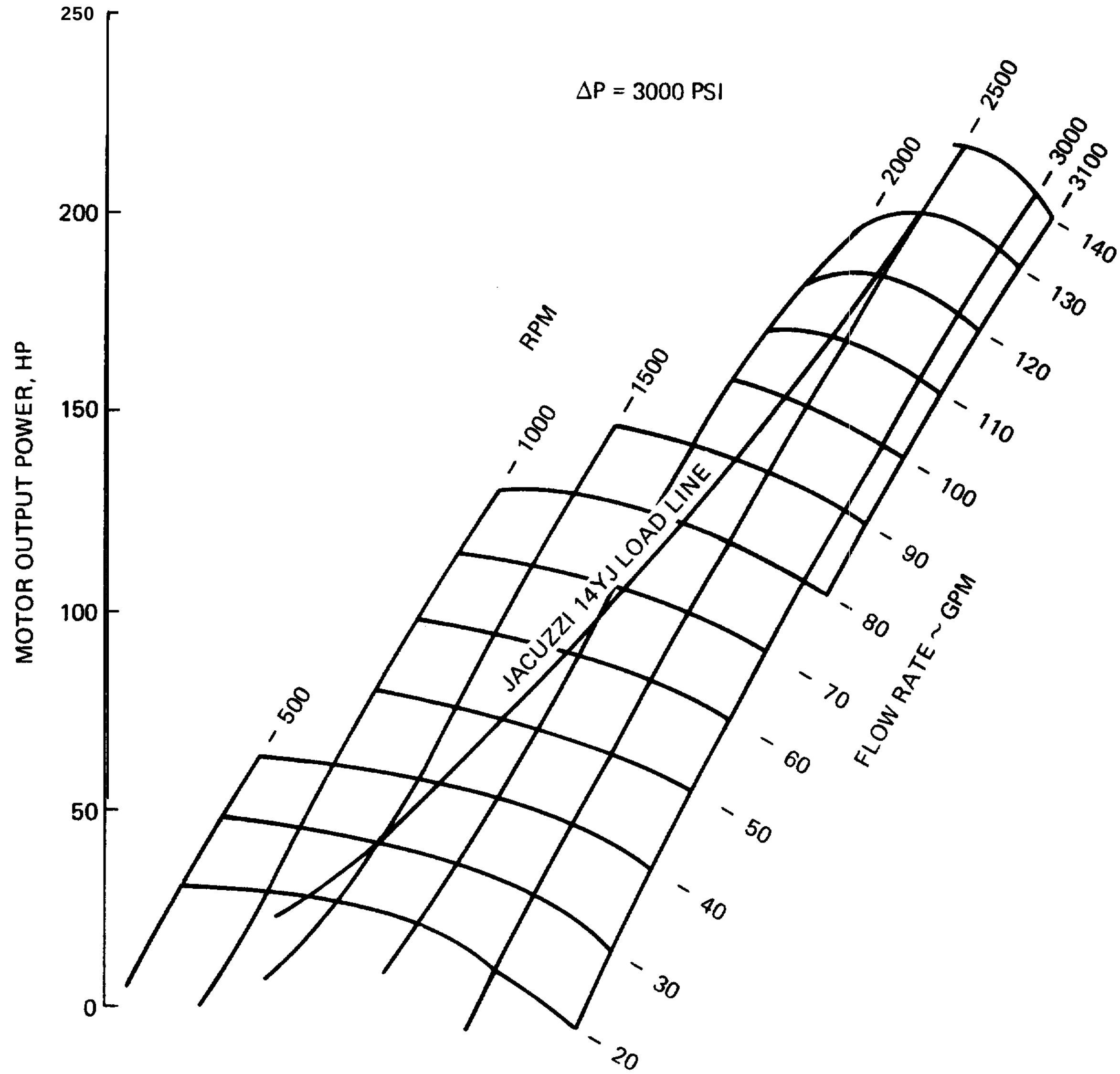


Fig. 2-29 Trimot A6V Hydraulic Motor Characteristics

line super imposed. Power, RPM, and thrust characteristics of the Jacuzzi units are shown in Fig. 2-30 and 2-31. The complete propulsion system provides three modes of hullborne operation:

- Four hydraulic motors driving four water jets (foils up or down)
- One FT9 driving two foilborne propellers (foils down only)
- Two FT9s driving two foilborne propellers (foils down only).

HULLBORNE ENGINES

(U) Two Lycoming TF35 engines are installed for the dual purpose of shipboard electric power and low-speed hullborne propulsion. The system is completely redundant with one engine capability for low speed (O-8 kt) hullborne maneuvering and maximum anticipated electric power generation (Winter Battle Condition as specified in Ref. 7). The TF35 engine characteristics are summarized in Table 2-9.

Table 2-9 TF35 Engine Characteristics

TURBINE INLET TEMP	N.A.
EXHAUST GAS TEMP	970°F
AI RFLOW	24 LB/SEC
DRY WEIGHT	1273 + 141 LB NON-ENGINE MOUNTED EQUIPMENT
COMPRESSION RATIO	6.9
SFC @MAX POWER	.532 LB/HP-HR
MAX POWER (59°F)	3500 HP
NO. OF COMPRESSOR STAGES	7
NO. OF TURBINE STAGES	2 HP/2 POWER
NO. OF COMBUSTORS	N.A.
COMBUSTOR TYPE	ANNULAR
LENGTH	52.2 IN.
WIDTH	34.4 IN.
HEIGHT	43.8 IN.

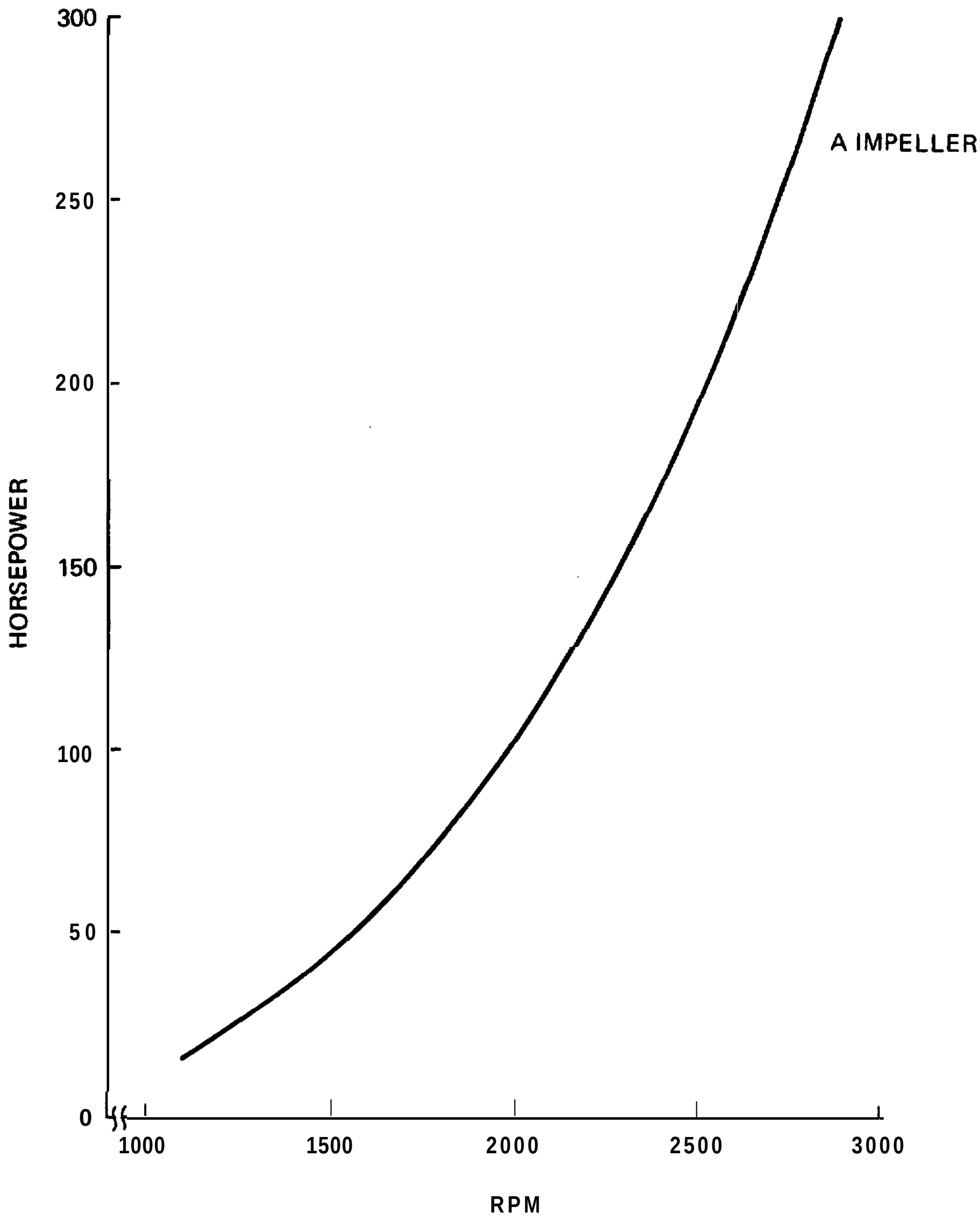


Fig. 2-30 Jacuzzi Jet 14YJ Power and RPM Characteristics

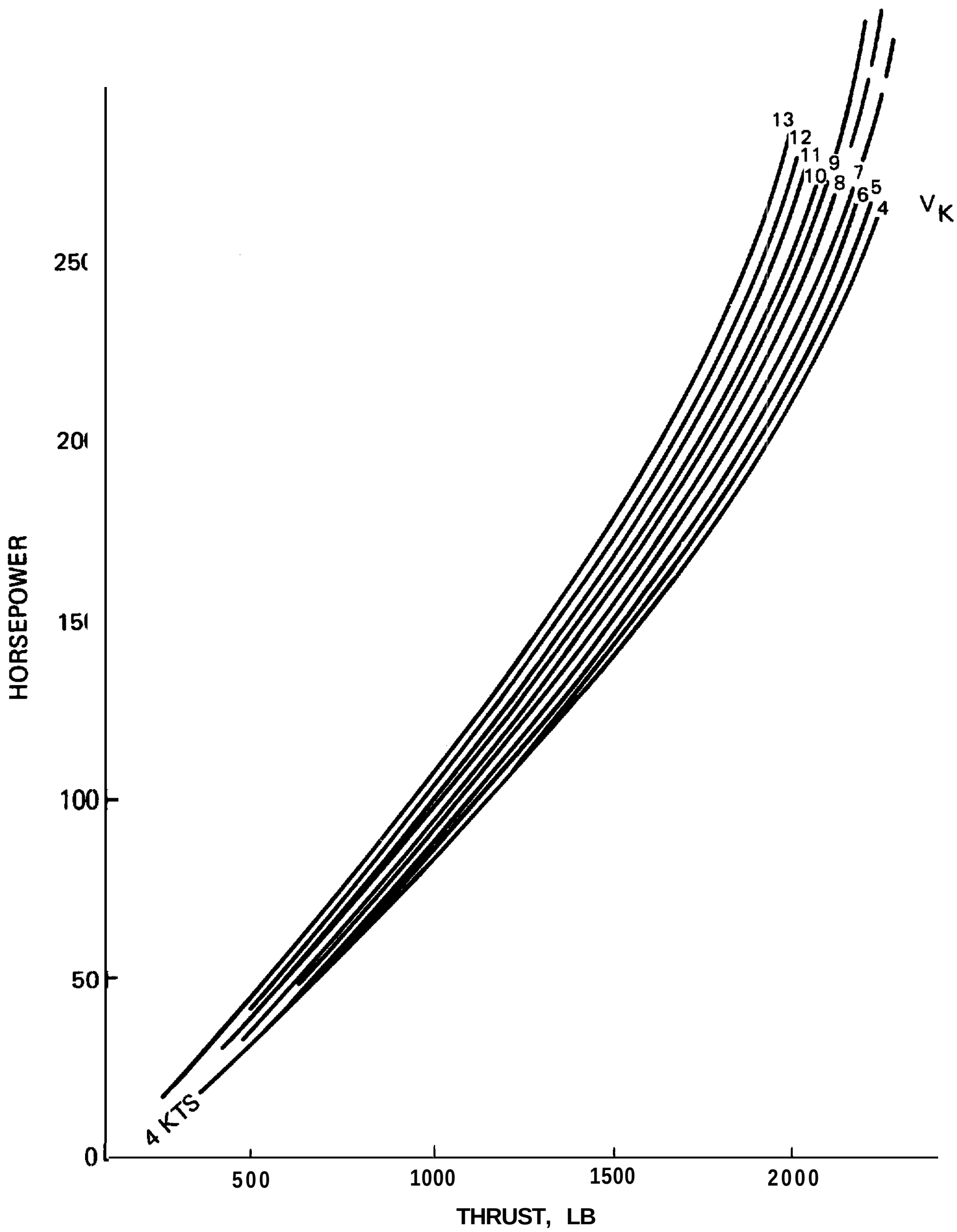


Fig. 2-31 Jacuzzi Jet 14YJ Thrust Characteristics

(U) Engine power characteristics of the TF35 gas turbine are shown in Fig. 2-32 for a 16°C day. Indicated on the map are the low-speed hullborne, steady state (thrust=drag) and average (825 HP) electric generator power requirements. The maximum ship speed of approximately 8 kt is due to the hydraulic motor power limitation.

TRANSMISSION

(U) The transmission installation of Design Ml65 is shown on Drawing No. M165-10076 Propulsion Machinery and Foil System Arrangement (Fig. 2-5). A schematic of the dual mesh transmission system is shown in Fig. 2-33.

(U) The foilborne dual mesh transmission configuration was arrived at by considering a long lead time development program. All bevel gearboxes have a 1:1 gear ratio and all the engine and propeller matching (speed reduction) is taken in the pod mounted planetary gearboxes. Engine, shoulder, and pod gearboxes are similar with the exception of the mounting requirements. This simplifies the system and development program and improves the system's maintainability. For this system, no disconnect clutches are needed, only over-running clutches to each engine.

(U) Referencing Fig. 2-33, the power flow from the engines to the propellers is as follows: engine power is split into two paths by the helical gears in the engine boxes. Ideally, the power is split in half with each bevel gear handling 50% of the total power. The power is then recombined by the back-to-back bevel gears and transmitted to the output shafts. The identical process is repeated in the shoulder and pod bevel gearboxes. Power is then transmitted aft through the pod planetary gearbox with the necessary speed reduction to match the propeller characteristics. Preliminary design considerations indicate that this reduction will be 12.84 to 1.0.

(U) Another possible transmission scheme is shown in Fig. 2-34. In this scheme the engine and planetary gearboxes are identical to those in the first scheme, Fig. 2-33. The shoulder and pod gearboxes are dual quad mesh gearboxes. However, two additional bevel gears per path (four per gearbox) have been added to the shoulder and pod gearboxes so that each bevel gear meshes with two other bevel gears. Tooth loads on the bevel gears are halved, permitting smaller diameter gears to be used, resulting in smaller shoulder and pod gearboxes. The smaller gearbox size of the dual quad mesh scheme is offset by the increase in complexity of the gearboxes and system. There are four more gears and eight more bearings per gearbox than in the system of Fig. 2-33. Also, bevel gear alignment becomes much more complicated and the bevel gearboxes are no longer identical internally.

- NOMINAL ENGINE
- CONDITIONS:
  - INLET AIR 59F
  - FUEL DIESEL (7 LB/U.S. GAL. LHV 18,400 BTU/LB)
- ELEVATION CORRECTION FACTOR, δ
  (TO BE APPLIED AS MULTIPLIER TO SHP AND Wf)

ELEVATION FT	δ
0	1000
1.000	.964
2.000	.930
3.000	.896
4.000	.864
5.000	.832
6.000	.801

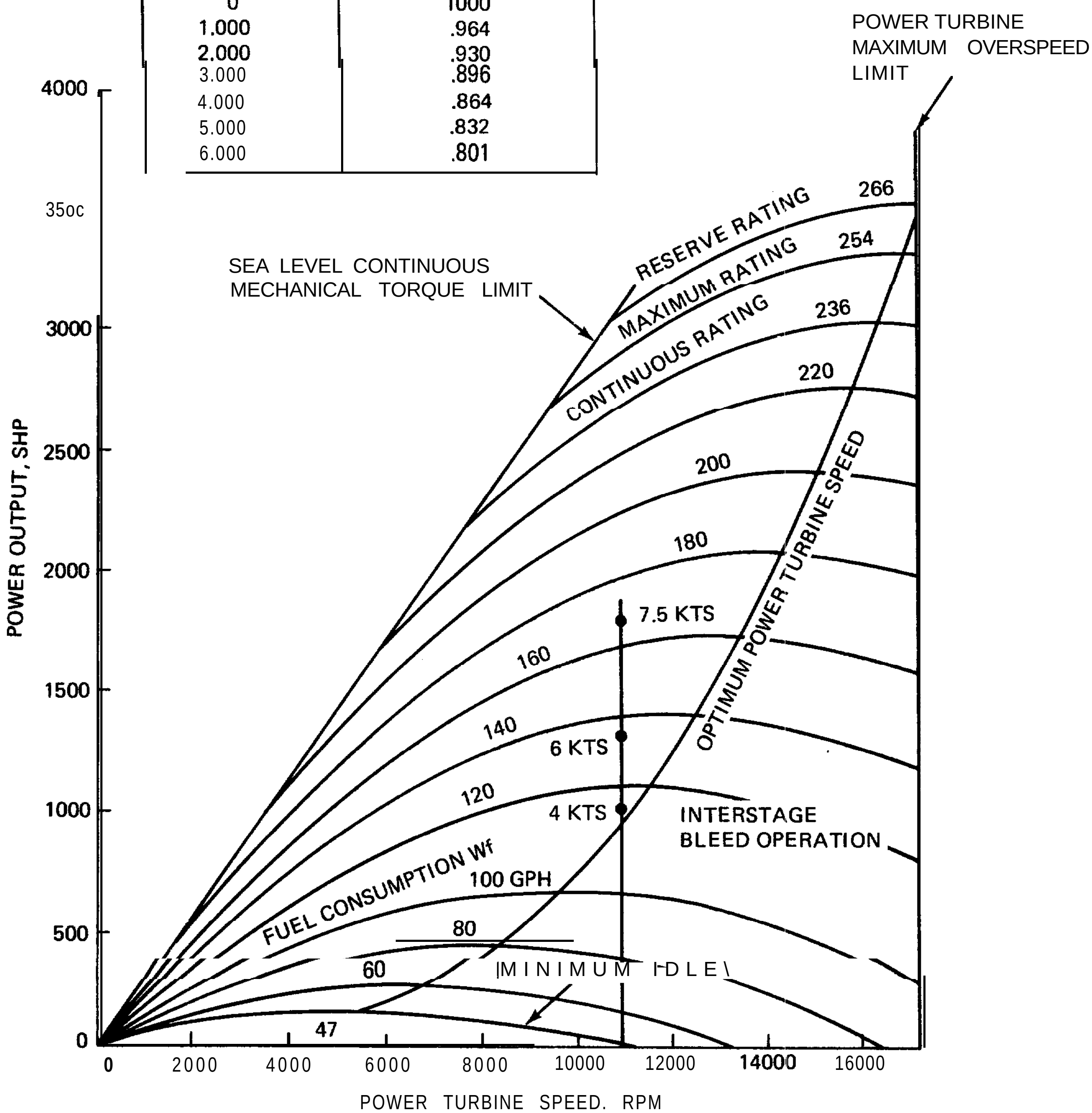


Fig. 2-32 Estimated Performance of Lycoming TF35 Gas Turbine

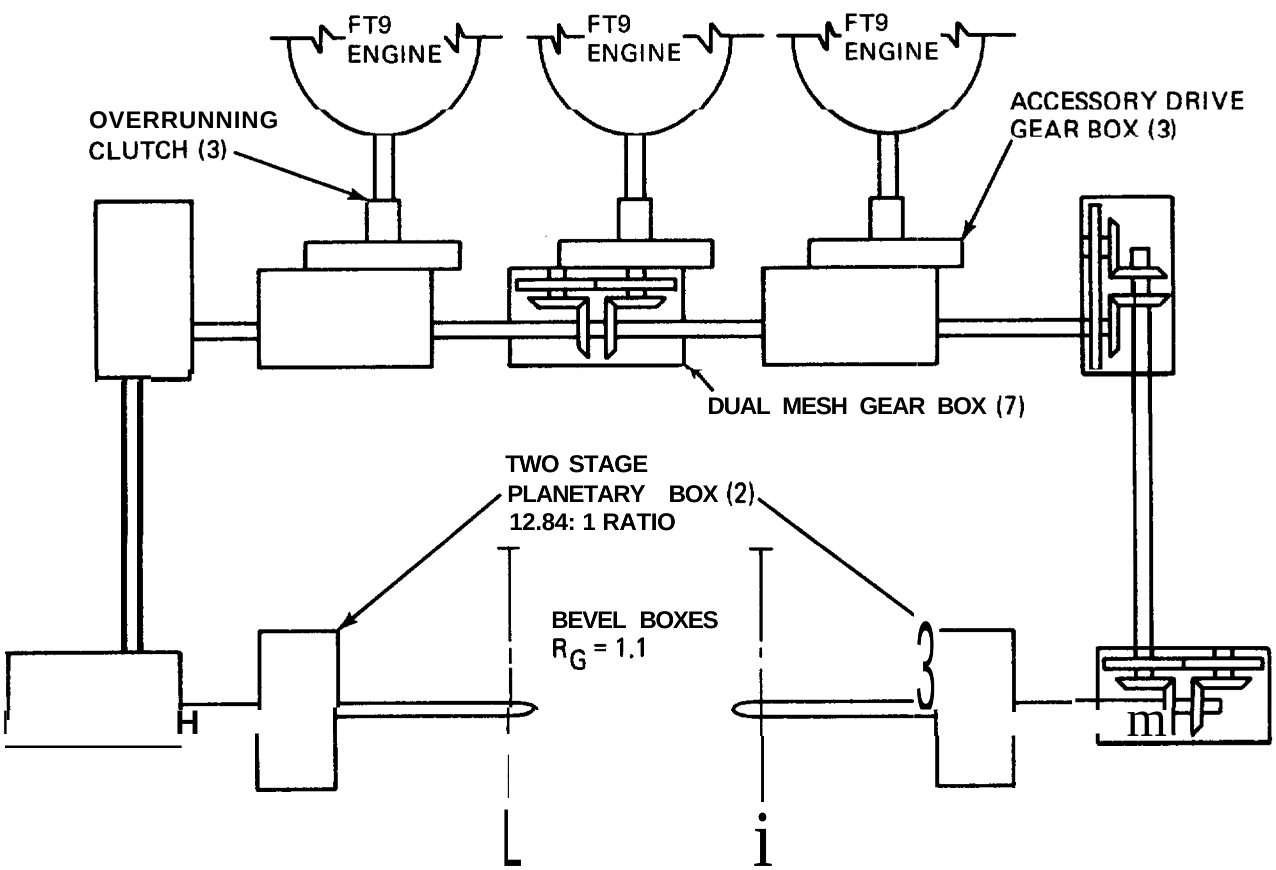


Fig. 2-33 Dual-Mesh Transmission System

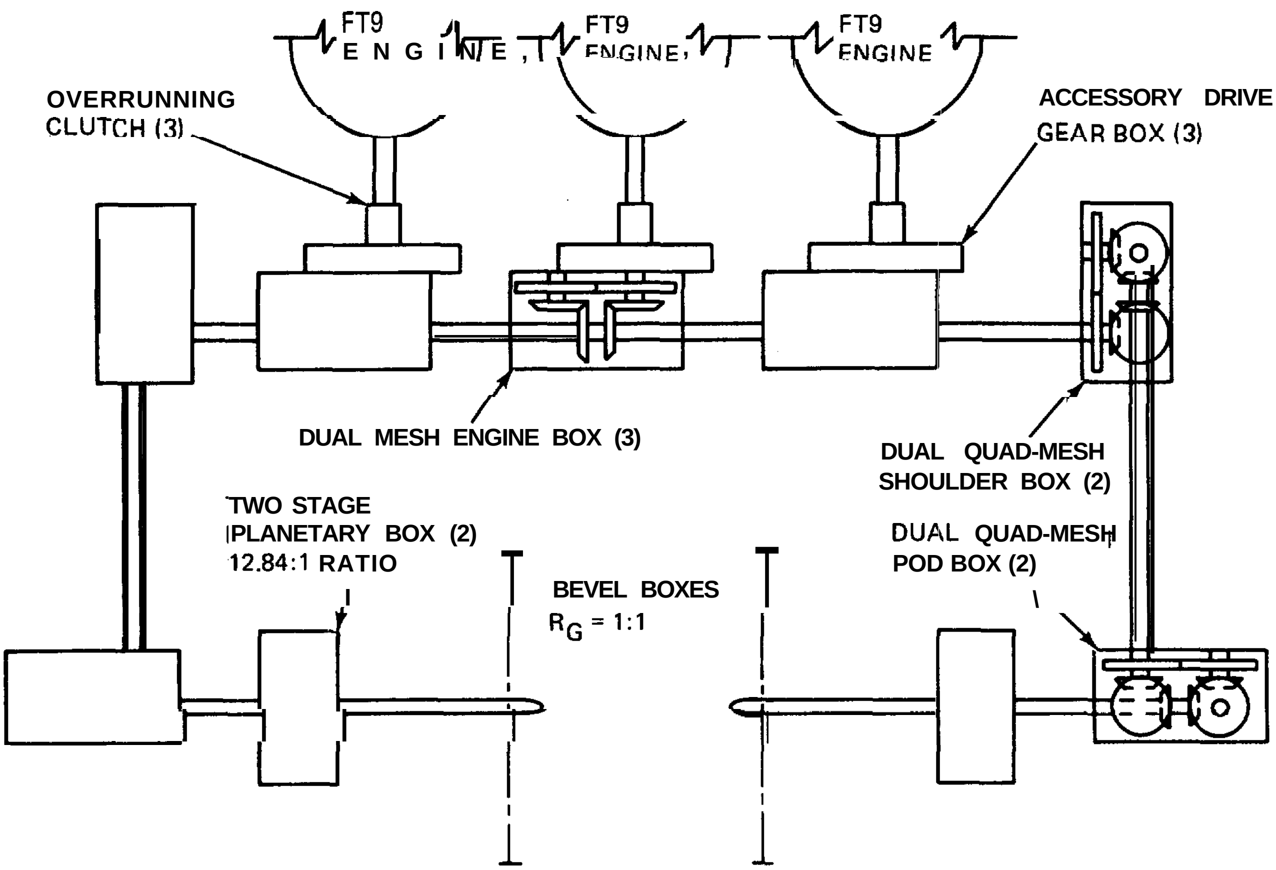


Fig. 2-34 Dual-Mesh/Dual-Quad Mesh Transmission System

MACHINERY ARRANGEMENTS

(U) The arrangement of the propulsion machinery is shown in Dwg. No. M165-10076 (Fig. 2-5). The major propulsion system components were arranged for ease of both overhaul and maintenance. The three Pratt and Whitney FT9 engines are placed in the main engine room located on the Second Platform. Drive shafts from the engines penetrate the watertight bulkheads at the aft end of the engine room and are coupled to the transmission gearboxes located in the next compartment aft. Access to each side of the engines from the Main Deck is provided.

(U) Engine installation and removal is accomplished via the main engine inlet trunks for the turbine end of the engines. If for logistic considerations, it becomes necessary to remove the complete engine or engines, removable hatches must be provided in the Main Deck between inlet and exhaust trunks as well as hatches in the top of the Deck House.

(U) The two Lycoming TF-35 engines, which provide power for the ship generators through integrally mounted gearboxes, are installed within a compartment on the Main Deck located aft of the main engine exhaust stacks. This compartment serves the secondary purpose of fairing what would have normally been a blunt base deck house aft of the main engine exhaust stacks.

(U) The transmission machinery room located on the Second Platform contains the engine gearboxes, the accessory drive gearboxes, and all athwartship shafting. Athwartship shafting is located on the retraction axis of the aft foil system to facilitate retraction of the aft foil and negate the need for disconnects on the transmission shafts. Also located within this compartment are the transmission lube oil and hydraulic fluid heat exchangers and other ancillary equipment. The transmission lube oil tank with its integral air separators is located in the next compartment aft with vacuum filter separators installed in close proximity to the tank to continuously process the lube oil.

ENGINE AIR INLETS AND EXHAUST SYSTEMS

(U) Induction air for the main engines is drawn through an opening in the top of the deckhouse just forward of the exhaust stacks. The induction air passes through three sets of demister water separators standing vertically in "V" formations, then passes over a faired dam and is drawn into three individual plenums. The plenum walls form the bounds of passages that provide access to the main engines via ladders to the Main Deck. Tubular screens in the plenum are provided for engine protection from foreign object damage. Air from the aft bulkheads of the plenums is then directed into the engines by the engine bellmouths.

(U) Air for the Lycoming TF-35 ship service engines is supplied from openings in the aft bulkhead of the main engine inlet chamber. After entering the bulkhead, the air is drawn through demister water separators where it is then ducted between the main engine exhaust stacks and discharged into the engine compartment.

(U) Conventionally insulated, vertical exhaust stacks are used for main and ship services gas turbine engines. Annular air passages around the stacks through which engine compartment cooling air is discharged afford an additional thermal barrier between the exhaust stacks and the surrounding structures.

GROUP 200 WEIGHTS

The calculated group 200 weights are presented in Table 2-10.

Table 2-10 Propulsion System Weight Breakdown

200 PROPULSION GROUP	WEIGHT, METRIC TONS
230 PROPULSION UNITS	29.0
240 TRANSMISSION	36.9
PROPELLERS	13.7
WATER JETS	1.7
250 SUPPORT SYSTEM	13.8
260 LUBE & OI L SYSTEM	'6.5
290 SPECIAL PURPOSE SYSTEM	4.7
TOTAL	101.3 MT

2.3.3 Electrical System

DESCRIPTION

(U) The shipboard electrical power system employed in Design M165 is taken from a previous propulsion system study outlined in Ref. '7, and modified to meet the requirements of the 70-kt design. The system consists of two Lycoming TF35 marine gas turbines each driving a shipboard accessory drive gearbox of helical spur gear design. Connected to the output of each gearbox is one 1050 kw, 60-Hz generator, one 90 kw, 400-Hz generator, and two Abex model no. AP27V series hydraulic pumps. The hydraulic pumps provide the necessary ship service requirements in the hullborne condition, including lift system retraction with cold main engines, and main engine startup.

LOAD SUMMARY

(U) The electric load analysis was developed from the results of Ref. 7. The electric load analysis results, which were developed in conjunction with the Naval Ship Engineering Center for HOC size ships, are presented in Table 2-11.

(U) Each TF35 gas turbine and its associated generators are capable of providing 100% of the Winter Battle Condition electric loads with reserve for either system growth or operation of the emergency transmission lube oil pump. Each generator can provide 100% maximum anticipated loads. Full system redundancy is therefore provided allowing for failure of any one generator or gas turbine, while providing total mission capability.

WEIGHTS

(U) Group 300 weights of the Ml65 design were taken from Ref. 7. The estimated group 300 weight is 46.7 mt, and the breakdown is presented in Table 2-12.

2.3.4 Command, Control, and Communication

COMMAND AND CONTROL

(C) The heart of the command and control system of Design Ml65 consists of one (1) AN/UYK-7 medium-scale, general-purpose digital computer, which serves as the Weapon Control Processor for the Fire Control System, and three (3) AN/UYK-20 general-purpose, militarized digital computers to meet the requirements of time critical systems (radar, sonar and display controlling). Display units consist of three (3) General Purpose Display AN/UYA-4's with their auxiliary cabinet (RDR Distribution switchboard 2780/UYA-4) and one OIC Display. One (1) MK90 Mod 0 Launching System Module Console acts as the interface between the AN/UYK-7, the missile system, and the AN/UYA-4 displays.

NAVIGATION

(C) The primary element of the navigation system is the Marine Aided Inertial Navigation System (MAINS) consisting of an inertial unit and a remote position indicator. Manual updating of the inertial systems is provided with an SR-500 Omega receiver. Navigational requirements for the Ml65 Combat Suite are provided by a LORAN AN/UPN-12, a DE-735 Depth Sounder, a magnetic compass and an autopilot system.

COMMUNICATIONS

(C) The communications system employed in Design Ml65 provides tactical data transfer between cooperating force elements; command, control and monitoring of sonobuoys; and internal/external voice networks for the tactical console operators. Internal communications

Table 2-11 Electric Load Summary

Load Category	Connected		Average Loads*, 60 HZ				Average Loads 400 HZ	
			Cruise		Battle			
	60 Hz	400 Hz	Summer	Winter	Summer	Winter	Cruise	Battle
Prop Aux & Steering	311.2		63.3					
Auxiliary Machinery	417.0		182.1	182.1	184.7	184.7		
Deck Machinery	43.5		5.0	5.0	7.5	7.5		
Shops	10.0		5.0	5.0				
I .C., CM., & Elect.	176.1	77.8	85.8	85.8	122.5	122.5	32.7	48.5
Ordnance Systems	181.3	31.5	17.0	17.0		105.4	3.1	18.9
Hotel	161.9		74.0	74.0	38.8	38.8		
Air Conditon & Vents	565.0		237.2	273.5	237.2	273.5		
L.O. Emergency Pumps	150.0		(150)					
Load Growth 20%“”			73.8	73.8	91.8	91.8	7.2	13.5
TOTAL	2016	109	893	930	1001	1038	43	81

*Totals include emergency demand of 150 kw for transmission L.O. backup pumps.
**Not applied to load categories 1, 8 and 9.

Table 2-12 Electrical System Weight Breakdown

300 Electric Plant Components	Weight, Metric Tons	%
310 Electric Power Generation	33.4	71.6
320 Power Distribution Systems	8.7	18.6
330 Lighting System	2.5	5.4
340 Power Generation Support Systems	1.8	3.9
390 Special Purpose Systems	.3	.6
Total	46.7	100

are handled by the AN/AIC-22 intercommunications system. External communication equipment consists of one AN/ARQ-35 HF data link, one AN/ARC-159 multimode UHF transceiver, one AN/ARC-52 UHF Voice radio, one AN/ARC-58 HF Voice radio, one AN/ARR-75 sonobuoy receiver and the CASS AN/ASA-76 Buoy Command Signal Generator.

SURVEILLANCE SYSTEMS

Surface

(C) The surface surveillance system consists of one AN/SPS-49, two dimensional, long range, air-search radar or one AN/SPS-58 long range, air-search radar system. Along with either the AN/SPS-49 or AN/SPS-58 is a AN/SPS-55 surface search radar system.

Underwater

(C) The major ASW sensor in Design M165 is the Active Passive Reliable Acoustic Path Sonar (APRAPS) consisting of a winch power unit, a deep acoustic unit, cable and appropriate electronic subsystems. The APRAPS system is mounted amidships and is winch-lowered through a trunk and hatch in the bottom of the hull. Along with the APRAPS system is a Variable Depth Sonar system located aft on the Second Deck and room is available on the First Platform at Station 1.5 for Foil-Mounted Sonar system equipment.

FIRE CONTROL SYSTEMS

(C) The Fire Control System is a versatile derivative of the airborne system currently installed in the Grumman F-14. The AN/AWG-9 (Type I) FCS performs limited-volume air search; automatic target acquisition and track; launch-zone computation; target illumination; weapon selection, preparation, and firing; and kill assessment. The Type I configuration is a fire control/surveillance system with limited-range search capability. Due to this limited search capability, a separate long-range radar and/or passive receiver is required. The surveillance radar is similar to the fire control radar but utilizes a AN/APS-116 antenna to give it 360° search coverage. Other systems which could be used instead of the AN/AWG-9 FCS are the MK74 MODII or the MK92. Along with the AN/AWG-9 FCS is the MK48 Fire Control System required to program and launch the MK48 torpedo from the M165 Design. This system which consists of a Weapon Tube Converter and a Status Display and Firing Console interfaces with the AN/TJYK-7 and the sonar and sensors systems.

COUNTERMEASURES

(C) The tactical jamming system used for electronic countermeasures is the AN/ALQ-99 EXCAP System. Electronic Support Measures (ESM) are provided by the AN/ALR-59, a system which was originally designed for the Grumman E-2C program. The IFF System provides Design Ml65 with the capability to interrogate and decode IFF data for air and surface targets. The IFF AN/APX-102 System uses a RT-868A/APX-76 receiver transmitter in conjunction with the SN 480/APX-102 synchronizer and the KY-658/UPA-60 video decoder.

SPACE ALLOCATION FOR C^3 SYSTEMS

(U) The equipment, weight, and volume requirements for the C^3 Systems are described in OPNAV 9330.5A OP-36. The Ml65 Design reflects these requirements in terms of space and weight allocation.

(U) The interior spaces allocated for the C^3 systems are as follows:

SPACE	LOCATION	DECK AREA	VOLUME
Combat Operations Center	01 Level	780 ft^2 (72.46 m^2)	7020 ft^3 (198.81 m^3)
Communications Room	01 Level	290 ft^2 (26.94 m^2)	2574 ft^3 (72.90 m^3)
COC Support Space	(Electronic Equip.) 2nd Deck, Fwd	150 ft^2 (13.94 m^2)	1500 ft^3 (42.84 m^3)
Sonar Equipment Rooms	1st Platform, Fwd	108 ft^2 (10.03 m^2)	864 ft^3 (24.47 m^3)
	2nd Deck, Midships	110 ft^2 (10.22 m^2)	880 ft^3 (24.92 m^3)
	2nd Deck, Aft	144 ft^2 (13.38 m^2)	1296 ft^3 (36.70 m^3)
Ships Navigation Equip.	(I. C. and Gyro Room) 1st Platform, Fwd	150 ft^2 (13.94 m^2)	1200 ft^3 (33.98 m^3)
	(Chart Space) 01 Level	80 ft^2 (7.34 m^2)	640 ft^3 (18.12 m^3)
	(Command & Control Sta) 02 Level	136 ft^2 (12.63 m^2)	1224 ft^3 (34.66 m^3)

WEIGHTS

(U) Group 400 weights are provided in Table 2-13.

2.3.5 Auxiliary Systems

(U) The Auxiliary Systems for hydrofoil ships includes both the conventional auxiliary systems plus the lift systems including the foils, struts, pods, and control mechanisms. Subsection 2.3.5.1 following describes the conventional systems, while Subsection 2.3.5.2 describes the lift systems.

Table 2-13 Command, Control and Communications Systems Weight Breakdown

SWBS No.	System	Weight Metric Tons
410	Command and Control	2.085
420	Navigation	1.158
430	interior Communications	0.016
440	Exterior Communications	0.187
450	Surveillance Systems (Surface)	5.276
460	Surveillance Systems (underwater)	10.467
470	Countermeasures	0.361
480	Fire Control Systems	2.619
490	Special Purpose Systems	2.217
	TOTAL	24.39

2.3.5.1 Auxiliary Systems (Less Lift Systems)

(U) The Auxiliary Systems (WBS 500, EX 567) of Design Ml65 consists of the following sub-groups:

510 Climate control including heating, ventilation, air conditioning, and refrigeration.

520 Sea water including the firemain and sprinkling, flushing, sanitary, engine exhaust cooling, ballast and water.

530 Fresh water including potable water and closed loop cooling water.

540 Fuel and Lube Oil Handling.

550 Compressed air, Hydraulic, and Fire Extinguishing.

560 Ship Control (excluding Lift Systems).

570 Replenishment.

580 Mechanical Systems including anchor and line handling, boat handling, and stowage.

590 Special Purpose.

(U) General functional descriptions and major equipment locations for each subgroup are provided in the following subsections. Detail schematics and component descriptions have not been developed at this time for Design M165.

<u>CLIMATE CONTROL</u> (WBS Groups 511-14, 516)

(U) Compartment Heating (WBS 511) is provided for all normally manned spaces by electric resistance type, forced air heaters similar to those installed on PHM-1.

(U) Ventilation (WBS 512) is provided as required, for all non-air conditioned spaces. A split zone system is being considered, with the forward zone serviced by fans in Auxiliary Machinery Room No. 1, and the aft zone by fans in Auxiliary Machinery Room NO. 2 and/or 4.

(U) Machinery Space Ventilation (WBS 513) is provided as required for all Main and Auxiliary Propulsion and Transmission Rooms, and Auxiliary Machinery Rooms. Positive air exhaust flow from the aft machinery spaces is forced in the stack areas into annular slots in the machinery uptakes providing partial infrared signature suppression. Turbine enclosures insure high velocity flow across high temperature machinery and minimize active fire extinguishing system requirements (see WBS 550). Fans are locally positioned drawing from combustion air plenums or main ventilation ducts.

(U) Air Conditioning (WBS 514) is provided to all normally manned spaces including electronic equipment spaces. In general, this includes the 02 and 01 Levels, the Main Deck superstructure forward of the Galley and associated spaces; and all crew and office spaces on the Second Deck and First Platform. Major air conditioning equipment is located in Auxiliary Machinery Rooms No. 1 and 2.

(U) Refrigeration (WBS 516) is provided for frozen and chilled food storage. Equipment and reefer spaces are located immediately aft of amidships on the Second Deck.

SEA WATER (WBS 520)

(U) The sea wate-r pumps supply the fire mains, sprinkler, washdown, and sanitary systems, A loop piping arrangement is fitted with the starboard main running under the Main Deck immediately outboard of the longitudinal bulkheads and the port main running under the Second Deck immediately inboard of the longitudinal bulkhead.

(U) The system supplies cooling to various components, flushing for sanitary fixtures, charges the sprinkler and washdown systems when required, and supplies water cooling to the turbine exhausts.

(U) The sprinkling system serves all normally unmanned, potentially hazardous spaces including the magazines, volatile stores, and missile compartments. The washdown countermeasures system is arranged to distribute sea water to weather surfaces for removal of contaminated material. Dual-purposes systems are provided at the aft VERTREP station for either sea water or foam.

(U) Plumbing drains are collected into the sewage holding tank amidships and treated before discharge. Similarly oily waste is collected into two holding tanks port and starboard and treated before overboard discharge of water.

(U) The main drainage and ballast system consists of low suction piping installed in all spaces to be serviced. Eductors, powered by the firemain, discharge overboard or to the oily waste holding tanks.

FRESH WATER SYSTEMS (WBS 530)

(U) These include the potable and fresh water systems, the air conditioning and electronic cooling water circulating system, the waste heat circulating system, the distilling plant, and gas turbine water wash systems. The galley and laundry steam system is also included in this group.

(U) The potable and fresh water system provides a continuous supply of hot and cold water to the various outlets and services throughout the ship. The system is arranged to receive water from shore or from another ship and from the distilling plant to fill the potable water tank. The distiller is located in Auxiliary Machinery Room No. 2. Hot potable water at approximately 150°F (66°C) is supplied from a recirculating system with an accumulator tank heated by -the waste heat circulating system. The waste heat circulating system utilizes heat recovery from the ships main turbine exhausts to service the following:

- Fuel Service and Transfer Heaters
- Lube Oil Purifier Heater
- Potable Water Heater
- Distilling Plants.

Electric supplemental heaters are included to maintain a minimum hot water discharge temperature of 170” F (77” C).

FUELS AND LUBRICANTS, HANDLING AND STOWAGE (WBS 540)

(U) Traditional hydrofoil ships have reported this group weight within WBS 260 Propulsion Support. For consistency with the SWBS for other ship classes, these functions are described herein.

(U) The fuel transfer and purifying systems provide for the filling of tanks, the transfer of fuel between tanks and refueling stations and the purifying and heating of fuel if required.

(U) The Fuel System services 15 tanks arranged as follows:

- FORWARD: 4 Deep plus 1 Double Bottom Storage, 2 Double Bottom Overflow.
- AFT: 3 Deep Storage
  3 Deep Service
  2 Deep Overflow.

(U) Lubricant stowage consists of non-integral tanks, transfer pumps, and two purifiers.

AIR, GAS, AND MISCELLANEOUS FLUIDS SYSTEMS (WBS 550)

(U) These systems include the pneumatic, fire extinguishing (other than water) and hydraulic pressure supply. The latter is the most extensive, supplying not only normal escort ship functions, but also the lift system flight actuation and retraction systems (included in WBS 567 following).

(C) It has been estimated that foilborne hydraulic control power (including steering) requirements for Design Ml65 are 3000 hp maximum in sea state six. These requirements are satisfied by six 500 hp primary pumps mounted (two each) on each Accessory Drive Gearbox in the Transmission Room; and on each TF-35 generator set. Hullborne requirements are satisfied by four 250 hp pumps mounted on the TF-35 generator set.

(U) The Pneumatic System takes air from each main FT9 propulsion gas turbine bleed connection and/or 1.00 CFM (2832 l/min) compressor. The system provides 125 psi (862 kPa) air for ship service intake de-icing, and for the PRAIRIE/MASKER air supply to each of the two propellers.

(U) Fire extinguishing systems include a Halon 1301 System, a CO_2 System, and an AFFF Foam System. The CO_2 System includes portable extinguishers and a fixed flooding (primary) system for the magazine and ordnance service spaces. The Halon 1301 System protects the main propulsion gas turbines and the TF35 generator sets and their enclosure modules, as well as all auxiliary, transmission, main engine, and hullborne engine rooms. Bilges of the outboard machinery spaces are also protected.

(U) The AFFF Foam System discharges foam or water to the VERTREP and Helo landing areas.

SHIP CONTROL SYSTEMS (WBS 560 EX 567)

(U) The ship control systems on Design Ml65 includes nozzle vectoring of the four pump jets used for hullborne operation actuated by hydraulic steering gear powered by the combined hydraulic system. Also, included within this group is the Automatic Flight Control System (ACS) electronics. The Hydrofoil Universal Digital Autopilot (HUDAP) combined with radar height sensors is utilized.

MATERIAL HANDLING SYSTEMS (WBS 570)

(U) Refueling-at-sea and material and personnel transfer stations are located on the 01 Level port and starboard amidships. The VERTREP station aft provides additional capacity for material and personnel transfer.

MECHANICAL HANDLING SYSTEMS (WBS 580)

(U) One 26-ft (7.9 m) lightweight motor whaleboat with davits has been provided at the 01 Level, starboard amidships. In addition, six (6) 15 person CO_2 inflatable life rafts (MIL (MIL-L-19496) have been provided. Total capability of the boat and rafts is 102 persons.

(U) A single 3000-lb (1360-Kg) anchor with 195 fathoms of anchor line is provided forward. The anchor windlass drive machinery is mounted below the Main Deck with the wildcat above. A capstan head is mounted above the wildcat for mooring purposes. A second capstan electrically driven is also provided aft for mooring.

SPECIAL PURPOSE SYSTEMS (WBS 590)

(U) Special Purpose Systems, spares, and repair equipment are not specified at this time.

GROUP 5 (EX 567) WEIGHTS

(U) The weight of the Auxiliary Systems less Lift Systems are presented in Table 2-14.

Table 2-14 Auxiliary System (Less 567) Weight Breakdown

500 Auxiliary Systems (EX 567)	Weight, Metric Tons	%
510 Climate Control	12.6	12.5
520 Sea Water Systems	17.6	17.5
530 Fresh Water Systems	5.0	5.0
540 Fuels & Lubricants - Handling & Storage	12.6	12.5
550 Air, Gas & Misc Fluid Systems	20.1	20.0
560 Ship Control Systems	5.7	5.7
570 Underway Replenishment Systems	2.5	2.5
580 Mechanical Handling System	17.1	17.1
590 Special Purpose Systems	7.2	7.2
TOTAL	100.4	100

2.3.5.2 Lift System

DESIGN PHILOSOPHY

(U) The lift system employed in Design Ml65 is a hybrid of the TAP-2 strut/foil system described in Ref. 10 and 11, an unpublished mixed foil concept devised by DWTNSRDC and reported in Ref. 2, and Grumman modifications for the introduction of transcavitating pods for housing control actuators and transmission machinery. The L/D ratios given by DWTNSRDC in Ref. 2 were modified for the addition of the pods and the extended strut length aft.

(U) The mixed foil concept is designed for four speed regions:

- 35 kt . . . . , ... , . . , ... , ... Takeoff mode
- 35 - 50 kt . . , , ... , ... , ... Low-speed cruise
- 50 - 60 kt . . . . , ... , ... High-speed cruise
- 60-70kt. . . . . Burst speed.

(U) In the takeoff mode and low-speed cruise mode, the lift system is comparable with existing subcavitating lift systems. By operating the foils fully wetted in this speed region, it is anticipated that the Ml65 lift system will provide L/D ratios necessary for takeoff and long-range patrol and interdiction mission requirements. In the higlh-speed cruise and burst speed regions, a lower surface tab is activated to reduce the lifting area on the foil and the strut is converted to a base-vented strut via ventilation doors located just behind the widest part of the strut.

(U) The high-speed cruise and burst speed capabilities are obtained with the foil operating in a super-ventilated condition. The foil in a super-ventilated condition is considered a more stable lifting surface than a foil in the supercavitated condition. Reference 12 summarizes that if a supercavitating foil is run in waves at cavitating speeds near the free surface, eventually it hits a large disturbance which ventilates the cavity. Once this condition is generated, the ventilated condition is maintained to depths of submergence lower than two chords even if the speed is reduced to that which originally formed the cavity on the foil, Since a ventilated cavity sustains itself far downstream it is necessary to lower the aft foil/pod assembly to prevent the tractor prop arrangement aft from operating in the forward foil's ventilated cavity.

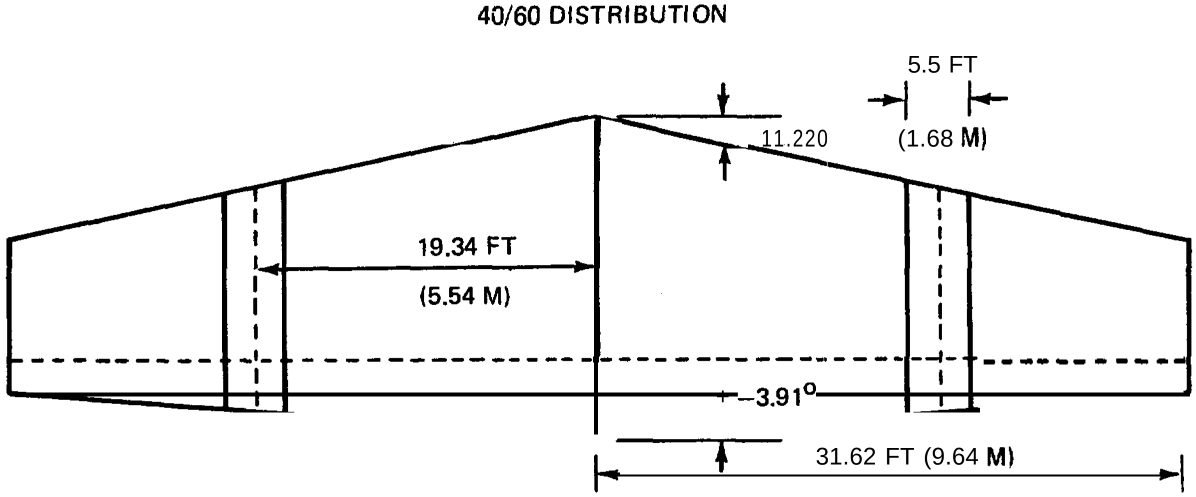
(U) It should be pointed out that even though the mixed foil concept is in its early stage of development, the L/D ratios used in Design Ml65 have been demonstrated from tests run at DWTNSRDC. There are however, a number of specific risk areas associated with the design which will be mentioned in the Technical Risk Assessment, Section 4.

DESCRIPTION

(U) The lift system selected for Design Ml65 consists of two pi-foil assemblies with the forward foil supporting 60% of the craft weight and the aft foil carrying 40% of the craft weight. The tail assembly consists of a foil supported by two struts with two pods located at the strut/foil intersection housing flap control mechanisms and transmission components. There are two propellers, one located at the forward end of each pod. The aft struts are mounted vertically on either side of the hull, joining the foil at the 52% semi-span station, The forward assembly consists of a foil, two struts and two pods for housing control actuators. The forward struts are mounted on fairings on either side of the hull with the upper portion containing the retraction trunnion and a vertical trunnion located on the strut steering axis. The lower portion of the forward strut is of constant chord and is steerable through ±15 deg.

(U) The pseudo-blunt based struts are symmetric NACA-16, 12% thick sections which operate in a fully wetted condition below 50 kt. For high speed operation, ventilation doors extend from the side of the strut to convert the strut to a blunt-based section. These ventilation doors are 20% chord flaps which are attached at the 50% chord station. When extended, they introduce the ventilation air midway back on the foil chord which is a favorable location for air distribution. The forward strut has a constant chord of 5.486 m from the strut/pod intersection to the hull fairing where the chord is then truncated to fit the retraction mechanism. The overall length of the forward strut from the strut/pod intersection to the retraction axis is 14.173 m. The aft strut has a constant chord of 6.096 m from the strut/pod intersection to the hull fairing where its chord is also truncated to fit the retraction mechanism. The overall length of the aft strut from the strut/pod intersection to the retraction axis is 14.478 m.

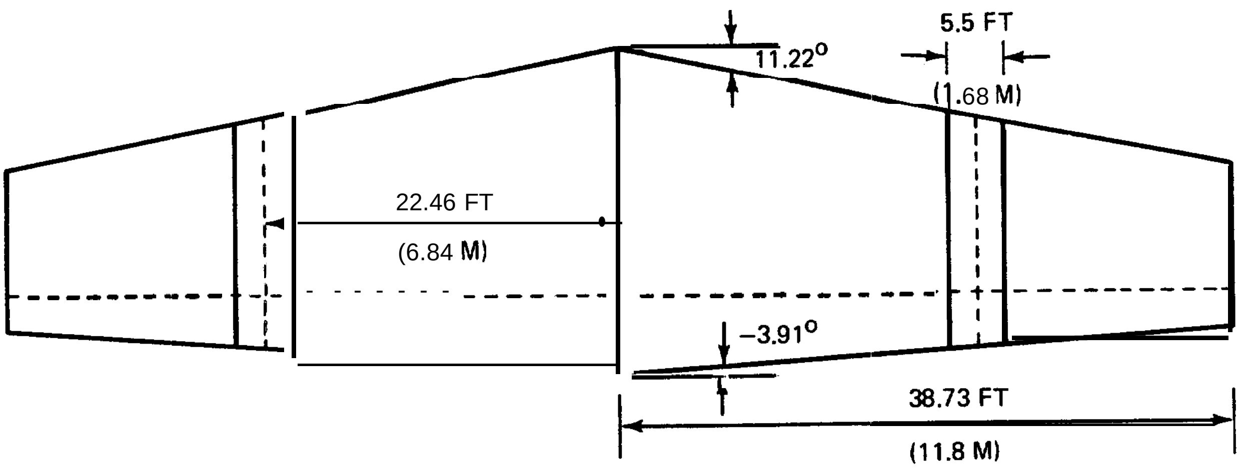
(U) The foils are 'NACA-16 or 64 series sections with a thickness-to-chord ratio of 7% and an, as of yet, undetermined camber. Both forward and aft foil planforms are identical with an aspect ratio of 5.0, a taper ratio of 0.5, and, in order to ensure a straight hinge line at the 75% chord station, a leading edge sweep of 11.22 deg and a quarter-chord station sweep of 7.5 deg are used. Both foils employ a 25% chord length subcavitating flap with ±15 deg travel for subcavitating control and a 10% chord supercavitating flap to a supercavitated section at speeds above 50 kt. The forward foil has an area of 74.322 m^2 with a span of 19.277 m, a 5.141 m root chord, and a 3.999 m mean aerodynamic chord. The aft foil has an area of 111.484 m^2 with a span of 23.610 m, a 6.296 m root chord, and a 4.897 m mean aerodynamic chord. See Fig. 2-35 and 2-36.



• FOIL LOADING	1400 PSF			FOIL SECTION
. AREA	800 FT^2	• ASPECT RATIO	5.0	NACA 64 SERIES
. SPAN	63.246 FT	. TAPER RATIO	.5	
. ROOT CHORD	16.865 FT	. C/4 SWEEP	7.5°	
. TIP CHORD	8.433 FT	• t/c	7%	
• MAC	13.117 FT	• POD DIA	5.5 FT	

Fig. 2-35 Forward Foil Geometry

40/60 DISTRIBUTION



- FOIL LOADING 1400 PSF
- AREA 1200 FT^2
- SPAN 77.46 FT
- ROOT CHORD 20.656 FT
- TIP CHORD 10.328 FT
- MAC 16.066 FT

- ASPECT RATIO 5.0
- TAPER RATIO 0.5
- C/4 SWEEP 7.5°
- [illegible] 7%
- POD DIAMETER 5.5 FT

FOIL SECTION
NACA 64 SERIES

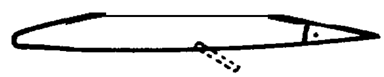


Fig. 2-36 Aft Foil Geometry

(U) Three pod configurations are presented in the following paragraphs.

(U) Pod "A" is portrayed on the Propulsion Machinery and Foil System Drawing M165-10076, Fig. 2-5 and Pods "B" and "C" are separately shown on the Transcavitating Pod Arrangement Drawing No. M165-10077, Fig. 2-6.

(U) In the Pod "A" configuration, the trailing edge of the struts and the trailing edge of the foils terminate at the same station. An annular protrusion, whose shape is undefined at this time, is placed near the strut and foil trailing edges to initiate a cavity at high speed, and to prevent separation at low speed to maintain attached flow on the abruptly faired pod afterbody. An annular translating cowl, surrounding the afterbody, aids flow into the base area when open at low speed especially during the take-off run. The cowl will remain within the pod cavity when closed at speeds above 50 kt.

(U) The ventilation path from the surface is within the strut and behind the strut mid-chord flaps, and then into the pod and pod cavity. Air will then flow through opened holes in the pod side walls to ventilate the base of the foil mid-span flaps for a short distance spanwise until this cavity joins and is fed by the pod base cavity. Once this air path is established, the foil mid span flap cavity should travel spanwise until ventilation has been completed. Air from the mid span flap cavity will then be drawn forward through the low pressure core of tip vortices and enter the vapor cavity on the upper surface of the foil, The ventilated cavity will then travel inboard until obstructed by the side wall of the pod. Adequate ventilation of the foil inboard of the pods then becomes a problem. One means of providing a ventilation path would be to provide a small pod located on the centerline configured to duct air from the ventilated mid chord flaps to the upper surface of the inboard foil.

(U) Realizing that it would be difficult and maybe impossible to establish an adequate ventilation path by these means, Pod "B" is presented as one step forward in the attempt to solve the problem.

(U) In the Pod "B" configuration, the annular protuberance designed to precipitate the pod base cavity, has been moved forward to provide a better ventilation path from behind the strut mid-chord flaps, into the pod cavity, and into the foil mid span flap cavities. Though doors are indicated in the side walls of the pods at the leading edge of the foils, a sufficient pressure differential may not be available at this point to establish a ventilation path. A fixed, or nontranslating cowl was added at this point.

(U) An alternate pod, Pod "C" was then considered. In this configuration, the foil is moved aft to the point where its leading edge coincides with the leading edge of the strut mid-chord flaps. The protuberance in pod contours is shown divided top to bottom and displaced axially along the pod. The upper part has been placed just forward of the foil leading edge and the leading edge of the strut mid span flaps. Ventilation once again is established by the open strut mid chord flaps, filling the upper pod cavity and foil upper surface cavity. The lower half of the protuberance has been retained in its position relative to the foil mid-chord flaps. Pod "C" appears to provide the most promising means of achieving ventilation objectives.

GROUP 567 WEIGHTS

(U) The calculated group 567 weights are presented in Table 2-15.

2.3.6 Outfit and Furnishings

DESCRIPTION AND PHILOSOPHY

(U) The hull of Grumman Design Ml65 is subdivided into twelve major compartments fore and aft, Crew berthing and living spaces are provided in the sixth and seventh compartments amidships within the hull, extending for 20% of the length from hull Stations 3 to 5, and within the deckhouse structure from approximately Station 2 to Station 6. This amidship location of crew accommodations is within the zones of minimum ship motions, both foil-borne and hullborne, and provides for the minimum response times for battle station manning.

(U) To meet expected trends in habitability, a series of small group living “apartments” have been provided, each housing from a minimum of 15 to a maximum of 21 enlisted personnel. Each “apartment” has ready access to separate sanitary and recreation/lounge spaces, as shown on Drawing M165-10074 (Fig. 2-4). Chief Petty Officer accommodations are provided in a separate area in the sixth major compartment complete with separate sanitary and lounge areas. No watertight bulkhead doors are provided below the Main Deck in the amidship area in order to insure a minimum amount of unnecessary passage through the crew berthing areas. The Main Deck would be used in the area (within the superstructure) as the damage control deck. Forward from Station 3 to the collision bulkhead and aft from Station 8, watertight bulkhead doors have been provided on the Second Deck for use by damage-control parties.

Table 2-15 Lift System Weight Breakdown

567 Hydrofoil Lift System	Weight, Metric Tons	%
567.117 Struts – Aft	38.5	21.2
Fwd	29.8	16.3
567.2 Pods	24.8	13.6
567.3 Foils – Aft	34.8	19.1
Fwd	24.3	13.3
567.4 Control Mechanism	12.0	6.6
567.5 Retraction Mechanism	18.1	9.9
Total	182.3	100

(U) All crew berthing areas are buffered from machinery noises from the Forward Auxiliary Machinery Room No. 1 and Aft Main Machinery Rooms by equipment service or stores spaces, and are isolated from wave slap noise by the fore and aft longitudinal bulkheads.

(U) Accommodations are provided in the Main Deck Level deck house for nine officers in seven staterooms, as shown on Drawing M165-10073 (Fig. 2-3).

(U) Galley and food service spaces aft on the Main Deck buffer the noise from the main propulsion machinery and air operations/maintenance areas, and serve three mess rooms; Crew, CPO, and Wardroom, located amidships in the Deck House.

(U) The Medical Treatment Room is on the starboard side amidship, with the Wardroom, Mess, and Officer Lounge readily accessible as battle dressing stations.

(U) Habitability standards used in the development of Design Ml65 were a minimum of 50% greater than those specified by OPNAV Instruction 9330.5, and the General Specifications for U. S. Navy Ships. Total accommodations have been provided for the following personnel:

Officers (01 to 05)	9
CPOs (E7 to E9)	9
Enlisted (El to E6).	68

A Ship's Office complex has been provided on the Second Deck in keeping with escort class ship type requirements. Access is provided to this combined office complex area for each department head from private staterooms directly above on the Main Deck,

(U) Ample storage and service spaces have been provided in keeping with the class type and expected extended mission duration times.

INSULATION

(U) Special attention to passive fire protection insulation for the primary aluminum hull structure has been provided for in the design. Where utilized, this insulation has been assumed to provide adequate HVAC and acoustical characteristics as well.

(U) A total of approximately 20.0 metric tons of fire protection insulation has been provided. In addition, a total allowance of 5.0 metric tons of HVAC and acoustic insulation has been provided for use in non-thermal protected locations. Radar cross-section absorption material. allowance of 1.0 metric ton has also been included.

GROUP 6 WEIGHTS

(U) Group 6 weights are presented in Table 2-16.

Table 2-16 Outfit and Furnishings Weight Breakdown

600 Outfit & Furnishings	Weight, Metric Tons	%
610 Ship Fittings	3.5	5.6
620 Hull Compertmentation	7.9	12.5
630 Preservatives & Coatings	32.6	51.7
640 Living Spaces	9.5	15.1
650 Service Spaces	3.1	4.9
660 Working Spaces	3.2	5.1
670 Stowage Spaces	3.2	5.1
690 Special Purpose Systems	–	
Total	63.0	100

2.3.7 Combat Systems

(C) The major weapon systems elements of Design Ml65 were taken from a conceptual design study of the combat system requirements of the Grumman HOC. Following the Grumman philosophy that a ship of this size should have the capability for close-in operations against low value targets, three guns have been incorporated into the design. The arrangement of the combat system elements is shown on drawings M165-10071, -72, -73, and -74, which are Fig. 2-l through 2-4 of this report.

(C) The ship-launched missile batteries consist of two rows of vertical, universal launchers located in single rows of 11 on each side of the vessel. These launchers exhaust the propellant gases outboard through ports in the shell plating located directly above the waterline. Each bank contains 11 standard (MR) missiles and canisters weighing 29,095 lb (13,195 Kg). There are two MK-25 torpedo launch tubes located on the Second Deck forward on each side of the vessel. Each launch tube has five (5) MK-48 torpedos stored in a cartridge directly above the tube for easy underway replenishment from the 01 Deck. The total weight of the MK-48 torpedo system is 39 , 800 lb (18,050 Kg).

(C) Close-in operations against low value targets are performed by one (1) 76 mm Oto Melera and two (2) twin 30 mm Emerlec guns. The 76 mm gun with 460 rounds of ammunition is located forward on the Main Deck with 3982 additional rounds of ammunitions located directly below on the Second Deck. The total weight of the Oto Melara and the ammunition is 75,450 lb (34,224 Kg). To increase the efficiency of the gun sweep on the 30 mm Emerlec guns, the port gun was raised 2.0 ft (0.61 m) above the starboard gun located on the 01 Level aft of the Communications Room. Each Emerlec carries 1970 rounds of 30 mm ammunition, making the total weight of both guns and the 30 mm ammunition 16,000 lb (7257.5 Kg).

GROUP 700 WEIGHTS

(U) The calculated group 700 weights are presented in Table 2-17.

2.4 SURVIVABILITY AND VULNERABILITY

2.4.1 Signature Characteristics

RADAR CROSS-SECTION

(C) The radar cross-section of the hull and superstructure would be basically identical to an equivalent size 50-kt hydrofoil. A somewhat larger reflective surface would be presented by the increased chord dimension of the forward and aft struts. The primary unknown in the evaluation of the radar cross-section of the 70-kt hydrofoil would be the evaluation of

Table 2-17 Armament Weight Breakdown

700 ARMAMENT	WEIGHT, METRIC TONS	%
710 Guns & Ammunition	10.0	41.1
720 Missiles & Rockets	12.6	51.9
750 Torpedoes	1.7	7.0
Total	24.3	100

the size of the spray wake issuing from the struts when the vehicle is operated in the supercavitating mode.

MICROWAVE AND INFRARED

(C) Microwave emissions from the 70-kt hydrofoil could be expected to be identical to those of a similar 50-kt design as they are a function of the mission equipment, which was not considered a variable in this comparison.

The additional power required to provide a 70-kt dash speed is provided by a third FT9 engine, thus increasing the quantity of exhaust gas by a factor of, roughly 1.5. The weight and volume requirements of the infrared suppression system would, correspondingly increase. When presented with a known threat from infrared weapons, the vehicle could be operated in the subcavitating mode to reduce the vulnerability to that of the 50-kt vehicle on which this comparison is based.

VISIBILITY

(U) As with the radar cross-section? the primary unknown in the evaluation of the effect of a 70-kt speed capability upon visibility lies in the evaluation of the magnitude of the spray wake created by the vehicle at 70 kt.

ACOUSTIC SIGNATURE

(C) Acoustic signature characteristics of Design Ml65 are expected to be similar to those of any hydrofoil ship of similar size in the region below approximately 50 kt. Above 50 kt, the acoustic signature is expected to be considerably higher due to the increased propulsive power requirements and the unknown effects of ventilation and potential negation of the PRAIRIE MASKING System.

2.4.2 Hardness

ARRANGEMENT CONSIDERATIONS

(C) Certain arrangement features of corresponding Grumman developed 50-kt hydrofoil designs are retained in Design M165. The longitudinal bulkheads provide double hull flooding protection to major areas of the hull sides, while allowing the actual shell plating to act as expendable standoff armor. The double bottom structure acts as additional double hull protection against inflicted damage as well as accidental grounding. Propulsion machinery is situated above the hullborne waterline, as no additional protection is afforded to equipment high in the ship, additional protection from flooding is gained should damage force hullborne operation.

(U) Due to the relatively small size of the platform, and the large volume requirements of vital equipment, some sacrifices had to be made in the physical separation of vital functions. This is particularly evident in the propulsion and generating machinery spaces which, because of the requirement for additional power, are crowded and vulnerable to damage by heat seeking devices.

ARMOR AND SPECIAL FEATURES

(C) The following vital spaces of Design M165 require armor protection to prevent ship loss, immobilization, or inactivation from lesser weapon threats.

- Command Operations Center
- Command and Control Station
- Generator Machinery Space
- Propulsion Machinery Space
- Missile Warheads
- Torpedo Warheads.

(C) To protect these spaces from 30 cal A. P. projectiles on vertical boundary surfaces as well as 5"/54 fragments on horizontal top surfaces requires approximately 28.3 mt of ceramic armor at an average area1 density of 39.1 Kg/m^2 (8 lb/ft^2).

FIRE PROTECTION

(C) Fire protective insulation with an area1 density of 4.9 Kg/m^2 is applied to all exposed aluminum structure above the design waterline. Active fire protection is provided as follows :

- Halon 1301 System for propulsion, generator? and auxiliary machinery spaces
- Fixed flooding and portable CO2 systems for ordnance
- Dual path fire main and sprinkler system.

(U) The fire main is supplied by pumps located in the forward and aft auxiliary machinery rooms. The aft fire main supply could also be provided by diverting the propulsion waterjet discharge to the firemain.

FLOODING CONTROL

(U) Floodable length calculations were performed for the full load displacement condition using the Ship Hull Characteristic Program (SHCP). The results of this calculation are presented, for homogeneous compartment permeabilities of 0.85 and 0.95, in Fig. 2-3’7.

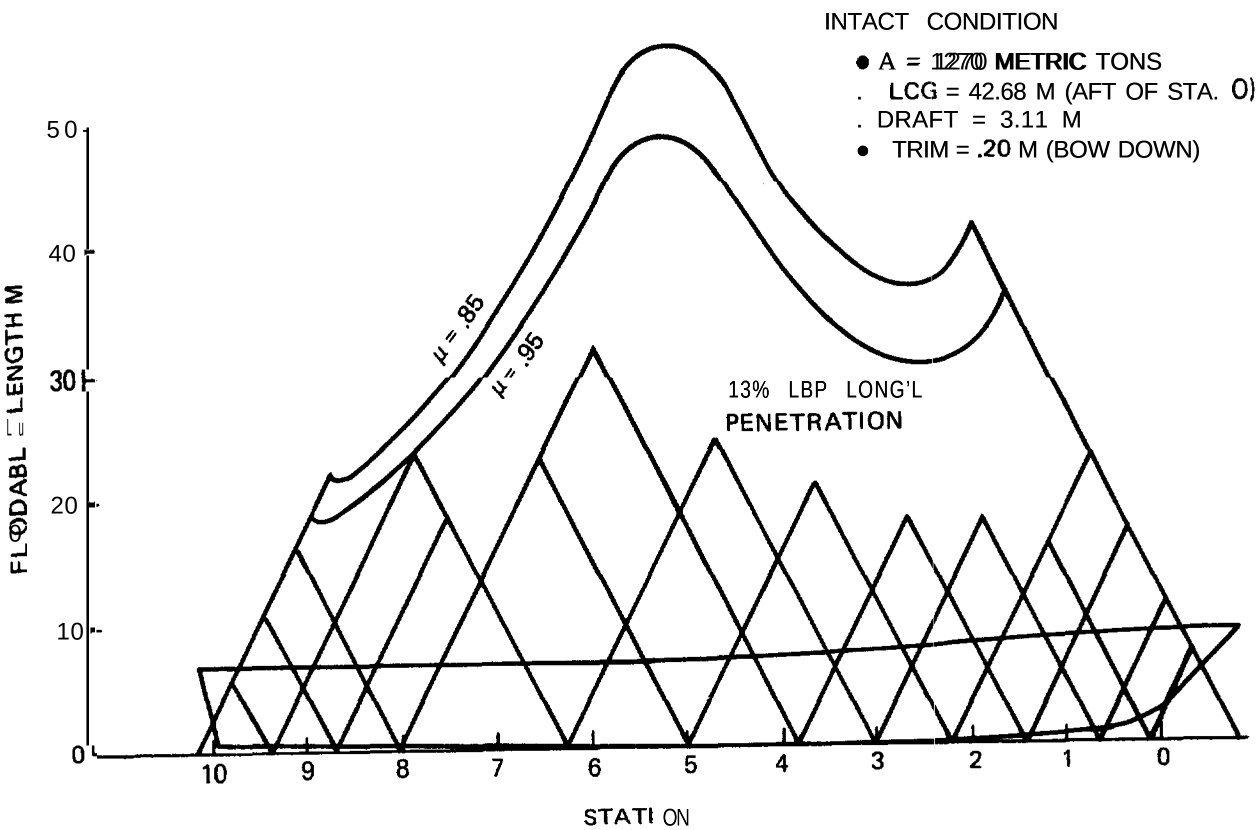


Fig. 2-37 Floodable Lengths

For this calculation, the margin line was assumed to be 76.2 mm (3 in.) below the sheer line. No transverse stability criteria or runoff correction was applied to the floodable length curves.

(U) The ability to sustain flooding in any two adjacent compartments is the general design requirement for ships of 20.48 to 91.44 m (100 to 300 ft) length (Ref. 9). Due to the combatant status of Design M165, greater protection is necessary, and adequate compartmentation is provided to survive 13% LBP longitudinal penetration of the bull, as indicated on the floodable length diagram. Minor adjustment of aft bulkheads would allow 15% LBP longitudinal penetration to be accommodated.

(U) Additional flooding control is provided by the use of longitudinal bulkheads and a double bottom structure to provide double hull protection to major areas of the shell. All port and starboard compartments are cross-ducted to prevent asymmetrical flooding. Dewatering is accomplished by eductors fed by the salt water fire and service system which discharge overboard.

SHOCK HARDNESS

(C) All propulsion and ship control components contained within the foilborne submerged components of the lift system are considered to be shock-hardened against underwater explosions, Previous assessments (conducted by the U. S. Navy) of the weight effect of shock hardening has indicated a penalty of 2.4%.

(C) Provision has been provided to also flood the lower portions of the struts, as well as the foils and pods with sea water in the event of expected operations in hazardous underwater explosion areas. Consideration is also being given to the utilization of all or portions of the underwater volumes of the lift system as part of the fuel tankage.

(C) The vulnerability of the 70-kt lift system to underwater explosion is expected to be somewhat higher than a 50-kt system due to the added complexity of the system. However, it is expected that a careful detail design will minimize this increased vulnerability.

Section 3

REFERENCE HYDROFOIL OCEAN COMBATANT (HOC)

(U) While the Technical Instructions issued by the Hydrofoil Program Office of DWTNSRDC directed that the resultant Design Ml65 be compared with the HOC, no specific definition of the HOC was provided. Several design agencies in recent years' have developed designs addressing the HOC requirements. While each of the designs produced represents a solution to the general HOC requirements, there are nevertheless significant differences in each design due to both tine level of analysis and the understanding and philosophies of each design agency at the time when each design was produced. Consequently, no clear acceptance of any one design as the probable HOC has developed. For comparitive purposes in this study Grumman elected to modify an existing corporate HOC design.

(C) The reference HOC used for comparative purposes in this study is a variant of Grumman Design M154D. Design M154D is one of a series of five designs developed by Grumman in the late CY 1974 to late CY 1975 time-frame in anticipation of the initiation of the Navy's HOC program in FY 1976. These designs range in size from M154E at 750 tons displacement., developed as a technology application design variant of the basic series for possible NATO interests, to Ml54 B and C which displaced 1600 tons. M154D was selected for comparison to Ml65 as it represented the closest combination of both displacement (1300 versus 1350 metric tons) and basic size and volurne (cubic number of 2590 versus 2560). M154D has a fixed (non-retractable) lift system and therefore no dedicated hullborne propulsion system.

(C) For comparison to Design M165, M154D was modified in the following manner:

- A retractable lift system was provided and propulsion system weights adjusted to reflect this change
- Hullborne Propulsion (with lift system retracted) was added
- All weight estimates were modified to the most current understanding of hydrofoil technology and to reflect consistent design philosophy with Design Ml65 (ballistic protection, shock hardness, fire protection, etc.).

(U) The modified design, designated M154D-2, thus represents, we believe, the closest comparative HOC design to Ml65 in that it represents the same level of analysis by the same design agency with a consistent level of technology definition at an identical period in time. Design M154D-2 does not, however, represent in the opinion of Grumman, the best nor the probable ultimate HOC design.

(U) Table 3-l presents the weight estimates for Design M154D-2 together with those of Design Ml63 (HYD-2) and M165. Figures 3-l through 3-6 present comparisons between the M154D-2 and Ml65 designs of the pertinent performance parameters. Table 3-2 presents a general characteristics and performance comparison of Design M154D-2 and M165, and Table 3-3 presents a comparison of the military payloads for both designs.

Table 3-I Weight Comparison

ELEMENT/SYSTEM		WEIGHT, METRIC TONS M163 (HYD-2)	M165 (70-KT DESIGN)	M154D-2 (50-KT DESIGN)
100	Hull Structure	410.6	228.3	234.5
200	Propulsion	164.0	101.3	99.0
300	Electric Plant	68.9	46.7	46.7
400	C & C	75.0	24.4	24.4
500 (Ex 567) Aux Systems		149.1	100.4	101.3
567	Total	(236.8)	(182.3)	(141.7)
567.117	Struts	(83.4)	(68.3)	(59.8)
567.2	Pods	(29.31	(24.8)	(12.61
567.3	Foils	(86.5)	(59.1)	(48.9)
567.4	Control	(14.4)	(12.0)	(7.8)
567.5	Retraction	(23.2)	(18.1)	(12.6)
600	Outfit & Furnishings	135.9	63.0	63.3
700	Armament	77.2	24.3	27.7
Margin (15%)		197.7	115.6	110.8
	Lightship	1515.2	886.3	849.4
10	Ships Force	16.2	10.1	10.1
20	Ord & Ord Dec Sys	113.0	61.6	65.3
30	Stores	22.8	14.5	17.8
40	Fuel	688.0	360.0	340.0
50	Liquids	23.3	14.8	13.0
Unassigned Payload		21.2	2.7	4.4
Total Loads		884.8	463.7	450.6
	Full Load	2400.0	'I 350.0	1300.0

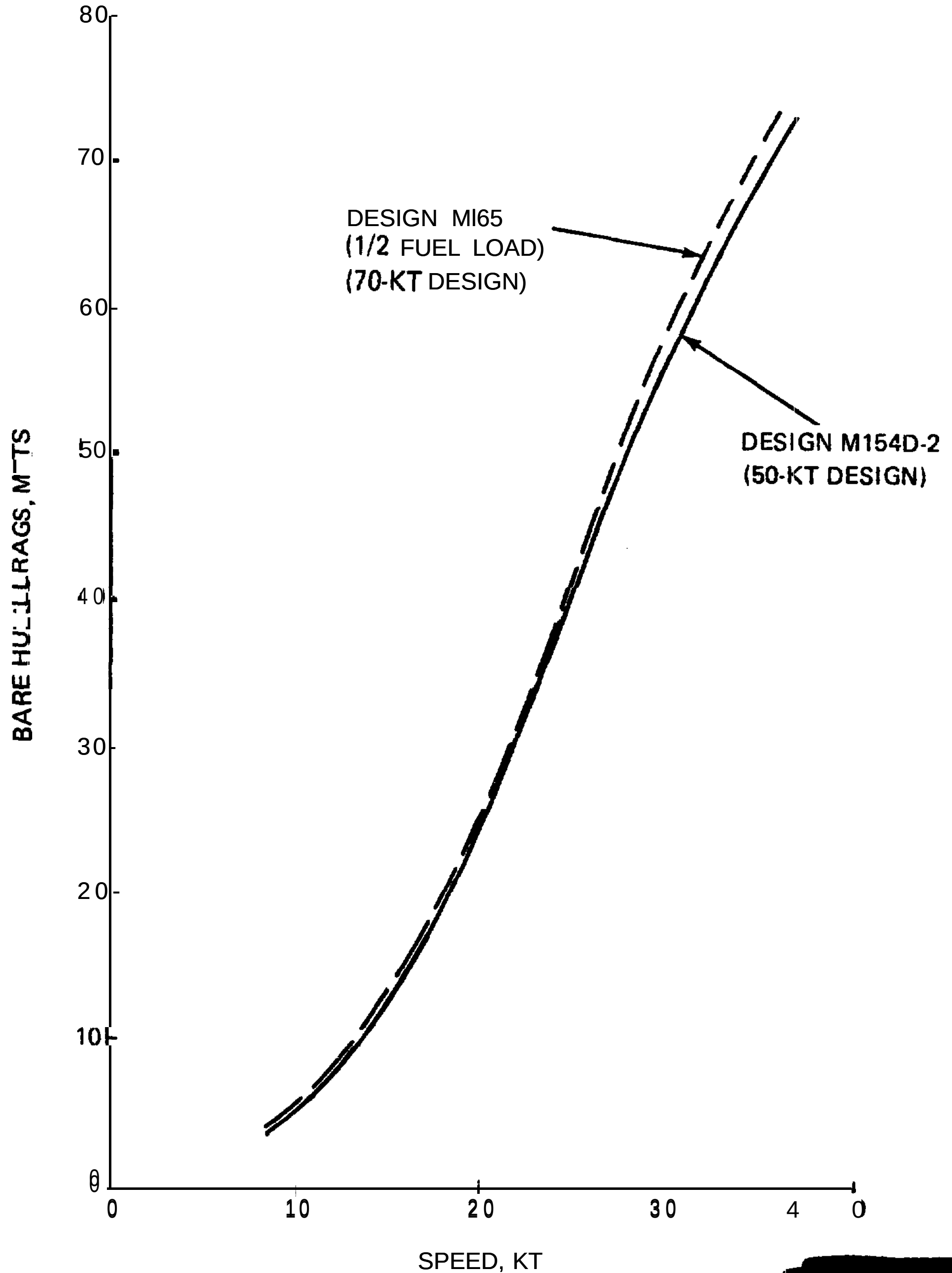


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Fig. 3-1 Bare Hull Drag Comparison (U)

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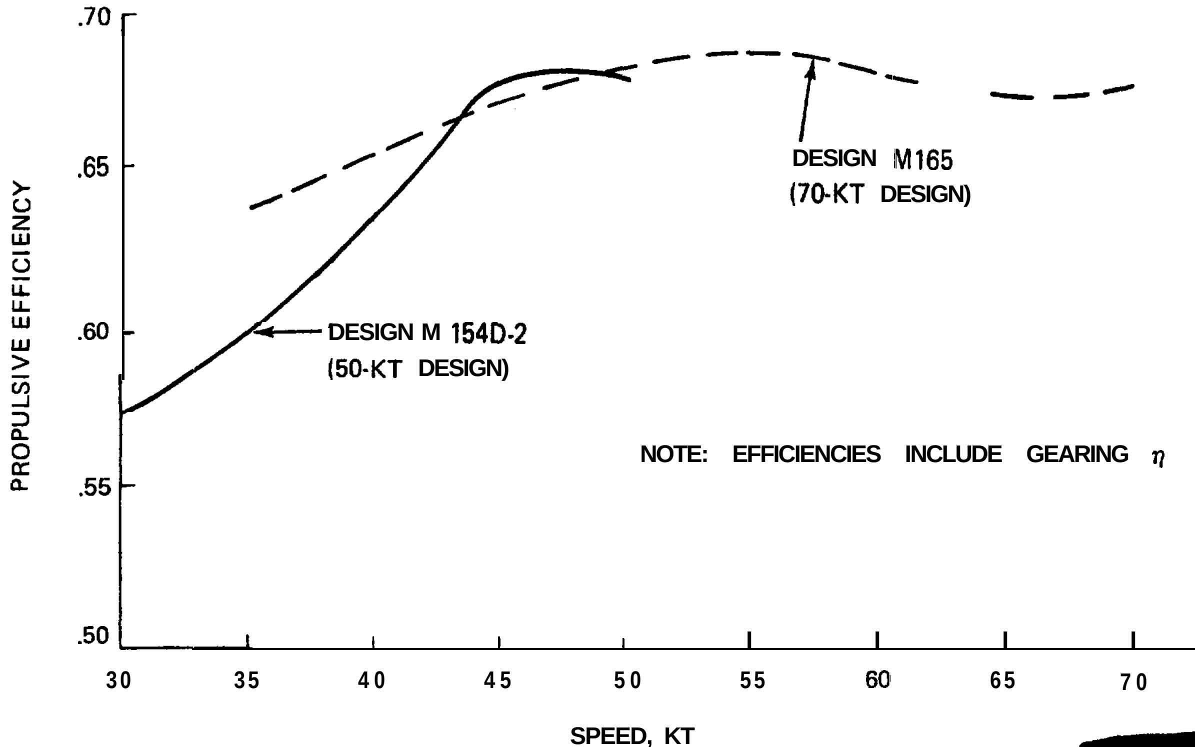

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Fig. 3-2 Propulsive Efficiency Comparison (U)

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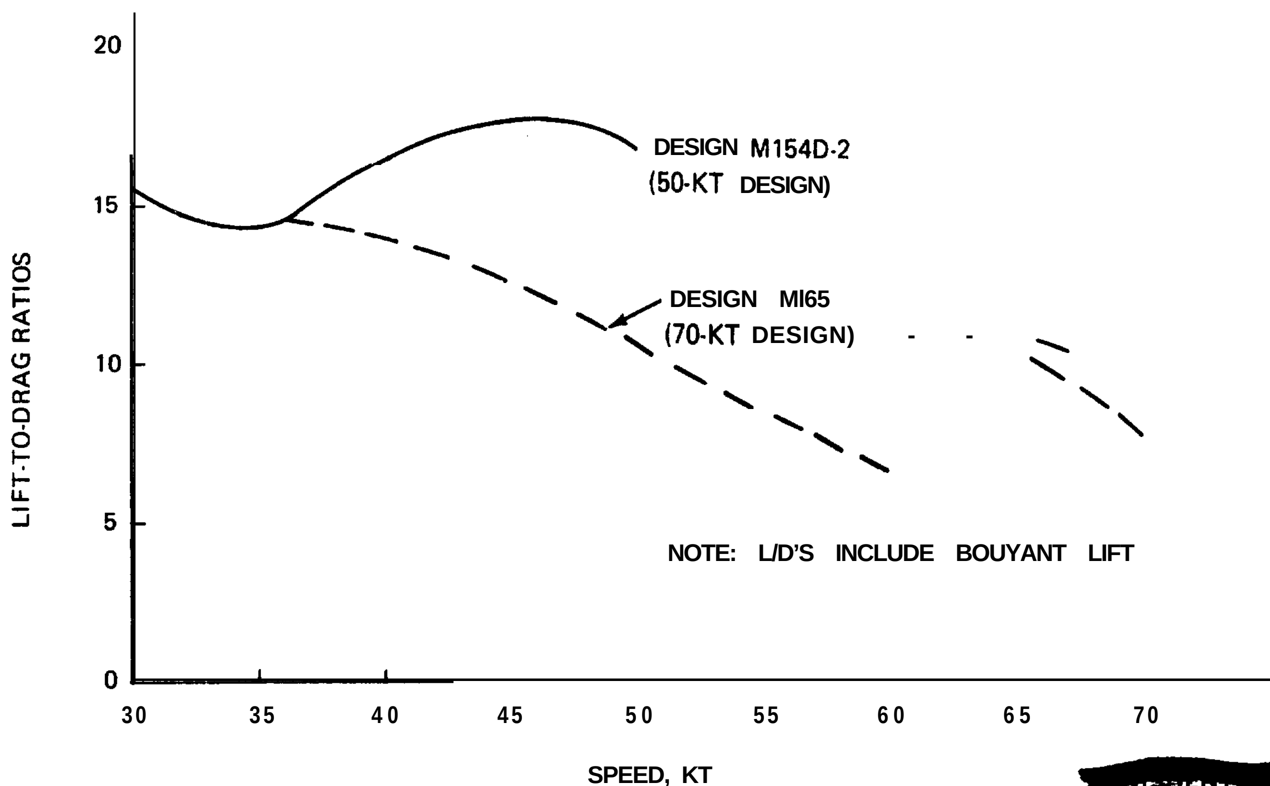

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Fig. 3-3 Lift-to Drag Ratio Comparison (Foilborne) (U)

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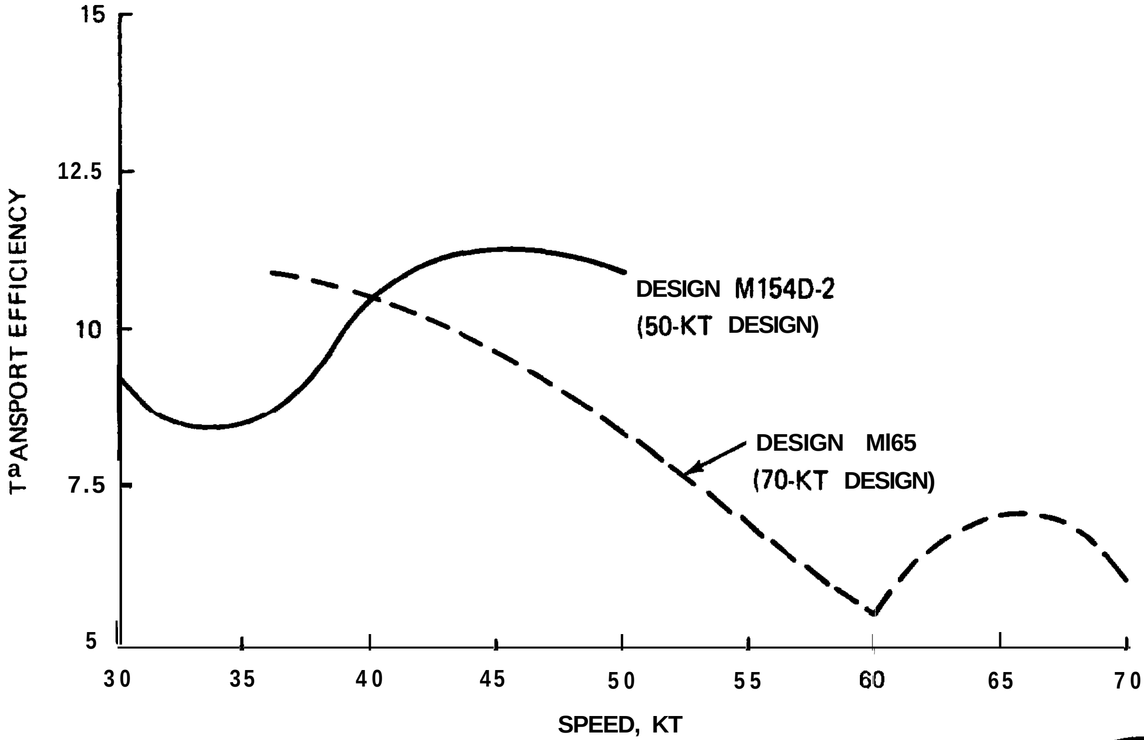

[redacted]

Fig. 3-4 Transport Efficiency Comparison (U)

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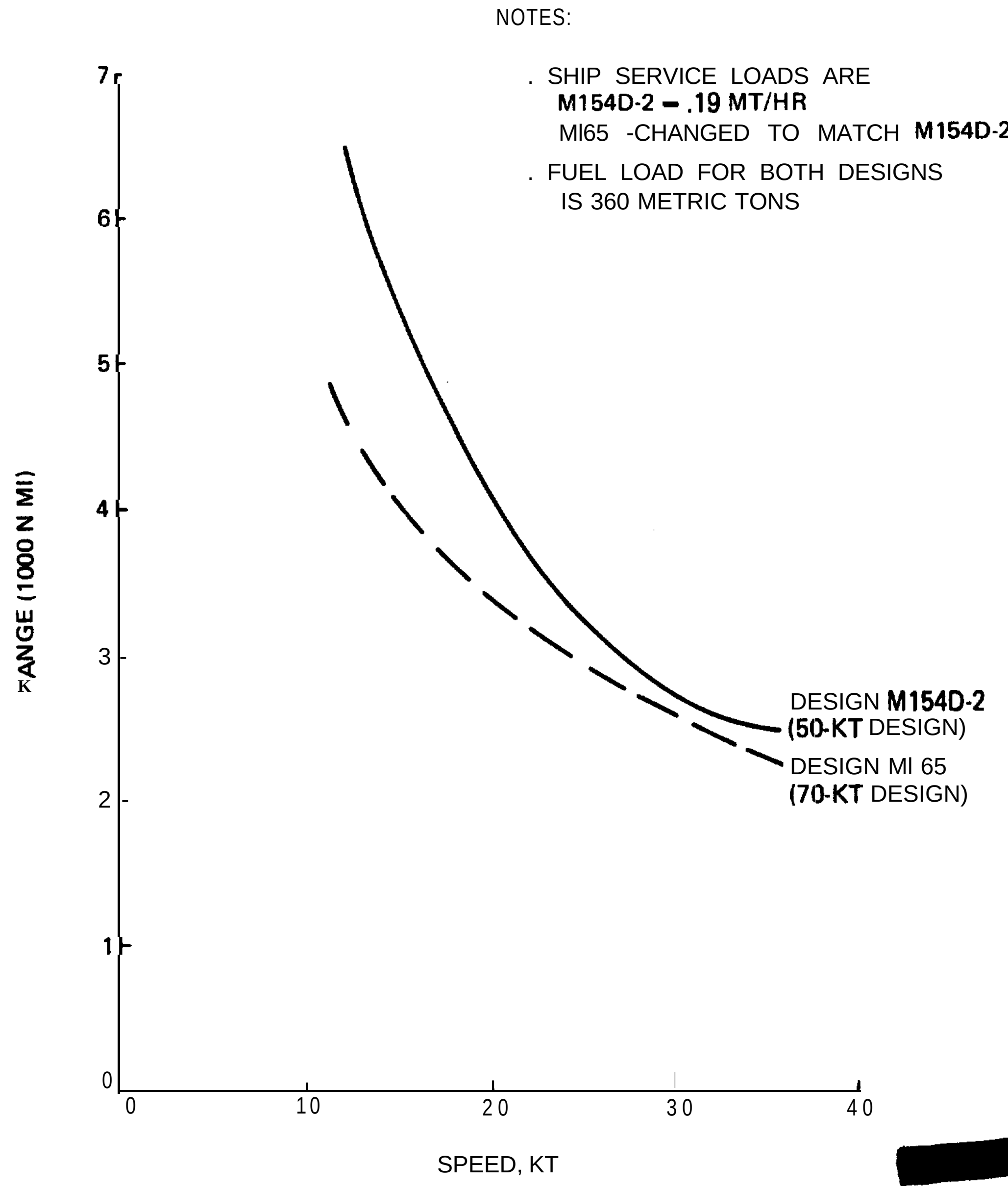

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Fig. 35 Hullborne Range Comparison **(U)**

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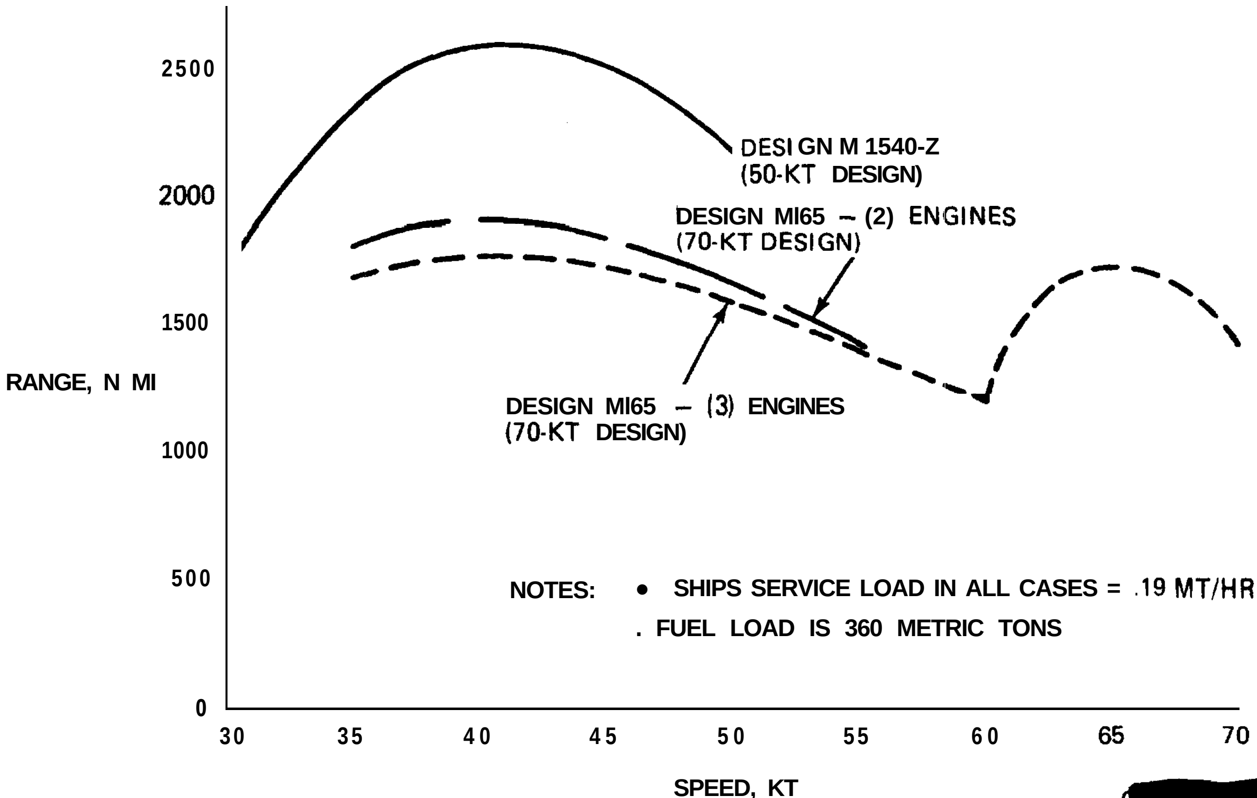

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Fig. 3-6 Foilborne Range Comparison (U)

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Table 3-2 General Characteristics and Performance Comparison (U)

	DESIGN M154D-2 (50-KT DESIGN)	DESIGN MI65 (70-KT DESIGN)
Displacement:	1300 metric tons	1350 metric tons
Cubic Number	2590	2560
Length Overall (Foils Extended)	285.9 ft (87.14 m)	271.5 ft (82.75 m)
Beam (Foils Extended)	60 ft (18.29 m)	77.5 ft (23.62 m)
Military Payload	449.22 metric tons	474.51 metric tons
L/D Ratio (35 kt)	14.4	14.6
L/D Ratio (50 kt)	16.8	10.6
Transport Eff. (35 kt)	8.5	10.9
Transport Eff. (50 kt)	10.9	8.4
Max Hullborne Range	6500 n mi @ 12 kt	4600 n mi @ 12 kt
Max Foilborne Range	2600 n mi @ 41 kt	1900 n mi @ 40 kt
Max Speed Foilborne	50 kt	70 kt
Takeoff Speed	25 kt	35 kt

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Table 3-3 Military Payload Comparison

	WEIGHT, METRIC TONS	
	DESIGN M154D-2 (50-KT DESIGN)	DESIGN MI65 (70-KT DESIGN)
Group 400 - Command and Surviellance Less Navigation System and Internal Communications	29.56	23.21
Group 700 - Armament	27.70	24.30
F20 -Ordnance	47.56	64.30
F14 - Marines	0.00	0.00
F15 - Troops	0.00	0.00
F 16 - Other Personnel	0.00	0.00
F33 - Marines Stores	0.00	0.00
F42 - JP-5	340.00	360.00
F43 - Gasoline	0.00	0.00
F46 - Lubricating Oil	0.00	0.00
F60 - Cargo	4.40	2.70
Total Military Payload	449.22	474.51

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Section 4

TECHNICAL RISK ASSESSMENT

(U) The technical risks involved with designing any large, high speed hydrofoil craft, such as Design M165, can be categorized into two main areas; those associated with the design of a large displacement (-1400 mt) vehicle, and those involved with incorporating a 70 knot burst speed capability into the design. Since the risks associated with designing a large displacement hydrofoil vehicle like Design Ml65 are analogous to those of Grumman Design M163, those risks relating to the displacement of Design Ml65 can be found in the Technical Risk Assessment section of Reference (8). These would include risks involving hull structure, electric plant, auxiliary systems, fire protection, hydraulic system, outfit and furnishings and certain lift system hydrodynamics not unique to a 70 knot design (plunging ventilation, free surface drag, interference drag and take-off drag).

(U) Those risks which are unique to Design Ml65 are associated with the type of strut/foil/pod system and propulsion system employed to incorporate the 70 knot burst speed capability into the design. Although the "mixed-foil" concept has been experimentally justified with model testing, full-scale design is outside the realm of current state-of-the-art techniques in hydrodynamics, loads and control systems.

4.1 PROPULSION

4.1.1 Prime Movers

(U) The prime movers on Design Ml65 are under development for other Navy applications. Current reports are that the Pratt and Whitney FT9 gas turbine is meeting or exceeding predicted performance. Installation of prime movers and ancillary equipment for hydrofoil ships is well understood, with no major departures from previous hydrofoil practice, and hence no unusual risks expected in regard to Design M165.

4.1.2 Propellers

(U) Propulsive efficiencies derived for Design Ml65 are based on the Newton-Rader A3/71 blade series which exhibit some of the highest efficiencies for cavitating blades. Operation of the propeller is at values of the advance ratio (J) not recommended by the propeller developers due to the unknown effects of partial cavitation. The performance quoted for Design. Ml65 is expected to be the highest attainable for an optimized propeller system. Also, since the propeller performance is assumed to be lthat of a variable pitch system, a hub design will have to be developed, and the blade design checked for blade clearances during pitch change.

4.1.3 Transmission

(U) The critical element in the development of the transmission for Design Ml65 is the dual mesh gearboxes shown schematically in Fig. 2-33 and 2-34. Since these gearboxes are outside the current state-of-the-art, there is a significant technical risk in pure technology and in the administrative impact on a potential total ship development program.

(U) The two main aspects of the dual mesh gearboxes which place them beyond the current state-of-the-art are:

- Bevel gearing
- Bearings.

GEARS

Bevel Gears

(U) Table 4-l contains the bevel gear data for the dual mesh scheme shown in Fig. 2-33 for Design M165. The helical gears in these preliminary gearbox designs should not present any problems because the load carrying capacity of the helical gears is well within acceptable limits. The bevel gears, however, do present a problem in the design.

Table 4-1 Bevel Gear Data for Dual-Mesh Scheme

TORQUE = 515,300 IN.-LB PER MESH	SPEED = 4000 rpm
PITCH DIA. = 25.5 IN.	RATIO = 1 :1
PRESSURE ANGLE = 20°	SPIRAL ANGLE = 25°
P.L.V. = 26,700 ft/MIN	DIAMETRICAL PITCH = 1.4118
COMP. STRESS = 175,000 PSI	BENDING STRESS = 33,600 PSI

(C) While compressive stress in these large bevel gears is within acceptable limits, the bending stress of 3,100 psi is beyond the highest bending stress experienced in an operational gearbox (the highest bending stress in an operational gearbox is 30,500 psi in the AGEH transmission).

(C) Another critical parameter is the diametral pitch. The pitch :in these preliminary gearboxes is coarser than any operational gearbox to date. By comparison again, the AGEH has the coarsest diametral pitch in an operational gearbox with a pitch of 2. The coarser the pitch the higher the probability of tooth scoring.

(C) Pitch line velocity of the bevel gears is also high. The H. S. Denison had a pitch line velocity of 20,700 ft/min. The highest pitch line velocity in an operational gearbox to date was 29,300 ft/min as employed on the F. H. E. 400, which was considered to be a highly developmental gearbox.

(U) Since these parameters (bending stress, diametral pitch and pitch line velocity) are above present operational gearbox levels, an extensive development program is required to demonstrate the validity of the design.

(U) At the high speeds and stresses that these gearboxes will be subjected to, cooling and lubrication of the gears becomes critical. There is also a possibility that vibration could excite a resonant mode.

Planetary Gears

(U) A planetary gearbox for the Ml65 hydrofoil is within the state-of-the-art. However, there are some potential problem areas. For sizing purposes, the large ring gear in the planetary gearbox was assumed to be ground, and will possibly be beyond present industrial capability. In addition, a tooth contact area development test will. be needed to ensure that there are no load concentrations on any one tooth or planet.

BEARINGS

(U) As of now, tapered roller bearings have the best chance of success. A critical area in these bearings is lubrication and cooling. Like gears, gas lubrication and cooling of bearings become critical as bearing speeds and loads increase. 'This has been shown in Timken Company tests. Skidding and preload setting are also problem areas and are related to each other. Satisfactory preload setting or settings have to be determined to prevent skidding and overheating in the operating range of these gearbox designs. New developments in the field of tapered roller bearings, notably Timken Company's hydra-rib bearing, have great potential for eliminating this problem. However, there is little data on this bearing in actual service.

4.2 LIFT SYSTEM

(U) The technical risks associated with the Design M165 lift system may be categorized into two groups:

- Those risks involved with the individual components in the system (mixed foil, pseudo-blunt based struts, transcavitating pods)
- 'Those risks involved with incorporating these individual components into a viable configuration for high-speed operation (pi system, tandem configuration, cavitation damage and control systems).

4.2.1 Mixed Foils

(U) The technical risks associated with the foil system are due to the lack of prototype model testing on the configuration, an insufficient understanding of the transition from a fully wetted section to a supercavitating/superventilating section, and the instability of the supercavitated/superventilated mode of operation.

(U) The mixed foil concept changes the subcavitating section into a supercavitating section by increasing the angle of attack to a value necessary to cavitate the upper surface (approximately two degrees of pitch) while simultaneously deploying a lower surface tab to open a cavity on the pressure side of the foil. Once the cavity is formed, atmospheric air is supplied to the cavity via the pseudo-blunt base strut and the cavity is ventilated. Although there seems to be enough experimental data available to justify the upper surface cavitation scheme, there is conflicting experimental data on the use of discontinuities on a surface to generate a cavity.

(U) In 1961, Grumman conducted a series of tests on stepped strut configurations to determine their feasibility in the 80 knot version of the HS Denison (Ref. 1). Tests were run with three different strut configurations consisting of blunt forebodies with streamlined afterhodies of reduced maximum thickness. In every case, the flow reattached quite close to the step and the unwetted areas did not ventilate so that where there were changes in drag as a function of cavitation numbers, the effect was detrimental. It is believed that this reattachment is related to the coanda effect. If indeed the flow does reattach on the lower surface, the increase in wetted area could create enough additional lift to broach the foil system.

(U) Extensive studies of foil cavity pressures performed at the Lockheed Underwater Missile Facility (LUMF) and reported in Ref. 6 indicate that a significant change in lift coefficient will be observed if the pressure inside the cavity fluctuates. Cavity stabilization can be achieved by ventilating the foil cavity, which not only produces a smoother ride in waves, but also enhances the lift to drag ratio of the system. Maintaining this ventilated condition requires a constant supply of air to the cavity. Two of the more common methods in which a foil cavity can be ventilated are (a) from the surface through the cavity wake trailing behind the base-vented strut and (b) by forced ventilation through an internal piping system. Method (b) seems impractical due to the large air flow rate required to maintain the cavity in Design M165. Method (a) is the simplest and most economic way to ventilate the foil cavity, but strut choking on a supercavitating foil with a blunt-based section has been observed in high-speed model tests. Once ventilation is destroyed, the result is an unpredictable lift force on the foil. Trade-off studies between foil cavity stability and overall efficiency are required in order to achieve a practical ventilation scheme for the lift system.

(U) A critical problem in Design Ml65 is obtaining a smooth transition from the wetted and/or supercavitating condition to a ventilated condition without atn abrupt lift force change on the section. Assuming that the ventilation doors, lower surface tabs and incidence system can be scheduled to assure a smooth transition, the control systems necessary to achieve this schedule will be relatively complex compared to those of existing subcavitating hydrofoils. Furthermore, the unsteady loads associated with this transition require further experimentation to determine a system which can generate adequate hydrodynamic forces to control the craft.

(U) Present-day theoretical flutter predictions are inadequate to determine the hydroelastic properties of the Design Ml65 foil/strut system. A combination strut/foil system suitable for operation in cavitating flow was designed in Reference (13). This particular design, which is stable with respect to flutter and divergence at speeds up to 110 knots, was only tested for one anticipated type of flow. Because other types of cavitating flows are expected to occur on the Ml65 strut-foil system which might effect stability with respect to flutter, further experimentation is required to validate the Ml65 design foil system.

4.2.2 Pseudo-blunt Based Struts

(U) Since the pseudo-blunt based struts act like conventional, fully wetted struts at speeds below 50 knots, there are no unique risks due to the struts at these speeds. When the ventilation doors are deployed (speeds above 50 knots), however, there are areas which will require additional theoretical and experimental verification. Information on strut side ventilation, resistance and choking should be investigated simultaneously on the strut/foil system so that a tradeoff study may be made for the optimum strut selection.

(U) Practical experience and experiments have shown that the sudden formation of an aerated cavity attached to the strut is responsible for much of the erratic behavior of hydrofoil craft. Ventilating this cavity drastically changes the flow field around the strut and is accompanied by a drastic change in the loads of the strut. Because the flow about a surface-piercing strut is so complex, a reliable mathematical model is not yet available for predicting the side force characteristics and the inception of ventilation on the struts.

(U) Studies conducted by NASA and Lockheed Underwater Missile Facility (LUMF), however, indicate that with a foil operating at a one-chord submergence, the measured ventilation angles on the pseudo-blunt based strut employed in Design Ml65 can limit the craft control in beam seas and degrade the craft maneuvering characteristics at high speeds.

(U) Strut flutter experiments on models with ventilated cavities have been conducted to determine bending flutter and torsional flutter on flexible hydrofoil struts. These experiments produced a practical high-speed design by specifying a blunt based strut profile and providing for variable foil cavitation. However, the scaling laws called for the model to be tested at a lower speed than used for a prototype. Only partial cavitation on the foil was observed in these experiments. On the other hand, full cavity flow on the upper surface of the foil in Design Ml65 is anticipated on a full-scale foil operating at high speeds. Further experimentation should be undertaken to determine strut/foil hydroelastic stability in the presence of a supercavitating/superventilating foil.

4.2.3 Transcavitating Pods

(U) The design of a high speed pod is one area which has been neglected in the TAP program. In the past, blunt based pods were capable of providing adequate volume for transmission machinery and actuation without producing large drag penalties at low speeds. For Design M165, the base area produced by the machinery requirements on the pods made blunt-based pods impractical for the low speed regions. To circumvent this problem, Grumman designed a transcavitating pod which theoretically acts like a fully wetted pod at low speeds and a blunt-based pod at speeds above 50 kt.

(U) These pods are in their earliest stage of development and will require extensive testing before they can be used. Critical design areas will be the design of a protruberance which will trip the cavity at 50 kt, design of an afterbody which will maintain attached flow below 50 kt, and design of the cowl section characteristics necessary to direct the flow into the duct while maintaining attached flow on its outer surface.

4.2.4 Overall Configuration

(U) There are two major problem areas associated with the overall configuration of Design M165. The first is the problem of cavitation erosion on the struts, pods and foils due to the collapse of cavitation bubbles on these surfaces. With the tractor prop design, the aft pods and localized areas of the struts and foil will be directly in the slip-stream of the propellers. Since Design Ml65 employs supercavitating props, the slip-stream will contain cavitation bubbles which will be collapsing on these surfaces constantly. Experiments with erosion resistant coatings, composites and exotic metals will have to be conducted to determine the most feasible preventive fix for this problem.

(U) The second problem arises from the persistance of the ventilated cavities which form on the forward struts and foil. Experiments indicate that these cavities are maintained to distances up to 200 ft aft of where they originate. This means that the aft foil/strut/pod array is operating in the cavity of the forward foil. If the cavity passes through the tractor prop there is a loss in thrust which causes the vehicle to crash and/or the engines to overspeed resulting in automatic shutdown. Finally, if the cavities shed off the forward struts pass over the rear struts, it will be impossible to control the vehicle.

Section 5

LIST OF SYMBOLS

B	-	Beam
$\overline{CN}$	-	Cubic Number
$C_{D_{MIN}}$	-	Minimum Drag Coefficient
C_L	-	Lift Coefficient
C_{L_α}	-	Lift Curve Slope
$C_{L_{TAB}}$	-	Lift Coefficient of Lower Surface Tab
G.R.	-	Gear Ratio
J	-	Advance Ratio
$\overline{KG}$	-	Height From Keel To Center-Of-Gravity
LBP	-	Length Between Perpendiculars
LCG	-	Longitudinal Center-Of-Gravity
LOA	-	Length Overall
N	-	Number of People
P/D	-	Pitch-To-Diameter Ratio
RPM	-	Revolutions Per Minute
SHP	-	Shaft Horsepower
sfc	-	Specific Fuel Consumption
V_K	-	Speed in Knots
VCB	-	Vertical Center of Buoyancy
VCG	-	Vertical Center of Gravity
σ_c	-	Cavity Cavitation Number
η	-	Propulsion Efficiency
A	-	Displacement
μ	-	Permeability

Section 6

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