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ADVANCED TECHNOLOGY
LIFT AND PROPULSION SYSTEM
PRELIMINARY DESIGN

FINAL REPORT
DECEMBER 1978

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Prepared by

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This report presents the results of a study which examines the technical feasibility of developing an advanced technology lift and propulsion system which could offer significant improvements over the presently demonstrated state-of-the-art operational capabilities of U.S. Navy hydrofoil ships in the 250 ton class. The lift system of the design consists of two foil/strut/pod arrays., A "tee" foil forward carries approximately 35 percent of the craft weight and a "pi" system aft carries approximately 65 percent of the

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craft weight. The propulsion system consists of two Allison 570 KA gas turbine engines, each driving a KaMeWa-type four-bladed, controllable pitch, supercavitating propeller by means of a right angle Z-type mechanical transmission system.

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PREFACE

(C) The Preliminary Design Study completed with this final report has validated the technical feasibility of developing an Advanced Technology Lift and Propulsion System. This development, if implemented, could offer significant improvements over the presently demonstrated state-of-the-art operational capabilities of U. S. Navy hydrofoil ships in the 250-metric ton class. These improvements, if expressed in propulsive power per full load displacement ton, show a reduction in requirements from the present state-of-the-art value of 54 HP/MT at takeoff conditions to 48; with a similar reduction from 62 HP/MT to 35 at 48 knots. This level of improvement leads to markedly reduced fuel requirements, thereby improving range and/or military payload capabilities of a given hydrofoil platform.

(U) The Advanced Technology Lift and Propulsion System represents a combination of developments in hydrofoil-unique systems not previously available, and thus, in total, can be considered to be at the forefront of practical and demonstrable hydrofoil technology. The foil sizing analysis described in subsection 2.4, and further in Reference ‘1, represents a procedure which optimally matches available thrust at takeoff and cruise conditions, to produce the most efficient foil system design. Production models of the foilborne prime movers are now available. These turbines are matched to a hydrofoil transmission currently under development. The propulsion elements of the system are completed with controllable pitch propellers matched to the entire system, with the knowledge and experience gained after over 15 years of hardware use on PGH-1, AGEH-1, and HS Denison.

(U) Schedules contained in Section 7 for further recommended development of the Advanced Technology Lift and Propulsion System show that delivery of low-risk hardware ready for at-sea evaluation could be achieved by the end of calendar year 1982. Implementation of these or similar schedules implies a significant departure from previous hydrofoil developments in that the hydrofoil unique systems, namely, the lift and propulsion system (and associated control systems), could be developed and evaluated independently of basic platform and combat systems. Thus, by late calendar year ‘1983, proof-tested

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hydrofoil unique systems would be available for future platform development considerations, allowing maximum focus on traditional shipboard and combat system engineering.

(U) At-sea evaluation of the Advanced Technology Lift and Propulsion System requires the availability of a test platform. The availability of this platform is not required prior to the beginning of fiscal year 1982. One ship of the existing PHM class would be required for this purpose. Vehicle description and performance will be presented for the total ship in the intended test configurations as one possible representative configuration of a total future vehicle design.

(U) Support and encouragement from many individuals during the conduct of this reported preliminary design is greatly appreciated. Special acknowledgement and appreciation is extended to Mr. D. Cieslowski, Dr. D. 'Moran, and Mr. W. O'Neill of the David W. Taylor Naval Ship R & D Center, and Mr. E. Jones of the Defense Research Establishment Atlantic for supplying the abundant, and in total, comprehensive foil section and cavitation data which made the basic foil section selection possible.

ADMINISTRATION

This report describes the results of a Preliminary Design Study of an Advanced Hydrofoil Lift and Propulsion System for hydrofoil ships in the 250-metric ton class, conducted by Grumman Aerospace Corporation for the Naval Ship Engineering Center.

The study resulted from an unsolicited proposal submitted by Grumman to the Naval Sea Systems Command, Advanced Technology Systems Division, NAVSEA 032, in January 1978. Actual activities were conducted under NAVSEC Contract N00024-77-C-4251, and were authorized by task assignments 6110-1352 (dated 14 April 1978), and 6110-1402 (dated 13, July 1978). Technical Point of Contact (TPOC) at NAVSEC for both assignments was Mr. Mark R. Bebar, Code 6114P4.

This final report represents completion of both tasks and has been issued as a combined report dated December 1978. At completion, the study represents a level of investigation of approximately 3750 direct total people-hours, including engineering and administration requirements. This activity was supplemented by corporate resources of approximately 400 hours in review and analysis of fundamental hydrofoil section data received from various U. S. Navy and Canadian sources during the course of the study.

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ILLUSTRATIONS

SECTION 1

INTRODUCTION

1 - INTRODUCTION

Within the last year, hydrofoil development in the United States entered into a new era of significant importance; both major industrial suppliers of hydrofoil technology to the U. S. Navy initiated, for the first time, serial ship production programs. In October 1977, the Boeing Company was awarded a production contract by the U. S. Navy for five Patrol Hydrofoil Missile (PHM) ships to be delivered over the next four years; in December of 1977, the Grumman Aerospace Corporation initiated the production of two lead hydrofoil ships, derivatives of the corporate-developed MARK II design. The two lead ships, contracted for by a foreign ally, are to be delivered within 27 months. Both awards, to Boeing and Grumman, are for hydrofoil ship designs based upon proven prototypes presently in operation.

The objective of the proposal, No. 77-131N (U), entitled "Development of a Hydrofoil Advanced Technology Lift and Propulsion System", dated January 1978, was to offer to the U. S. Navy a plan to blend hardware elements of both these current programs into an advanced development program offering significant operational enhancement for hydrofoil ships in the 250-metric ton class. The proposed approach, based upon proven technology, is considered to be a feasible, low risk, minimum cost program.

The design reported on herein can be considered as two parts:

- Advanced Technology Lift and Propulsion System Development
- Modification to the PHM class hull structure to demonstrate at sea the above-mentioned lift and propulsion system.

The lift system of the design consists of two foil/strut/pod arrays. A "tee" foil forward carries approximately 35 percent of the craft weight, and a "pi" system aft carries 65 percent of the craft weight. The forward system is similar to the present PHM/PCH forward foil, with minimum risk associated with its design. The aft "pi" foil arrangement is within state-of-the art design practice, but a comprehensive hydrodynamic test program has been formulated to validate its performance.

(U) The propulsion system consists of two Allison 570 KA gas turbine engines, each driving a KaMeWa-type four-bladed, controllable pitch, supercavitating propeller by means of a right angle Z-type mechanical transmission system. The proposed transmission is based upon technology developed for the FLAGSTAFF MARK II hydrofoil program.

(U) The modifications to the PHM-3 hull structure for the design may be categorized into two basic groups; new construction necessary for the incorporation of the propulsion system and additional fuel tanks, and modifications to the existing structure for the incorporation of the entire Advanced Technology Lift and Propulsion System.

(C) The most significant advantage offered to the U. S. Navy 'by this design is a marked improvement in foilborne and hullborne range for hydrofoil ships in the 250-metric ton class. Figure l-l presents the military payload capability of the design versus range. Figure l-l also contains the demonstrated range and military payload of the PHM-1 (680 n mi with a military payload of 31.49 metric tons) and the required values for the PHM-3 (750 n mi with a military payload of 32.19 metric tons).

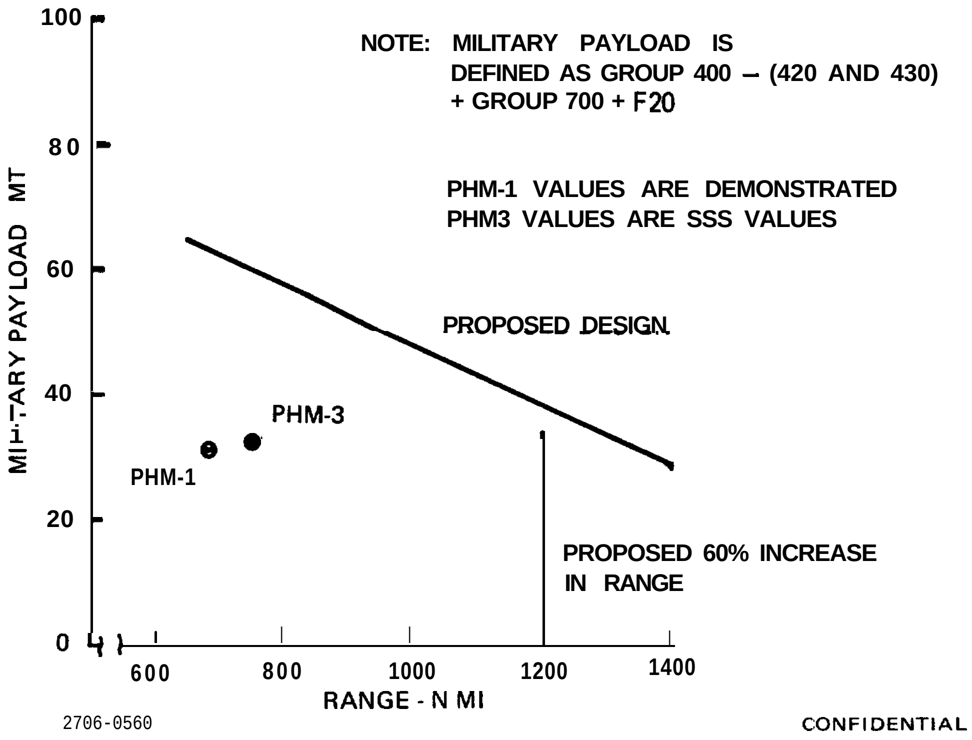

Fig. l-l Military Payload vs Range (U)

(C) To demonstrate foilborne range capabilities of 1200 n mi, this design requires an additional usable fuel load of approximately 11.0 metric tons above the existing PHM of 47.2 metric tons.

(C) At the full load usable fuel weight, the design has the capability of carrying 38.0 metric tons of military payload, a 6.5 metric ton increase over the PHM-1 demonstrated value. If the range requirement of the design is 750 n mi (SSS value of PHM-3) the military payload, assuming sufficient hull volume and/or deck area were identified, could be 60 metric tons (an 86 percent increase in the military payload of PHM-3).

(U) The second most significant advantage, while difficult to quantitatively define pending design development and hardware evaluation, is the potential for reduced maintenance and increased availability of the total hydrofoil ship.

(U) The propulsion system requires considerably less volumetric space than that occupied by a comparable waterjet system such as is specified for the PHM-3 series. The elimination of all propulsor components aft of Bulkhead 30 provides adequate space for the installation of the necessary lube oil components, while still improving the accessibility to the hullborne diesel engine and other machinery in the compartment. Similarly, lowering the Ship Service Power Unit No. 2 to the Platform level will greatly enhance its accessibility for maintenance.

(U) The reduction in maintenance time, due to the improved accessibility of machinery components, should tend to increase the availability of the total ship. This availability should be further enhanced by the inclusion of the low risk transmission components and by the use of crack-resistant HY 100 steel for the struts and foils. The fact that both the basic strut and foil material and the coatings proposed for it are field repairable, should also contribute to the in-service craft availability.

SECTION 2

VEHICLE GENERAL DESCRIPTION

2- GENERAL DESCRIPTION

2.1 GENERAL DESCRIPTION

The design as presented herein is for an open ocean naval combatant hydrofoil ship. The hull is of conventional shape with a retractable foil system of the fully submerged type in a canard arrangement. The forward foil system is an inverted "tee" configuration with a flap lift control system. The foil is rigidly attached to a steerable strut. The strut is pivoted about a kingpost attached to its upper end, supported by bearings in a yoke fitting which, in turn, is supported by bearings in a lateral axis about which the foil system rotates for retraction upward and forward. The aft foil system consists of a continuously tapered "pi" foil, rigidly connected to the two aft struts. The upper ends of the struts terminate in lateral shafts which transfer the foil system lift loads into the hull, and provide the axis for retraction of the unit upward and aft. Downlock and lateral load provisions are provided by additional fittings on the struts just above the hullborne waterline. Foilborne control of the ship is achieved by trailing-edge flaps on both foils and the steerable forward system, all operated by servo-controlled hydraulic actuators. Other actuators perform retraction and locking functions,

Foilborne propulsion is provided by two controllable pitch propellers, each independently driven by a Detroit Diesel Allison 570 KA gas turbine engine and mechanical transmission. Hullborne propulsion utilizes the existing PHM-3 MTU 8V331TC81 diesel engines, driving waterjet pumps. Hullborne propulsion water enters the pumps through inlets flush with the bottom of the hull.

Hull structure, both existing and modified, consists of a longitudinally stiffened shell supported by transverse bulkheads and frames, all welded of 5000 Series aluminum alloys. The Deckhouse is of 6000 Series aluminum alloy sheet-and-stringer riveted structure mechanically attached to aluminum frames of 5000 Series aluminum alloy, which are welded into the framing 'of the Main Deck.

Foil system basic structure is of HY 100 low carbon alloy steel. The primary structure and some secondary structure are welded, with some mechanically-fastened secondary structure in areas where access or part interchangeability are factors.

2.2 PRINCIPAL CHARACTERISTICS

Ship Geometry

The general arrangements and key dimensions of the design are shown in Figures 2-1, 2-2, and 2-3. Figure 2-l depicts the Foil System Arrangement, Figure 2-2 the Inboard Profile, and Figure 2-3, the Deck Plans of the craft. Selected principal characteristics are as follows :

Length overall (foils retracted)	44.70 m
Length overall (hull)	39.304 m
Length between perpendiculars	36.00 m
Breadth extreme (over foils)	14.51 m
Breadth extreme (hull)	8.40 m
Depth, molded, amidships	4.16 m
Draft, mid-keel to DWL at max section	1.833 m
Light Ship Displacement	183.2 MT
Full Load Displacement	266.13 MT (with 64.27 MT fuel).

2.3 GENERAL ARRANGEMENTS

The general arrangement of the design remains identical to that of the PHM-3 series throughout those compartments forward of Frame 21. Aft of Frame 21, in the machinery spaces, changes to the arrangements have been kept to a minimum, consistent with the requirements of the proposed propulsion and transmission system.

Arrangement Revisions (Excluding Machinery)

Other than the changes to machinery spaces noted in the following paragraphs, arrangement modifications are minimal. Due to the installation of the transmission gearboxes in Bulkhead 30, it becomes necessary to revise the access between Auxiliary Machinery Room No. 2 and the Diesel Engine Room by eliminating the two watertight doors currently installed in tbe PHM-3 series and substituting a smaller door on the centerline of the craft. Also, to avoid interference with the propulsion shafting, the emergency escapes and vertical ladders for Auxiliary Machinery Room No. 2 are to be relocated as shown in Figure 2-3.

Bolted plates are also incorporated into the Main Deck and 01 Level as required to facilitate machinery removal and maintenance.

As one of the predicted advantages of the Advanced Technology Lift and Propulsion System is the potential for increased range, a study of the craft compartmentation was made to ascertain those areas which would be best suited for carrying additional fuel. To retain a lift distribution of approximately 35-65 percent on the foil system, it is imperative that the additional fuel be carried in the aft portion of the craft. Because of this, the number of available compartments becomes limited.

That area occupied by the foilborne propulsor on the centerline of the PHM-3 series between Frames 28 and 33 lends itself ideally to the installation of new fuel tanks inasmuch as (based upon a review of the PHM-1 drawings) there are neither major components nor a significant amount of ship system piping located between the side keelsons.

Additional tankage can also be incorporated into the fuel systems by conversion of the outboard bilge areas between Frames 21 and 25 into fuel tanks. While these areas on the PHM-1 appear to contain a small amount of ship's system components and piping, relocation of these items does not appear to present any difficulty in accomplishing the proposed modifications.

The capacity of usable fuel in the proposed additional tankage as defined in Figures 2-3 and 2-4 would be:

Frame 21-25 Port	3.99 Metric tons
Frame 21-25 Starboard	3.99 Metric tons
Frame 28-30 Centerline	4.65 Metric tons
Frame 30-33 Centerline	4.44 Metric tons
	TOTAL 17.0'7 Metric tons

Machinery Space Arrangement Changes

Figures 2-5 and 2-6 present the proposed and an alternate arrangement of the machinery spaces. The proposed arrangement, Figure 2-5, has been selected as the basis for the development of the modified General Arrangement drawings, Figures 2-2 and 2-3, and Structural Modifications, Figure 2-4, inasmuch as it is felt that turbine removal would be less complicated than would be possible with the Alternate Arrangement, Figure 2-6.

The principal advantage accrued thru the implementation of the Alternate Arrangement would be the fact that there would be less encroachment into the clear area of the Main Deck made available by the elimination of the LM 2500 exhaust stack.

To accommodate the air inlet and exhaust requirements of the Allison 570 KA gas turbine, which are in reversed positions from those of the General Electric LM 2500, it becomes necessary to extend the aft end of the Deckhouse.

With the removal of the LM 2500 gas turbine and the associated waterjet propulsion components, ample space is made available for the installation of the Advanced Technology Propulsion System.

The two Allison 570 KA gas turbines are shown installed within a fore-shortened Main Engine Compartment. However, to retain the longitudinal bulkheads in their current locations, it will be necessary to modify the Allison-recommended air inlet and exhaust configurations. It is not anticipated that this will present a design or operational problem, inasmuch as in discussions held with Allison, it was emphasized that performance would not be significantly degraded by dimensional modification, provided the required cross-sectional areas were maintained. With the engine compartment volume available, this poses no problem in the design.

To minimize the possible detrimental effects of vibration on the engine output shaft bearings, the hull-mounted gearbox is to be located as close as practical to the aft air inlet bulkhead while still providing serviceability for the gearbox-mounted auxiliaries.

The inboard right angle bevel gearboxes (shoulder boxes) are mounted in recesses in watertight Bulkhead 30. The output shafts from these boxes run transversely through the aft strut trunnion mounts on the strut retraction axis to the upper bevel gearboxes mounted on top of the struts.

The water separator/demister units for each engine are of the integral three-stage type, modified from those currently installed on the DD-963 class destroyers and similar to those specified for Grumman Design M-161. On these units, the second stage filters are readily removeable for maintenance or replacement. Also, all drains are integral with the unit and discharge directly onto the Main Deck, thereby requiring no internal ship piping.

A blow-in door is provided in the aft bulkhead of each plenum to provide adequate combustion air in the event of clogged filters. The blow-in door would also provide access to the plenums for inspection and maintenance. Additional descriptions of the blow-in doors are included in subsection 3.5.

Cooling air for the main gas turbine engines will be supplied by axial flow fans as specified in, subsection 3.5. This air will exhaust thru the main engine stacks, in the process cooling the turbine exhaust, thereby reducing the craft's IR signature.

While not directly concerned with the Advanced Technology Propulsion System, the two ship service power units (SSPU), along with their associated equipment, would be relocated due to the modifications required to be made for the installation of the Allison 570 KA gas turbine engines. SSPU No. 1, formerly located within the Deckhouse on the Main Deck, has been relocated to the forward end of the engine compartment on the platform. The SSPU will be separated from the main propulsion turbines by a new bulkhead. This relocation is necessitated by the space required for the turbine exhaust stacks in the former Auxiliary Machinery Room No. 1.

SSPU No. 2, situated in Auxiliary Machinery Room No. 3, is to be relocated as a deck-mounted unit, in lieu of being suspended from the overhead, to make the unit more accessible for servicing and also to lower the craft's vertical center of gravity.

Combustion air supply, generator cooling air,and turbine exhausts for both SSPUs will remain basically the same, rerouted or extended as required.

The ship's service switchboard, presently located in Auxiliary Machinery Room No. 1, will, for the same reason, be moved forward to the space formerly occupied by the LM 2500 air intake plenum.

The area made available by the removal of the waterjet propulsor in the diesel engine room becomes suited for the installation of the transmission lube oil storage tanks and other components of the transmission lube oil system, which would be mounted on the extended tank top (see subsection 3.5).

Main Engine Removal

The proposed arrangement permits the main engine to be removed with a minimum of disturbance to other components. After removal of the hull-mounted gearbox and shafting, the aft plenum bulkhead is to be removed. With the exhaust collector removed, the engine is moved aft, after which it may be raised through the main and upper deck bolted plate hatches.

2.4 FOIL SIZING AND CAVITATION CHARACTERISTICS

Foil Sizing Analvsis

Grumman has developed a procedure whereby the drag polar for any given hydrofoil vehicle can be expressed as a function of the total foil area and total dynamic lift. The drag polar presents the hydrodynamic characteristics of the craft and with the specification of a foil area, the cruise general drag polar characterizes the craft/propulsion system for the hydrofoil. The procedure for deriving the drag polar for any vehicle is presented in Reference 1.

The generalized hydrofoil craft drag is a sum of component drag coefficients. This sum produces three general coefficients for a drag polar which is quadratic in the lift coefficient. These three coefficients appear in the definition for particular performance characteristics in various combinations amenable to the deductive identification and evaluation of particular optimums by classic mathematical techniques.

The normal procedure for sizing the foils is based on the philosophy that the optimum hydrofoil design is one which utilizes all of the available thrust at the takeoff and design speed conditions by sizing the foils to produce the maximum lift-to-drag ratio at design speed. For a given propulsion system, this technique also maximizes the dynamic lift of the hydrofoil. This process is identified as the two-point power limited design in the Generalized Performance Analysis.

The two-point power limited procedure is outlined in detail in References 2 and 3, and will not be discussed in this report. The precise mathematical proof that the two-point power limited procedure maximizes range has not yet been fully developed, but a specific example can be employed1 to demonstrate the effect of the two-point power limited solution on range.

Figure 2-7 presents the power limited dynamic lift of a hydrofoil in the 1000-metric ton displacement range. The two curves represent the takeoff speed (25 knots) power limited and the design speed (50 knots) power limited solutions. The intersection of these two curves is the two-point power limited solution. If we want to investigate any other foil area, it is necessary to follow the most restrictive curve, i.e. , for areas less than the two-point power limited solution, the design is takeoff limited and for areas above the two-point power limited solution the design is design speed limited (this envelope is shaded in the figure). The question which must be answered is: "Is there any combination of dynamic lift and total foil area other than the two-point power limited solution which will maximize the range of the vehicle?"

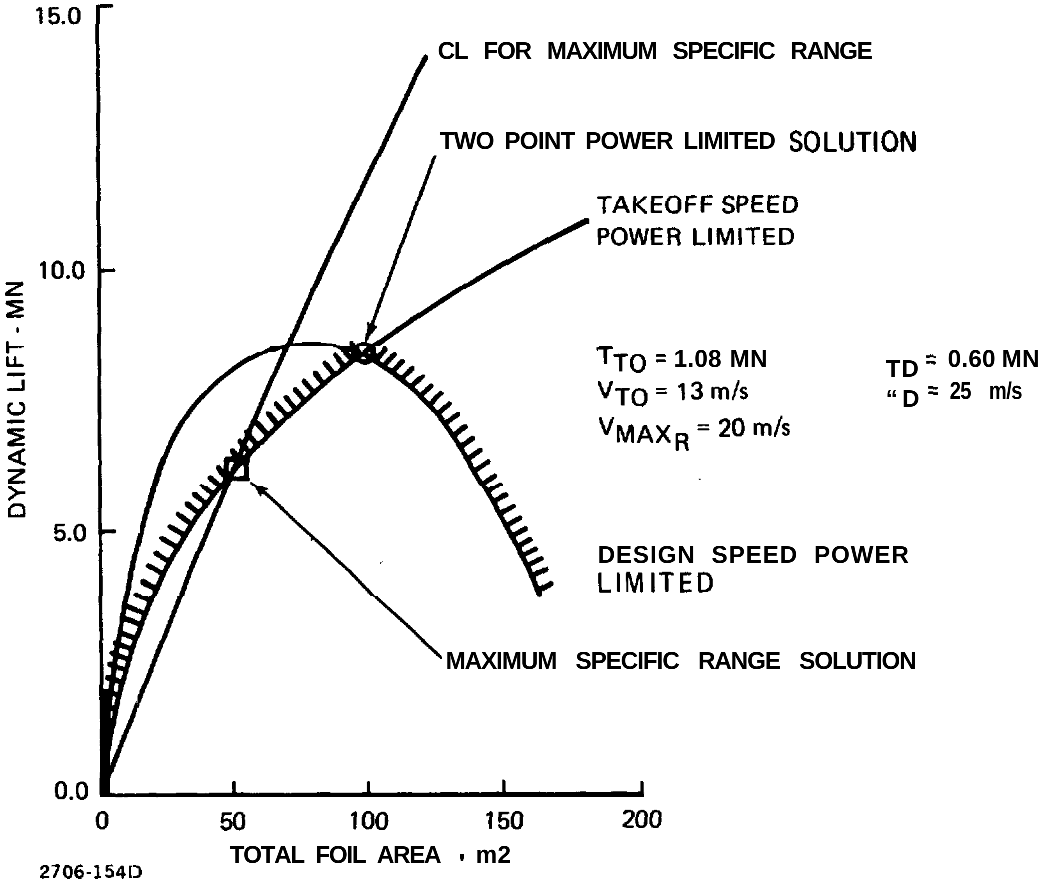

Fig. 2-7 Dynamic Lift vs Foil Area - Two Point Solution (U)

By varying the foil area from 0 to 170 m^2, while tracking the dynamic lift along the shaded line in Figure 2-7, it is possible to evaluate the specific range and range for each dynamic lift and foil area combination. These range calculations are presented in Figures 2-8 and 2-9, and the equations employed in their derivation are:

$$C_{L_D} = L/qS$$

$$C_{L_{MAX_R}} = -\frac{1}{10}\left\{\frac{C_1}{C_2}\right\}\left[1+\sqrt{1+60\,\frac{C_0\,C_2}{C_1^{\,2}}}\right]$$

$$C_{D_{MAX_R}} = C_0 + C_1\,C_{L_{MAX_R}} + C_2\,C_{L_{MAX_R}}^{\,2}$$

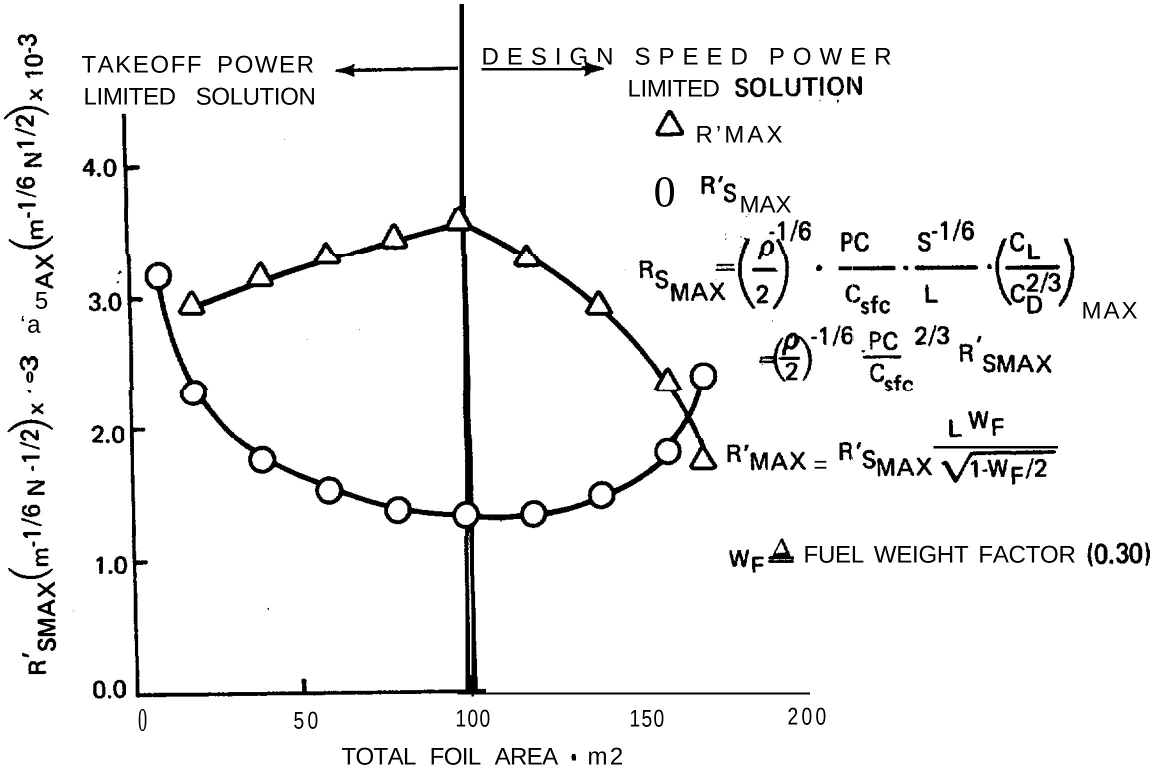

Fig. 2-8 Effect of Foil Area on Specific Range and Range (U)

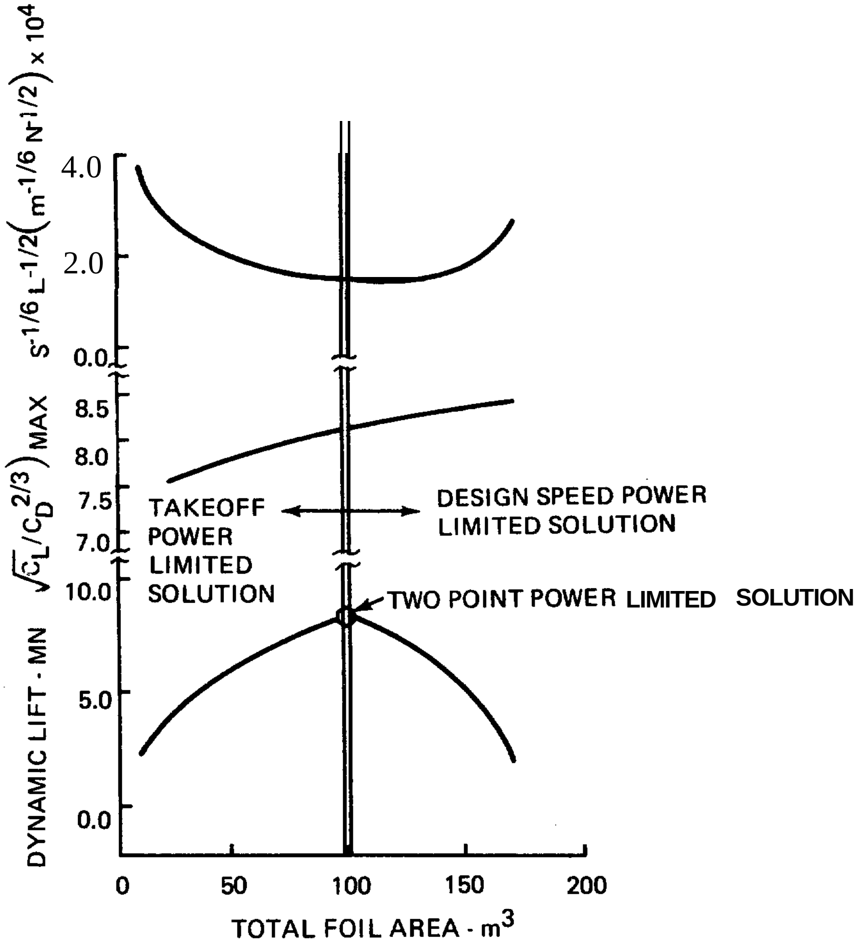

Fig. 2-9 Effect of Foil Area on Dynamic Lift and $\sqrt{C_L}/C_D^{2/3}$ (U)

and the drag polar coefficients which are characteristic of a 1000-metric ton hydrofoil design are:

$$C_0 = 5.47 \times 10^{2} + \frac{5.593 \times 10^{-2}}{\sqrt{S}} - \frac{0.12512}{S} + 0.005\, C_{\ell_i}^{2}$$

$$C_1 = -0.01\, c_{\ell_i}$$

$$C_2 = 0.0831 \text{ for } V_{MAX_R} = 20 \text{ m/s}$$

and

$$R'_{S_{MAX}} = \frac{1}{S^{1/6}\sqrt{L}} \left. \frac{\sqrt{C_L}}{C_D^{2/3}} \right)_{MAX},$$

$$R'_{MAX} = R'_{S_{MAX}}\, L\, \frac{W_F}{\sqrt{1 - W_{F/2}}}$$

W_F = FUEL WEIGHT FACTOR

$= \frac{\text{FUEL WEIGHT}}{\text{DYNAMIC LIFT}} = 0.30$

As one tracks the takeoff power-limited solution the specific range indicator ($R_{S_{max}}$) is decreasing as the area is increased. The range indicator (R_{max}) is increasing due to the increase in dynamic lift, which. reflects an increase in total available fuel for a fixed fuel weight factor. This increase in range indicator occurs up to the two-point power limited solution. In the two-point power limited solution the dynamic lift has been maximized (see Figure 2-9) and an increase in the area above this solution results in a decrease in the dynamic lift. Although the specific range indicator is increasing, the decrease in total dynamic lift (i. e., less available fuel for the same payload) reflects a decrease in the range indicator.

Similar analyses were performed on a 2000-metric ton and a loo-metric ton displacement hydrofoil with the same general results. The conclusion is that the two-point power limited solution maximizes the dynamic lift but in doing so it reduces the specific range. The product of the specific range (which reflects foil efficiency) and the fuel weight term (which is reflected by the dynamic lift) generally produces the maximum range at the two-point power limited solution.

Two-Point Power Limited Design Procedure

For any given hull and propulsion system on a hydrofoil ship, there is an infinite number of foil area and dynamic lift combinations which will produce an infinite set. of conditions at the takeoff and cruise speeds. ‘For any given set of takeoff and cruise speed conditions (i. e., thrust available a.t takeoff and cruise speed, takeoff speed and design speed) there is only one combination of foil area and dynamic lift which will satisfy the drag equation and fully utilize the specified cruise and takeoff thrusts of the propulsion system.

The starting point of the two-point power limited design process is the determination of the craft drag polar. The hydrofoil craft drag polar is considered to be a quadratic in the lift coefficient (C_L):

$$C_D = C_0 + C_1 C_L + C_2 C_L^2$$

and is the summation of five individual drag coefficients:

1. Parasite drag
2. Separation drag

3. Induced drag
4. Surface drag
5. Wave drag

Each of these drag components can be expressed as a function of foil geometry, except for the parasite drag, which has a strong dependency on vehicle size and propulsion system.

The parasite drag coefficient is the most complex terrn of the craft drag polar coefficient equation when that equation is expressed in general form. It is the sum of many components of distinct reference areas where those distinct reference areas do not necessarily have a fixed relationship to the variable total foil area, which is the reference for the total parasite drag coefficient. The parasite drag coefficient must contain the effect of foil planform, submergence and speed, and must do so in an analytic form which promotes the definition of optimization.

The derivation of the parasite drag coefficient is not presented here but is summarized in Figures 2-10, 2-11 and 2-12. Figure 2-1.0 contains the friction drag coefficients (based on the Schoenherr coefficient) of the individual foil/strut/pod components and the profile drag coefficients for the individual components forward and aft. Figure 2-11 presents the profile drag coefficients normalized to the total foil area, and Figure 2-12 reveals more clearly the structure of the generalized parasite drag coefficient as a quadratic in $1/\sqrt{S}$ having coefficients which are a function of the foil submergence.

The incremental foil profile drag or separation drag is significant in hydrofoil design due to cavitation considerations and foil section selection. The separation drag source is not readily defined but the separation drag coefficient is inherently of polar drag form:

$$C_{D_{SEP}} = K_{sep} \left\{ C_L - C_{\ell_i} \right\}^2$$

where K_{sep} and C_{ℓ_i} are foil section characteristics.

The classical aerodynamic value of the induced drag coefficient is employed and appears in the drag polar as:

$$C_{D_i} = \frac{1+\delta}{\pi A} C_L^2$$

where the circulation distribution factor (δ) is a function of aspect ratio and taper ratio.

The exact form of the surface image drag is still a matter of academic debate, but past design experience indicates that Wadlins' formulation is a good approximation. The surface image drag coefficient takes the form:

$$C_{D_{SURF}} = \frac{K_1 C}{8\pi} \frac{1}{\mathrm{COS}\Lambda} C_L^2$$

where

$$\frac{K_1 C}{8\pi} = \overline{2\pi\left\{16\left({}^{h}/_{c}\right)^2 + A^2\right\}} \left[\sqrt{16\left({}^{h}/_{c}\right)^2 + A^2 + 1} + 1\right]$$

The hydrofoil wave drag is assumed to be proportional to the two-dimensional wave drag where the constant or proportionality is a function of depth (in spans) and aspect ratio, and takes the form:

$$C_{D_W} = \frac{K_b - 1}{{}^{h}/_{c}} \cdot \frac{e^{-2/F_h^2}}{2 F_h^2} \cdot C_L^2$$

where

$$F_h \triangleq \frac{V}{\sqrt{gh}}$$

For conservatism, the three-dimensional correction term $(K_b - 1)$ is assumed to have a value of 1.0.

COMPONENT	FRICTION DRAG COEFFICIENT		PROFILE DRAG COEFFICIENT	
	FORWARD	AFT	FORWARD	AFT
FOILS	$2.36698 \times 10^{-3} + C_r$	$2.31021 \times 10^{-3} + C_r$	$2.168\ C_{f1}$	$2.168\ c_{f2}$
PODS	$2.09517 \times 10^{-3} + C_r$	$2.05453 \times 10^{-3} + C_r$	$1.0905\ c_{f1}$	$1.0823\ C_{f_2}$
STRUTS	$2.4003 \times 10^{-3} + C_r$	$2.2632 \times 10^{-3} + C_r$	$(2.2354 + 0.01509h)C_{f1}$	$(2.2350 + 0.01509h)C_{f2}$

2706-057D

Fig. 2-10 Friction and Profile Drag Coefficients (U)

COMPONENT	GENERALIZED DRAG COEFFICIENTS	
	FORWARD ARRAY	AFT ARRAY
FOILS	$\left\{0.7588 - \frac{0.49106}{\sqrt{S}} + \frac{0.07230}{S}\right\} C_{f_1}$	$\left\{1.4092 - \frac{1.06254}{\sqrt{S}} + \frac{1.9883}{S}\right\} C_{f_2}$
PODS	$\frac{7.1164}{S} C_{f_1}$	$\frac{18.1341}{S} C_{f_2}$
STRUTS	$\frac{0.4645(h-1)}{S}\left\{2.2354 + 0.01509h\right\} C_{f_1}$	$\frac{1.3935h - 1.50915}{S}\left\{2.2350 + 0.01509h\right\} C_{f_2}$
SPRAY	$\frac{(5.1559 \times 10^{-3}\ t\ 1.3714 \times 10^{-3}h\ t\ 5.0 \times 10^{-5}h^2)}{S}$	$\frac{(2.3034 \times 10^{-2} + 6.0694 \times 10^{-3}h + 2.25 \times 10^{-4}h^2)}{S}$
AIR	$\frac{0.03912}{S}$	

2706-058D

Fig. 2-11 Generalized Drag Coefficients (U)

COMPONENT	SKIN FRICTION C_f*		PROFILE DRAG COEFFICIENT	
	HAMA APPROX.		C_f x FACTORS ACCOUNTING FOR S,, WAKE, ETC.	
	FQRWARD	AFT	FORWARD	AFT
FOILS	2.8404×10^{-3}	2.7722×10^{-3}	6.1580×10^{-3}	6.010×10^{-3}
PODS	2.5142×10^{-3}	2.4654×10^{-3}	2.7417×10^{-3}	2.6683×10^{-3}
STRUTS	2.6804×10^{-3}	2.7158×10^{-3}	$6.4388 \times 10^{-3} + 4.3471 \times 10^{-5}h$	$6.0698 \times 10^{-3} + 4.09875 \times 10^{-5}h$
*C_r = 20% ALLOWANCE				

2706-059AD

Fig. 2-12 Parasite Drag Coefficient Decomposition (Sheet 1 of 2) (U)

COMPONENT	C_d X NORMALIZED AREA (TOTAL FOIL AREA IS REFERENCE)		
	FORWARD	AFT	TOTAL
FOILS	$2.1553 \times 10^{-3} - \frac{1.3948 \times 10^{-3}}{\sqrt{S}} + \frac{2.0533 \times 10^{-4}}{S}$	$3.9066 \times 10^{-3} - \frac{2.9455 \times 10^{-3}}{\sqrt{S}} + \frac{5.5113 \times 10^{-3}}{S}$	$6.0619 \times 10^{-3} - \frac{4.3402 \times 10^{-3}}{\sqrt{S}} + \frac{5.7166 \times 10^{-3}}{S}$
PODS	$\frac{0.}{S}$ 01789	$\frac{0.0447}{S}$	$\frac{0.0626}{S}$
STRUTS	$\frac{(6.625 \times 10^{-5}h^2 + 9.7912 \times 10^{-3}h - 2.9908 \times 10^{-3})}{S}$	$\frac{(1.8739 \times 10^{-4}h^2 \text{ t } 2.7684 \times 10^{-2}h - 9.160 \times 10^{-3})}{S}$	$\frac{(2.5364 \times 10^{-4}h^2 \text{ t } 3.7464 \times 10^{-2}h - 1.2151 \times 10^{-2})}{S}$
SPRAY	$\frac{(5.1559 \times 10^{-3} - 1.3714 \times 10^{-3}h + 5 \cdot 0 \times 10^{-5}h^2)}{S}$	$\frac{(2.3034 \times 10^{-2} \text{ t } 6.0684 \times 10^{-3}h - 2.25 \times 10^{-4}h^2)}{S}$	$\frac{(2.8190 \times 10^{-2} + 7.4398 \times 10^{-3}h\ 2{,}75\times 10^{-4}h^2)}{S}$
AIR	$\frac{0.03912}{S}$		$\frac{0.3912}{S}$
TOTAL	$2.155 \times 10^{-3} - 1.3948 \times 10^{-3}/\sqrt{S}$ $\frac{+2.026 \times 10^{-2} + 1.1163 \times 10^{-2}h + 1.1625 \times 10^{-4}h^2}{S}$	$3.09066 \times 10^{-3} - 2.9455 \times 10^{-3}/\sqrt{S}$ $\frac{+0.1032 + 3.3752 \times 10^{-2}h + 4.1239 \times 10^{-4}h^2}{S}$	$6.0619 \times 10^{-3} - 4.3402 \times 10^{-3}/\sqrt{S}$ $\frac{\text{t } 0.1235 + 4.4915 \times 1\ 0^{-2}h \text{ t } 5.2864 \times 10^{-4}h^2}{S}$

2706-059BD

Fig. 2-12 Parasite Drag Coefficient Decomposition (Sheet 2 of 2) (U)

(C) Using the **planform** parameters given in Figures 2-16 and 2-17 the coefficients for the drag polar at the takeoff speed condition (h = 3.96 m, V_k = 25 knots) and. the design speed condition (h = 1.524 m, V_k = 50 knots) are obtained. The individual drag coefficient components and how they enter the drag polar equation are presented in Figures 2-13 and 2-14.

(U) Accounting for the center of gravity effect on the lift coefficients forward and aft, drag polars for the design at takeoff and design speed are:

TAKEOFF

$$C_{D_{TO}} = 6.5119 \times 10^{-3} - \frac{4.3402 \times 10^{-3}}{\sqrt{S}} + \frac{0.30977}{S} -$$

$$0.003C_L + 0.09502C_L^{\ 2}$$

DESIGN

$$C_{D_D} = 6.5119 \times 10^{-3} - \underline{4.340\sqrt{S} \times 10^{-3}} + \underline{0.19317}S -$$

$$0.003C_L + 0.08356C_L^{\ 2}$$

(U) The two equations which generate the two-point power limited solution become:

$$D_{TO} = C_{D_{TO}} \; q_{TO} \; S = f(L, S) = \frac{T_{TO}}{1 + M_{To}}$$

$$D_D = C_{D_D} \; q_D \; S = q(L, S) = \frac{T_D}{1 + M_D}$$

where the M_{TO} and MD terms are the thrust margins $\left(\frac{T-D}{D}\right)$ at the takeoff and design speed conditions, and the T_{TO} and T_D terms are the total available thrusts at these two **conditons.**

COMPONENT	C_0	C_1	C_2
PARASITE	$6.0169 \times 10^{-3} - \frac{4.3402 \times 10^{-3}}{\sqrt{S}} + \frac{0.030977}{S}$	-	-
INDUCED		-	0.0537 (0.04074)”
SEPARATION	4.5×10^{-4}	-0.003	0.005
SURFACE	-	-	0.0084 (0.01086) *
WAVE	-	-	0.03105 (0.0367) *
TOTAL	$6.5119 \times 10^{-3} - \frac{4.3402 \times 10^{-3}}{\sqrt{S}} + \frac{0.30977}{S}$	-0.003	0.09815 (0.09330) *

*NUMBERS IN PARENTHESES REPRESENT AFT FOIL CONFIGURATION.

2706-060D

Fig. 2-13 Takeoff Drag Polar Coefficients (U)

COMPONENT	C_0	C_1	C2
PARASITE	$6.0619 \times 10^{-3} - 4.34\sqrt{S}$ [illegible] S	-	-
INDUCED			0.0537 (0.04074)”
SEPARATION	4.5×10^{-4}	-0.003	0.005
SURFACE			0.02249 (0.01941)”
WAVE			0.01187 (0.0140)*
TOTAL	$6.5119 \times 10^{-3} - \frac{4.3402 \times 10^{-3}}{\sqrt{S}} + \frac{0.19317}{S}$	-0.003	0.09306 (0.07915) *

*NUMBERS IN PARENTHESES REPRESENT AFT FOIL CONFIGURATION.

2706-061 D

Fig. 2-14 Design Speed Drag Polar Coefficients (U)

For the present design, these two equations become:

TAKEOFF CONDITION

$$553.1683 - 368.701\sqrt{S} - 0.003L + 1.11858 \times 10^{-6}\frac{L^2}{S} +$$

$$3.7434 \times 10^{4} = \frac{T_{TO}}{1 + M_{TO}}$$

DESIGN CONDITION

$$2212.688 - 1474.80\sqrt{S} + 6.5634 \times 10^{4} - 0.003L +$$

$$2.45918 \times 10^{-7}\frac{L^2}{S} = \frac{T_D}{1 + M_D}$$

where a hull spray drag of 11.12 kN has been added to the takeoff drag **equation.**

(C) For this design, with 1.372 m diameter **KaMeWa** type propellers and an **overall** transmission gear ratio of **10:1,** the total thrusts available at the takeoff and design speed conditions are:

T_D = 185.170 kN

T_{TO} = 322.035 kN

By varying the thrust margins at takeoff and design speed it is possible to construct a matrix of dynamic lift versus total foil area **(Figure 2-15).**

(C) The design condition (L = 261.71 MT, S = 38.83 m^2) is based on a thrust margin at takeoff of 0.35 and a thrust margin at design speed of 0.05. The foil loading of 66.075 kPa is comparable to the present loading on the forward foil of the PCH, and the takeoff and design speed lift coefficients (0.7778 and 0.1945 respectively) are consistent with state-of-the-art values.

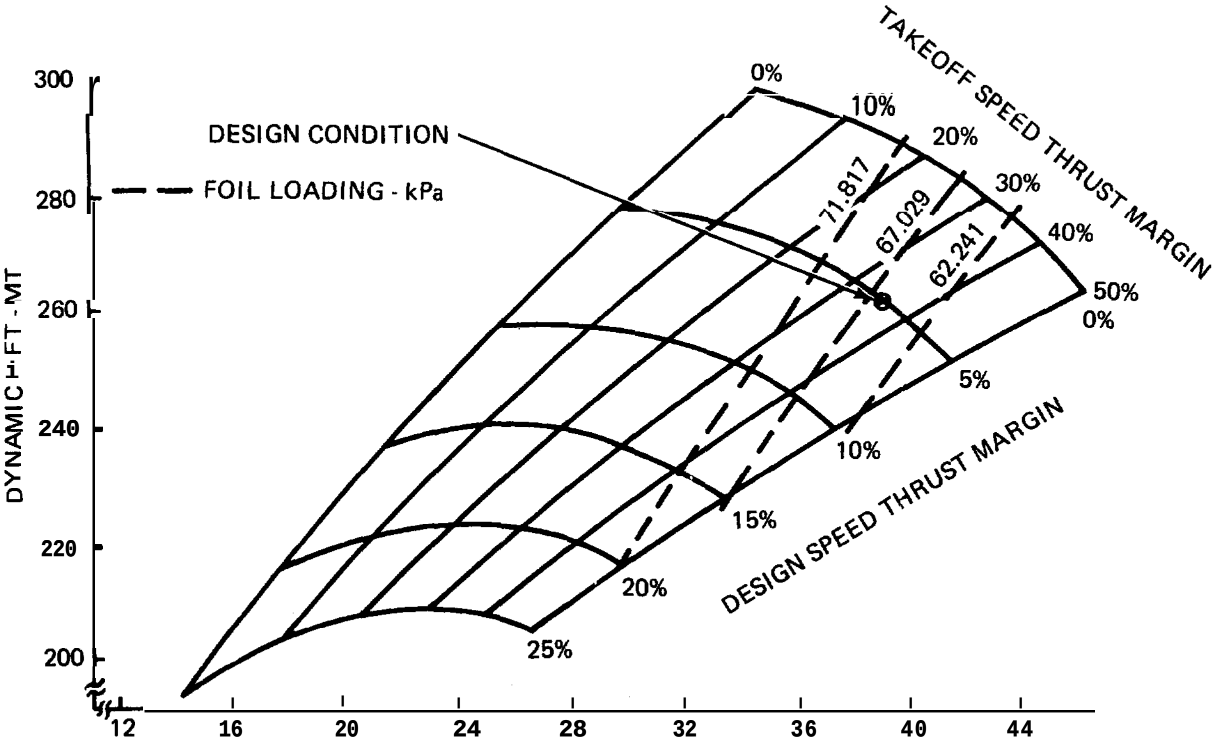

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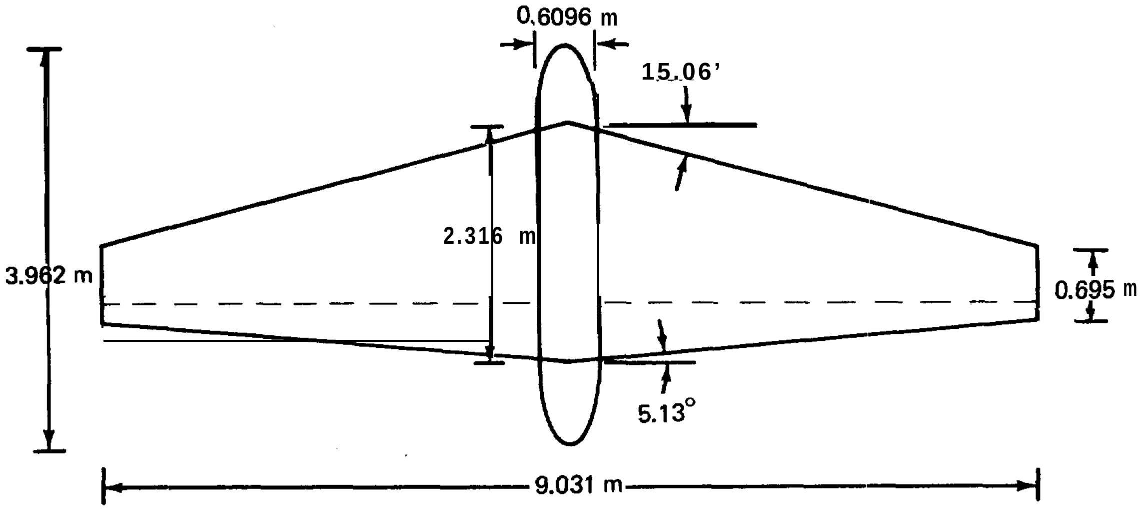
Fig. 2-15 Effect of Thrust Margin on Dynamic Lift and Foil Area (U)

(U) The forward and aft strut/foil arrays are presented in Figures 2-16 and 2-17, and the pertinent planform parameters are tabulated on the figures. As the figures indicate, the hydrofoil configuration selected for the design consists of a single "tee" foil forward supporting 35 percent of the vehicle weight and a "pi" foil assembly aft supporting 65 percent of the vehicle weight. The aft assembly consists of a foil, two struts, two pods housing the flap control mechanism and the power transmission, and two controllable pitch KaMeWa-type propellers located at the aft end of the pods. The forward assembly consists of a foil, one steerable strut and one pod housing the flap control mechanism.

(U) All of the struts are NACA 16 series sections with a constant chord (1.524 m forward and 2.286 m aft) over their length. The thickness-to-chord ratios at the strut/pod intersections are 0.10 and at the baseline 0.15. These values are based on cavitation considerations and have been demonstrated on the PGH-1 FLAGSTAFF.



ASPECT RATIO	6.00	DESIGN FOIL LOADING	66.072 kPa
TAPER RATIO	0.30	AREA	13.591 m^2
1/4 CHORD SWEEP	10.17°	SPAN	9.031 m
L. E. SWEEP	15.06'	ROOT CHORD	2.316 m
T. E. SWEEP	-5.13"	TIP CHORD	0.695 m
SECTION	NACA 16-308	AVERAGE CHORD	1.505 m
		MHC	1.650 m

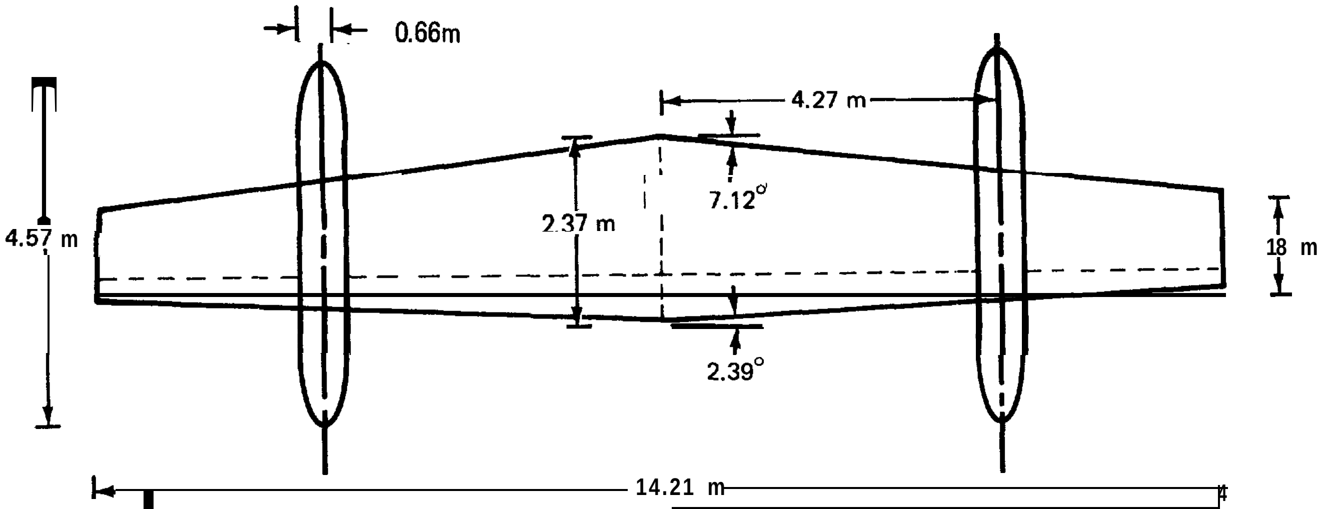
2706-050D

Fig. 2-16 Forward Foil Geometry (U)

The basic pod lines consist of an ellipsoidal nose (l/d = 2.0), a prismatic mid-body and an ogival afterbody (l/d = 3.0). These shapes are employed to delay cavitation on the pod up to design speed as demonstrated on the PGH-1. The foils are rigidly attached to the pods both forward and aft.

The foil section is identical forward and aft (NACA 16-308) and the planform parameters aspect ratio, taper ratio, quarter-chord sweep angle and leading edge sweep angle have all been determined using various optimization analyses developed by Grumman as part of the Generalized Performance Analysis. The foil streamwise section is an eight percent thickness-to-chord ratio NACA 16 series with a type a = 1.0 meanline and a design section lift coefficient of 0.30. The forward and aft foils both have 25 percent chord flaps with an envelope of approximately +25° to -15° for control.

The strut length provided allows for "platforming" operation in sea state 5 with an acceptable frequency of hull impact.



ASPECT RATIO	8.0	DESIGN FOIL LOADING	66.075 kPa
TAPER RATIO	0.5	AREA	25.24 m^2
1/4 CHORD SWEEP	4.76°	SPAN	14.210 m
L. E. SWEEP	7.12'	ROOT CHORD	2.368 m
T. E. SWEEP	-2.39°	TIP CHORD	1.184 m
SECTION	NACA 16-308	AVERAGE CHORD	1.776 m
		MHC	1.842 m

2706-063

Fig. 2-17 Aft Foil Geometry (U)

Forward and Aft Foil Cavitation Characteristics

Foil Section Cavitation Characteristics

As both the forward and aft foil employ the same section (NACA 16-308 with a type a = 1.0 meanline) the foil section cavitation characteristics forward and aft are identical. The section 'cavitation bucket equation derivation is presented in Reference 4 and only the results are presented here. The total velocity ratio (pressure coefficient) for the section is

$$\sqrt{S} = \frac{V}{V} \pm \frac{\Delta V}{V} \pm \frac{\Delta Va}{V} \left\{ c_\ell - c_{\ell_{i_{eff}}} \right\} = \Psi \pm \frac{\Delta Va}{V} c_\ell$$

where

$\frac{V}{V}$ = velocity distribution due to thickness distribution

$\frac{\Delta V}{V}$ = velocity increment due to camber

$\frac{\Delta Va}{V}$ = velocity increment due to angle of attack

$C_{l_{i_{eff}}}$ = effective design lift coefficient

C_l = section lift coefficient

Upper and lower signs refer to upper and lower surfaces, respectively. The effective design lift coefficient is a section function and the value employed here is 83 percent of the design lift coefficient (taken from an unpublished analysis of the data of Reference 5).

Using Reference 6 we obtain values for the velocity ratios on a **NACA 16** series with a type a = 1.0 meanline and plot the pressure coefficient as a function of the section lift coefficient (Figure 2-18).

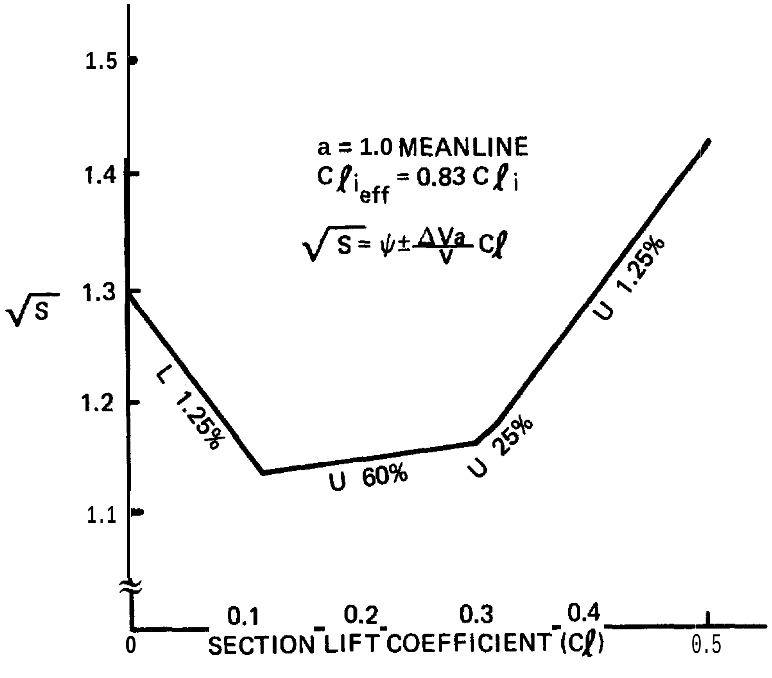


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Fig. 2-18 Pressure Coefficient Distribution- NACA 16-308 (U)

Cavitation occurs when the local pressure drops to vapor pressure; i.e.,

$$S - 1 = \frac{P_o - P}{4} \Rightarrow \frac{P_o - P_v}{q} = \sigma = \frac{P_A - P_v + \rho gh}{q}$$

$$\left\{ \Psi \pm \frac{\Delta V_a}{V} C_l \right\}^2 - 1 = \frac{P_A - P_V + \rho gh}{4}$$

Solving for the section lift coefficient

$$C_\ell = \frac{\sqrt{1 + \sigma} - \Psi}{\pm \Delta V_{a/v}}$$

and converting this to the foil lift coefficient

$$C_L = \frac{\sqrt{1 + \dfrac{P_A - P_V + \rho g h}{q'}} - \Psi}{\pm \dfrac{\Delta V_a}{V} \dfrac{C_\ell}{CL}}$$

where the prime term (q') represents the effect of quarter-chord sweep on cavitation

$$q' \triangleq q \cos^2 \Lambda_{c/4}$$

For the section bucket, $C_\ell / C_L = 1.0$ and $A = 0.0°$, the section cavitation bucket equation becomes:

$$\frac{W}{S} = \frac{512.9\ V^2}{\pm \Delta V_{a/v}} \left\{ \sqrt{1 + \frac{97862 + 10052h}{512.9\ V^2}} - \psi \right\}$$

V - m/sec

W/S - pascals

h - m

Plots of section foil loading vs. speed for various submergences are presented in Figure 2-19.

Flap Lift Cavitation Bucket

The derivation of the flap lift cavitation bucket is too complex to present in this section but can be found in Appendix A of Reference 7. In its most general form the equation is:

$$\left\{ \frac{\Delta V_a}{V} - \omega \right\} \frac{W}{S} = \pm \frac{\left\{ \sqrt{S} - \Psi \right\} q'}{C_\ell / C_L)_\delta} - \left\{ \omega + \xi_i \frac{\Delta V_a}{V} \right\} \frac{W}{S} \Big)' -$$

$$\left\{ \omega + \xi_\alpha \frac{\Delta V_a}{V} \right\} \frac{W}{S} \Big)_\alpha$$

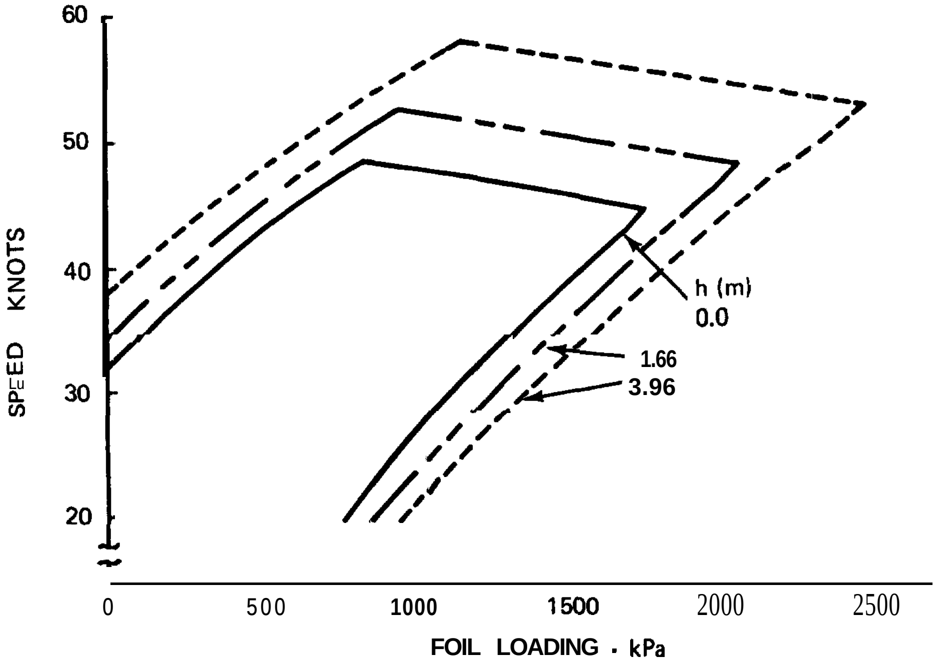

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Fig. 2-19 Section Cavitation Bucket - NACA 16-308 (U)

where

$$\omega = \zeta \left\{ \left(\frac{\Delta V_a}{V} - \frac{\Delta V}{V} \right)_F \right\}$$

$$\psi = \frac{V}{V} + \frac{\Delta V}{V} \mp \frac{\Delta Va}{V} C_{\ell_{i_{eff}}}$$

$$\xi_i = \frac{C_\ell / C_L)_i}{C_\ell / C_L)_\delta} - 1$$

$$\xi_\alpha = \frac{C_\ell / C_L)_\alpha}{C_\ell / C_L)_\delta} - I$$

$$\left.\frac{W}{S}\right) = \left.\frac{W}{S}\right)_i + \left.\frac{W}{S}\right)_o$$

$$\left.\frac{W}{S}\right)_o = C_{L_o} q$$

$$\left.\frac{W}{S}\right)_\alpha = C_{L\alpha} \theta q$$

$$C_{L_o} = C_{L_i} \frac{C_{\ell_{i_{eff}}}}{2\pi}$$

$$\left.\frac{W}{S}\right)_i = C_{L_i} iq$$

ζ = FLAP LOAD DISTRIBUTION PARAMETER

To use this equation for determining the cavitation characteristics for the design, we must develop the spanwise loading distribution for the forward and aft foil configurations. The methodology used in this report is based on the theories developed by John DeYoung and Charles Harper in the late 1940's.

Their approach incorporates a simple lifting surface theory, valid for all wings having a straight quarter-chord line across the semi-span. The details of these theories and the computer program for determining the spanwise loading distributions are found in Reference 8.

Based on these lifting surface theories the nondimensional. circulation distributions ($G \triangleq \Gamma/bV$) per degree of flap deflection (δ_1) take the shapes depicted in Figures 2-20 and 2-22. The three distributions on Figure 2-20 represent the variation of the spanwise circulation distribution on the forward foil with flap span. The forward foil employs a fully exposed span flap which corresponds to a 93.25 percent outboard flap on the figure. The forward pod encloses the other 6.75 percent of the foil. Three distributions were investigated on the aft foil configuration. The lines labelled 2 and 3 on Figure 2-22 represent assumptions on treating the tip of the foil intersection. The distribution used for the remainder of this analysis is labelled 1 on the figure . This distribution is based on the assumption that the aft foil is a "tee" configuration with the same span as the "pi" aft foil on the design. This distribution presents a conservative estimate for the actual distribution since the strut/pod effects have been neglected.

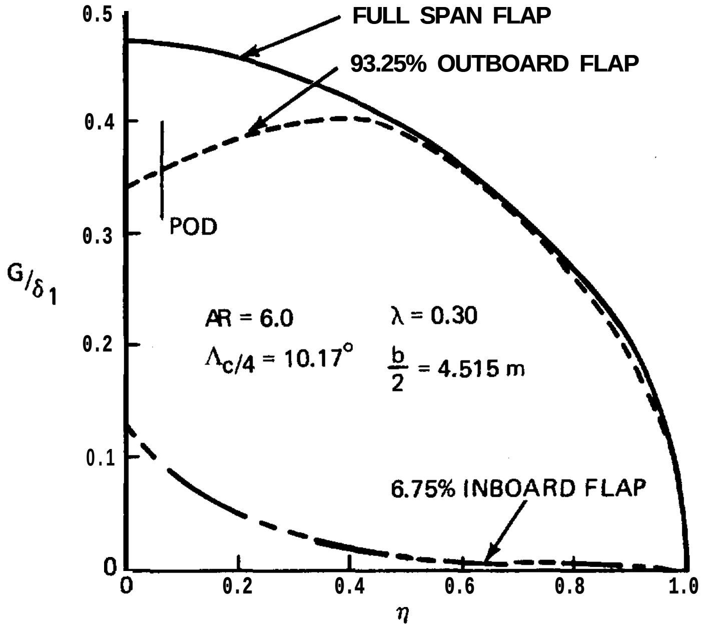

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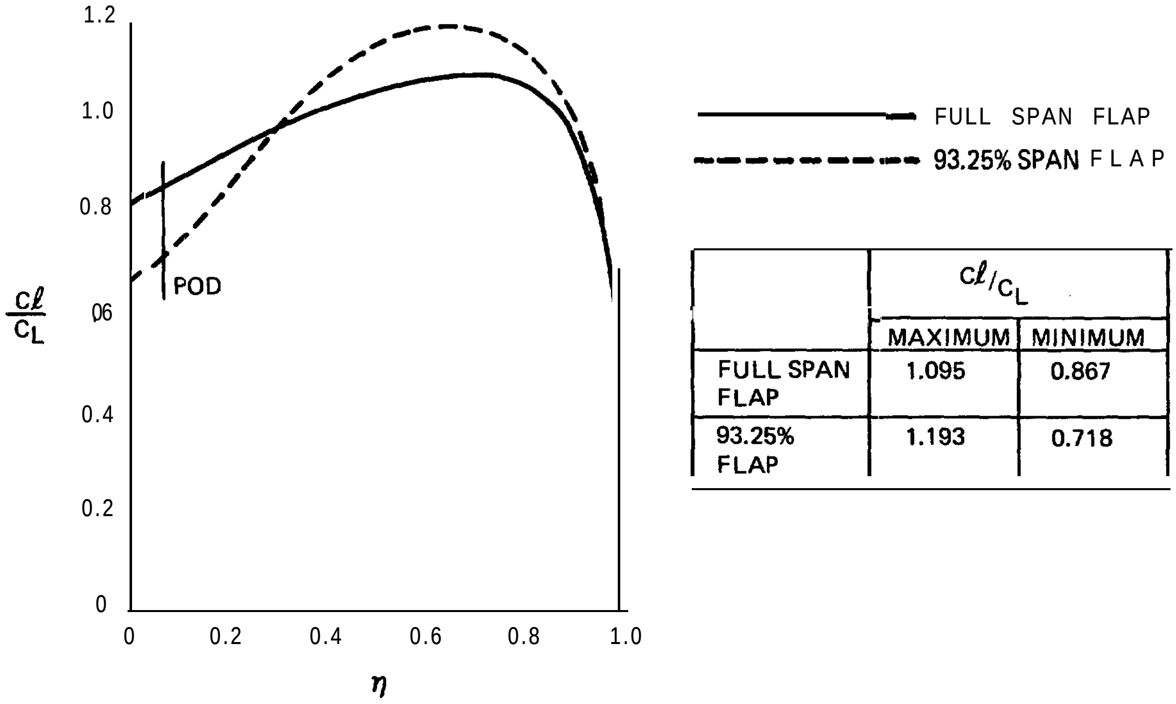
Fig. 2-20 Forward Foil - Nondimensional Circulation Distribution (U)



	$c\ell/C_L$	
	MAXIMUM	MINIMUM
FULL SPAN FLAP	1.095	0.867
93.25% FLAP	1.193	0.718

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Fig. 2-21 Forward Foil – Spanwise Lift Distribution (U)

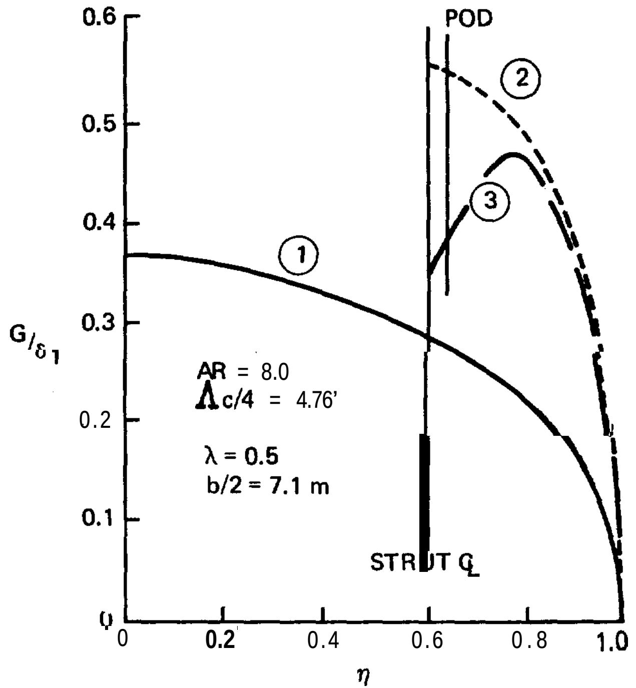

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Fig. 2-22 Aft Foil - Nondimensional Circulation Distribution (U)

To convert these nondimensional circulation distributions into **spanwise** loading distributions of the form C_ℓ/CL the $(G/\delta 1)$ distributions must be normalized by:

$$\int_0^1 \frac{G\eta}{\delta_1} \, d\eta$$

where

$$\int_0^1 \frac{G\eta}{\delta_1} \, d\eta = \frac{C_L}{2A\delta_1}$$

$$\frac{C\ell C}{C_L C_{ave}} = \frac{G\eta}{\delta} \Big/ \int_0^1 \frac{G\eta}{\delta} \, d\eta$$

and

$$\frac{C\ell C}{C_L C_{ave}} \triangleq \frac{2\left\{1-\eta(1-A)\right\}}{\lambda+1}$$

Using these relationships the forward and aft foil **spanwise** lift distributions (C_ℓ/C_L) are determined and presented in Figures 2-21 and 2-23. The significant values necessary to predict the cavitation characteristics on the foils are the maximum and minimum C_ℓ/C_L **ratios.** For the forward foil these values are:

$$\left.\frac{C_\ell}{C_L}\right)_{MAX} = 1.193 \qquad \left.\frac{C_\ell}{C_L}\right)_{MIN} = 0.718$$

and for the aft foil configuration:

$$\left.\frac{C_\ell}{C_L}\right)_{MAX} = 1.083 \qquad \left.\frac{C_\ell}{C_L}\right)_{MIN} = 0.962$$

Returning to the flap lift cavitation equation the parameters for the forward and aft foil configurations can be determined from Figures 2-21 and 2-23 and Reference 7. For a 25 percent chord flap the values of the parameters ζ and $d\alpha/d\delta$ are obtained from Reference 7, and become:

$$\zeta = 0.453 \qquad d\alpha/d_\delta = 0.535$$

as both the forward and aft foils employ a 25 percent chord flap, these values are the same in the forward and aft foil flap lift cavitation equations. The other parameters in the equation are presented below for the forward and aft foil configurations.

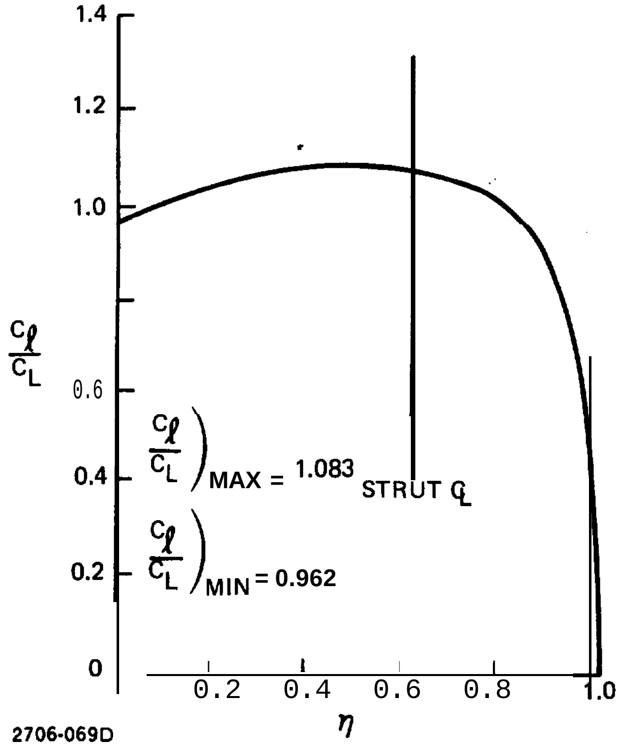

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Fig. 2-23 Aft Foil - Spanwise Lift Distribution (U)

FORWARD FOIL

$$\left.\frac{C_\ell}{C_L}\right)_\delta = \left.\frac{C_\ell}{C_L}\right)_i = \begin{matrix} 1.193 & \text{MAX} \\ 0.718 & \text{MIN} \end{matrix}$$

$$\left.\frac{C_\ell}{C_L}\right)_\alpha = \begin{matrix} 1.095 & \text{MAX} \\ 0.867 & \text{MIN} \end{matrix}$$

$$\left.\begin{aligned} C_{L\alpha} &= 0.0713/\text{DEG.} \\ C_{L_i} &= 0.0648/\text{DEG.} \\ C_{L_\delta} &= 0.0347/\text{DEG.} \end{aligned}\right\}$$

These values are obtained by integrating the nondimensional spanwise circulation distributions. A relative section lift curve slope (K) of 0.92 is employed.

$$C_{L_o} = C_{L_i} \frac{c_{\ell_{i_{eff}}}}{2\pi} = 0.1471$$

$$\omega = 0.453 \left\{ \frac{\Delta V_a}{V} - \left.\frac{\Delta V}{V}\right)_F \right\}$$

- Values of $\left.\frac{\Delta V}{V}\right)_F$ are obtained from Figure 2-24.

$$\psi = \frac{V}{V} \pm \frac{\Delta V}{V} \mp 0.249 \frac{\Delta V_a}{V}$$

$$\xi_i = 0.0$$

$$\xi_\alpha = \begin{array}{l} -0.082 \text{ - UPPER SURFACE VALUE} \\ 0.2075 \text{ - LOWER SURFACE VALUE} \end{array}$$

$$W/S)_o = 0.1473\ q \qquad W/S)_\alpha = 0.0713\ \theta\ q$$

$$W/S)_i = 0.0648\ i\ q$$

AFT FOIL

$$\left.\frac{C\ell}{C_L}\right)_\delta = \left.\frac{C\ell}{C_L}\right)_i = \left.\frac{C\ell}{C_L}\right)_\alpha = \begin{array}{l} 1.083 \text{ MAX} \\ 0.962 \text{ MIN} \end{array}$$

$$C_{L_\alpha} = C_{L_i} = 0.07499/\text{DEG.}$$

$$C_{L_\delta} = C_{L_i}\ d\alpha/d\delta = 0.0401/\text{DEG.}$$

$$C_{L_o} = 0.1703$$

$$\omega = 0.453 \left\{ \left(\frac{\Delta V_a}{V} - \frac{AV}{V} \right)_F \right\}$$

$$\psi = \frac{V}{V} \pm \frac{\Delta V}{V} \mp 0.249 \frac{\Delta V_a}{V}$$

$$\left.\frac{W}{S}\right)_o = 0.1703\ q$$

$$\left.\frac{W}{S}\right)_i = 0.07499\ i\ q$$

$$\left.\frac{W}{S}\right)_\alpha = 0.07499\ \theta^o\ q$$

$$\frac{W'}{S} = \left\{ 0.07499\ i + 0.1703 \right\} q'$$

$$\xi_i = \xi_\alpha = 0.0$$

[redacted]

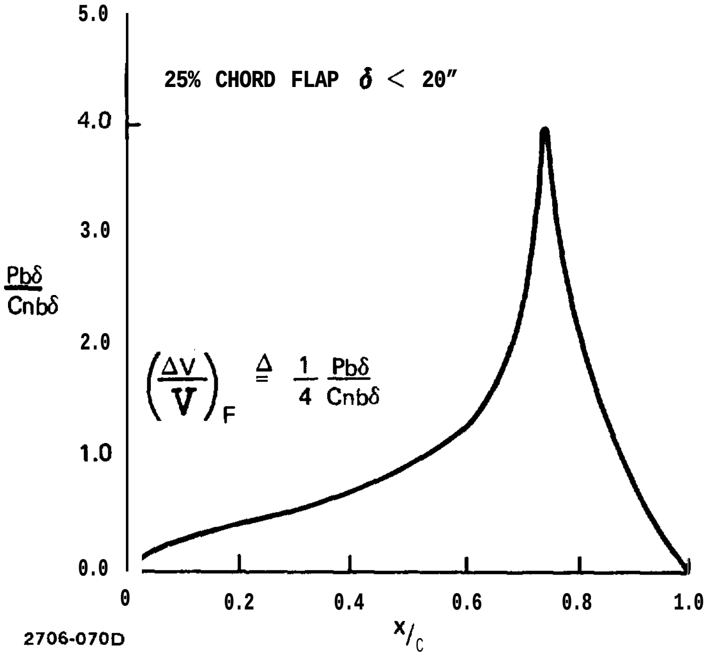

Fig. 2-24 Allen's Flap • Basic Load Distribution (U)

The values for the various velocity increments, ψ's and Popes' viscous terms as a function of chord station are presented in Figure 2-25. These values were taken from References 6 and 7, and are for a NACA 16-308 section with an a = 1.0 type meanline.

X(%c)	v/V	$\Delta v_a/V$	$\Delta v/V$	ψ_{up}	ψ_{low}	$\left(\frac{\Delta V}{V}\right)_F$	POPE'S FUNCTION, P_{ac}
0	0	4.253	0.0623	0.997	0.997	0	0
1.25	1.024	1.345		0.751	1.297	0.020	3.0762
2.5	1.049	0.969		0.870	1.228	0.035	4.3256
5	1.060	0.686		0.951	1.169	0.050	5.2869
7.5	1.066	0.555		0.990	1.142	0.062	5.6713
10	1.068	0.475		1.012	1.124	0.070	5.4794
15	1.072	0.378		1.040	1.104	0.090	4.7945
20	1.076	0.319		1.059	1.093	0.108	4.1095
30	1.081	0.245		1.082	1.080	0.145	2.7397
40	1.085	0.197		1.098	1.072	0.188	1.3699
50	1.089	0.160		1.111	1.067	0.245	0
60	1.093	0.131		1.123	1.063	0.322	-1.3699
70	1.087	0.103		1.124	1.050	0.565	-2.7397
75	1.077	0.090		1.117	1.037	1.002	-3.4246
80	1.067	0.076		1.110	1.024	0.578	-4.1095
90	1.020	0.048		1.070	0.970	0.215	-5.4794
95	0.973	0.031		1.028	0.918	0.102	-5.2869
100	0	0		0.062	0.062	0	0

2706-071D

Fig. 2-25 Velocity Increment Distributions • NACA 16-308 (U)

[redacted]

[redacted]

(U) To determine the final form of the flap lift cavitation equations, it is necessary to establish a relationship between the pitch, incidence and flap angles. The problem is greatly simplified if we restrict the derivation to the case of i = 0.0'.

$$C_L = C_L)_\theta + C_L)_i + C_L)_\delta + C_{L_o}$$

$$= C_{L_\alpha}\theta + C_{L_i} i + C_{L_\delta}\delta + C_{L_o}$$

and for the forward and aft foil configurations:

Forward:

$$C_L = 0.07138 \quad + 0.03476 \quad + 0.1471$$

Aft:

$$C_L = 0.074990 + 0.0401\delta + 0.1703$$

[redacted] For the design load condition, the total lift coefficient at takeoff is 0.7778. If we restrict the flap angle to some value at takeoff, for example, 15 degrees, then it is possible to determine what pitch angle (θ) will be required forward and aft to produce the lift coefficient. Figures 2-26 and 2-28 present the flap lift cavitation buckets for the forward and aft foils, respectively. In both figures the takeoff flap angle was restricted to 10 and 15 degrees, and the pitch angle was set by these values. In both figures, the design point (V_k = 50, W/S = 66.07kPa) is within the bucket (cavitation free) for the 15 degree flap deflection at takeoff and outside the bucket (cavitated) for the 10 degree deflection.

(U) The total lift coefficient equations can be used to determine the flap schedule forward and aft as a function of speed. Figures 2-27 and 2-29 present the forward and aft foil flap schedules for a maximum flap deflection of 15 degrees at takeoff, Figure 2-27 shows that the forward flap is trimmed at approximately 44 knots and has a -1.8' deflection at design speed. Figure 2-29 shows that the aft flap is trimmed at 53 knots and has a 0.5^o deflection at design speed.

[redacted]

[redacted]

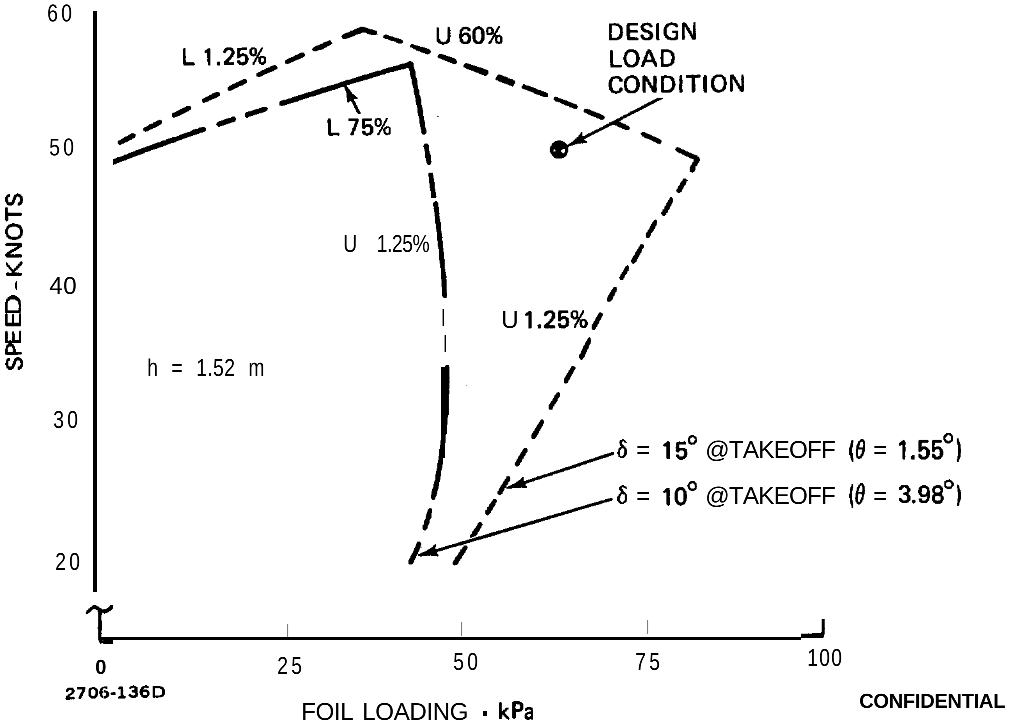

Fig. 2-26 Forward Foil - Flap Lift Cavitation Buckets - NACA 16-308 (U)

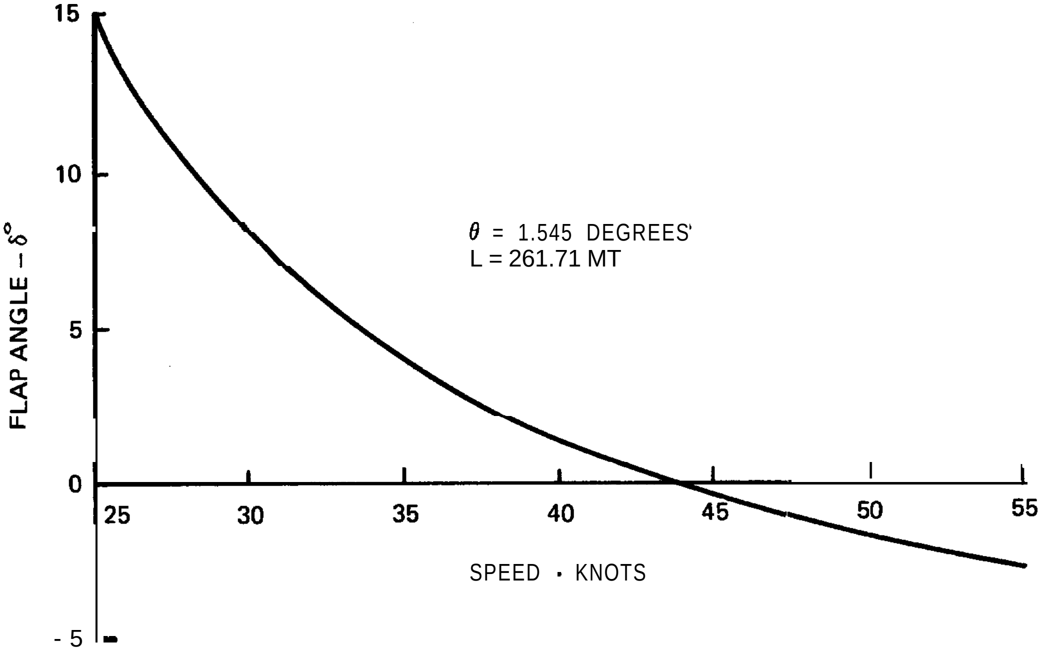

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Fig. 2-27 Forward Foil - Flap Schedule (U)

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[redacted]

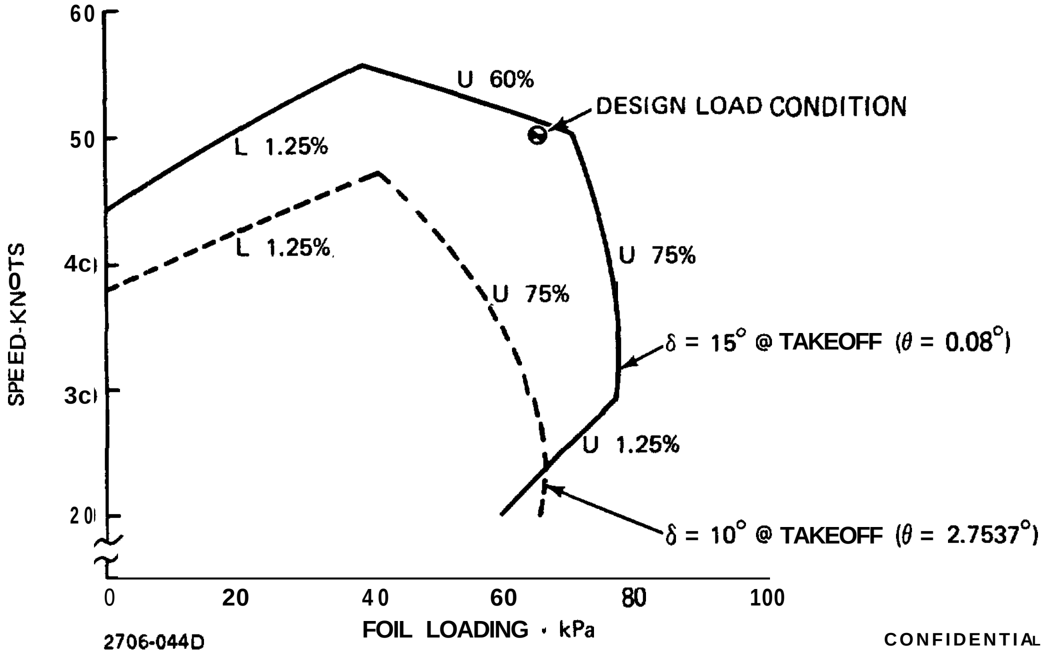

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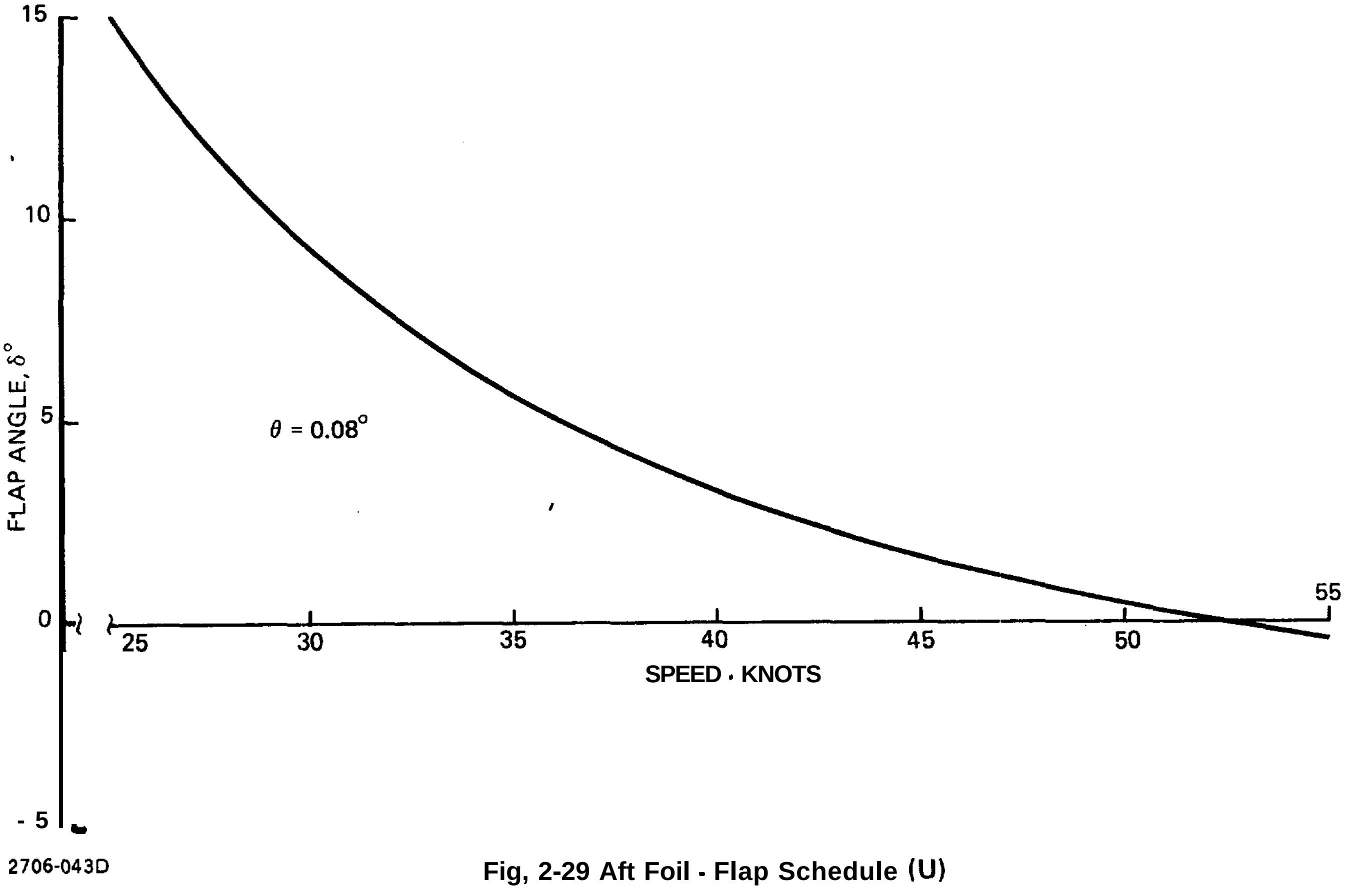
Fig. 2-28 Aft Foil • Flap Lift Cavitation Buckets • NACA 16-308 (U)



Fig, 2-29 Aft Foil - Flap Schedule (U)

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SECTION 3

SHIP SYSTEM DESCRIPTIONS

3 - SHIP SUBSYSTEM DESCRIPTIONS

3.1 SHIP SUBSYSTEM DESCRIPTION

In addition to those systems peculiar to the proposed installations, the implementation of the Advanced Technology Lift and Propulsion System requires that minor modifications be made to certain portions of the ship's piping systems and hull structure.

3.2 HULL STRUCTURE

The modifications to the hull structure for the design, as shown on Figure 2-4, may be categorized into two basic groups, the new construction not included on PHM-3 series craft, and the modifications to existing PHM-3 series structure.

Under the scope of this design study, no analyses were performed on any portions of the primary hull structure. Rather, scantlings for use in the computation of the weight summation were derived from a review of PHM-1 drawings and NAVSE.A Drawing No. 802-5000457, Rev, D, "PHM-3 series - Midship Section and Configuration of Transverse Bulkheads 3, 15, 25, and 30.025". In view of the full load growth potential of the craft, an analysis of the PHM-3 series scantlings should be conducted during a subsequent detail design unless assurances can be given that an adequate margin of safety exists.

The principal new construction is related to that required for the installation of the main engine air intake plenum on the Main Deck, and to the fabrication of additional fuel tankage as specified in subsection 2.3.

The Deckhouse extension as shown on Figure 2-4 reflects the arrangement of Figure 2-5, but is, however, readily adapted to the Alternate Machinery Arrangement, Figure 2-6. Construction would be similar to that of the PHM-3 series Deckhouse which is presumed to be of light scantling, riveted construction.

The fuel tanks would be of all-welded aluminum alloy construction. Between Frames 21 and 25, it would be required to plate over the tanks at the platform level, and also to reinforce the tank end bulkheads to suit the hydrostatic and dynamic heads. Further investigation into the craft stability may deem it necessary to connect the wing tanks with a cross-flooding duct to eliminate the effects of unsymmetrical flooding.

Between Frames 28 and 33, the construction consists of installing tank boundaries at the offsets of the PHM-3 side keelsons. A tank top would be fabricated of scantlings and construction similar to that of the existing forward fuel tanks.

The principal areas of modification are also delineated on Figure 2-4 and are associated with the installation of the Allison 570 KA gas turbine engines and the mechanical transmissions. Bulkhead 30 and the engine closure bulkheads require additional analyses due to the new loads imposed on them by the transmission components and the main engine mounts, respectively. Other minor alterations are required to be made to Bulkhead 33 and the transom to close the openings formerly occupied by the waterjet propulsor . In addition, divisional bulkheads and bolted plate hatch covers would be required in those locations shown on Figure 2-4.

Hull fairings located forward of the aft struts will undoubtedly require modification due to the propulsion thrust loads, the increased width of the upper strut section and the relocation of the retraction axis which affects the travel of the retraction actuator. These changes, being of an indeterminate nature at present, are referenced, but not detailed, on Figure 2-4.

3.3 PROPULSION SYSTEM

The foilborne propulsion system consists of two Allison 570 KA gas turbine engines, each driving a KaMeWa-type 4-bladed, controllable pitch, supercavitating propeller by means of a right angle Z-type mechanical transmission system.

Foilborne Engines

Characteristics of the Allison 570 KA gas turbines are summarized in Figure 3-l.

TYPE	FREE POWER TURBINE · COLD END DRIVE
POWER TURBINE INLET TEMPERATURE, T_{T_5}	850°C
AIRFLOW (26.7°C)	18.2 kg/s
COMPRESSION RATIO	12:1
NO. OF COMPRESSOR STAGES	13
NO. OF TURBINE STAGES	2 HP/2 POWER
COMBUSTOR TYPE	THROUGH FLOW ANNULAR
LENGTH	1.83 m
DIAMETER (MAX)	0.8 m
WEIGHT (DRY)	612 kg

2706-073D

Fig. 3-1 Foilborne Engine Characteristics (U)

Installed engine power and fuel flow characteristics are shown in Figure 3-2, for a 26.7°C day with 100 mm and 150 mm H_2O inlet and exhaust losses at the maximum airflow condition. Fuel LHV is assumed to be 42.3 MJ/kg. Also indicated on the engine map are the nominal intermittent and continuous power lines and the nominal propeller match points.

The engine performance map for this proposed application is bounded by three basic engine limits: maximum turbine temperature (850°C) ; maximum power turbine rotor speed (11,000 RPM); and the transmission torque limit (4530 N• m). Maximum power turbine speed of 11,000 RPM was chosen for added RPM margin at high power settings to avoid automatic overspeed shutdowns. The maximum torque limitation is set by the transmission system (4530 N• m) rather than the engine maximum output torque (5435 N .m), in order to protect the transmission system. A maximum torque limiting feature will be investigated for the engine fuel control system, in addition to the inherent torque limiting provided by a controllable pitch propeller.

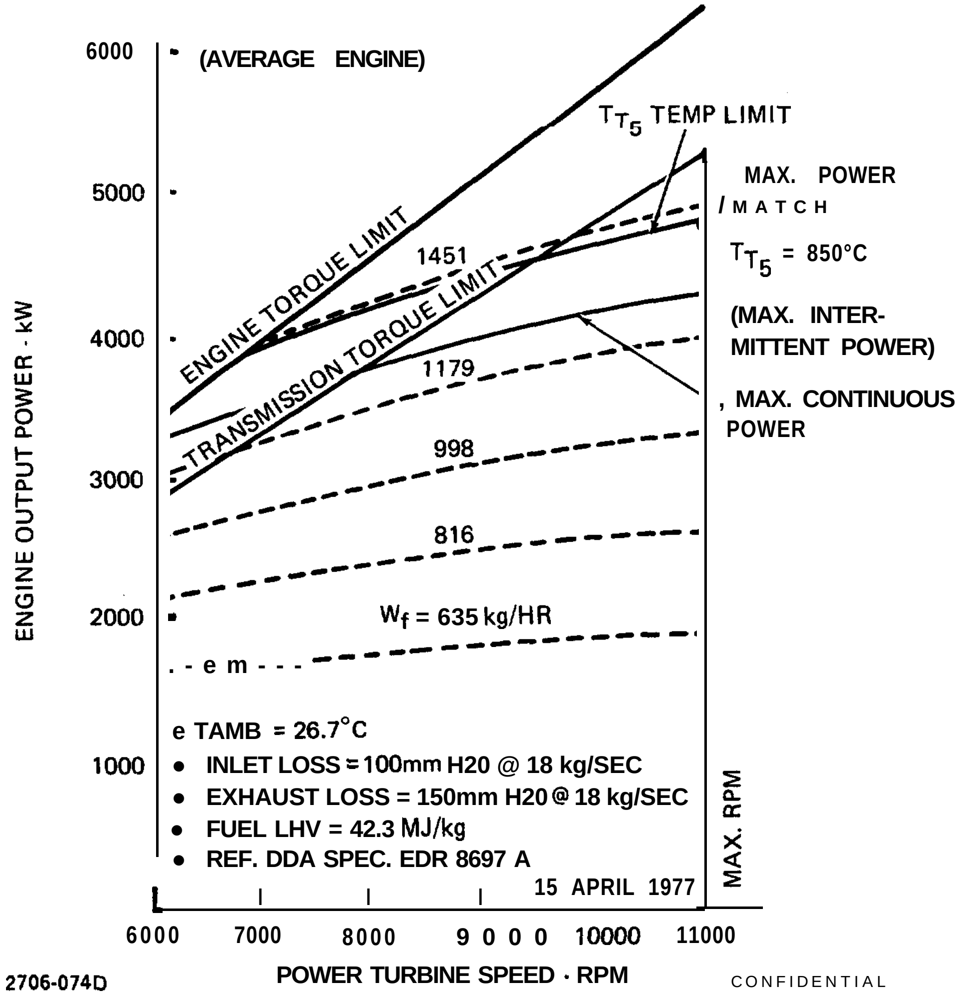

Fig. 3-2 Allison 570 KA Engine-Installed Performance (Average Engine) (U)

Propeller Characteristics

Propeller performance is based on preliminary data supplied by KaMeWa for a previous hydrofoil program. KaMeWa's performance estimates are based on model tests and full scale application of a 4-bladed, supercavitating controllable pitch propeller. This propeller design, in turn, has been derived from the successful 3-bladed supercavitating propeller used for ten years on PG(H)-1 FLAGSTAFF.

Propeller design characteristics are summarized in Figure 3-3.

Preliminary choice of a 4-bladed propeller is based on the foil/strut/pod wake characteristics determined from model tests of the PG(H)-1 FLAGSTAFF propeller system. In that configuration, a three-lobed wake, spaced at ~120°, was present at the propeller disc. A. 4-bladed propeller will avoid simultaneous passage of blades through these wake lobes and reduce the torsional excitation forces. Final decision on the number of blades, however, will be determined after detailed examination and/or tests of the aft foil system wake characteristics.

TYPE	SUPERCAVITATING, CONTROLLABLE PITCH, PUSHER INSTALLATION
NO. OF BLADES	4
DIAMETER	1.4 m
EXPANDED BLADE AREA RATIO, EAR	0.65
HUB DIAMETER RATIO, d_h/D_o	0.35
DESIGN PITCH RATIO, $P_{.7}/D_o$ (DESIGN)	1.5
PITCH RATIO @TAKEOFF, $P_{.7}/D_o$ (TAKEOFF)	PROGRAMMED FOR 1100 RPM

2706-075D

Fig. 3-3 Foilborne Propeller Characteristics (U)

Transmission

The transmission for the proposed propulsion system is based on the technology developed for the Grumman M-151 hydrofoil program. The proposed transmission will utilize the M-151 spiral bevel and modified pod planetary gearsets with a new low-risk hull-mounted spur gearbox designed for use with the Allison 570 KA engine. Use of the existing component designs will considerably reduced development risk and evaluation time.

A schematic of the proposed transmission is shown in Figure 3-4.

The hull-mounted gearbox is located at the inlet of the Allison 570 KA engine. Its pinion input shaft centerline is in line with the output shaft of the turbine, which drives through the engine inlet. The centerline of the output gear is in line with the input pinion for the shoulder bevel gearbox.

The shoulder bevel gearbox is located just aft of the hull-mounted gearbox with its pinion input shaft in line with the hull-mounted gearbox output shaft. The centerline of the bevel gearbox output shaft is in line with the input of the strut bevel gearbox and coincident with the aft strut retraction axis.

The strut bevel gearbox is located inside the trunnion supports at the top of the strut and has its input shaft in line with the output of the shoulder bevel gearbox and coincident with the aft strut retraction axis. The output shaft of the strut bevel gearbox is in line with the centerline of the input shaft of the pod bevel gearbox.

The pod bevel gearbox is located in the strut/pod section with the pinion input shaft centerline coincident with the centerline of the output shaft of the strut bevel gearbox, and the centerline of the output shaft in line with the centerline of the pod planetary sun gear.

The pod planetary gearbox is located aft of the pod midbody section and forward of the propeller shear coupling device and propeller cartridge. The centerline of the sun pinion is in line with the output shaft of the pod bevel gearbox assembly, and the centerline of the planet carrier output shaft is in line with the centerline of the propeller shaft through the shear coupling device.

Figures 3-5 through 3-7 present the major gear design parameters of the three types of gearboxes described above, and compare them to demonstrated and/or accepted values, where applicable. These comparisons show that the gear designs proposed for this design are at or below accepted design and/or demonstrated capability.

Machinery Arrangement

Arrangement of the propulsion system machinery has been incorporated into the existing PHM structural arrangement with minimum change to existing structure. Some structural change and relocation of existing machinery has, however, been necessary. Within the constraints, major propulsion system elements were arranged for ease of overhaul and maintenance.

As the machinery arrangement is a major part of the proposed modification, subsection 2.3 of this report is dedicated as a detailed description of the general and machinery arrangements. Subsection 2.3 also describes machinery system features and components, such as:

- Engine removal
- Engine cooling
- Intake and exhaust systems
- Engine and transmission mount systems
- SSPU arrangement.

PARAMETER	DESIGN VALUE	CONSERVATIVE PRACTICE
DESIGN INPUT (kW PER MESH)	5220	
GEAR RATIO	2.187	
DIAMETRAL PITCH	6.75	
DESIGN INPUT TORQUE (N·m)	4530	
DIAMETERS (mm)	180.6/395.2	-
PRESSURE ANGLE (DEG.)	20°	20° MIN.
BENDING STRESS (MPa)	228.27	320.28
COMPRESSIVE STRESS (MPa)	833.04	988.02
PITCH LINE VELOCITY (m/s)	104	127

2706-076D

Fig. 3-5 Hull-Mounted Spur Gear Design Parameters (U)

3.4 LIFT SYSTEM

The installation of a mechanical transmission system, the enhanced hydrodynamic capabilities and the resultant growth margin applicable to the full load displacement, necessitate the design of a totally new lift system comprising forward and aft struts and foils, and the modification of their associated up and down locks and retraction gear.

Loading Conditions

Four loading conditions, as defined in the Boeing Co. Report D312-80100-1 "PHM Structural Design Loads," were reviewed to verify the critical conditions for design, Descriptions of these four conditions, excerpted from the aforementioned report, follow:

PARAMETER	DESIGN	CONSERVATIVE PRACTICE	DEMONSTRATED
DESIGN INPUT (kW PER MESH)	5220	–	6860 (AGEH-1 LOWER BEVEL GEAR BOX)
GEAR RATIO	1.02062		1.0189 TO 2.550
DIAMETRICAL PITCH	6.25	2.0 MIN	2.0 (AGEH) TO 6.25 (PGH-1)
DESIGN INPUT TORQUE (kN·m)	10.4		5.12 TO 40.8 (AGEH)
DIAMETERS (mm)	394.0/402.3	–	279.4/330.0 (SES-100A) TO 647.7/660.4
SPIRAL ANGLE (DEG.)	25	25	25 TO 30
PRESSURE ANGLE (DEG.)	25	20 MIN	20 TO 25
BENDING STRESSES (MPa)	196.5	172.4	209.1 (SES-100A) 211.8 (AGEH) 200.0 (PCH-1)
COMPRESSIVE STRESSES (MPa)	1043.2	1034.2 MAX	1363.3 (SES-100A) 1341.7 (PCH-1)
PITCH LINE VELOCITY (m/s)	99	127 MAX	95 (PGH-1). 149 (FHE)
SCORING INDEX	21,600	26,000 MAX 27,230 (FHE) 27,780 (PCH-1)	23,100 (SES-IOOA)

2706-077D

Fig. 3-6 Spiral Mesh Bevel Gear Design Parameters (U)

APPLICATION	DESIGN M-151 MODIFIED FOR ADVANCED TECHNOLOGY APPLICATION		CRITICAL DEMONSTRATED VALUE	PRESENT M-151 HARDWARE
	TAKEOFF	CRUISE		TAKEOFF
TYPE	PLANETARY	PLANETARY	–	PLANETARY
CONDITION	DESIGN	DESIGN	–	DESIGN
POWER (kW)	5220	3102	29,828	4029
RPM, IN/OUT	4730/1091	3474/801	8,000/1,200	43301999
RATIO	4.3333	4.3333	6.667	4.3333
INPUT TORQUE (kN·m)	10.5	8.5	71.2	8.8
DIAMETRAL PITCH	5.714	5.714	7.059	5.714
ROOT STRESS (SUN/PLANET)(MPa	216.9/149.4	175.5/120.9	208.2	228.5/157.4
COMPRESSIVE STRESS (MPa)	965.8	868.8	721.2	991.3
SCORING INDEX	12,704	9290	16,131	12,642
PITCH LINE VELOCITY (m/s)	33	24	51	30
FACE WIDTH (mm)	95.3	95.3		76.2

2706-078D

Fig. 3-7 Pod-Mounted Epicyclic Gear Design Parameters (U)

- "Foilborne-One-Factor Load", or Dynamic Lift, shall refer to the lift imposed on the foil in normal steady-state foilborne operation in the calm sea
- "Limit load" is the calculated maximum load expected in authorized service, including the effects of acceleration and dynamic magnification. Foil system structure shall be designed for ultimate

loads which include a factor of safety of 1.5 times the limit load. Ultimate loads shall not exceed the yield strength of the material nor cause failure by elastic instability

- Maximum Foilborne Lift - The foils and struts shall withstand vertical loads equivalent to the foil one-factor load plus an incremental vertical acceleration of 0.5g applied with a dynamic magnification factor of 2.0, the whole assumed to have a 60-40 percent distribution about the foil centerline

- Foil Emergence - The foil/strut system shall withstand loads associated with partial emergence of a foil. For a forward foil, 85 percent of the entire foil one-factor load shall be applied to a single semispan with zero load on the other semispan. For the aft foil, zero load shall be applied to one tip outboard of the strut centerline, with the remaining part of the foil being subjected to the entire foil one-factor load. The immersed part of the foil in either case shall be assumed to be ventilated, with a correspondingly lower lift-to-drag ratio

- Broach Recovery - The forward foil system shall be capable of withstanding loads associated with the broach recovery condition. For this condition, the yield factor of safety shall be 1.20 and the ultimate factor of safety 1.50. Under yield loads the structure shall not deform elastically or plastically so as to interfere with the intended function of the foil system. The structure shall not fail under ultimate loads. The broach recovery condition shall include combined effects of the following:

  a) Maximum ship speed for rough water operation

  b) Forward flap at maximum down position

  c) Lift on one foil semispan at fully ventilated flow (assume to average 47.9 kPa) and on the other semispan at unventilated flow (assumed to average 153.2 kPa)

  d) Foil drag shall be one-sixth of the total foil lift acting off the centerline on the unvented side so as to produce a rudder torque equal to the maximum steady-state steering actuator output

e) Foil pitching moment shall correspond to the lift forces acting at 50 percent of the mean hydrodynamic chord on the vented semispan and 25 percent of the mean hydrodynamic chord on the unvented semispan.

The numerical values associated with these four conditions are shown on Figure 3-9 and are based upon the foil area and loading shown in the figure.

	SHEAR, MN	MOMENT, MNm
FORWARD FOIL	1.53	3.06
AFT FOIL, AT CENTER LINE	0.956	-2.05
AFT FOIL @ η = 0.588 (STRUT LOCATION)	-0.14	1.18
STRUT LOAD, @ η = 0.588	-3.00	-

2706-001D

Fig. 3-8 Design Ultimate Loads – Maximum Foilborne l ift 'Condition (U)

Foil Design

In the preperation of the design for the foils, a classical approach was utilized to obtain the preliminary scantlings. Strut design would be accomplished in much the same way.

From the spanwise foil load distribution, obtained from hydrodynamic analysis, the shear and bending movement curves were developed by the method described in Peery, Aircraft Structures, Section 5.3 and plotted as Figure 3-10 for the forward foil, and Figures 3-11 and 3-12 for the aft foil. The design ultimate loads are tabulated on Figure 3-8.

It is to be noted that the moment of inertia (I) for a solid section spanning the possible range of t/c values was first plotted to establish a baseline, and to visually indicate the margin available for the selection of hollow plate/spar sections.

Foil upper and lower skin thicknesses were based upon the ultimate load conditions utilizing the material yield stress of 689 MPa.

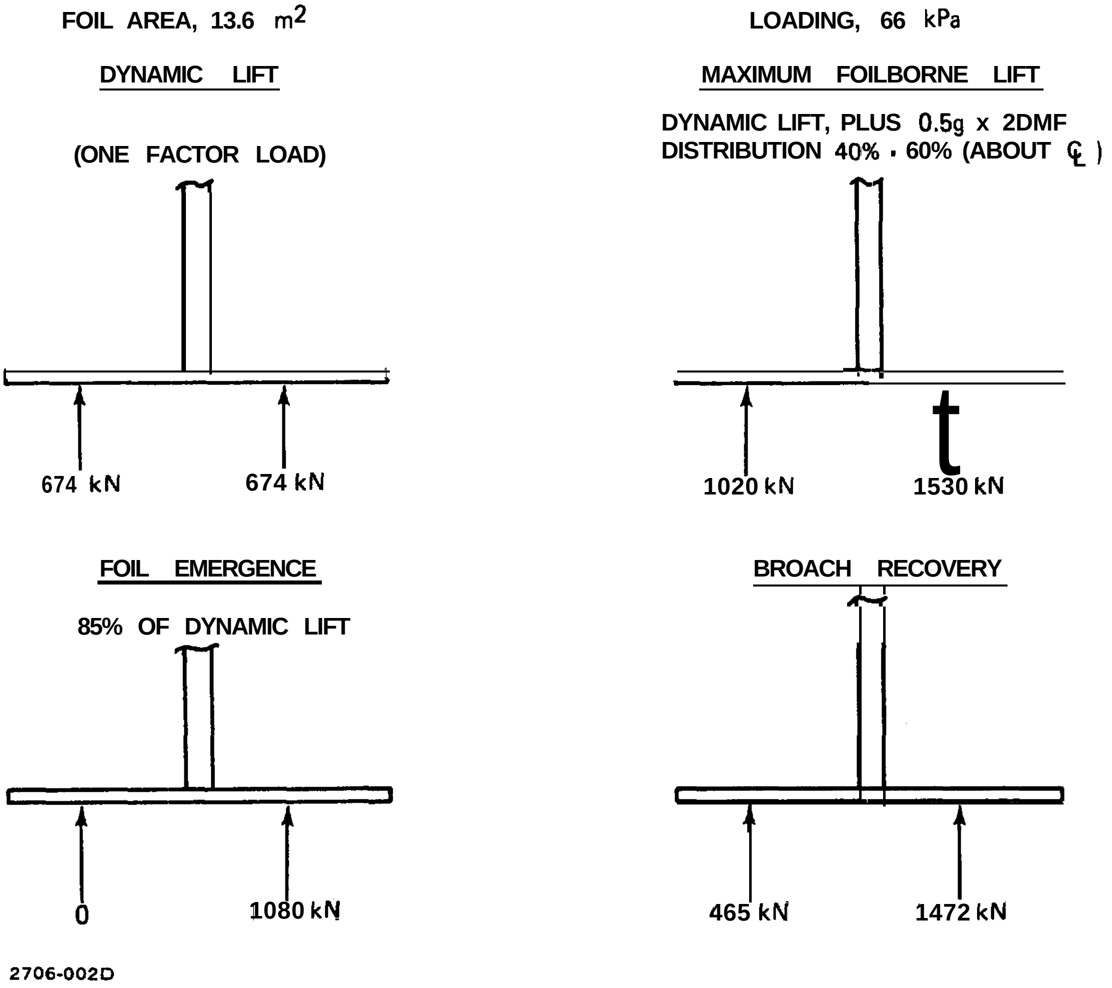

Fig. 3-9 Forward Foil - Loading Conditions (U)

The preliminary design procedure for the forward and aft foils is further discussed in the following paragraphs.

Forward Lift System

Strut

The forward strut, as shown in Figure 3-13, is to be dimensionally similar to the PHM-3 series except that the strut will be lengthened to provide 1.5 meters submergence to the foil chord plane. Scantlings will, of necessity, be modified to satisfy the revised loading conditions and the use of **HY 100** steel as the basic structural material per subsection 5.6.

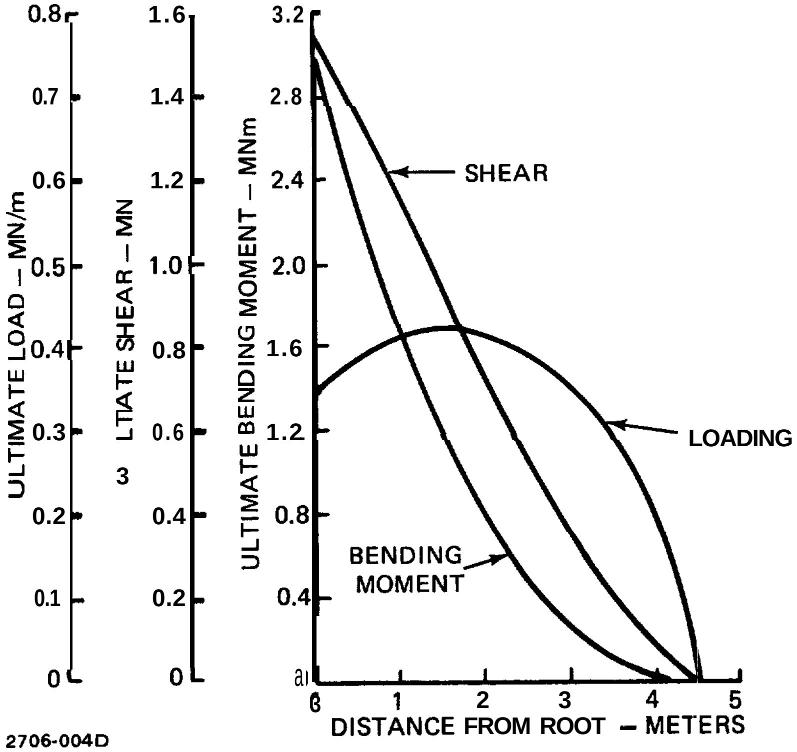

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Fig. 3-10 Forward Foil - Ultimate Load Condition, Shear and Bending Moments(U)

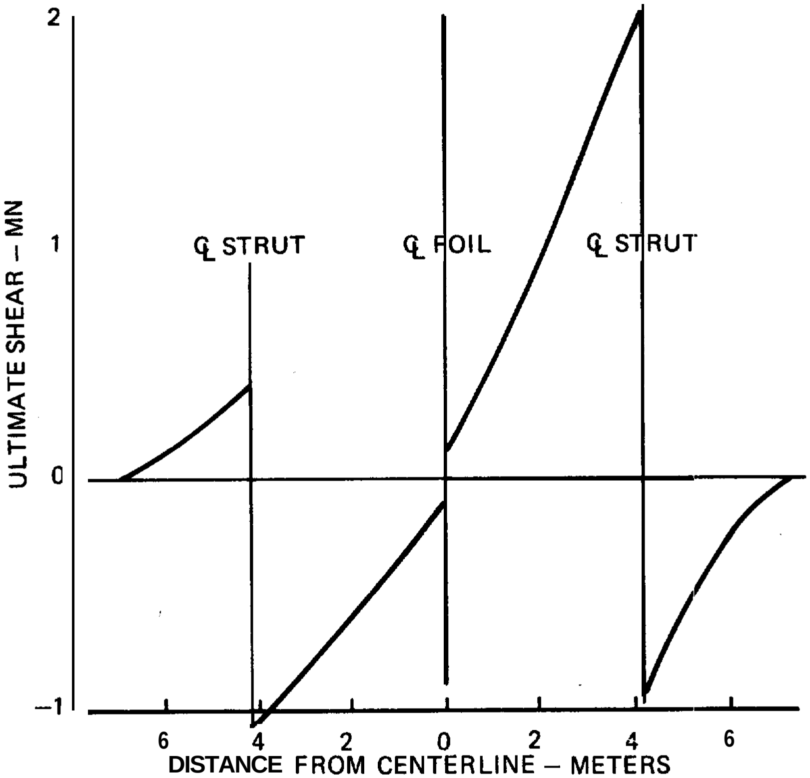

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Fig. 3-11 Aft Foil Ultimate Shear - Maximum Foil Lift Condition (U)

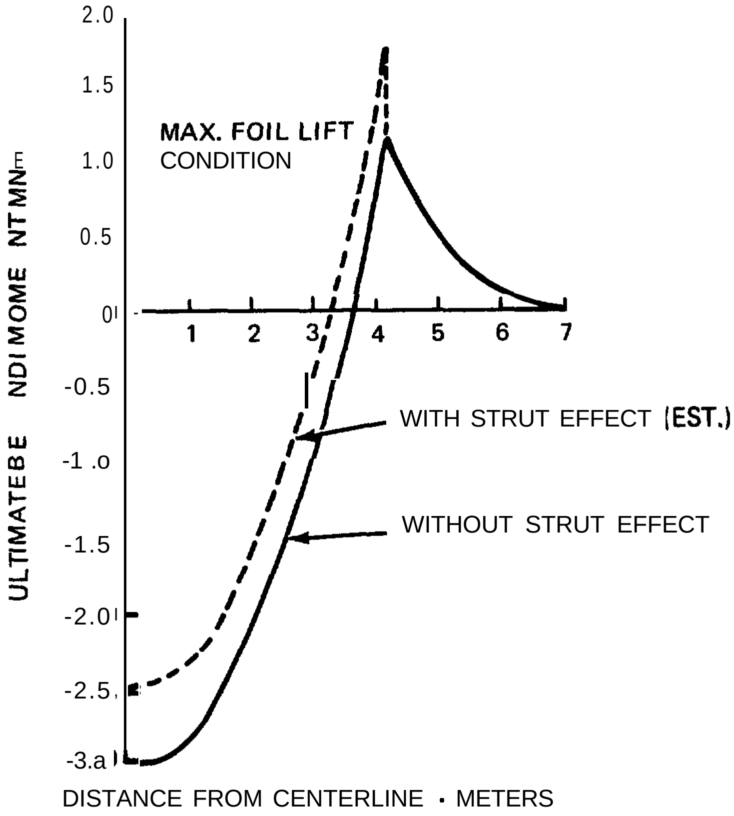

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Fig. 3-12 Aft Foil Ultimate Bending Moment (U)

Foil

The selection of foil planform and section, as previously discussed in subsection 2.4, in conjunction with the spanwise load distribution shown on Figure 3-10, dictated the selection of the preliminary scantlings shown on Figure 3-13. Trailing edge flaps are hinged at the 75 percent chord line.

Figures 3-14, 3-15 and 3-16 were derived from the ultimate load shear and bending moment curves (Figure 3-10), to enable the selection of suitable sections. Note that all curves except Figure 3-14 are based upon the NACA 16 series foil section. The rationale for the selection of this section over the series 64 is presented in subsection 5.5. Figure 3-14 was included to substantiate this selection based upon root section stress at ultimate load. Figure 3-15 graphically presents the preliminary method of foil skin and t/c selection. From Figure 3-10, the moment of inertia required to satisfy the ultimate load moment was plotted as "I Required" against foil thickness ratios. As maximum "I" for the selected sections would be developed by a solid section, it was plotted as a baseline,

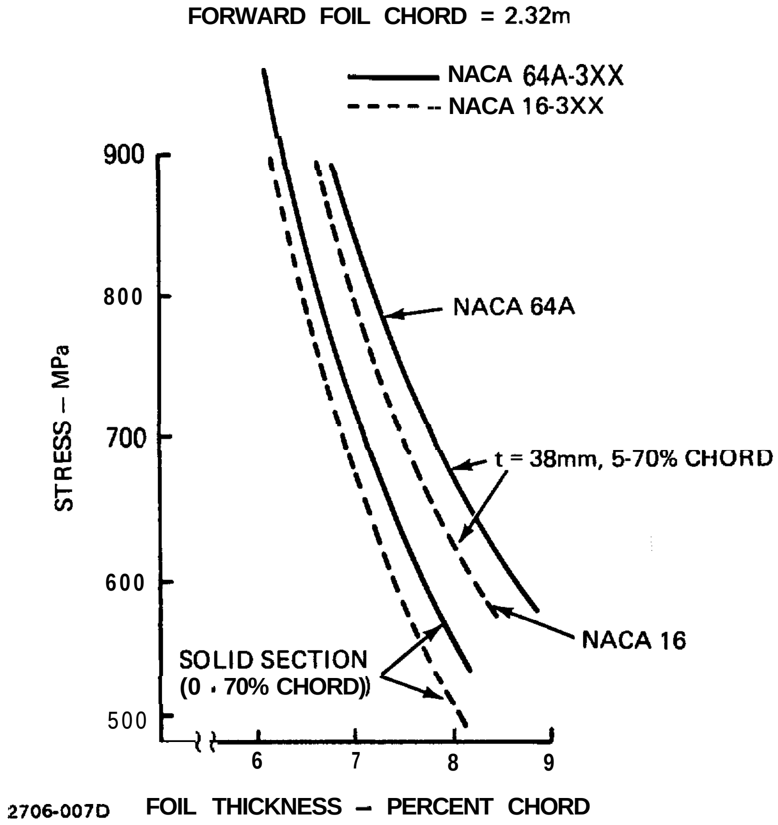

Fig. 3-14 Root Stress vs Foil Thickness (U)

Preliminary skin thickness to satisfy requirements were obtained by cross-plotting the moments of inertia, t/c values, and calculated skin thicknesses on Figures 3-16. From this figure, it is apparent that the 8 percent section is the most realistic one for the ultimate moment of 3.0 MN·m. The selection of 38 mm material for the skin is undoubtedly conservative, but it provides the margin for a more comprehensive detail design analysis which would include factors other than root bending, and would verify the predicted scantlings, which are based upon the use of HY 100 steel for both skins atnd internals.

Pod

The pod lines have been modified to reflect the characteristics of the Grumman M-151 design which has been successfully tested and for which drag characteristics can be reliably predicted. Construction is anticipated to be a combination of HY 100 steel and fiberglass.

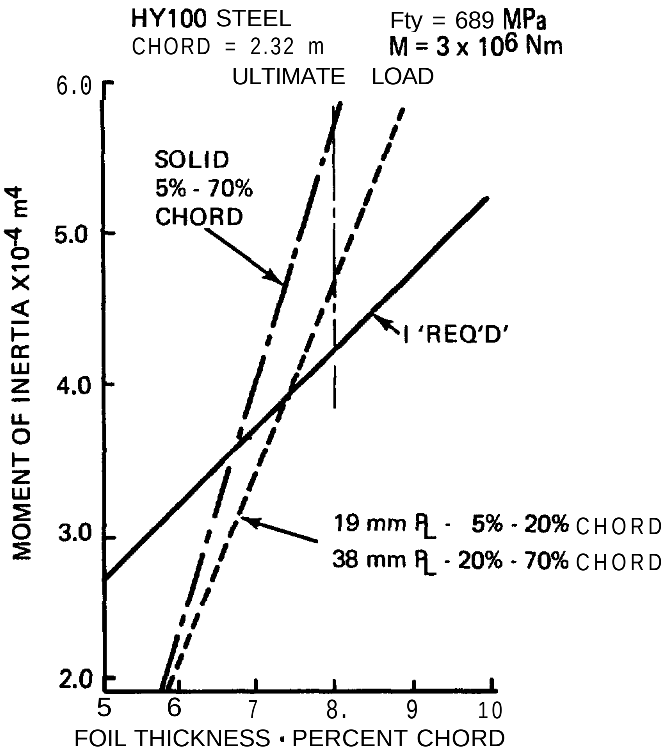

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Fig. 3-15 Forward Foil • NACA 16-30X • Moment of Inertia vs Percent Foil Thickness (U)

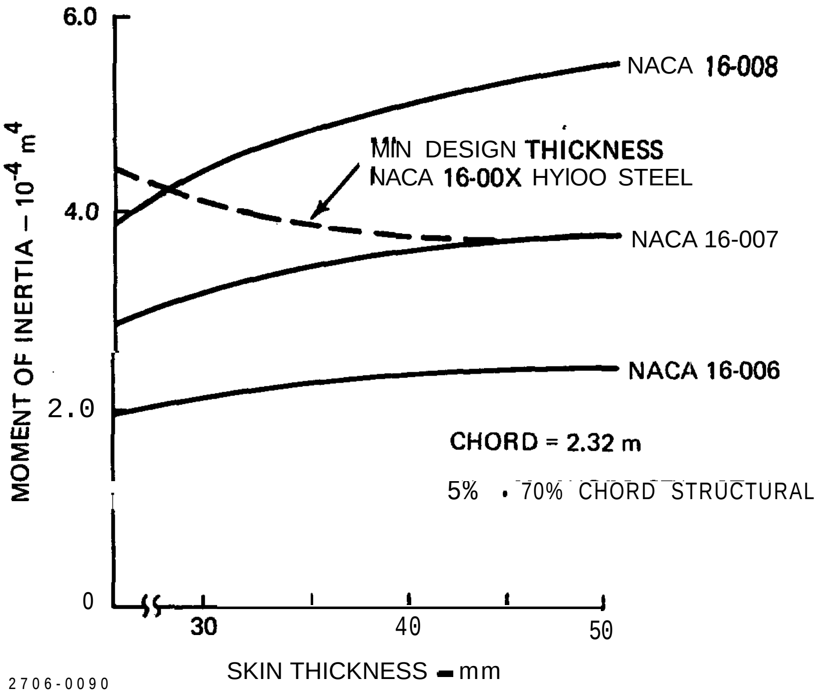

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Fig. 3-16 Forward Foil • Moment of Inertia vs Skin Thickness (U)

Yoke and Kingpost

There are no anticipated changes to the yoke and kingpost except for the substitution of HY 100 steel for the material currently specified for the PHM-3 series. Prior to detail design, an analysis would be required to verify the selection of material.

'Up and Down Locks

Subject to a more refined analysis, there is no necessity to consider revisions to the up and down lock systems currently specified for the PHM-3 series. In the event that a variable incidence system (subsection 5.4), is required, the downlock link would be modified to include a positioning actuator as shown on Figure 5-14.

Flap Control System

No changes to the flap control system are contemplated at this time, pending further review under a Detail Design Study.

Retraction

It is assumed that the PHM-3 series retraction actuator has an adequate margin to accommodate the increased retraction moment of the strut/foil system and that no change will be necessary. This assumption would be verified during a Detail Design Study.

Aft Lift System

Struts

The aft struts, as shown on Figure 3-17, have been redesigned to eliminate the propulsion water duct and to incorporate the mechanical transmission strut bevel gearbox, vertical shaft, and pod mounting. The strut length has been adjusted to reflect a foil chord plane submergence of 1.5 meters. The upper bevel gearbox is mounted with its input shaft located on the retraction axis so that there is no gear mesh disengagement during retraction.

Provision for sea water supply for heat exchangers, fire system, deck wash, etc., is made by the installation of a corrosion-resistanlt duct in the leading edge of the strut. Connection to the hull seawater system is made through a compression fitting between the top of the strut and the underside of the fairing.

Construction is of conventional welded spar and skin method with HY 100 steel used throughout. A constant chord section has been selected to simplify construction.

Foil

The aft foil design differs from the PHM-3 series in that it incorporates tapered leading and trailing edges, and has eliminated the foil anhedral. The planform and section selection have previously been discussed in subsection 2.4. Trailing edge flaps are hinged at the '75 percent chord line. The preliminary scantlings shown on Figure 3-17 have been developed from the spanwise load distribution as shown on Figures 3-18 and 3-19. Figures 3-20 through 3-23 were plotted to obtain preliminary skin thickness in a manner similar to that previously described for the forward foil, except that conditions at both foil centerline and at strut locations were investigated.

In addition, two additional comparitive plots are included as Figures 3-24 and 3-25. Figure 3-24 compares root stress at ultimate load vs. percent foil thickness, and Figure 3-25 compares the solid section moments of inertia for NACA 16 and NACA 64 series sections. Additional analysis beyond the scope of this contract is necessary to further verify the predicted scantlings, which are based upon the use of HY 100 steel for both skins and internals.

Pod

The pod houses the lower bevel gearbox, planetary gearbox, and interfaces with the controllable pitch propeller cartridge. The lines have been developed from a Grumman design for which reliable hydrodynamic characteristics have been developed. The mid-body section which houses the gearboxes is considered an integral part of the transmission, and as such becomes the responsibility of the transmission manufacturer to fabricate. The nose cone is of molded fiberglass construction and, if desired, may house transducers or sensors. The pod nominal diameter is determined by the diameter of the planetary ring gear and is, therefore, tentative, as shown in Figure 3-17, pending acceptance of overall gear train reduction which is discussed in subsection 5.3.

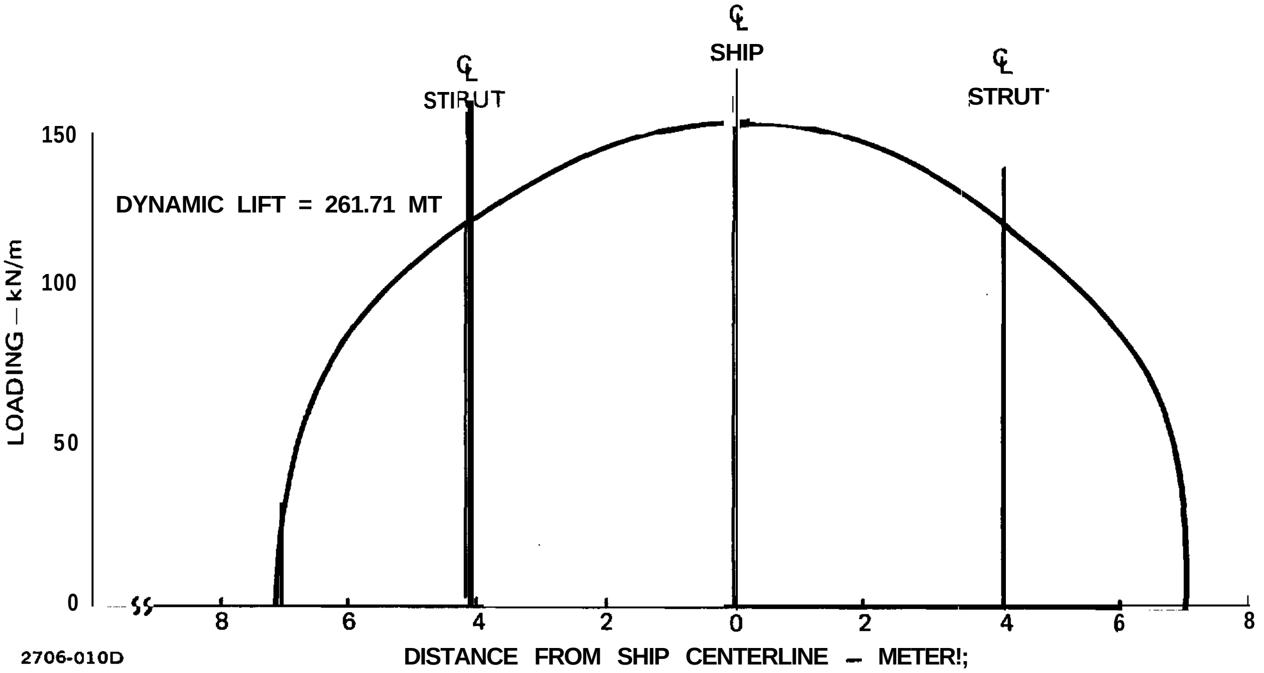

Fig. 3-18 Aft Foil · One Factor Loading (U)

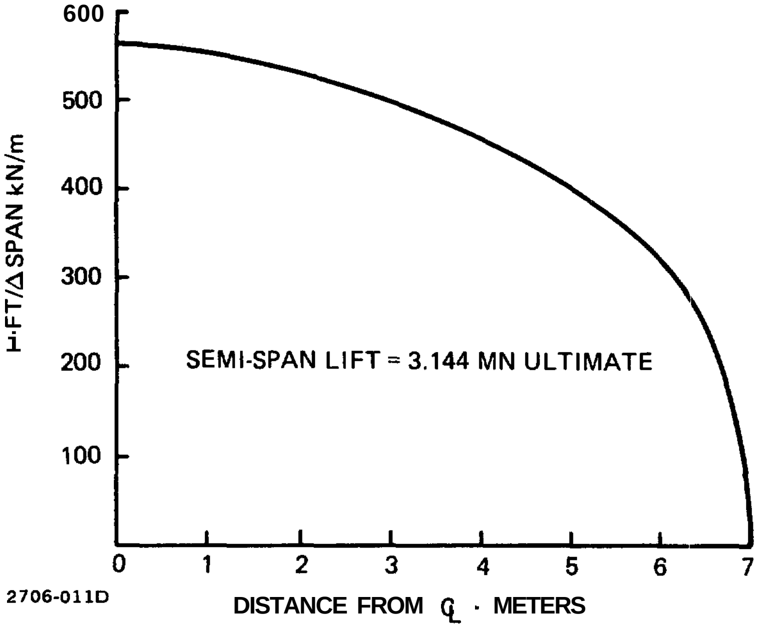

Fig. 3-19 Aft Foil Ultimate Lift · Maximum Foil Lift Condition (U)

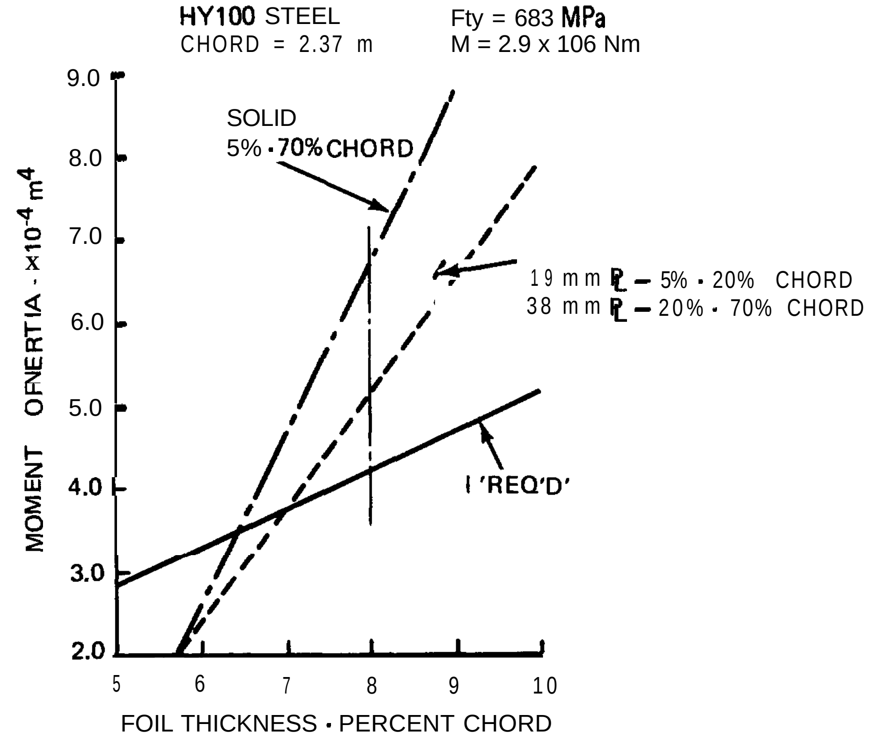

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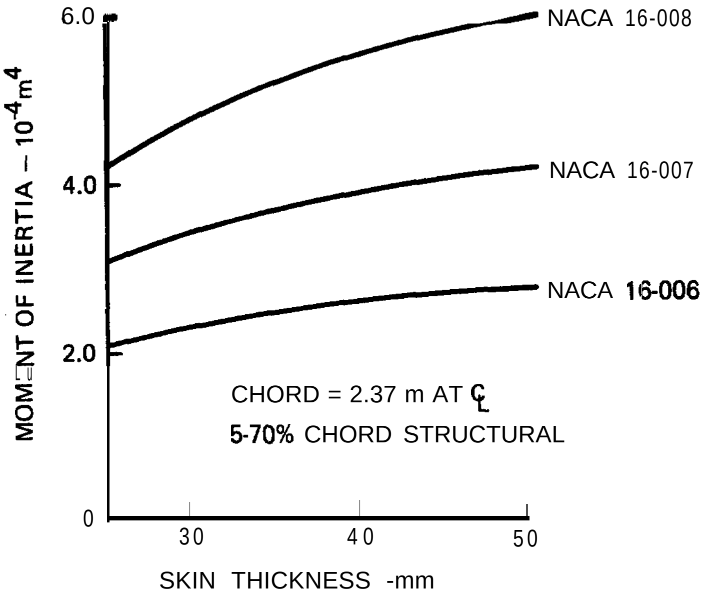
Fig. 3-20 Aft Foil - NACA 16-30X - Moment of Inertia vs Foil Thickness (U)



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Fig, 3-21 Aft Foil Moment of Inertia vs Skin Thickness at Centerline (U)

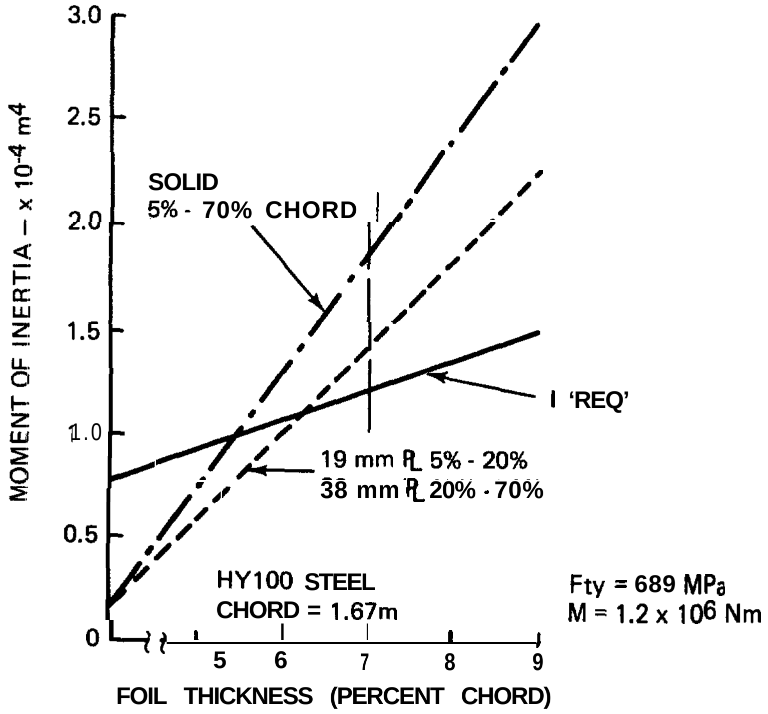

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Fig. 3-22 Aft Foil – NACA 16-30X – Moment of Inertia vs Foil Thickness (U)

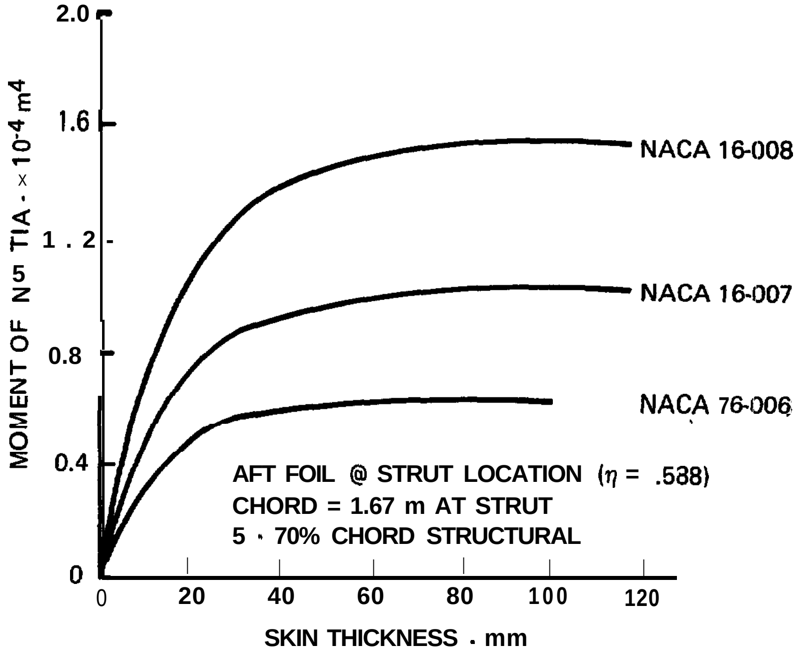

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Fig. 3-23 Aft Foil - Moment of Inertia vs Skin Thickness at Strut (U)

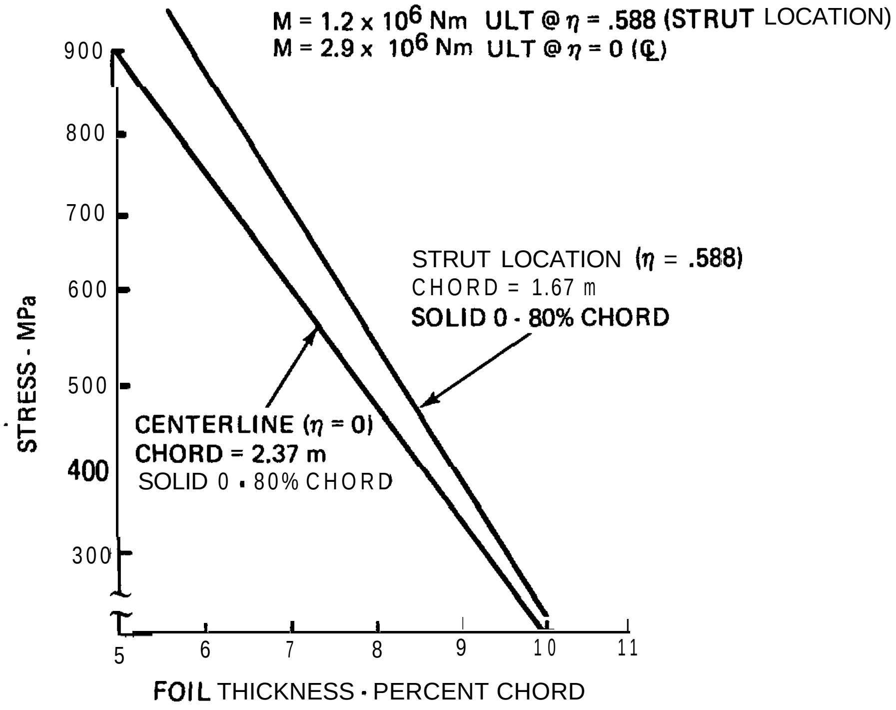

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Fig. 3-24 Aft Foil – NACA 16-30X – Stress vs Percent Solid Foil Thickness (U)

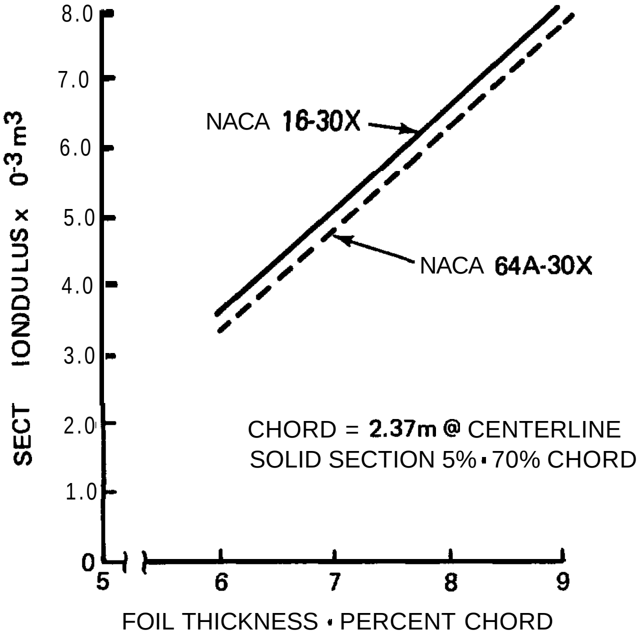

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Fig. 3-25 Aft Foil - Section Modulus vs Percent Foil Thickness (U)

Flap Control System

The flap control system for the aft foil is, in principle, th.e same as the PHM-3 series. However, due to the location of the foil, forward of the transmission components located in the pod, it is necessary to introduce additional linkage between the actuator and the flap cranks. Pending detailed analysis which is outside the scope of a preliminary design, it is assumed that there is sufficient margin in the PHM-3 flap control system design that modifications to the actuator would not be necessary.

Retraction

Retraction of the aft foil assembly is similar to the PHM-3 series. The retraction axis on Bulkhead 30 has been lowered about 250 mm to provide sufficient deckhead clearance to install the inboard hull bevel gearbox. It is anticipated at this time that the actuator pivot point would remain in the same location, and that the revised geometry would not require an actuator of different stroke or diameter.

Up and Down Locks

PHM-3 series up and down locks and lateral restraint fittings are to be retained. In the course of subsequent detail design, they should be further analyzed to confirm their adequacy for the new strut design and thrust loads.

Installation of Upper Bevel Gearbox

The aft strut pivot trunnion is the primary carry-through structure between the strut and hull, and the support for the strut upper bevel gearbox. Access for installation of the gearbox is provided by means of a removable cover which forms the trunnion outboard closure. The two upper gearbox support fittings install through the forward and aft trunnion walls and are secured by means of split fittings. The third support fitting is located inside the trunnion below the gearbox lower drive separation plane, and is accessible via the outboard trunnion cover.

On installation of the bevel gearbox, the inboard drive shaft coupling is moved outboard on centerline and attached. The gearbox and inboard drive are then moved inboard to align with the lower driveshaft coupling. After securing with the three mounting fittings, the lower drive coupling assembly is completed.

Finally, the outboard cover is installed on the trunnion along with the outboard 'boot strap" fitting to complete the structural attachment.

The preceding description is conceptual only, as analysis of the trunnion box is beyond the scope of a Preliminary Design Study. It is felt, however, that while there undoubtedly are undefined problems, they will not cause any major reassessment of the installation.

3.5 MISCELLANEOUS SHIP SYSTEMS

Other than the combustion air system, transmission lube oil system, and propeller pitch control system, which are major elements of the Advanced Technology Lift and Propulsion System, certain other ship systems require minor modifications to properly adapt them to the new arrangement. While diagrams for all systems on the PHM-3 series were not available during this study, reference was made to PHM-1 drawings to obtain guidance information for future efforts.

Main Engine Demister

The main engine demisters were derived from an earlier design, and are of relatively lightweight and compact design. Sizing of the demister was accomplished by a direct ratio of the air flow requirements of the 501 KF engine (16.3 kg/s) to the 570 KA engine (19.5 kg/s). This method of sizing was corroborated by the manufacturer of the earlier demister. Each demister will be a 3-stage unit and will meet the performance requirements of the engine manufacturer. Each engine will be provided witlh a blow-in door mounted in the aft bulkhead of the deckhouse to relieve system pressure at a preselected level by allowing a portion of the intake air to bypass the demister. These doors will also provide access to the plenums. The air velocity thru each clean demister will be approximately 5.8 m/s.

Main Engine Air Inlet and Exhaust Plenum

Both the air inlet and exhaust plenums were designed from the information and details contained in Detroit Diesel Allison Dwg. No. 6894901 for the 570 KA engine. The major deviation from the recommended plenum configurations was that the inside radius of each plenum was reduced about 50 mm to maintain the existing width of the engine compartment. To compensate for the reduction in width, the length of each plenum was proportionately increased to provide the equivalent cross-sectional area. The engine manufacturer indicated that this configuration would not significantly affect the engine inlet or exhaust losses.

The aft sloping bulkhead of the inlet plenums is to be fabricated as a portable installation to be removable in the event that main engine removal is required.

Main Engine Cooling Air

Recommended cooling air requirements for each engine are approximately 3.8 m^3/s. The existing 508 mm diameter air ducts may be used by modifying the duct and installing vaneaxial blowers within the ducts in the engine compartment .

The engine manufacturer is reviewing the possibility that the cooling air requirements could be reduced if certain high heat rejection components such as the electronic fuel controller were locally cooled. In such a case, the blower size and weig'ht would be significantly reduced but additional ducting would be required. The engine cooling air will be exhausted up the main engine exhaust ducts in a fashion similar to the PHM-3 series, as shown in Figure 2-5.

Transmission Lube Oil System

The transmission lube oil system, as shown on Figure 3-26, consists of identical and independent port and starboard pump-driven systems which provide temperature conditioned, pressurized oil to each gearbox and to the strut and pod seals. In addition, the transmission lube oil system provides make-up oil to the prop pitch control head tank. This make-up system is required clue to *a* differential pressure *across* the pod's propeller cartridge seal which may result in a small amount of oil leaking from the propeller cartridge into the planetary gearbox.

Each system utilizes a single element positive displace-ment supply pump driven off of the hull-mounted gearbox and an electric pre-lube pump. An oil heater in each main tank and remotely operable valves permit recirculation and temperature conditioning during the pre-lube cycle. Electric: pumps are employed for pre-lube scavenging while each gearbox utilizes gear-driven pumps for scavenging while running.

The port and starboard systems are connected only by a common fill line and optional replenishment tank. Further investigation may favor a larger capacity main tank and elimination of the replenishment tank.

Main Engine Lube Oil System

The lube oil system for the Detroit Diesel Allison 570 KA gas turbine engine as shown on Figure 3-26 is self-contained with the exception of an external fuel/lube oil heat exchanger. This heat exchanger serves a dual purpose as it provides heat for the fuel while the fuel is cooling the oil. This will effectively reduce the required capacity of the lube oil/seawater heat exchangers in the lube oil systems.

Propeller Pitch Control System

The propeller pitch control system, as shown on Figure 3-27, consists of identical and independent port and starboard hydraulic systems, each having servo, control, and bearing lubrication supply and return circuits, which provide pitch control to the variable pitch propellers. A 0.114 m^3 pressurized head tank supplies the main pump which is gear-driven off of the hull-mounted gearbox. The main pump provides pressurized fluid to the servo, control and bearing lube circuits. An electric motor-driven pump provides the power to drive the propeller blades to zero pitch prior to system start-up. The 'head tank is interconnected by piping and remotely operable valving to the transmission lube oil tank to make up for any loss of fluid across the propeller cartridge seal. This interconnection is possible inasmuch as the propeller pitch control system uses the same fluid as the transmission lube oil system.

Electrical control of the 3-way pitch control solenoid is provided by signals from the engine electrical control panel which monitors turbine speed.

Sea Water System

The craft seawater system as installed on the PHM-3 series obtains its water supply through a takeoff from the main propulsion water duct. Because this duct is eliminated, the supply system must be modified. Intake ducts of adequate capacity are installed in the leading edges of the two aft struts, as shown in Figure 3-17, which would mate with a similar duct within the hull through a compression type seal.

Hydraulic System

Modifications to the hydraulic system are minimal, and are primarily concerned with the relocation of the hydraulic pumps from the single General Electric LM 2500 gearbox to the two hull-mounted gearboxes for the Allison 570 KA engines, and the relocation of Ship's Service Power Unit. No. 1 from the Main Deck to the Platform. For these relocations, the system schematic would not require changing, but physically, piping modifications would be required.

Connections required to be made between the hull systems and the aft strut would be through swivels and/or flexible hoses. A typical style of swivel which would satisfy the requirements for the hydraulic system is shown on Figure 3-29. In addition, if the option to install the variable incidence system (subsection 5.4) is exercised, additional circuitry to the added actuator would be required, as well as modification to the retraction actuator system to eliminate the opposing force when incidence change is affected. This modification is as shown on Figure 3-28.

Fuel System

The fuel system storage capacity will be increased by approximately 17 metric tons by the addition of four tanks. Two tanks will be located in the wings between Bulkhead 21 and Bulkhead 25 with an interconnecting duct, if found necessary, between the tanks to insure damage control flooding. Each wing tank will have its own suction line, pump, vent, and discharge lines connected to its respective port and starboard headers. Further investigation may reveal that the wing tank pumps may be eliminated by manifolding their suction lines to the port and starboard fuel pumps serving fuel tank No. 4. The other two additional tanks are located on centerline, one between Frame 28 and Bulkhead 30 and the other between Bulkhead 30 and Bulkhead 33. Each of these tan'ks will have independent pumps and accessories similar to the existing fuel tanks. Capacities of the individual tanks are as noted in subsection 2.3.

Air Start System

The air system will be utilized to start the main engines from the ship service power units (SSPU) bleed air as is done in the PHM-3 series design. The air start ducting from the aft SSPU forward to Frame 29 will remain the same. Forward of Frame 29, the ducting will be routed outside the engine

At the request of NAVSEC 6114, the Propeller Pitch Control Diagrammatic has been included in Grumman Letter Report PMM-NSE-L79-31, Reference 16.

Fig. 3-27 Propeller Pitch Control Diagrammatic (U)

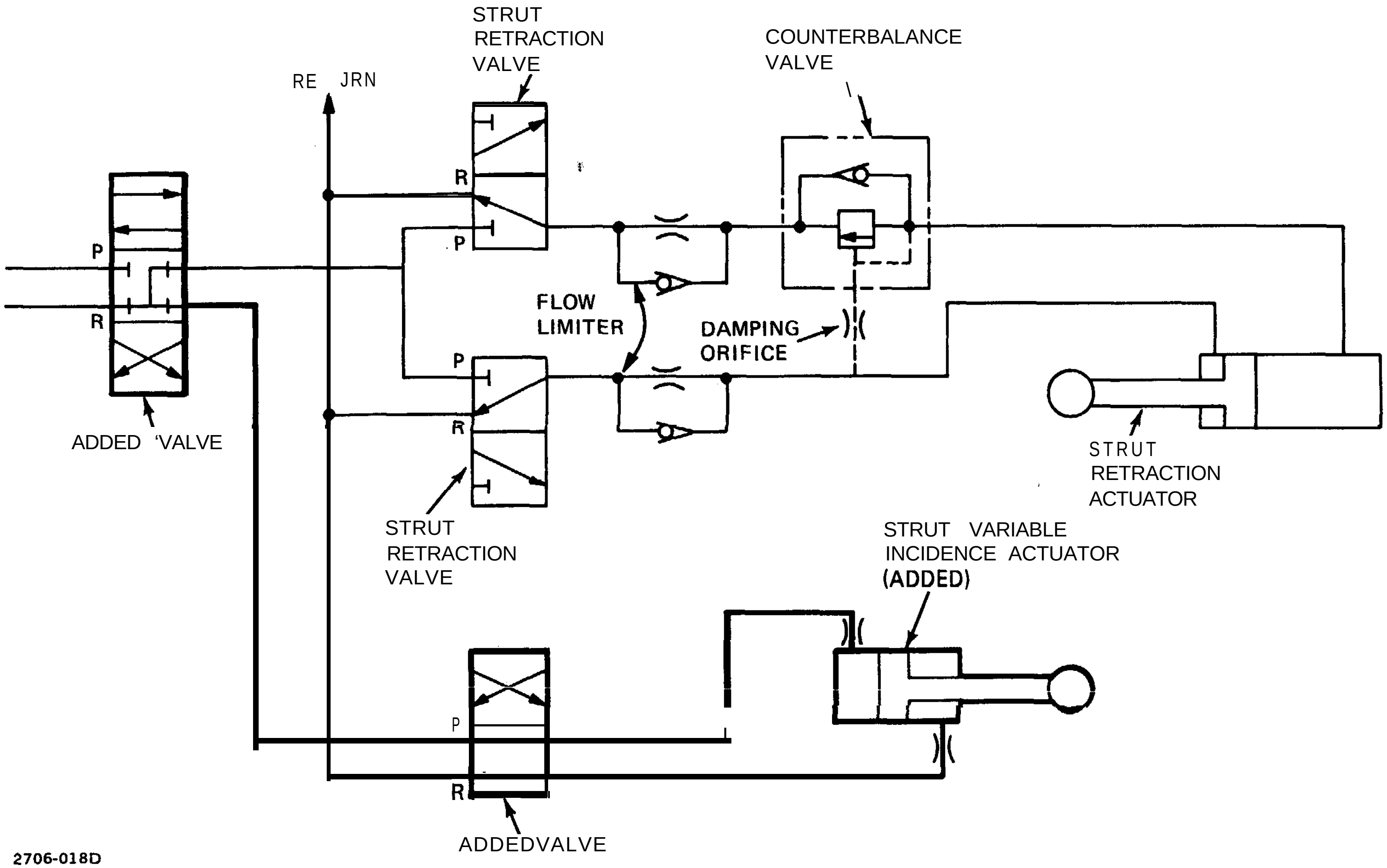


Fig. 3-28 Hydraulic System Modifications for Variable Incidence (U)

compartment and be manifolded to the forward SSPU's air start duct between Frames 26 and 27 (Figure 2-5). At this point, the air start duct would penetrate the engine compartment bulkhead and be connected to each engine's starter through isolation valving. This routing permits starting both engines from either SSPU.

Compressed Air System

The existing compressed air system will be expanded to provide pressurized air to the following systems:

a) Prop Pitch Control Head Tank (0.05 MPa)
b) Transmission Lube Oil Main Tank (0.06 MPa)
c) Transmission Lube Oil Pod Seal Tank (0.14 MPa) .

Fire Detection and Extinguishing

The existing engine fire detection and extinguishing system may be used by increasing the number of detectors and extending the fire extinguishing coverage to the two engine compartments and the gearbox locations.

Command and Control

The installation of the mechanical transmission system and the controllable pitch propeller system includes transmitting devices for temperature, pressure, vibration, etc., which require monitoring at the Engineer's Operating Station and/or the Helm Station.

Additionally, electric engine control throttles will be required for the two Allison 570 KA gas turbine electronic controls in lieu of those for the single General Electric LM 2500 engine.

Electrical System

Although an analysis of the electrical system does not fall within the scope of this study, certain modifications and deviations from PHM-3 series are obvious, and subject to review during a subsequent Detail Design Phase. Principal among these would be the changes necessitated by the relocation of the ship's service power units and the switchboard. In addition, service would be required to be provided to the additional electrically driven fuel, lube oil, and propeller pitch pumps with necessary wiring, controls, and protective devices,

SECTION 4

PERFORMANCE

[redacted]

4 - PERFORMANCE

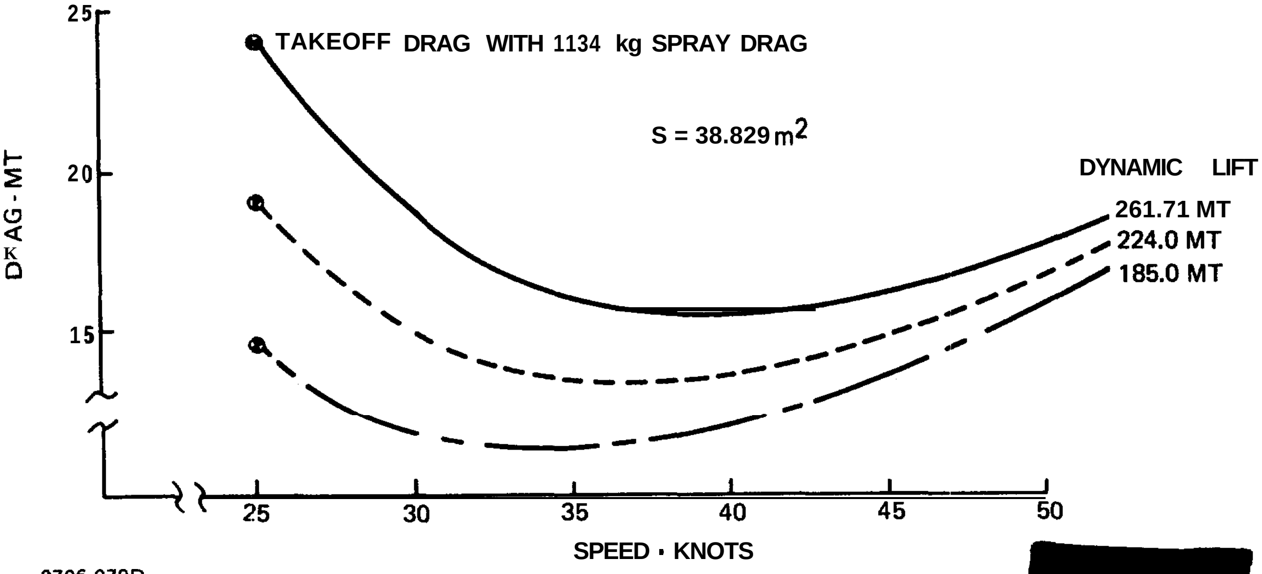
4.1 VEHICLE PERFORMANCE

(U) The performance of the design is illustrated by the figures in the following subsections, together with supporting narrative, as appropriate.

4.2 DRAG, THRUST AND POWER

Drag vs Speed

(U) Figure 4-l presents the takeoff and cruise drags as a function of speed for three dynamic lift conditions. The takeoff drag values contain an estimated hull spray drag term of 1134 kg. The full load design condition drag curve corresponds to the dynamic lift equal to a 261.71 metric ton plot.



[redacted]

Fig. 4-1 Drag vs Speed - Smooth Water (U)

[redacted]

A decomposition of the parasite drag components is presented in Figure 4-2 for the full load condition. The drag coefficients used to obtain these drag components are found in Figures 2-11 and 2-12 of subsection 2.4.

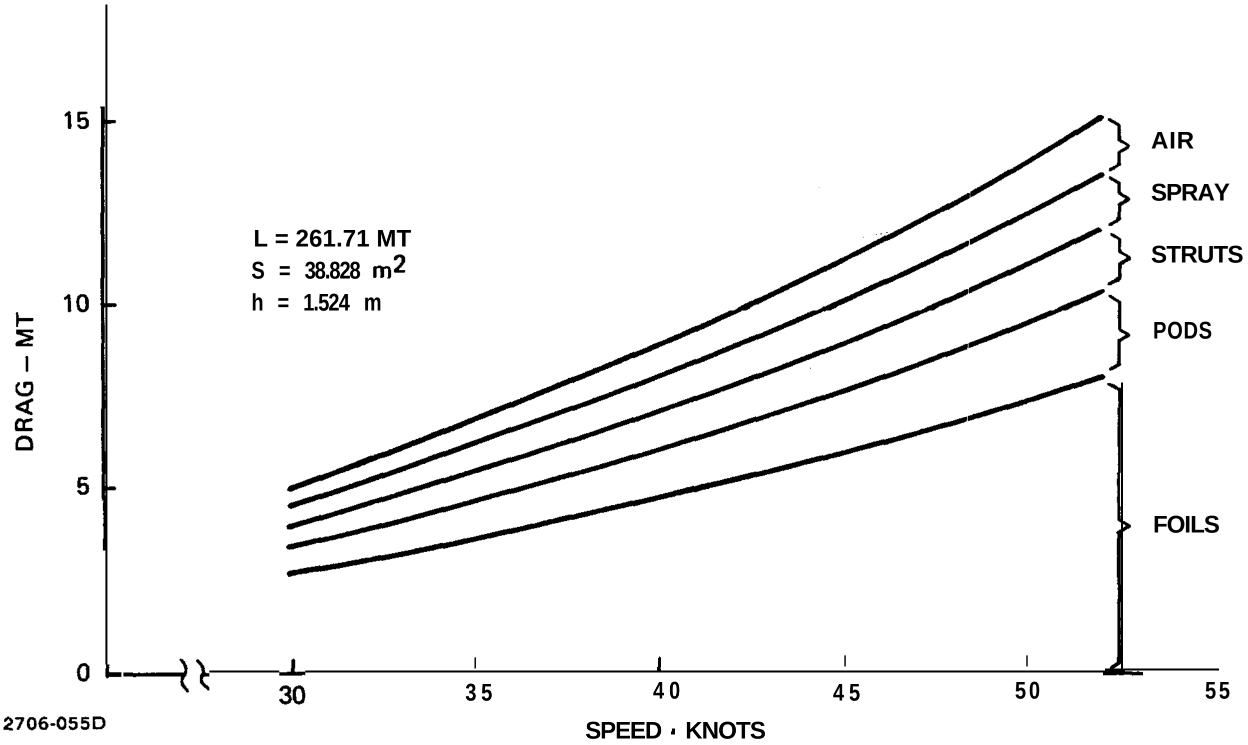


Fig. 4-2 Parasite Drag Decomposition (U)

Figure 4-3 is a decomposition of the total drag at the Design M-167 full load condition. These drags were obtained using the **equations** presented in subsection 2.4.

Thrust and Drag vs Speed

Figure 4-4 is a plot of thrust and drag vs. ship speed for several dynamic lift conditions. The thrust curves shown for maximum intermittent and continuous power settings were obtained from the propeller/engine match for an 26.7’ C day as shown in Figure 3-2 of subsection 3.3. Available engine power and matched RPMs and delivered power to the propellers are summarized below:

	MAX. INTERMITTENT	CONTINUOUS
ENGINE POWER (kW)	4735	4026
ENGINE RPM	11000	9500
POWER EXTRACTION (kW)	75	75
TRANSMISSION POWER LOSS $(1 \cdot \eta_{TRANS})$ (kW)	283	237
PROP DELIVERED POWER (kW)	4377	3714

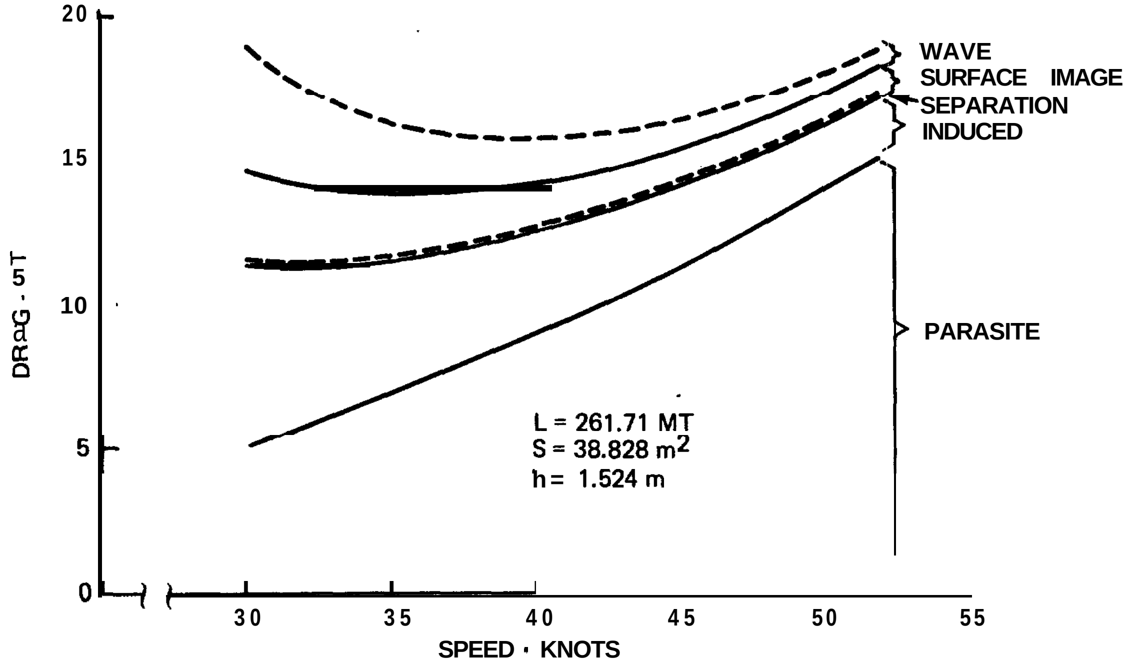


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Fig. 4-3 Cruise Drag Decomposition (U)

[redacted] Power extractions of 75 kW per engine are estimated values for propeller and transmission system pumps (pitch and lube oil) and for foil actuation hydraulics. At the full load dynamic lift condition of 261.71 metric tons, Figure 4-4 shows a takeoff thrust margin of 35 percent and a design speed thrust margin of 5 percent

Maximum Speed and Takeoff Thrust Margin vs Dynamic Lift

(U) Figure 4-5 demonstrates the sensitivity of dynamic lift to takeoff thrust margin and maximum speed. As the dynamic lift increases, the drags due to lift increase, which is reflected by a decrease in both the maximum speed and the takeoff thrust margin.

[redacted]

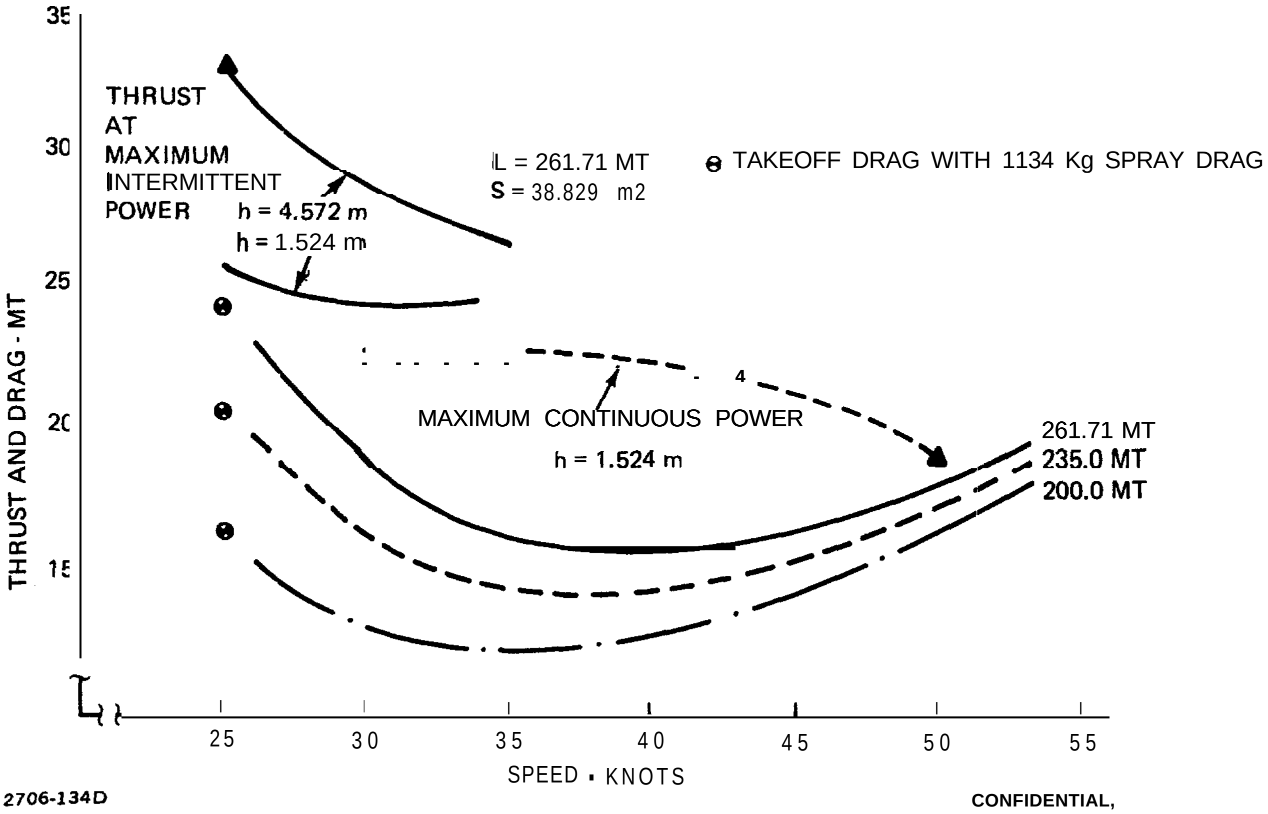

Fig. 4-4 Thrust and Drag vs Speed (U)

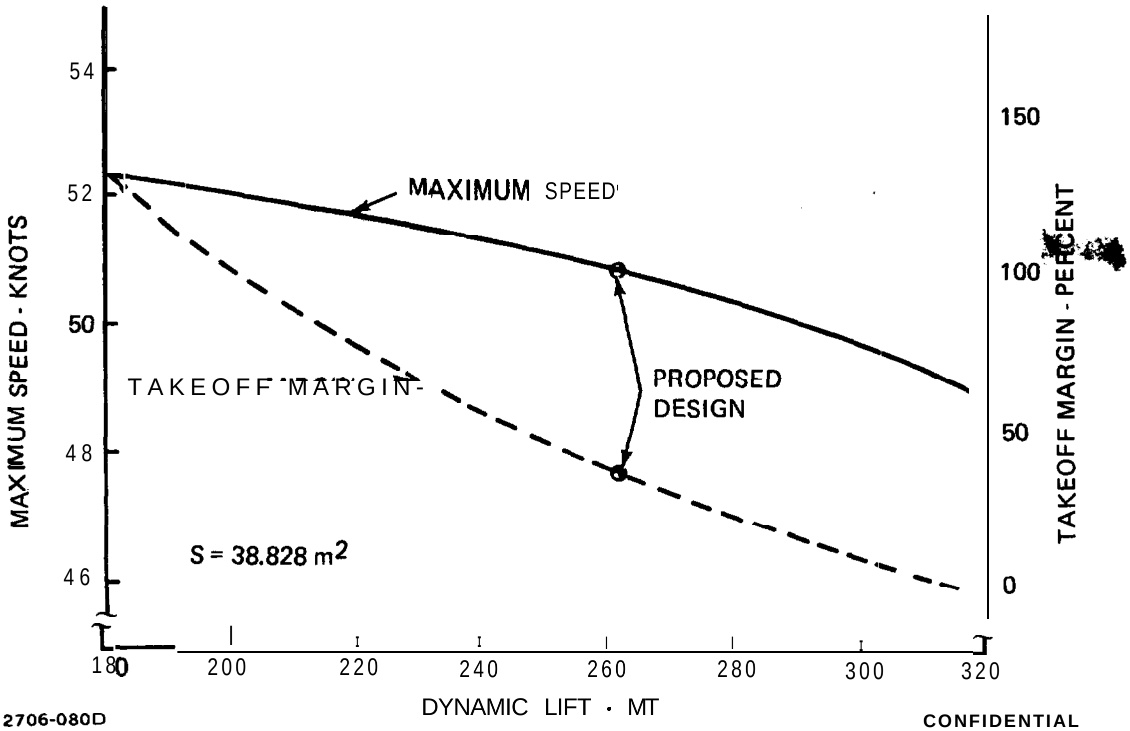

Fig. 4-5 Maximum Speed and Takeoff Thrust Margin vs Dynamic Lift (U)

[redacted]

[redacted]

[redacted] The full load dynamic lift condition of 261.7 metric tons shows a takeoff thrust margin of 35 percent and a maximum speed of 50.9 knots (based on the continuous power thrusts presented in Figure 4-4). If the design were operating in the one-half fuel load condition (-230 metric tons based on 64 metric tons of fuel), the maximum speed would increase to 51.8 knots and the takeoff thrust margin would increase to 64 percent.

[redacted] Standard design procedure requires a takeoff thrust margin of 25 percent (PHM-1 demonstrated a takeoff thrust margin of 22 percent during sea trials). Based on a 25 percent thrust margin at takeoff, the foils could produce 275 metric tons of dynamic lift and achieve a top speed of 50.3 knots at maximum continuous power.

Variation of Dynamic Lift and Maximum Speed with Takeoff Speed

[redacted] The effect of increasing the takeoff speed from 25 knots to 35 knots is presented in Figure 4-6. A takeoff speed of 28.5 knots produces a maximum dynamic lift of 262.6 metric tons. Above this takeoff speed, the dynamic lift drops off sharply and the thrust margin at design speed and maximum speed increase slightly.

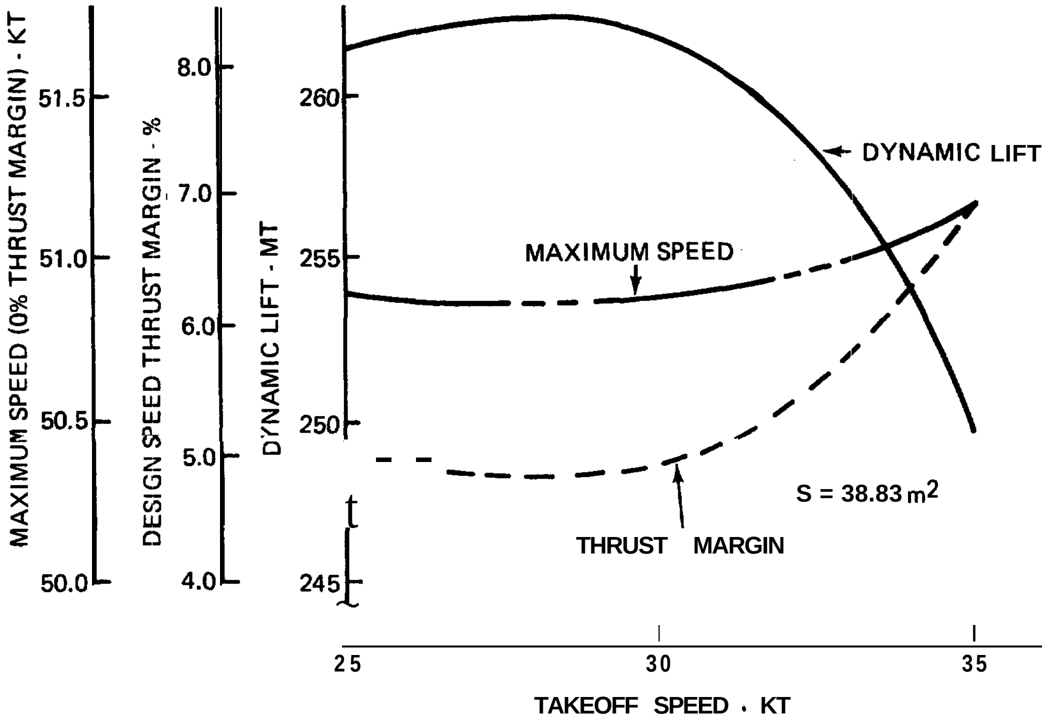

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Fig. 4-6 Effect of Takeoff Speed on Dynamic Lift and Design Speed (U)

[redacted]

[redacted]

Power Requirements

(U) Ship foilborne powering requirements for the three dynamic lift conditions presented in Figure 4-4 are shown in Figure 4-7. Engine power requirements include the effects of transmission efficiency and all power extractions from the engine for ship systems. For the condition presented, the total power extraction for foil actuation hydraulics, and propeller and transmission subsystems (lube oil and pitch pumps) was estimated to be 75 kW. Total engine power required is therefore derived by the following relation:

$$BP_{engine} = (DP_{propeller}/\eta_{Trans}) + 75$$

where: DP = delivered power to propeller

η_{Trans} = Transmission Gear Efficiency

NOTE:
GEAR EFFICIENCY = 94%
POWER EXTRACTION = 75 kW/ENGINE

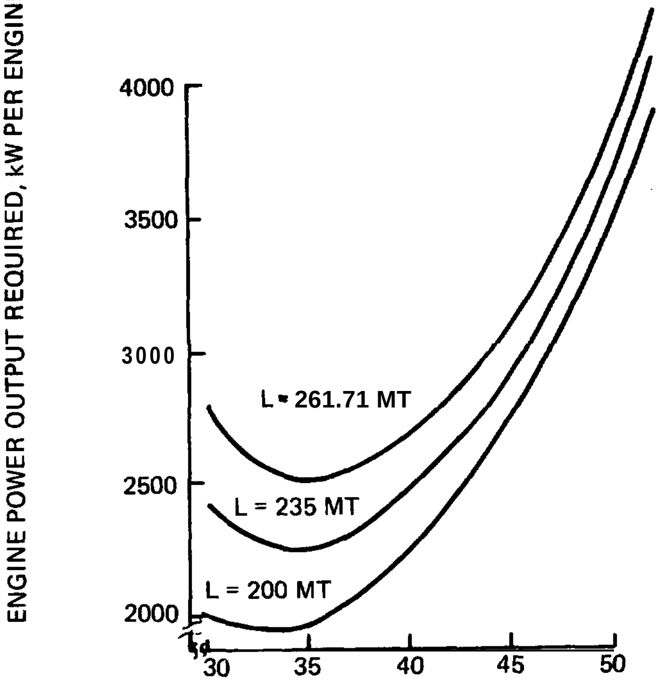

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Fig. 4-7 Power Requirements - 1.372 m Diameter Propeller (U)

[redacted]

[redacted]

Propeller/Engine Match

(U) Power requirements for the 261. '71 and 200 MT dynamic lifts are shown matched to the Allison 570 KA engine in Figure 4-8. Although the matched power and RPM characteristics are within the engine and transmission

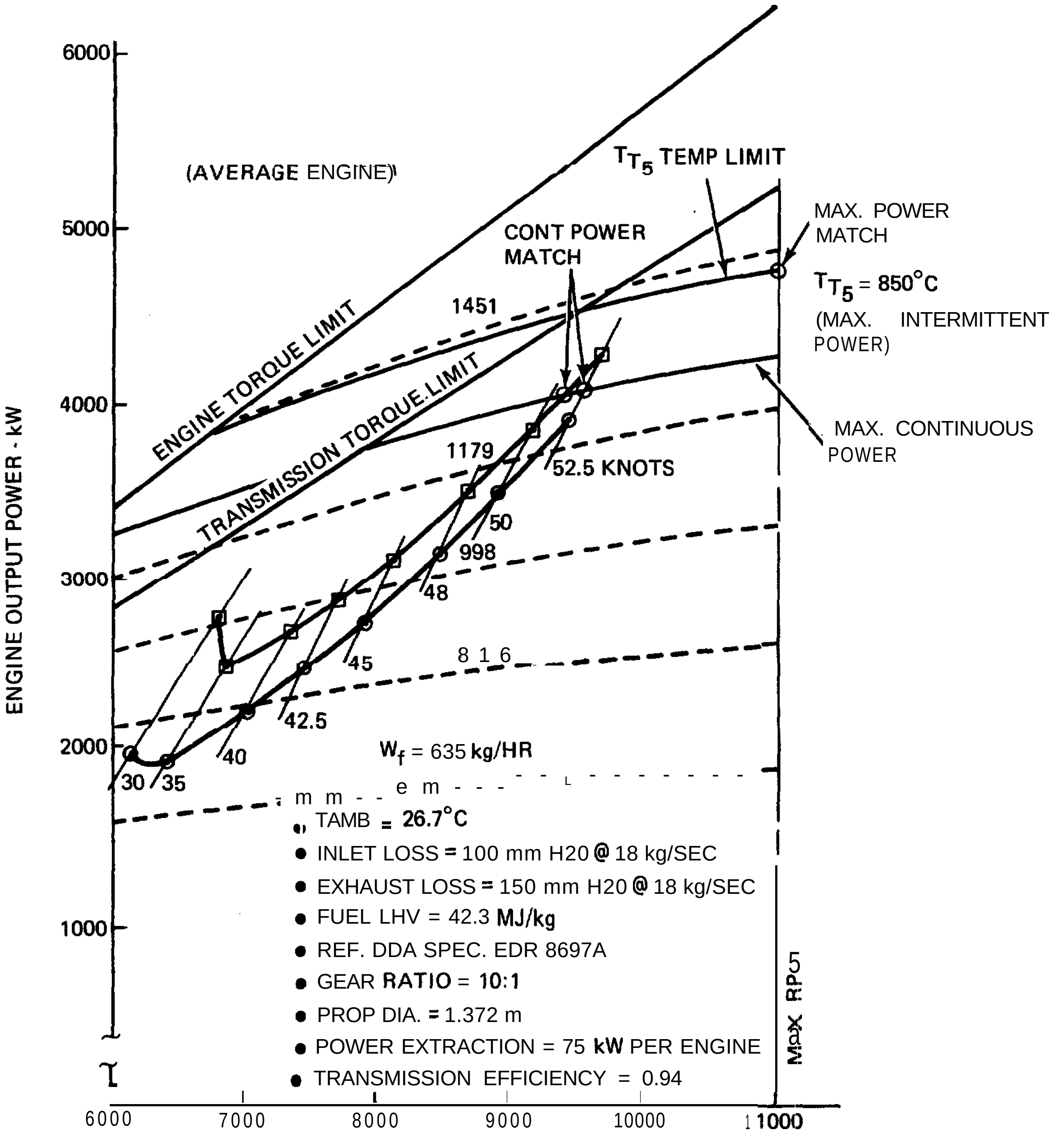

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Fig. 4-8 Propeller/Allison 570 KA Engine Match Installed Performance (U)

[redacted]

operating envelopes, the matched operating lines are relatively close to the transmission torque limit. A shift to higher engine RPMs may, therefore, be desirable by using a slightly higher transmission gear ratio, This possibility will be investigated in detail during subsequent phases. Final matched characteristics and exact gear ratio selection will be based on the complete propeller performance characteristics as generated by propeller model tests.

The intersection of the power required and fuel flow rate lines defines the propulsion engine fuel requirements for an average engine and were used for the generation of the specific range characteristics discussed in the following subsections.

4.3 FOIL & PROPULSION SYSTEM EFFICIENCIES

Foil Efficiency

Figure 4-9 presents the cruise dynamic lift-to-drag ratios for various dynamic lift conditions. Maximum lift-to-drag ratio for the full load design condition (261.71 metric tons) is 16.8 at 39.5 knots. As the dynamic lift decreases, the speed for maximum lift-to-drag ratio and the magnitude of the lift-to-drag ratio decrease, which is characteristic of conventional hydrofoil designs.

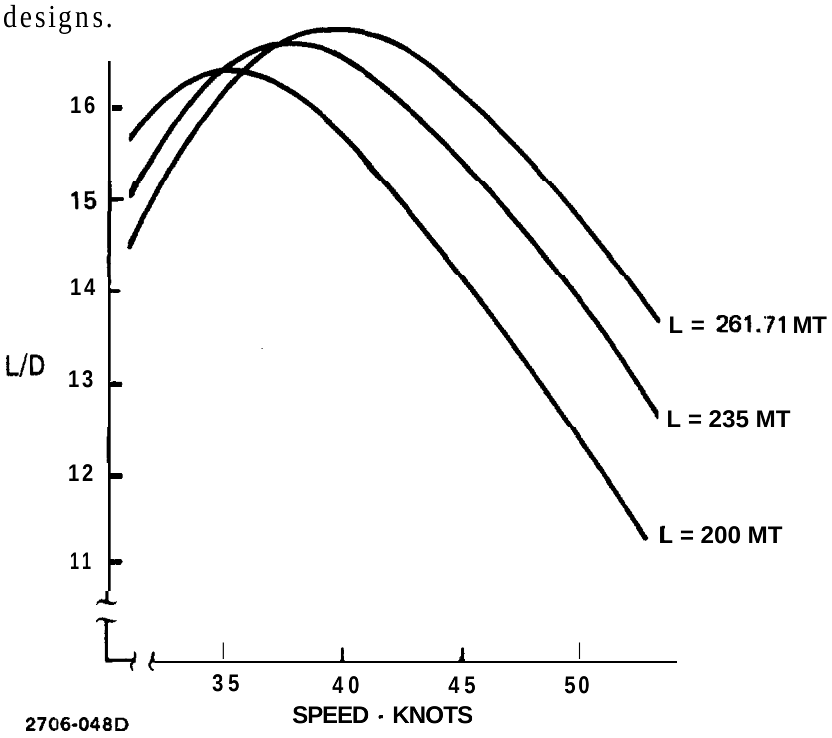

Fig. 4-9 Lift-to-Drag Ratio vs Speed (U)

Foilborne Propeller Efficiency

(U) Foilborne steady-state speed matched efficiencies are presented in Figure 4-10. At normal cruise speeds of 43 to 45 knots, dynamic lift produces less than a 1 percent variation in propeller efficiency. From 43 knots to design ship speed, the drag and propeller characteristics are such that the propeller can operate at its design pitch ratio (P/D), and at or near the advance ratio (J), for maximum efficiency for all dynamic lift conditions.

(U) Near minimum foilborne ship speed (~ 35 knots), the propeller starts to match at off-design conditions (P/D and/or J) with a larger variation in matched efficiency. Even at these speeds, however, the total variation is less than 2 percent.

(U) Propeller performance is based on a Taylor wake fraction (l-w) of 0.95 and a thrust deduction (l-t) of 0.95. Relative rotative efficiency, M_{RR}, is not expected to be below 0.98, and has been implicitly included in the conservative thrust deduction factor.

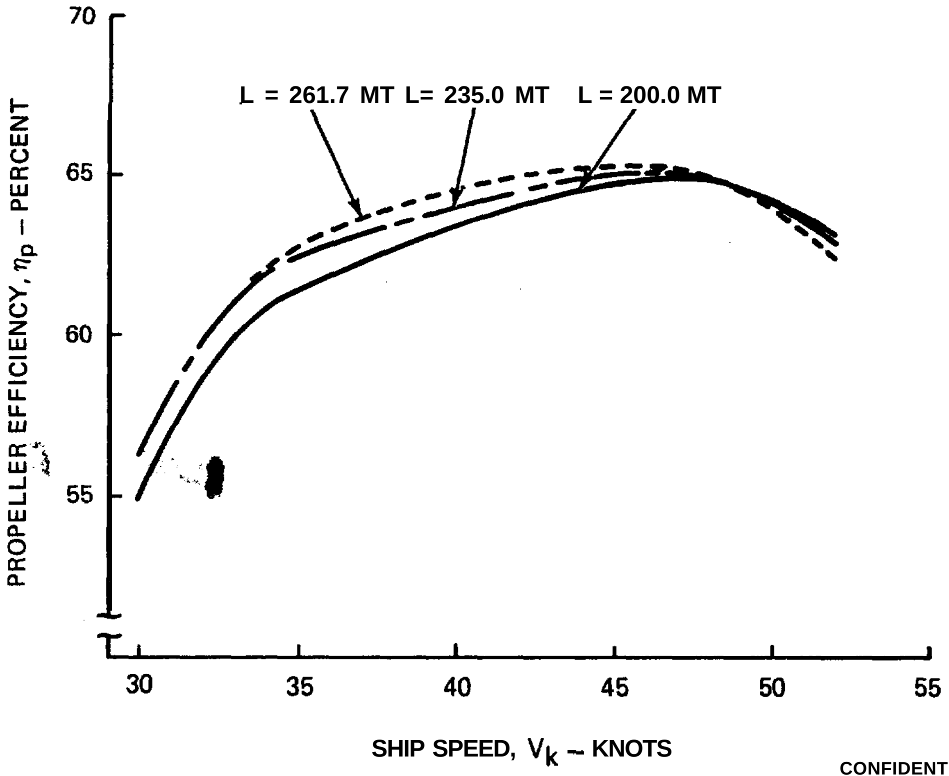

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Fig. 4-10 Matched Propeller Efficiencies at Foilborne Cruise (U)

[redacted]

4.4 RANGE AND ENDURANCE

Specific Range

(U) The matched fuel flows for the three dynamic lift-power characteristics shown previously (Figure 4-7) were combined with the PHM-3 ship service fuel flow rate to obtain the average engine foilborne specific range characteristics shown in Figure 4-11. The peaks of the specific range characteristics define the speed for maximum range vs. dynamic lift characteristics.

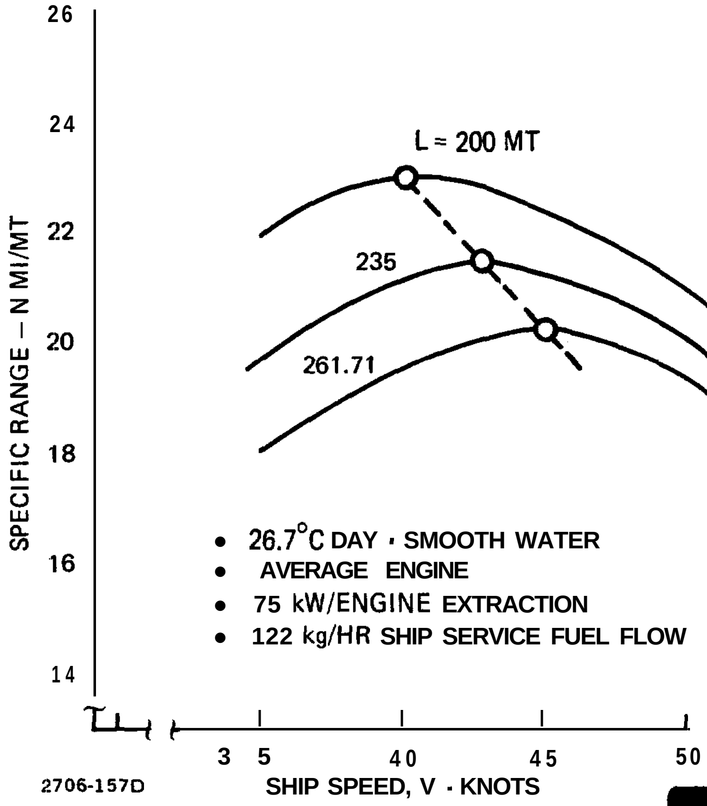

Fig. 4-11 Specific Range vs Speed (U) [redacted]

(U) Maximum specific range characteristics as a function of dynamic lift are shown in 'Figure 4-12. Specific range for both average and 5 percent degraded engines and APUs are shown. The 95 percent engine characteristic was derived by increasing total fuel flow rate by 5 percent. *All* subsequent range characteristics are based on this 95 percent engine specific range characteristic.

[redacted]

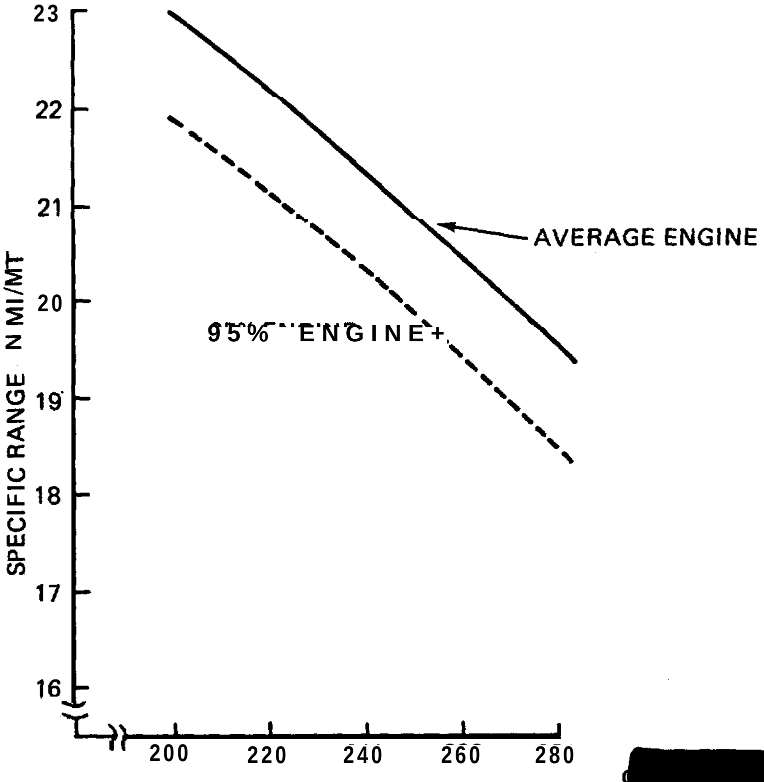

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Fig. 4-12 Maximum Specific Range vs Dynamic Lift (U)

Usable Fuel Summary

(U) The existing fuel tankage is analogous to that of the PHM-3 and carries a total of 47.2 metric tons of usable fuel, as outlines in the PHM-3 Quarterly Weight Report. Additional fuel tankage has been identified and is discussed in subsection 2.3. This additional tankage can be decomposed into two categories:

1. Readily available tankage - a minimum amount of rerouting of existing piping and electrical wiring.
2. Available tankage - requires rerouting of existing piping and electrical wiring.

(U) Figure 4-13 presents the total usable fuel load summary for the design.

[redacted]

[redacted]

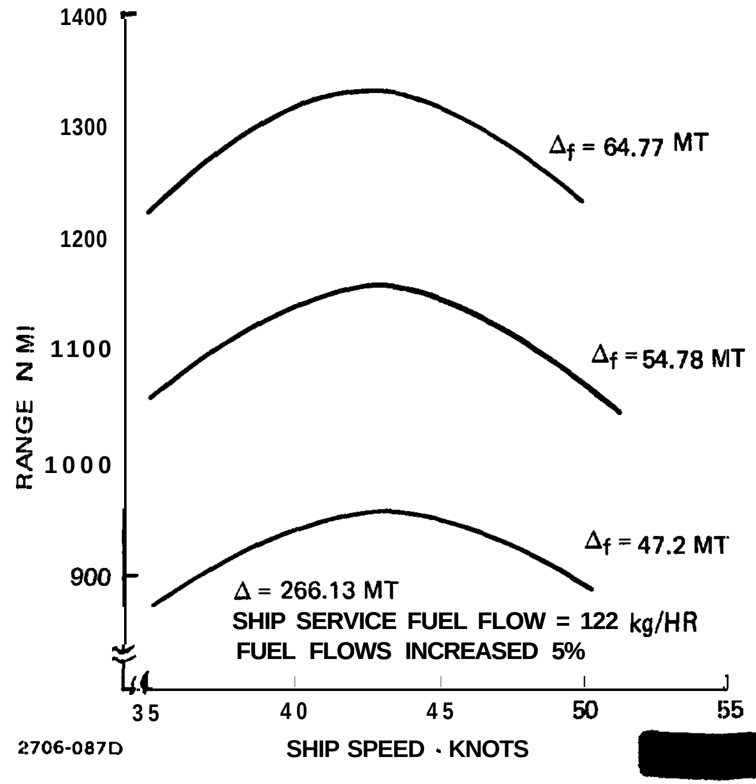
Existing PHM-3 Tankage:	47.20 MT
Readily Available Tankage:	
Between Frames 28-30	4.64 MT
Between Frames 30-33	4.44 MT
Available Tankage:	
Between Frames 21-25	7.99 MT
TOTAL USABLE FUEL	64.27 MT

2706-086D

Fig. 4-13 Usable Fuel Summary (U)

Range

(U) Absolute range as a function of ship speed and fuel load for the maximum ship displacement of 266.13 metric tons is presented. in Figure 4-14. The fuel loads indicated correspond to the existing, readily available, and available usable fuel tankages as discussed above. Range values were derived by using these usable fuel loads with the specific range vs dynamic lift characteristics of Figure 4-12 at the half-fuel dynamic lift condition as an approximation for fuel burn-off.



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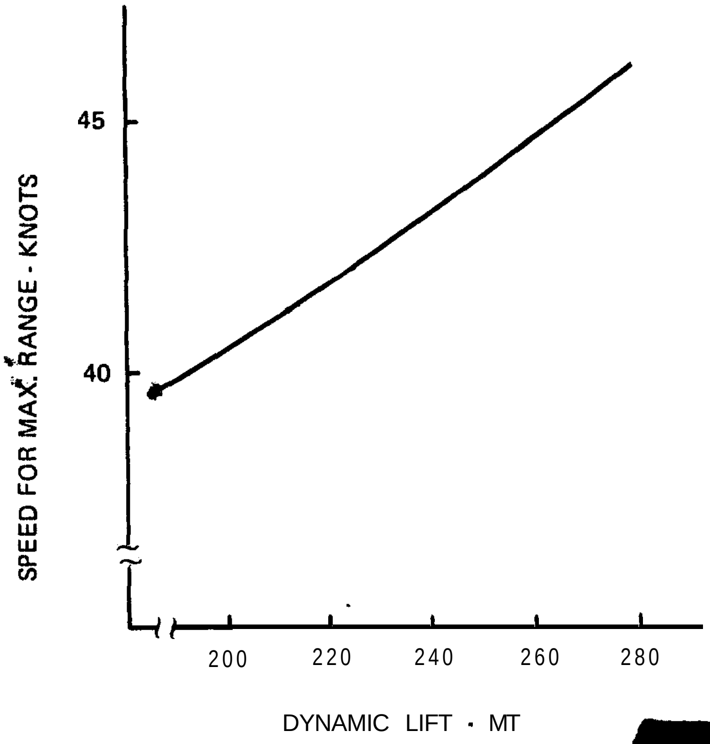
[redacted]

Fig. 4-14 Range vs Speed (U)

[redacted]

Speed for Maximum Range

[redacted] Figure 4-15 presents the speed for maximum range as a function of dynamic lift. At the full load condition, the speed for maximum range is approximately 45 knots. At the half-fuel load dynamic lift condition of 230 metric tons the speed for maximum range reduces to 42.7’ knots.

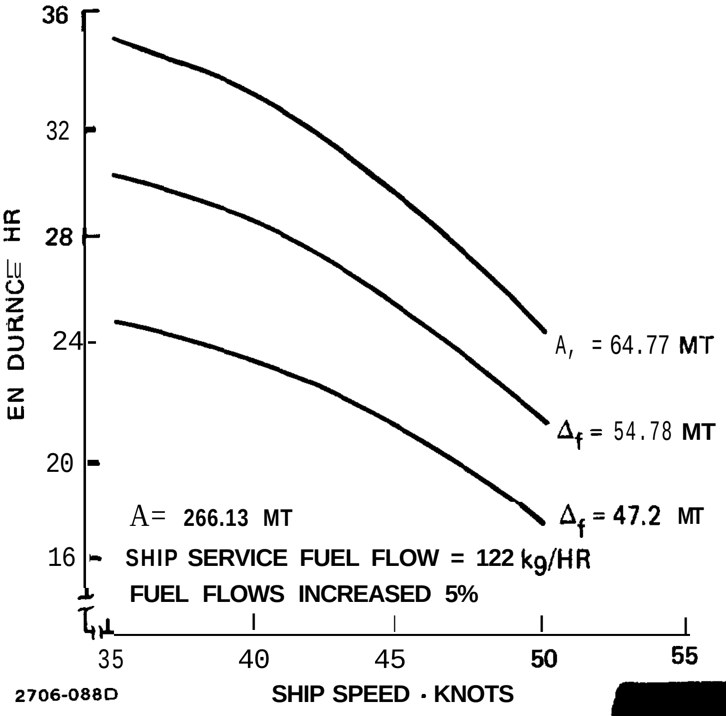


2706-052D [redacted]

Fig. 4-15 Speed for Maximum Range (U)

Endurance vs Speed

(C) Figure 4-16 presents the endurance vs speed characteristics for the dynamic lift conditions used in Figure 4-14 for the range calculations. For the full load condition at speed for maximum range, the endurance is 29.3 hr.



[redacted]

Fig, 4-16 Endurance vs Speed (U)

4.5 FUEL AND PAYLOAD CHARACTERISTICS

Required Fuel Loads

[redacted] Usable fuel load requirements for the PHM-3 SSS range of 750 n mi and a 60 percent increase range of 1200 n mi are presented in Figure 4-17. Again the specific range characteristics of Figure 4-12 at the half-fuel dynamic lift conditions were used to generate the fuel load requirements. The 750 n mi PHM SSS range can be attained with the existing PHM-3 tankage for all dynamic lift load conditions. A 60 percent increased range of 1200 n mi is possible by utilizing the readily available tankage (see Figure 4-13) for al.1 dynamic lift load conditions up to 241.3 metric tons.

a Usable fuel load requirements as a function of range for the maximum displacement of 266.13 metric tons are shown in Figure 4-18. The fuel requirement for a 1200 n rni range and the range attainable with the existing PHM-3 usable fuel load are indicated and compared to the PHM-1 demonstrated and SSS required ranges.

[redacted]

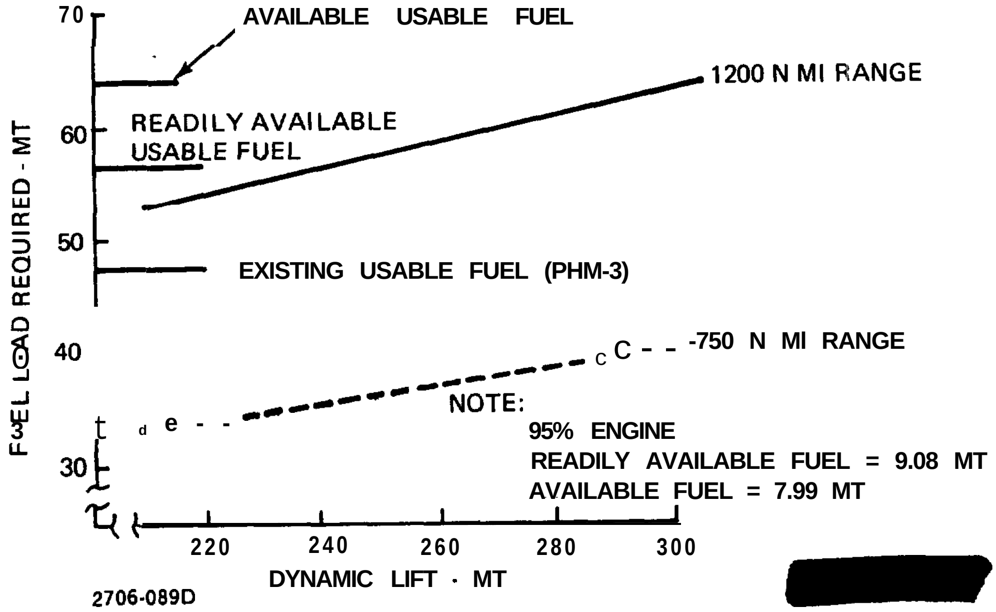


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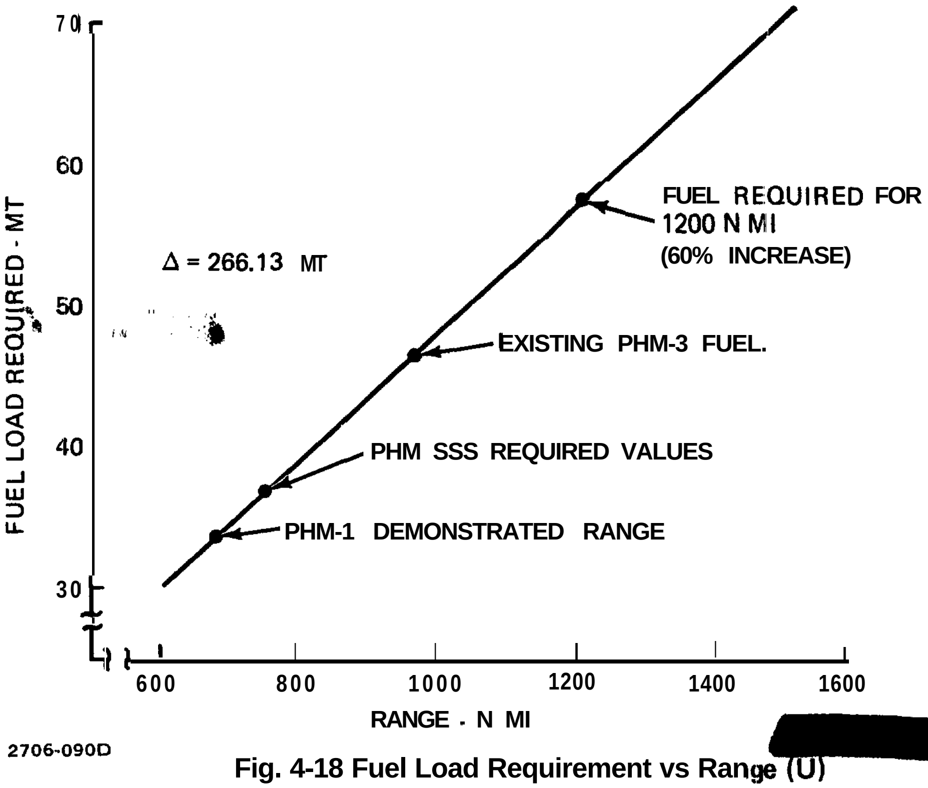
Fig. 4-17 Fuel Load Requirements vs Dynamic Lift (U)



[redacted]

Fig. 4-18 Fuel Load Requirement vs Range (U)

[redacted]

Loads - Fuel vs. Range

[redacted]he (loads - fuel)/range tradeoff is shown in Figure 4-19. It is assumed that the loads total 64.27 MT and remain constant with all fuel load conditions. The usable fuel load requirements of Figure 4-18 were then subtracted from the total loads for each range for a loads minus fuel value. This value was, in turn, compared with the PHM-3 loads minus fuel, and the difference obtained and plotted in Figure 4-19. The design equalled or exceeded the PHM payload capability for ranges up to 1300-t n mi.

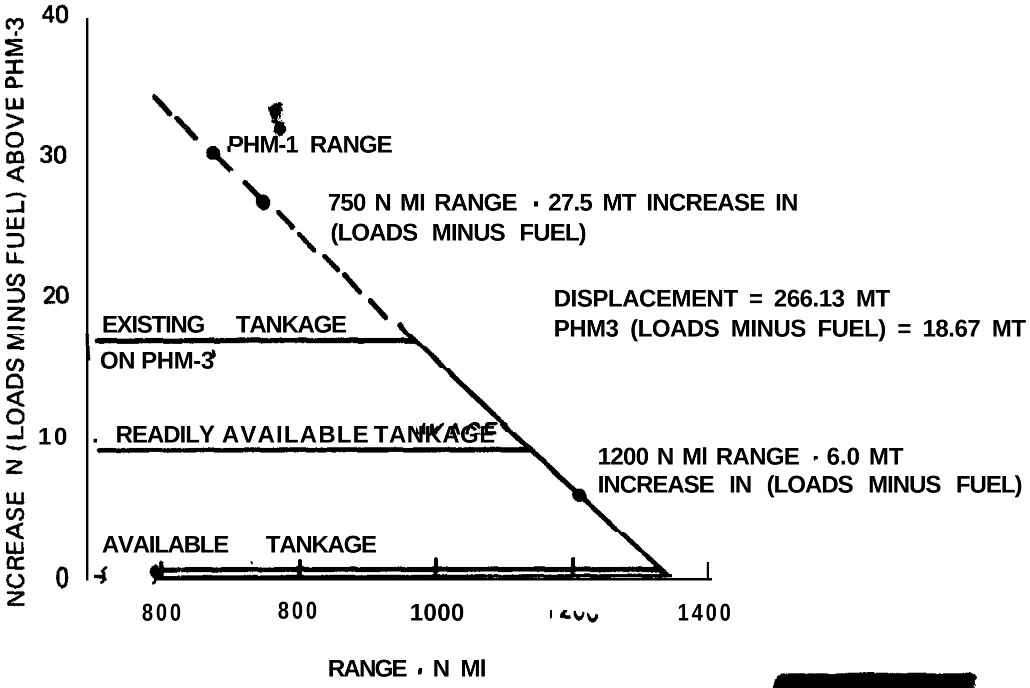


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Fig. 4-19 Payload vs Range (U) [redacted]

4.6 WEIGHT SUMMARY

(U) The weight summary is presented in Figure 4-20. Also included in this figure is a. SWBS Group weight comparison with the PHM-3 inasmuch as PHM-3 was used as the baseline for developing the present weight estimate. PHM-3 weights were obtained from the Quarterly Weight Report, PHM-3 Series, Boeing Document No. D312-80314-2 dated 25 January 1977. The composite weight and center-of-gravity statement is found in Appendix A. of this report.

SWBS GROUP	PHM3	DESIGN M-167
100 - HULL STRUCTURE	47.38 MT	50.27 MT
200 - PROPULSION	24.83	20.99
300 - ELECTRIC PLANT	7.53	7.53
400 - COMMUNICATIONS AND CONTROL	10.53	10.53
500 - AUXILIARY SYSTEMS	19.85	19.85
567 - HYDROFOIL LIFT SYSTEMS	32.28	34.38
600 - OUTFIT AND FURNISHINGS	14.60	14.60
700 - ARMAMENT	9.52	9.52
LIGHTSHIP WEIGHT - LESS MARGIN	166.52	167.67
MARGINS:		
DETAIL DESIGN AND CONSTRUCTION	2.46	2.46
PRELIMINARY DESIGN	—	6.61
NAVSEA	6.45	6.45
LIGHTSHIP WEIGHT	175.43	183.19
LOADS:		
SHIPS FORCE	2.63	2.63
ORDNANCE	15.04	15.04
POTABLE WATER	1.00	1.00
FUEL (USABLE)	47.20	47.20
FULL LOAD	241.30	249.06
WATERJET WATER	8.43	0.00
FULL LOAD	249.73	249.06
EXTRA PAY LOAD		17.07
FULL LOAD		266.13

706-092D

Fig. 4-20 SWBS Group Weight Comparison (U)

Figure 4-20 shows that the only SWBS weight groups which differ significantly from the PHM-3 are Groups 100 (Hull Structure), 200 (Propulsion) and Group 567 (Lift System). A more detailed weight accounting of the hull. structural changes is presented in Figure 4-21.

The LM-2500 engine foundation was removed and replaced with a lighter foundation to accommodate the Allison 570 KA engines. The engine closure bulkheads at Frames 23 and 29 were also relocated to accommodate the Allison engines in the existing compartment (see Figure 2-4).

Hull structural members were added to the PHM-3 structure to provide additional fuel tankage as discussed in subsection 3.2.

STRUCTURE		WEIGHT (MT)
EXISTING PHM-3 STRUCTURE		47.383
REMOVE:	F/B ENGINE FOUNDATION	0.233
	FRAMES 23 & 29	0.232
ADD:	PLATFORM (25-33)	0.352
	KEELSON (25-33)	0.409
	TANK FRAMES (25-33)	0.253
	TANK BULKHEAD (25)	0.093
	MAIN DECK MOD. (21-31)	0.094
	DECKHOUSE AND 01 LEVEL (21-30)	0.541
	BULKHEAD MOD.	0.502
	‘TRANSOM MOD.	0.014
	‘TURBINE AIR INLET	0.056
	ENGINE FOUNDATION	0.200
	TANK TOP OUTBOARD	0.276
	LAYOUT FACTOR	0.558
	TOTAL WEIGHT REMOVED	0.465
	TOTAL WEIGHT ADDED	3.348
PROPOSED DESIGN STRUCTURE		50.266

2706-0930

Fig. 4-21 SWBS Group 100 Weight Summary (U)

Modifications to the Main Deck, 01 Level, Bulkhead and Transom were made for relocating engine exhausts and intakes to suit the Allison 570 KA gas turbines. These changes represent a total increase of 2.574 metric tons above the present PHM-3 hull structural weight of 47.383 metric tons.

Figure 4-22 presents a SWBS Group 200 weight comparison on the account number level between PHM-3 and this design. A decrease of 3.84 metric tons from the PHM-3 propulsion system weight is demonstrated in the figure. Most of this weight reduction is accomplished by the replacement of the LM-2500 gas turbine (9.88 metric tons) with the two Allison 570 KA gas turbines (5.88 metric tons).

Figures 4-23 and 4-24 present those items which were added to, and removed from, the PHM-3 weight statement to develop the present design Group 200 weight statement.

SWBS GROUP 200	PHMS	PROPOSED DESIGN
230 • ENGINES	9.88 MT	5.88 MT
240 • TRANSMISSION AND PROPULSOR SYSTEMS	10.01	9.60
250 • PROPULSION SUPPORT SYSTEMS (EXCEPT FUEL AND LUBE OIL)	3.35	2.53
260 • PROPULSION SUPPORT SYSTEMS (FUEL AND LUBE OIL)	0.27	0.38
290 • SPECIAL PURPOSE SYSTEMS	1.32	2.60
TOTAL GROUP 200	24.83	20.99

2706-094D

Fig. 4-22 SWBS Group 200 Weight Summary (U)

SWBS ACCOUNT NO.	ITEM	WEIGHT (MT)
230	ENGINE ASSEMBLY (2)	1.225
240	SHAFTING (2)	0.903
	POD MECHANISM (2)	4.278
	HULL-MOUNTED GEARBOX (2)	0.644
	BEVEL GEARBOX (4)	1.566
	PROP PITCH CONTROL SYSTEM	0.070
250	DEMISTERS	0.214
	UPTAKES	1.500
260	F/B ENGINE FUEL HEATER AND LUBE OIL COOLER (2)	0.068
	TRANSMISSION LUBE-OIL SYSTEM	0.296
	POD SEAL OIL TANK	0.018
290	OIL IN SYSTEM	1.406
	BILGE PUMP	0.025
	SPACE HEATER WITH FAN	0.010
	GAS TURBINE ROOM AIR SUPPLY FAN	0.023
	TOTAL (LESS MARGIN)	12.246
	PRELIMINARY DESIGN MARGIN (15%)	1.840
	TOTAL (ADDED ITEMS)	14.086

706-095D

Fig. 4-23 SWBS Group 200 Weight Summary of Added Items (U)

The weight estimate contains a 15 percent design and construction margin on all changes. In addition, layout factors are included in the calculations to account for unknowns at the Preliminary Design Stage (20 percent for built-up structural items and 5 percent for welded, analyzed hydrofoil system components).

SWBS ACCOUNT NO.	ITEM	WEIGHT (MT)
234	FOILBORNE ENGINE ASSEMBLY	5.225
241-1	FOILBORNE REDUCTION GEARS	2.405
243-I	FOILBORNE TURBINE TO PUMP SHAFT	0.017
246	PROPULSOR SHROUD AND DUCTS	0.916
247	WATERJET PUMP AND NOZZLE	4.533
251	DEMISTERS	1.559
256	ENGINE WASHDOWN SYSTEM	0.050
259	UPTAKES	0.923
262	LUBE-01 L SYSTEMS	0.272
298	FOILBORNE OPERATING FLUIDS	0.182
	TOTAL (ITEMS REMOVED)	16.082

2706-096D

Fig. 4-24 SWBS Group 200 Weight Summary of Removed Items (U)

4.7 STABILITY

The design modifications discussed herein should result in a slight improvement in the transverse stability of the PHM-3 design. In assessing the effects of the design changes, the following items were considered:

- Changes in the vertical center of gravity (KG) of the ship which were reflected in the weight statements
- Changes in the $\overline{KG}$ resulting from exclusion of the waterjet water inboard of the molded hull surface. This was considered as a mass excluded from the hull. No free surface correction was made for exclusion of the waterjet ducting as, at small heel angles, the ducting would have been totally immersed
- The addition of new fuel oil tankage increased the free surface moment of transference. Calculations for the full load condition were based on a 10° heel angle with tanks 95 percent full. Port and starboard tanks were assumed to be cross-connected. At lower tank levels, this moment of transference will be greater than reflected here. This may necessitate some liquid loading instruction regarding filling and burning-off of the port and starboard tanks

- Because of the greater carrying capacity, hull draft in the full load condition is greater. Modification of the full load $\overline{KB}$ and $\overline{BM}$ were based on changes in the properties over the increment of draft on the PHM-3 curves of form
- Modifications to the foil arrays resulted in changes to the foil array buoyancy and centers of buoyancy as outlined in **Figure** 4-25 showing the RHM-3 distribution from Table 6-l of Reference 9. The modified buoyancy distribution is presented in Figure 4-26.

The net effect of the above described alterations are summarized in Figure 4-27. An improvement in the stability at small angles can be expected for the lightship and full load conditions. A similar improvement should be attainable at the minimum operating condition subject to some constraints on the use of the port and starboard wing tanks.

Item	Volume, m^3	VCB, m Above BL	VMOM, m^4	LCB, m Aft of F.P.	LMOM, m^4
Forward Array Total	(2.2951	-1.906	(-4.3751	2.374	(5.448)
Foil	0.920	-3.670	-3.376	2.539	2.336
Pod	0.043	-3.429	-0.147	2.701	0.116
Strut	1.332	-0.640	-0.852	2.249	2.996
Aft Array Total	(9.446)	-1.907	(18.0121	29.240	(276.204)
Foil	2.697	-4.481	-12.085	29.630	79.912
Pod	0.746	-3.648	-2.721	28.910	21.567
Struts (Ducts are lost volume)	6.003	-0.534	-3.206	29.106	174.725
Total F/A Buoyancy, m^3	11.741	-1.906	-22.384	23.989	281.652
In Ton-Meters	12.043	-1.906	-22.953	23.989	288.854

2706-0970

Fig. 4-25 PHM-3 Foil Buoyancy Summary (U)

Item	Volume, m^3	VCB, m Above BL	VMOM, m^4	LCB, m Aft of F.P.	LMOM, m^4
Forward Array Total	(2.582)	-2.230	(-5.759)	2.385	(6.158)
Foil	1.145	-3.970	-4.546	2.539	2.907
Pod (78% Flooded)	0.043	-3.750	-0.161	2.701	0.116
Strut	1.394	-0.755	-1.052	2.249	3.135
Aft Array Total	(11.039)	-2.141	(-23.638)	29.496	(325.606)
Foil	2.808	-3.970	-11.148	29.630	83.201
Pod (20% Flooded)	2.197	-3.716	-8.164	30.000	65.910
Struts	6.034	-0.717	-4.326	29.250	176.495
Total F/A Buoyancy, m3	13.621	-2.158	-29.397	24.357	331.764
In Ton-Meters	13.971	-2.158	-30.150	24.357	340.292

2706-098D

Fig. 4-26 Present Design Foil Buoyancy Summary (U)

SOURCE OF CHANGE	AFFECTS	APPROX. CHANGE TO $\overline{GM}$ (m)	
		FULL LOAD	LIGHTSHIP
Arrangement Changes From Weight Statements	$\overline{KG}$	+0.39	+0.46
Deduct Waterjet Water IB Molded Hull	$\overline{KG}$	-0.02	-0.04
Add New Fuel Oil Tankage Free Surface (Computed at 95% Full, 10" Heel, P/S Tanks Connected)	ΣFS	-0.10	-O-
Alter Hull Draft	KG	+0.05	-o-
	$\overline{BM}$	-0.21	-O-
Alter Foil Array Buoyancy and Distribution	$\overline{KB}$	-0.03	-0.04
Total Net Change from PHM-3	GM	+0.08	+0.38

$$GM = \overline{KB} + \overline{BM} - KG - \Sigma FS$$

2706-099D

Fig. 4-27 Effects of Design Modifications on PHM-3 Stability (Foils Down) (U)

SECTION 5

TRADEOFF STUDIES

5 - TRADEOFF STUDIES

5.1 TRADEOFF STUDIES

During the development of the design, tradeoff studies were performed to determine the feasibility of various components in the design and to provide alternate design possibilities (and their effect on vehicle performance).

Section 5 presents five of these tradeoff studies ranging from propeller pitch settings to material selection.

5.2 FIXED PITCH VS CONTROLLABLE PITCH PROPELLERS

Thrust Considerations

The resistance characteristics of a hydrofoil ship have a unique effect on the thrust requirements and engine matching characteristics of the propulsor. Unlike displacement ships, the maximum power and thrust requirement occurs about midway through the ship speed regime rather than at maximum speed, due to the takeoff drag hump. Consequently, a fixed pitch propeller designed for either maximum or takeoff ship speed may not produce the required thrust at the other condition due to any one of the following reasons:

- Low off-design efficiency
- Low power due to engine mismatch at RPMs exceeding engine limits
- Low power due to engine mismatch at low RPMs to avoid over-torquing either the engine and/or the transmission.

With a fixed pitch propeller, this situation is usually compromised by selecting a propeller design which provides adequate, rather than maximum, performance across the speed range.

A comparison of thrust characteristics of CP and fixed pitch propellers with a 10:1 gear ratio transmission is presented in Figure 5-l. Curve A in Figure 5-l shows that maximum cruise and takeoff thrusts are produced by a 1.37-l. 45 m diameter CP propeller. Curve B shows the effect of fixing pitch to be the same at both cruise and takeoff for a 1.37 m diameter propeller.

Although this is not a complete study, it does show considerable performance advantages of a CP propeller. A fixed pitch, P/D = 1.5 propeller has limited takeoff thrust capability due to its low RPM and power match at the transmission torque limit.

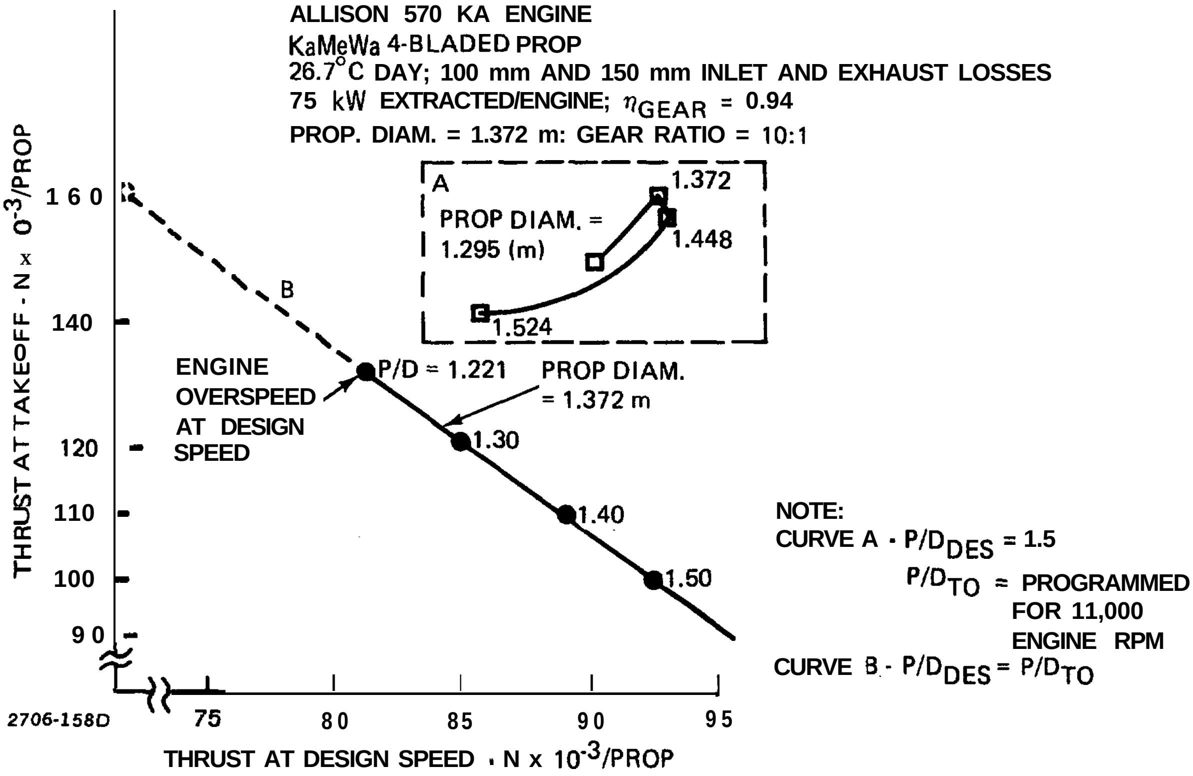

Fig. 51 Comparison of Fixed and Controllable Pitch Propellers (Thrust Available) (U)

Alternatively, a finely pitched propeller with a P/D = 1.221 shows considerable takeoff performance, but a loss of cruise efficiency, A P/D = 1.221 also represents the minimum pitch required to prevent the engine from overspeeding at the design ship speed.

Torque Considerations

A CP propeller programmed for a particular power-RPM operating line or with a torque feedback signal has inherent overprotection for the foilborne propulsion system. At the same time it has the capability of matching the engine at its maximum power output at any ship speed. Finally, thrust and power response to throttle change are considerably faster than with a fixed pitch system.

Reliability Considerations

(U) The Grumman PG(H)-1 FLAGSTAFF was the first (and only) hydrofoil to use a CP supercavitating propeller. During more than ten years of operation, there have been no major reliability problems with the pitch control system. In addition, since launching of PG(H)-1 FLAGSTAFF, numerous patrol boats have been outfitted with KaMeWa CP propellers and have provided excellent reliability. The Navy's DD-963 class destroyers and FFG frigates use the KaMeWa-designed CP hub, with no reliability problems to date. Earlier model CP propellers had blade retention and/or blade root stress problems, This strength problem does not seem to appear in the small propeller sizes used for patrol and hydrofoil craft.

System Complexity Considerations

(U) External to the hub pitch mechanism, the major system complexity consists of a hydraulic fluid system. The proposed hydraulic system is based on the system currently being developed for the Grumman Design M-151. In addition to the hydraulic system, a control signal processor is required. The pitch control modes which are integrated with the engine controls, and are currently being developed for the Grumman Design M-161 are not considered to be exceptionally complex in terms of hardware.

Effect on Vehicle Performance

(U) An investigation of the effects of fixed and controllable pitch propellers on performance was performed using the thrust characteristics of the propellers presented in Figure 5-l.

(C) Employing the two-point power limited solution presented in subsection 2.4, a total of five designs were developed and are summarized in Figures 5-2 and 5-3. In each design the takeoff thrust margin was 35 percent and the design speed thrust margin was 5 percent. The propeller diameter was maintained at 1.37 m and the transmission gear ratio was set at 10:1.

(U) Figure 5-l demonstrates that the maximum takeoff thrust is obtained with a variable pitch propeller. The fixed P/D of 1.221 produces the maximum takeoff thrust of the fixed pitch propellers, but the thrust is 18 percent lower than the variable pitch propeller at takeoff, and 12 percent lower in design speed thrust. This reduction in the available thrusts represents a 20 percent reduction in total dynamic lift. The fixed P/D of 1.3 produces the maximum dynamic lift of the fixed pitch propellers, but this value is still 19 percent lower than the variable pitch propeller design.

PITCH / DIAMETER	TAKEOFF THRUST kN	DESIGN THRUST kN	DYNAMIC LIFT, MT	FOIL AREA, m^2	FOIL LOADING, kPa
Variable	322.1	185.1	261.71	38.829	66.07
1.221	264.2	162.4	210.48	31.994	64.49
1.300	241.1	169.9	212.22	37.574	55.35
1.400	217.1	178.4	209.06	43.573	47.02
1.500	196.6	185.2	201.22	48.418	40.75

NOTES: FOILSIZING WAS BASED ON A 35% TAKEOFF THRUST MARGIN AND A 5% DESIGN SPEED THRUST MARGIN.

PROPELLER DIAMETER = 1.372 m

GEAR RATIO = 10:1

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Fig. 5-2 Comparison of Fixed and Controllable Pitch Propellers (Dynamic Lifts and Foil Areas) (U)

(U) If the propeller pitch is set at 1.5, the thrust at design speed of the fixed and controllable pitch propellers is identical, but the takeoff thrust of the fixed pitch propeller is 30 percent lower than that of the variable pitch. This reduction in available thrust at takeoff corresponds to a 35 percent reduction in the dynamic lift.

(U) Figure 5-4 is included to demonstrate the effect of pitch to diameter on dynamic lift and design speed thrust margin. This figure shows that the variable pitch propeller produces the maximum dynamic lift for any design speed thrust margin.

5.3 TRANSMISSION STUDIES

Transmission Gear Ratio Changes

(U) The present transmission is based on the technology developed for the Grumman Design M-151 foilborne propulsion system. The changes for the proposed design include a low-risk design hull-mounted

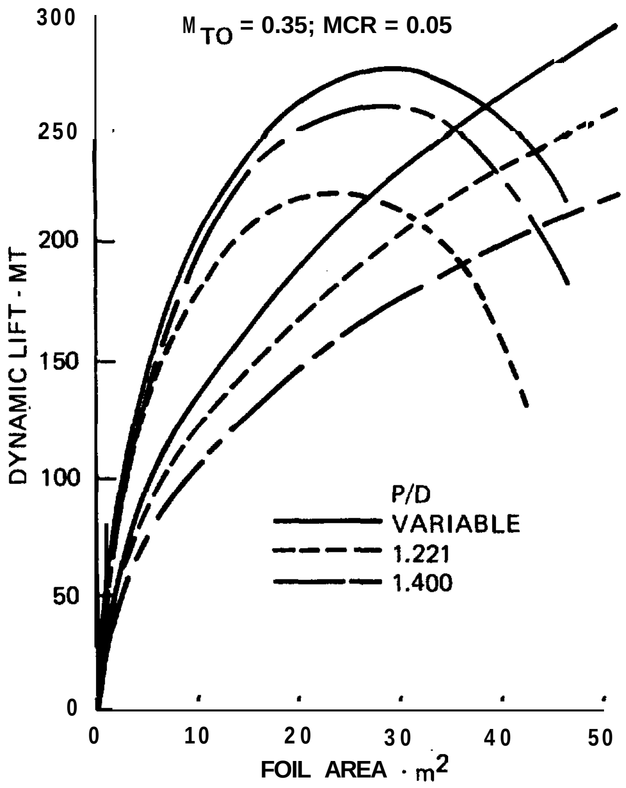

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Fig. 53 Dynamic Lift vs Foil Area for Various Pitch-to-Diameter Ratios (U)

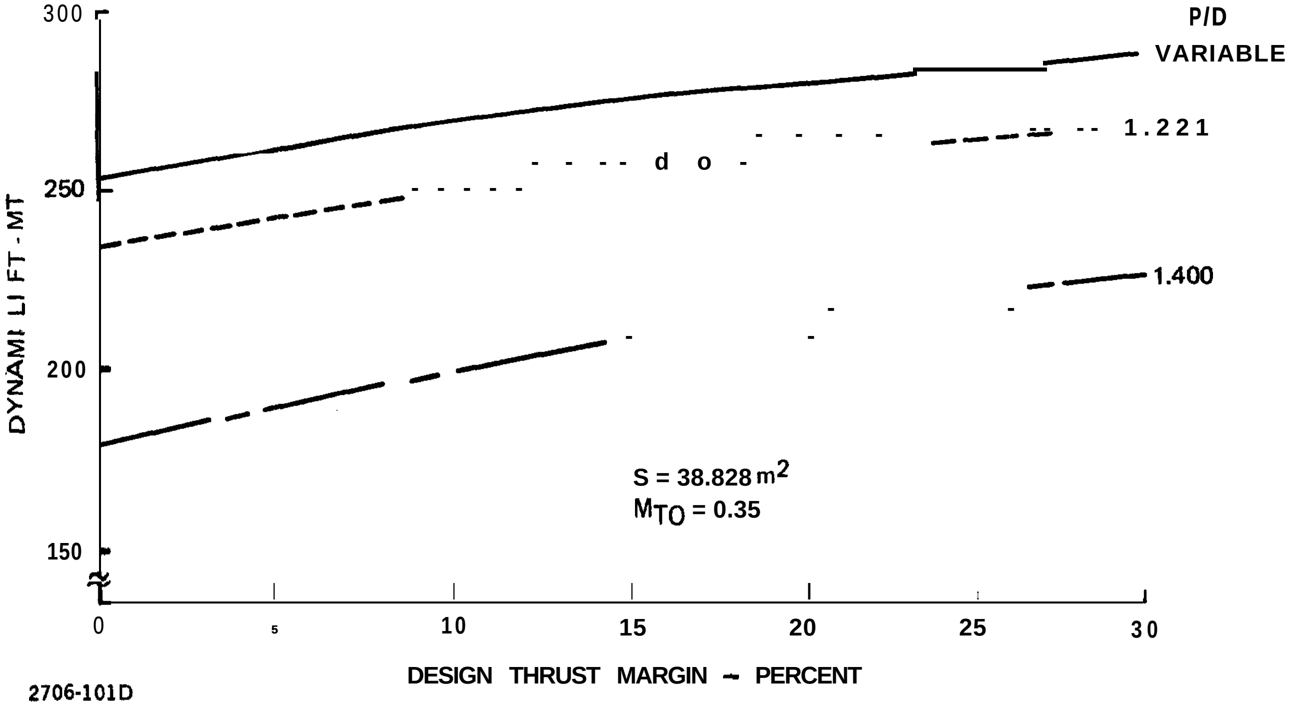

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Fig. 5-4 Dynamic Lift vs Cruise Margin for Various Pitch-to-Diameter Ratios (U) gearbox, designed and fabricated to suit the Allison 570 KA gas turbine output and the existing spiral bevel gearboxes used on the Design M-151, and a minor modification to the planetary gearbox of the Design M-151.

A tradeoff study was performed to determine the effects of varying the overall gear ratio on the vehicle performance. For this study, six mechanical single mesh transmissions were considered. A schematic showing the six transmission systems under consideration is presented in Figure 5-5. In each configuration, risk factors were assigned based on a qualitative analysis of the changes which were necessary and the anticipated effects of these changes. A summary of these risk factors is presented in Figure 5-6.

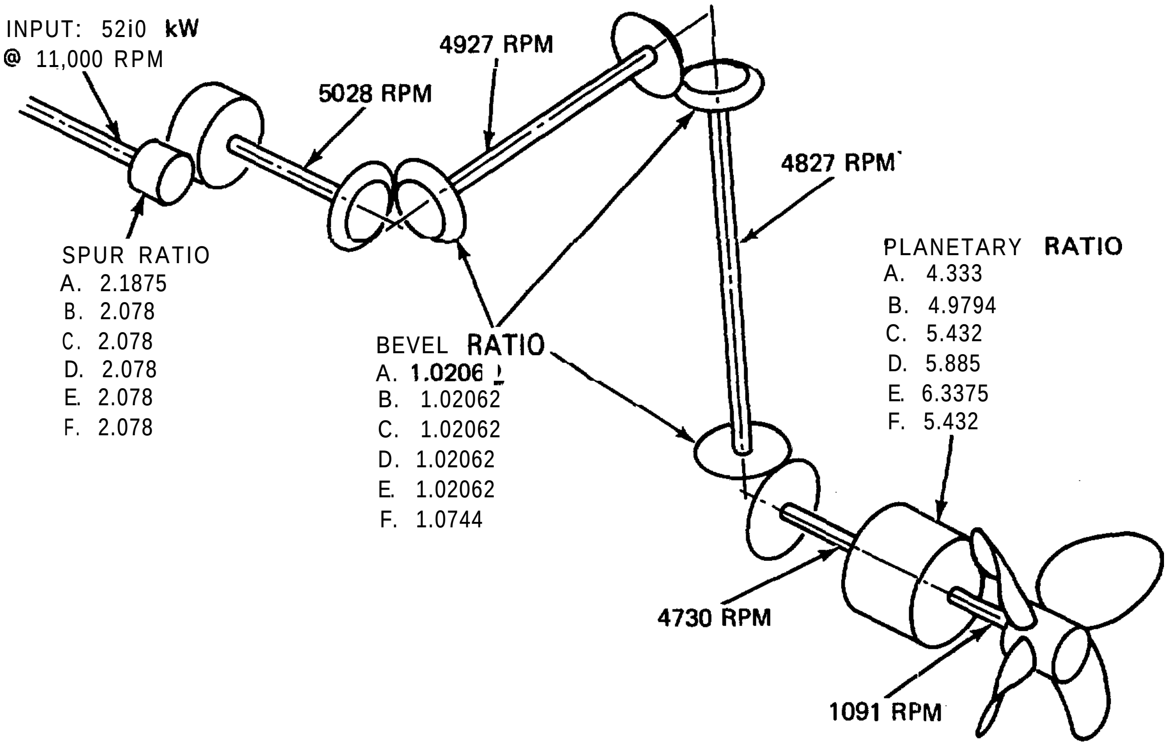

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Fig. 5-5 Advanced Technology Transmission Schematic (U)

A new, low-risk, hull-mounted gearbox was designed to match the Allison 570 KA gas turbine with the required characteristics of the propellers for the ship. The gearbox has a 48-tooth pinion and a 105-tooth gear resulting in a gearing ratio of 2.1875/1 with a diametral pitch of 6.75. This gearbox includes provisions for accessory drive gears which could be used to

GEAR RATIO	CONFIGURATION CHANGE OF DESIGN M-151 TRANSMISSION	DEVELOPMENT DESCRIPTION	RISK” FACTOR
10/1	Redesigned Hull-Mounted Gearbox (2.18711) Existing Bevel Gearbox (1.0206/1) Existing Planetary Gearbox (4.333/1)	HMGB Ratio Changed From 3.104/1 to 2.187/1	1
11/1	Redesigned Hull-Mounted Gearbox (2.187/1) Existing Bevel Gearbox (I .0206/1) Redesigned Planetary Gearbox (4.9794/1)	HMGB Ratio Changed From 3.104/1 to 2.187/1 PGB Ratio Changed From 4.333/1 to 4.9794/1	3
12/1	Redesigned Hull-Mounted Gearbox (2.187/1) Existing Bevel Gearbox (1.0206/1) Redesigned Planetary Gearbox (5.432/1)	HMGB Ratio Changed From 3.104/1 to 2.187/1 PGB Ratio Changed From 4.33311 to 5.432/1	3
13/1	Redesigned Hull-Mounted Gearbox (2.187/1) Existing Bevel Gearbox (1.0206/1) Redesigned Planetary Gearbox (5.885/1)	HMGB Ratio Changed From 3.10411 to 2.187/1 PGB Ratio Changed From 4.33311 to 2-Stage 5.885/1	8
14/1	Redesigned Hull-Mounted Gearbox (2.187/1) Existing Bevel Gearbox (1.0206/1) Redesigned Planetary Gearbox (6.3375/1)	HMGB Ratio Changed From 3.104/1 to 2.187/1 PGB Ratio Changed From 4.33311 to 2-Stage 6.3375/1	8
14/1	Redesigned Hull-Mounted Gearbox (2.187/1) Redesigned Bevel Gearbox (1.0744/1) Redesigned Planetary Gearbox (5.432/1)	HMGB Ratio Changed From 3.104/1 to 2.187/1 BGB Ratio Changed From 1.0206/1 to 1.0744/1 PGB Ratio Changed From 4.33311 to 5.432/1	10

“1 • Minimum Design Risk
10 • Maximum Design Risk

2706-103D

Fig. 5-6 Transmission Gear Ratio Risk Assessment (U)

power any accessories as required. A layout of this hull-mounted gearbox is presented in Figure 5-7.

For each of the bevel gearboxes, an analysis was performed to determine the compatibility between the existing spiral bevel gearing arrangement and the upgraded Advance Technology Lift and Propulsion System. The effects of increasing torque are shown in Figures 5-8 and 5-9. Also shown are the gearing design stress allowables after they have been reduced by varying the derating factors (Kd & C_d). In each case, the anticipated operating stresses are well within demonstrated operating ranges resulting in a low-risk transmission system.

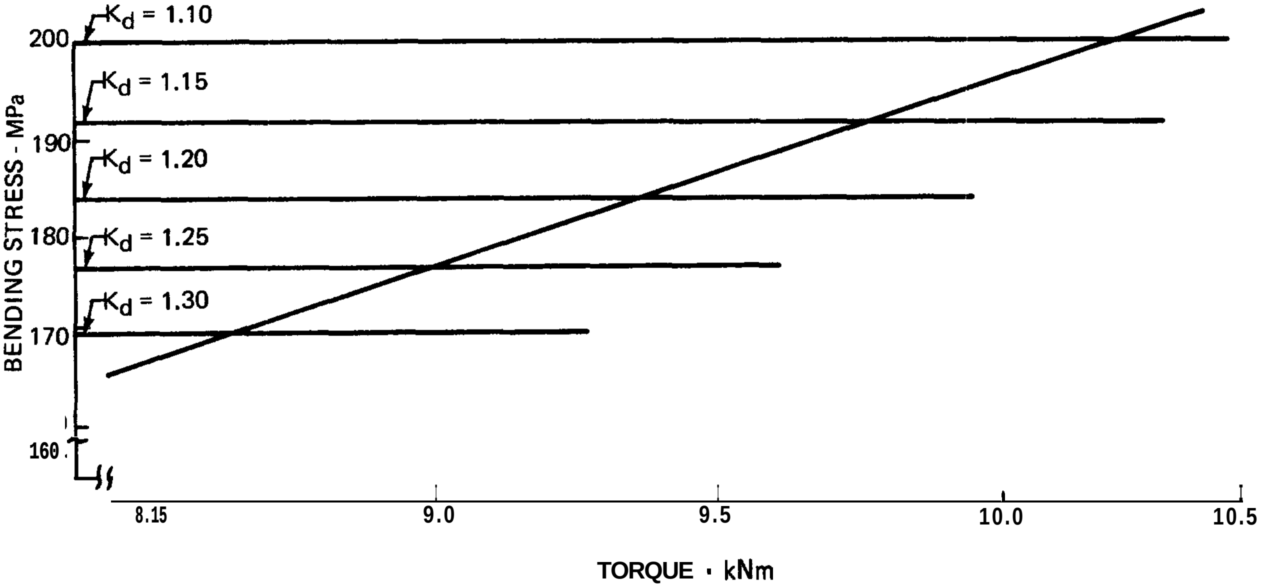

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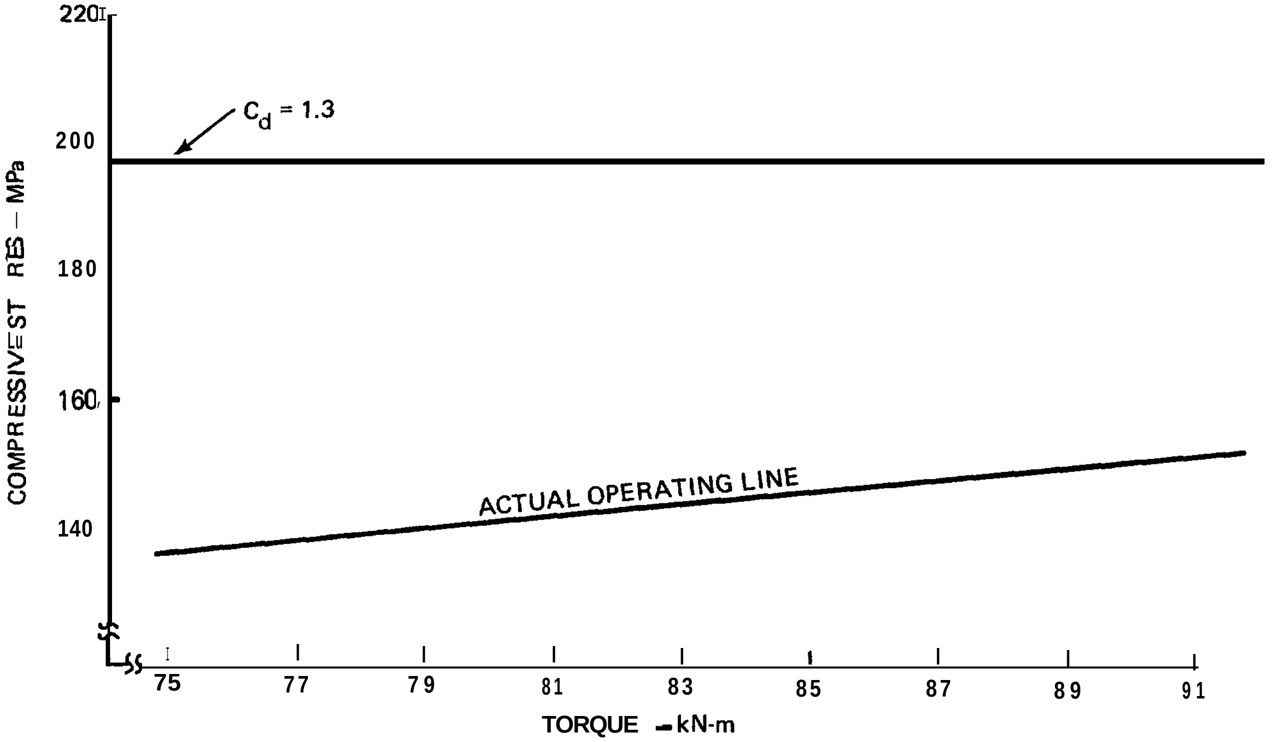
Fig. 58 Spiral Bevel Gears Bending Stress vs Torque for Derating Factors of 1.30 to 1.10 (U)

For the planetary gearbox, an analysis was also performed to determine the compatibility between the existing spur gearing arrangement and the upgraded Advance Technology Lift and Propulsion System. The effects of increasing torque are shown in Figures 5-10, 5-11, and 5-12. Also shown are the gearing design stress allowables after they have been reduced by varying derating factors (K_d & C_d).

As can be seen from the graphs, the use of an unmodified Design M-151 epicyclic gearbox for the design would stress the gears beyond current conservative practice limits. Figures 5-13 and 5-14 also show that the gearbox would be operating above demonstrated values. For these reasons, the following minor modification to the planetary gearbox is recommended. By increasing the face width of the spur gears from 76 mm to 95.3 mm, the operating stresses are reduced to an acceptable value, resulting in a low-risk transmission



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‘Fig. 5-9 Spiral Bevel Gears Compressive Stress vs Torque (U)

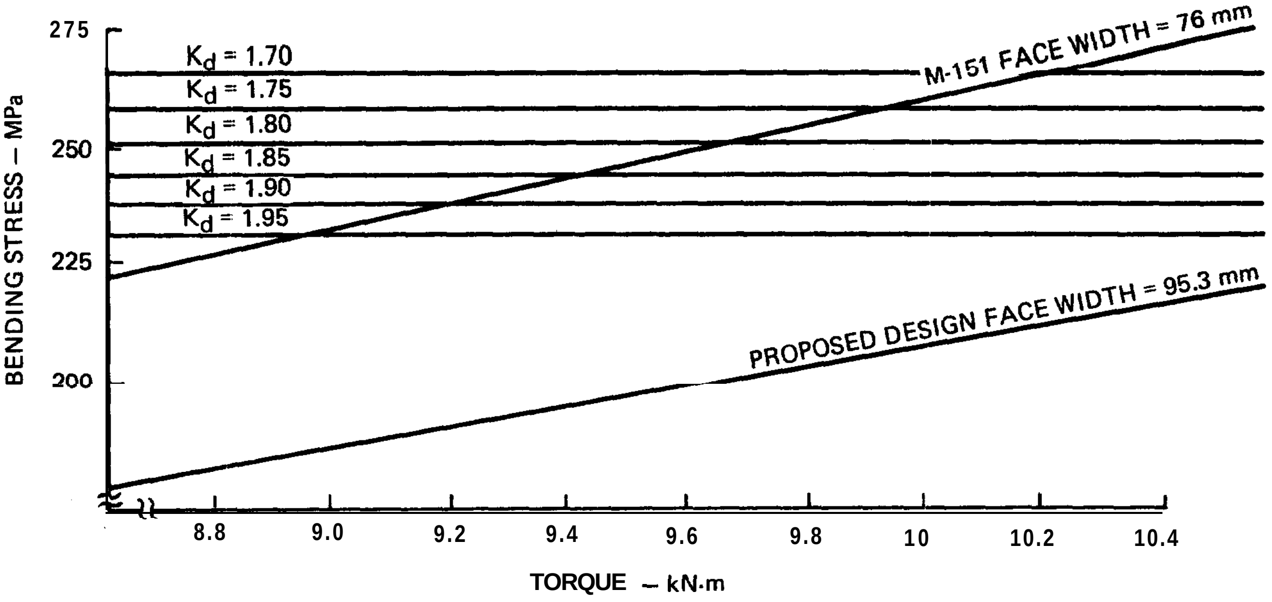

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Fig. 5-10 Sun Gear Bending Stress vs Torque and RPM for K_d = 1.95 to 1.70 (U)

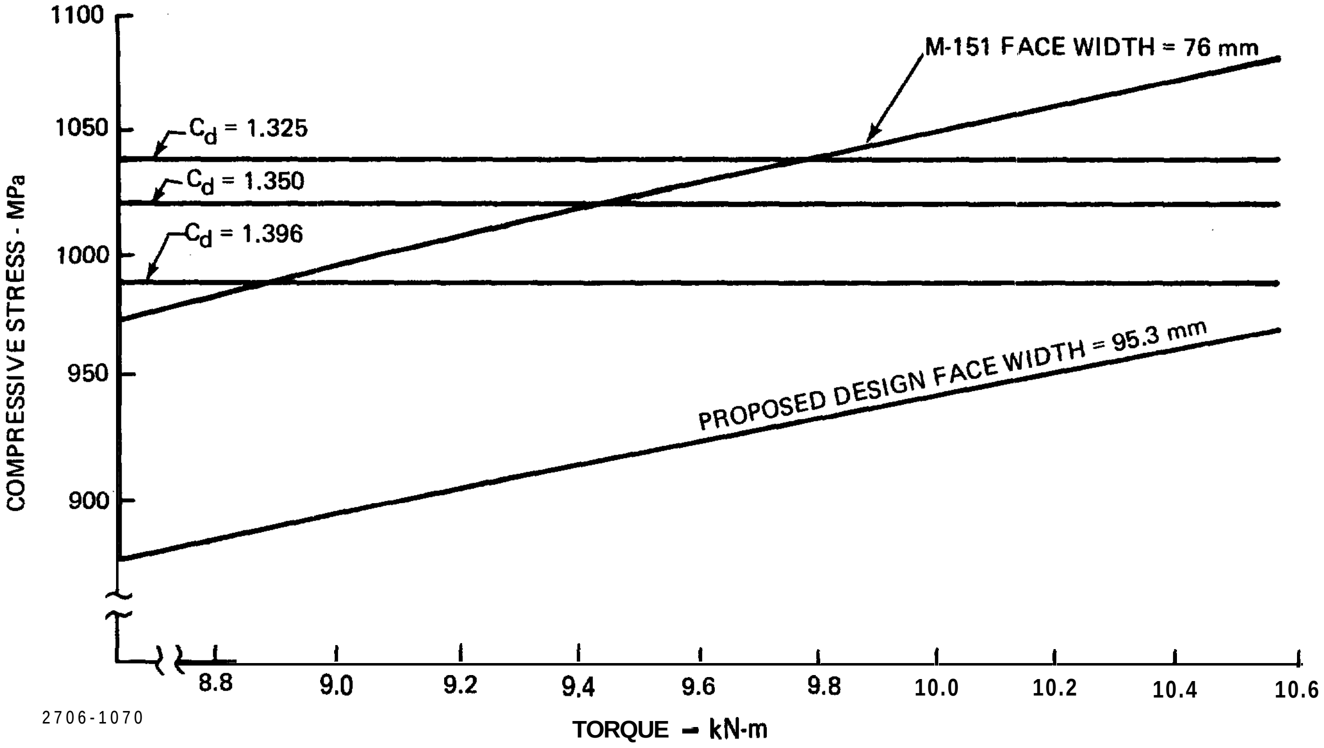

Fig. 5-11 Sun Gear Compressive Stress vs Torque for Cd = 1.396 to 1.325 (U)

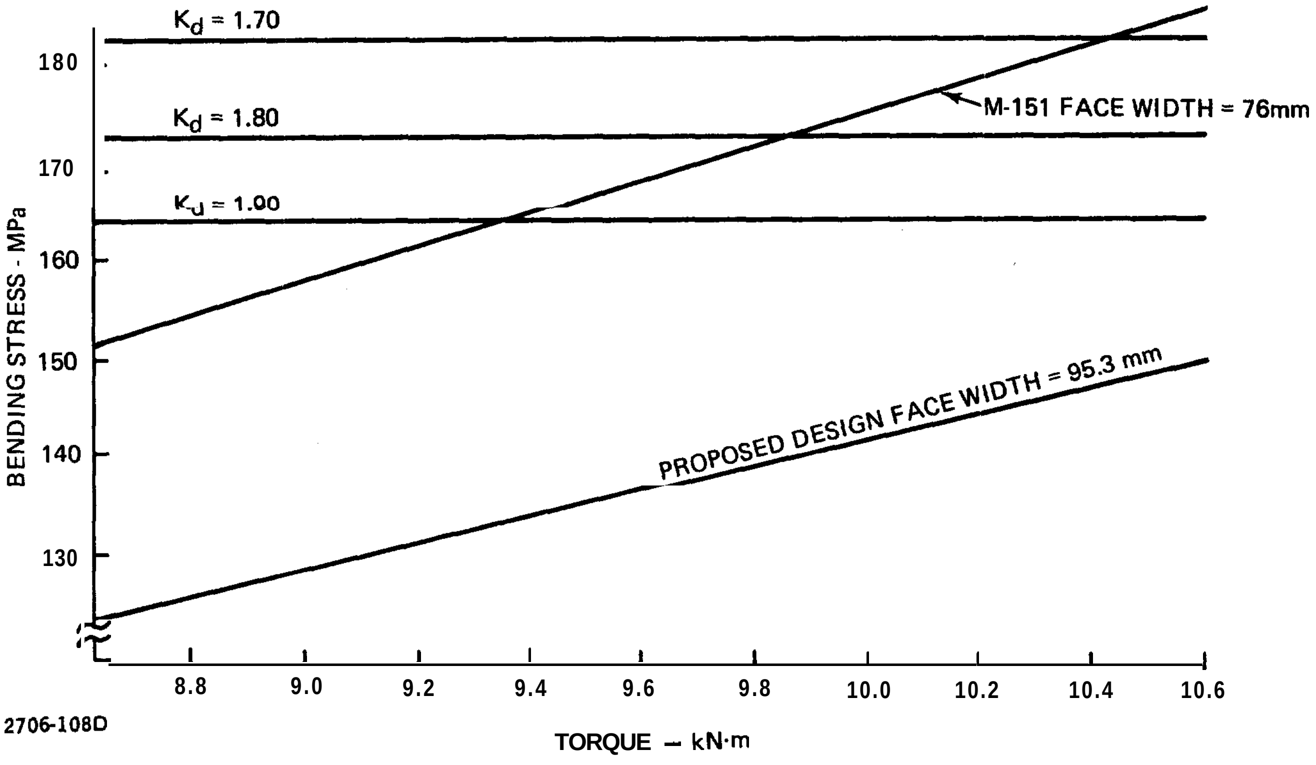

Fig. 5-12 Planetary Gear Bending Stress vs Torque and Output RPM for K_d = 1.90 to 1.70 (U)

APPLICATION	PGH-1	FHE-400	C-W*	C-W	C-W	CRITICAL DEMONSTRATED VALUE	M-151
Type	Planetary	Compound Star	Planetary	Planetary	Planetary	–	Planetary
Condition	Design	Design	As Tested	900 PRPM	600 PRPM	–	Design
Power (kW)	2,610	10,961	29,828	18,643	18,643	29,828	4,027
RPM, in/out	4,687/1,071	8,000/1,200	4,000/1,012	3,600/911	.2,400/607	8,000/1,200	4,330/999
Ratio	4.375	6.667	3.942	3.942	3.942	6.667	4.333
input Torque, (Nm)	5,316	13.077	71.177	49,430	74,140	71,177	6,880
Diametral Pitch	7.059	–	3.640	3.640	3.640	7.059	5.714
Root Stress (Sun/Planet), (MPa)	180.64/126.17	206.84	199.95/140.10	138.86/97.29	208.22/145.96	208.22	228.49/157.41
Compressive Stress, (MPa)	666.24		1399.64	586.05	721.19	'721.19	991.26
Scoring Index	8,126		16,131	11,646	12,900	16,131	12,642
Pitch Line Velocity, (m/s)	28.25	–	51.05	49.73	30.55	51.05	30.23

*Curtiss-Wright Designs

2706-109D

Fig. 513 Epicyclic Gearbox Comparison (U)

APPLICATION	M-151	M-161 MODIFIED FOR ADVANCED TECH. APPLICATION		M-151 MODIFIED FOR ADVANCE TECH. APPLICATION		CRITICAL DEMONSTRATED VALUE
Condition	TAKEOFF	TAKEOFF	CRUISE	TAKEOFF	CRUISE	
Power (kW)	4,027	5,220	3,100	5,220	3,106	29,800
RPM, in/out	4.3301999	4,730/1091	3,474/801	4,730/1,091	3.4741801	8,000/1,200
Ratio	4.3333	4.3333	4.3333	4.3333	4.3333	6.6670
Input Torque, (Nm)	8,880	10,538	8,527	10,538	8,527	71,180
Diametral Pitch	5.714	5.714	5.714	5.714	5.714	7.059
Root Stress (Sun/Planet), MPa	228.5/157.4	271.1/186.8	219.4/151.1	216.9/149.4	175.5/120.9	208.2
Compressive Stress, MPa	991.3	1079.8	971.4	965.8	868.8	721.2
Scoring Index	12,642	15.020	10,982	12,704	9,290	16,131
Pitch Line Velocity, (m/s)	30.23	33.02	24.26	33.02	24.26	51.05
Face Width, (mm)	76	76	76	95.3	95.3	–

2706-110D

Fig. 514 Epicyclic Gearbox Comparison • Design M-167 (U) system. A layout of the unmodified planetary gearbox can be seen in Figure 5-15. It is obvious that the change from 76 to 95.3 mm face width can be accomplished without major modification to the gearbox.

Effect of Gear Ratio Change on Performance

(U) A study was performed to determine the effect of the transmission gear ratio on the performance of the design. The simplest way to determine this effect was to see how a change in the gear ratio affects the dynamic lift capability of the system.

(U) Figure 5-16 shows the variation of design speed thrust and takeoff thrust with gear ratio and propeller diameter. Gear ratios of 10, 11, 12, 13, and 14 were examined, but Figure 5-16 contains only 10, 12, and 14 for clarity. Figure 5-17 summarizes the thrust variation for all the gear ratios that were studied.

(U) Figure 5-16 shows that changing the transmission gear ratio has little effect on the design speed thrust (maximum increase of 0.5 percent from present design of 185.17 kN to 11/1 gear value of 186.149 kN). The increase occurs in the takeoff thrust available where a 13/1 gear ratio produces a 5.2 percent increase in the thrust. The 13/1 gear ratio, however, has a risk factor of 8 due to the anticipated changes in the hull-mounted gearbox and the planetary gearbox.

(C) Using the thrusts presented in Figure 5-17 and employing the two-point power limited design process described in subsection 2.4, designs were developed for the five gear ratios under consideration. Three sets of takeoff/design speed thrust margins were investigated; the results are presented in Figure 5-18. Using the current takeoff/design speed margin of 0.35/0.05, the maximum increase in dynamic lift (1.8 percent) is obtained with a gear ratio of 12/1 and a propeller diameter of 1.52 m.

(U) Figure 5-18 also demonstrates the effect of takeoff thrust margin on vehicle displacement. If the present margins were reduced to 25 percent at takeoff and 0.0 percent at design speed, maintaining the same transmission gear ratio of 10/1, an increase of 8.1 percent in dynamic lift could be achieved.

At the request of NAVSEC 6114, the Foilborne Transmission Planetary Gearbox Arrangement has been included in Grumman Letter Report PMM-NSE-L79-31, Reference 16.

Fig. 5-15 Foilborne Transmission Arrangement - Planetary Gearbox (U)

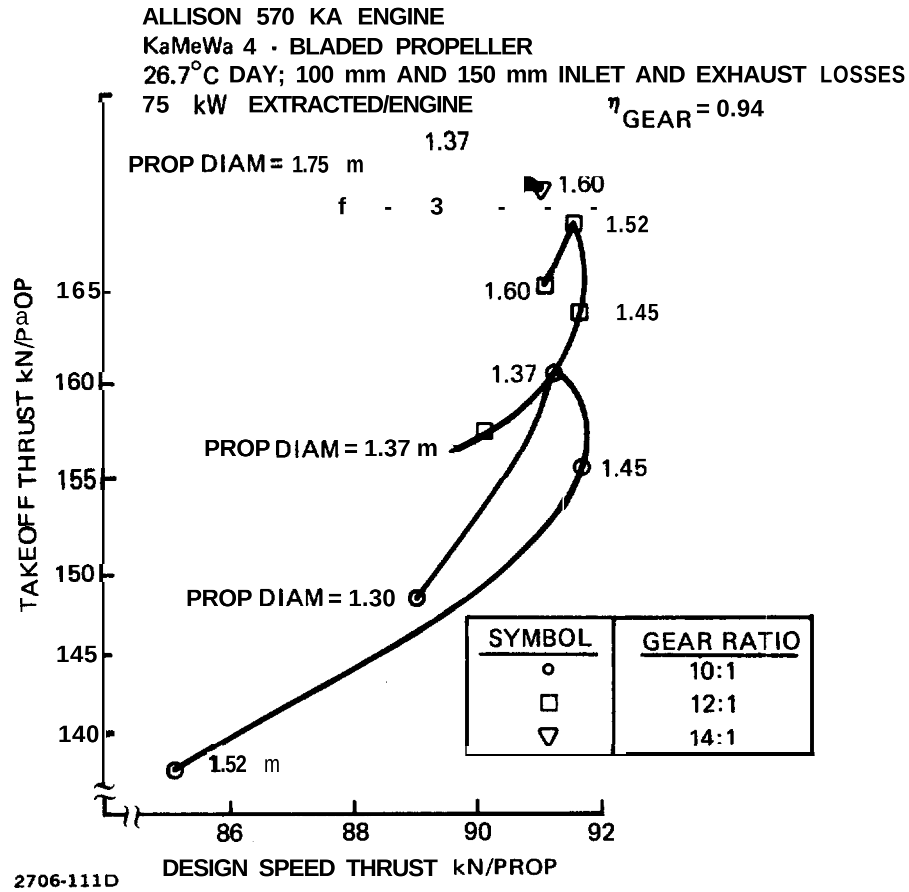

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Fig. 516 Propeller/Gear Ratio Selection (U)

GEAR RATIO	PROPELLER DIAMETER, METERS	TOTAL THRUST, kN TAKEOFF	TOTAL THRUST, kN DESIGN SPEED	RISK FACTOR
10/1	1.3716	322.035	185.170	1
11/1	1.4478	328.885	186.149	3
12/1	1.524	334.756	185.971	3
13/1	1.6002	338.938	184.948	8
14/1	1.6002	337.603	184.948	8/10

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Fig. 517 Effect of Gear Ratio on Propeller Diameter and Thrust (U)

THRUST MARGINS	GEAR RATIO	DYNAMIC LIFT, MT	FOIL AREA, m^2	FOIL LOADING, kPa	RISK FACTOR
Takeoff Thrust	10/1	283.04	41.407	67.010	1
Margin = 0.25	1 I/I	286.59	41.335	67.969	3
	12/1	287.86	40.739	69.269	3
Design Thrust	13/1	287.14	39.843	'70.648	8
Margin = 0.0	14/1	286.81	39.957	'70.366	8/10
Takeoff Thrust	10/1	264.96	37.846	68,627	1
Margin = 0.30	1 I/I	268.26	37.769	69.627	3
	12/1	269.34	37.194	70.988	3
Design Thrust	13/1	268.51	36.334	72.444	8
Margin = 0.05	14/1	268.23	36.445	72.150	8/10
Takeoff Thrust	10/1*	261.71	38.828	66.075	1
Margin = 0.35	11/1	265.09	38.774	67.022	3
	12/1	266.33	38.220	68.311	3
Design Thrust	13/1	265.68	37.376	69.685	8
Margin = 0.05	14/1	265.37	37.481	69.406	8/10

*Present Design Condition

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Fig. 5-18 Effect of Gear Ratio and Thrust Margins on Dynamic Lift and Foil Area (U)

5.4 VARIABLE INCIDENCE SYSTEM

(U) The inclusion of a variable incidence system on the forward strut/foil array of the design is contingent upon further hydrodynamic studies of the rough water takeoff conditions. In general, flap lift control systems require excessive flap deflections to produce the necessary lift coefficient for takeoff. These flap deflections reduce the lift-to-drag ratio and invite cavitation at the flap hinge.

(U) One way to reduce the flap envelope on a flap lift control system is to incorporate a variable incidence device into the strut/foil. The combination of the incidence angle and flap angle produces the required lift coefficient and reduces the possibility of hinge line cavitation.

(U) From the preliminary hydrodynamic studies presented in subsection 2.4 the incidence angles required to maintain a takeoff flap angle of 15 degrees are of the order of two degrees. As rough water performance analyses would increase this value, the forward foil variable incidence system was designed for four degrees of incidence.

To determine the structural feasibility of the system, a review of several candidate methods was made, and Figure 5-19 is included as the recommended solution which would require a minimum amount of modification to PHM-3 series lift system components.

The entire installation is located within a modified downlock mechanism and consists of a trunnion-mounted commercial, double acting actuator of approximately 200 mm diameter and 100 mm stroke. Actuation would be sequenced such that the downlock actuator must be engaged prior to the variable incidence actuator being energized.

To eliminate the opposing force of the retraction actuator, bypasses would be installed in the hydraulic system as noted in subsection 3.5.

The full stroke of the actuator would provide approximately 4 degrees of forward incidence to the foil.

5.5 FOIL SECTION COMPARISON

The original proposal "Development of a Hydrofoil Advanced Technology Lift and Propulsion System", No. 77-131N (U), (Grumman Aerospace Corporation) used a NACA 64A-306 foil section with a type a = 0.8 modified meanline for the forward and aft foil configurations. The material proposed for fabrication of the forward and aft struts and foils was HY 130 steel. The material used in the Preliminary Design Analysis is HY 100. A discussion on the change in material is presented in subsection 5.6 and the foil section change to a NACA 16-308 with a type a = 1.0 meanline is presented in the following paragraphs.

NACA 64A-30X Section Selection

To date, all fully submerged U.S. Navy hydrofoils utilize the NACA 16 series foil section. The 16 series has unfavorable separation characteristics inherent in the NACA 1 series sections. The cavitation inception characteristics, however, are very favorable due to the relatively flat pressure distribution characterized by the a = 1.0 type meanline. The large trailing edge angle required to achieve this pressure distribution, however, encourages turbulent, trailing edge separation.

Layne (Reference 10) presents a comparison between the NACA 16-309 and the NACA 64A-309 sections with a 20 percent chord flap, The use of the

64A-309 is considered preferable for flapped foils because of its tendency to maintain unseparated flow. This is achieved by concentrating the minimum pressure forward allowing the pressure recovery of the tail to occur over a greater proportion of the chord, thereby decreasing the adverse pressure gradient.

The original foil selection of an NACA 64A series section was based on the results presented in Layne's report. The highlights of his results were:

- The NACA 64A-309 foil exhibited higher lift-to-drag characteristics than those of the NACA 16-309 section for a given pitch angle, flap angle, and velocity
- The NACA 64A-309 foil attained higher values of lift prior to incipient cavitation than did the NACA 16-309, although cavitation occurred approximately at the same pitch angle for the same velocity for both foils
- The NACA 64A-309 foil maintained effective flap control up to δ = 17.5 degrees for lower velocities. At the higher velocities and higher flap angles, this effectiveness decreased markedly. In comparison, the NACA 16-309 foil exhibited only a fraction of the effectiveness of the NACA 64A-309 foil
- Variation in flap angle had considerably more effect on increasing lift in the case of the NACA 64A-309 foil. For velocities in the 30-knot range, the flap effectiveness ratio for the NACA 64A-309 was twice that of the NACA 16 -309 foil.

Based on these conclusions, the design proceeded with a NACA 64A-308 with an a = 0.8 modified meanline. Figure 5-20 shows a comparison between the NACA 64A-308 and the NACA 16-308. This figure shows the shift in the maximum thickness location from the NACA 16 series 60 percent chord value to the 40 percent chord station for the NACA 64A series. The difference in the a = 0.8 modified and a = 1.0 meanlines is also displayed on the figure.

Analysis of NACA 16 and NACA 64A Series Model Data

An analysis of the cavitation data reported by Layne in Reference 10 was performed to determine the validity of the NACA 16 series data which became

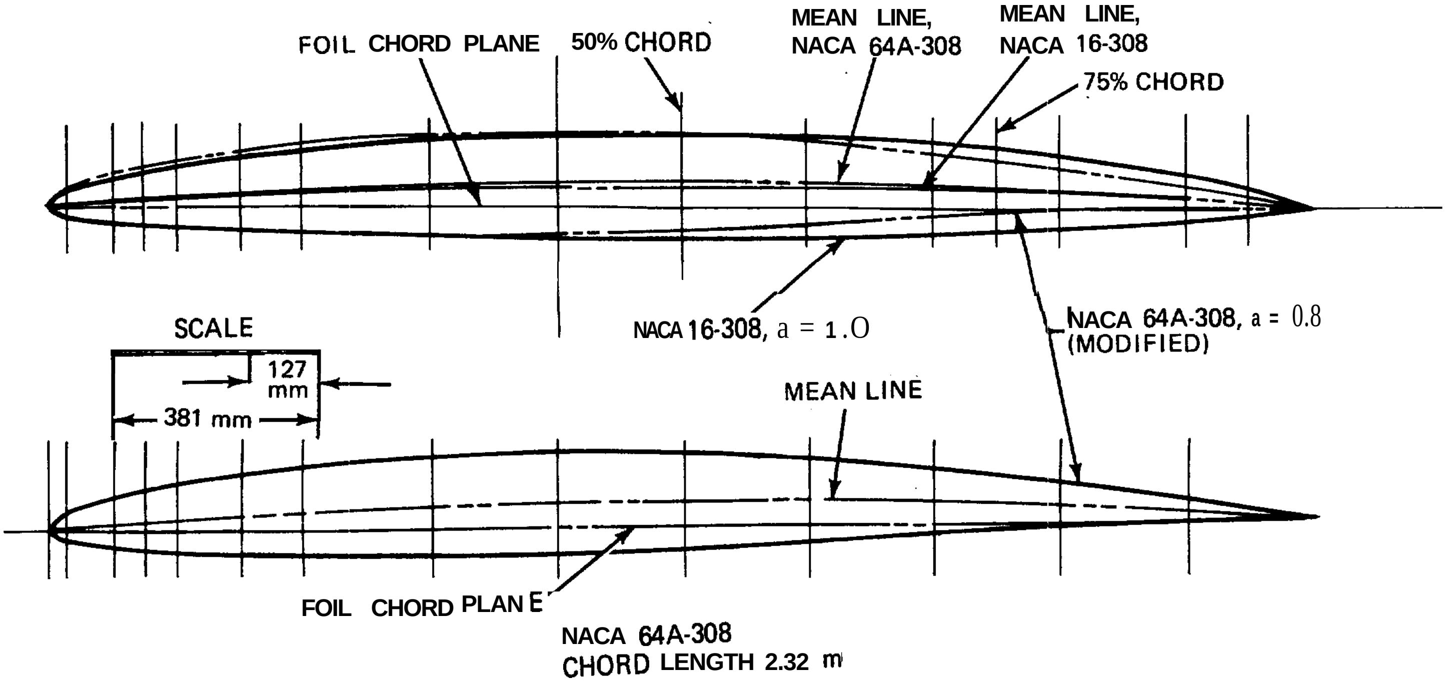

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Fig. 5-20 NACA 64A-308 vs NACA 16-308 Section Profiles (U)

suspect after a preliminary analysis. The highlights of this analysis are presented in this section.

Using the foil section cavitation equation presented in subsection 2.4 and the planform parameters given in Reference 10, the theoretical section cavitation buckets for the NACA 16-309 and the NACA 64A-309 were developed (Figure 5-21). From these foil section cavitation buckets, the theoretical foil cavitation buckets for the two sections were developed for the model submergence of 0.125 m (Figures 5-22 and 5-23).

Figure 5-22 contains two sets of experimental cavitation data and shows a comparison between the theoretical incipient cavitation bucket and the experimental data for the NACA 16-309 section. Layne's experimental data for incipient cavitation is presented in Figure 5 of Reference 10. The other source for the experimental data is a report by Norton and Wisler on the cavitation characteristics of the PCH forward foil (Reference 11). There is some correlation between the theoretical bucket and Norton and Wisler's data, but Layne's data does not correlate with the theoretical bucket. Layne's data on the NACA

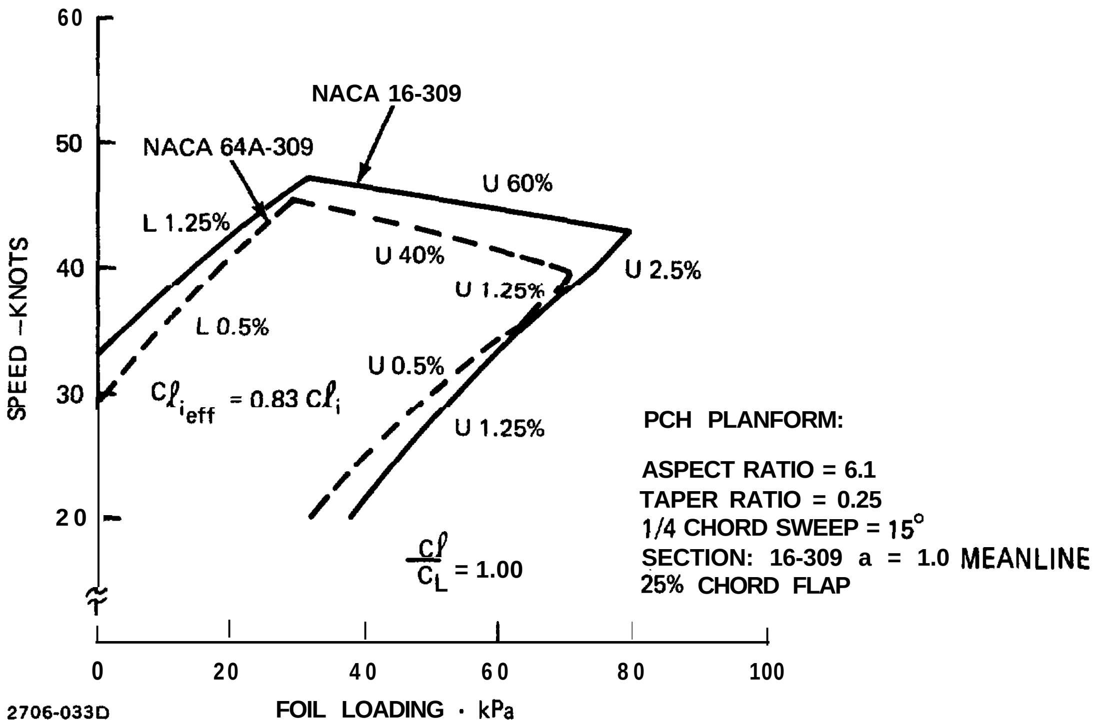

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Fig. 5-21 NACA 16309 and NACA 64A-309 Section Cavitation Buckets (U)

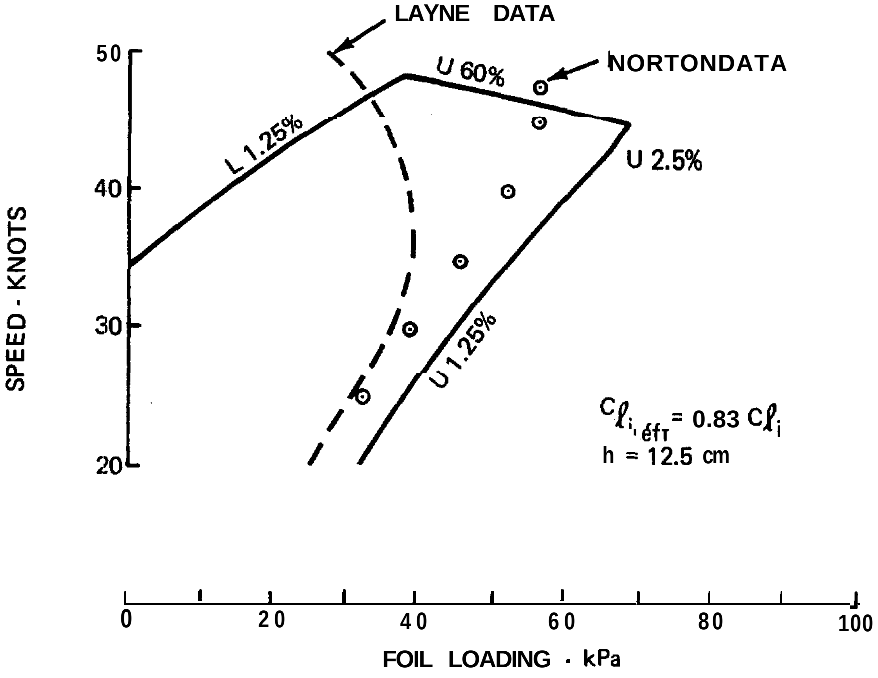

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Fig. 5-22 PCH Forward Foil - Cavitation Bucket (Model Submergence) - NACA 16-309 (U)

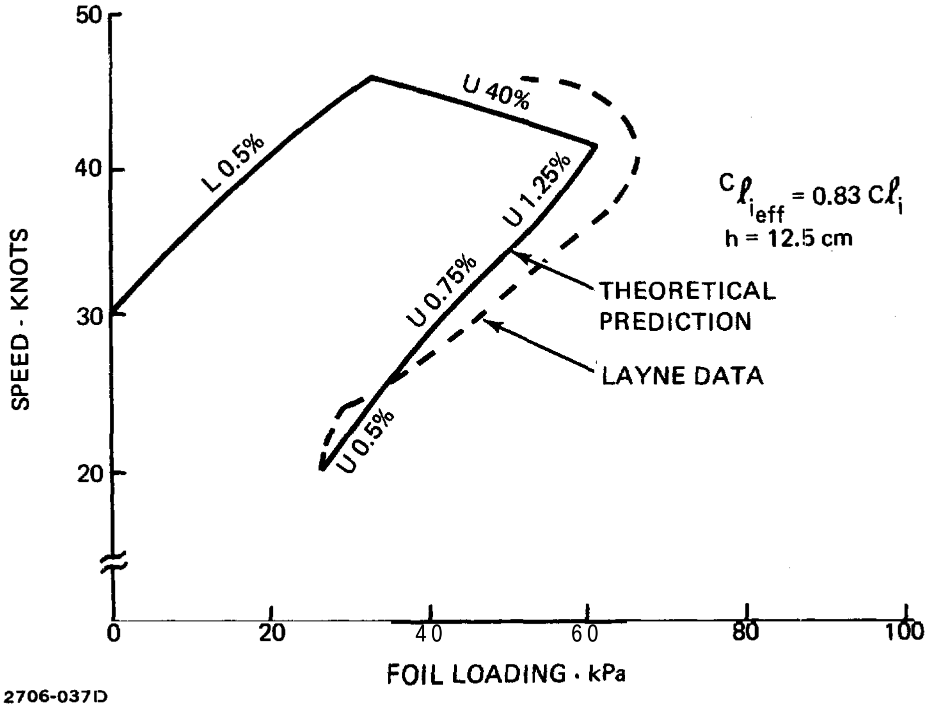

Fig. 5-23 PCH Forward Foil Planform - Cavitation Bucket, NACA 64A-309 (U)

16-309 also contradicts the PCH prototype data presented in Figure 11 of Reference 7. This figure shows that the PCH forward foil (a NACA 16-309) operates cavitation free at 43 knots with a foil loading of approximately 66 kPa.

Figure 5-23 presents Layne's experimental data for the NACA 64A-309 compared with the theoretical prediction. There is relatively good correlation between the prediction and the data.

Full Scale Flap Lift Cavitation Bucket Comparison

Following the procedure outlined in subsection 2.4 for developing the flap lift cavitation bucket, the cavitation characteristics for the NACA. 16-308 forward foil are presented in Figure 5-24. The two buckets represent the effect of limiting the flap angle at takeoff to 10 and 15 degrees. To determine the feasibility of utilizing a NACA 16-308 foil, a similar set of cavitation buckets were formulated using the same procedure outlined in subsection 2.4.

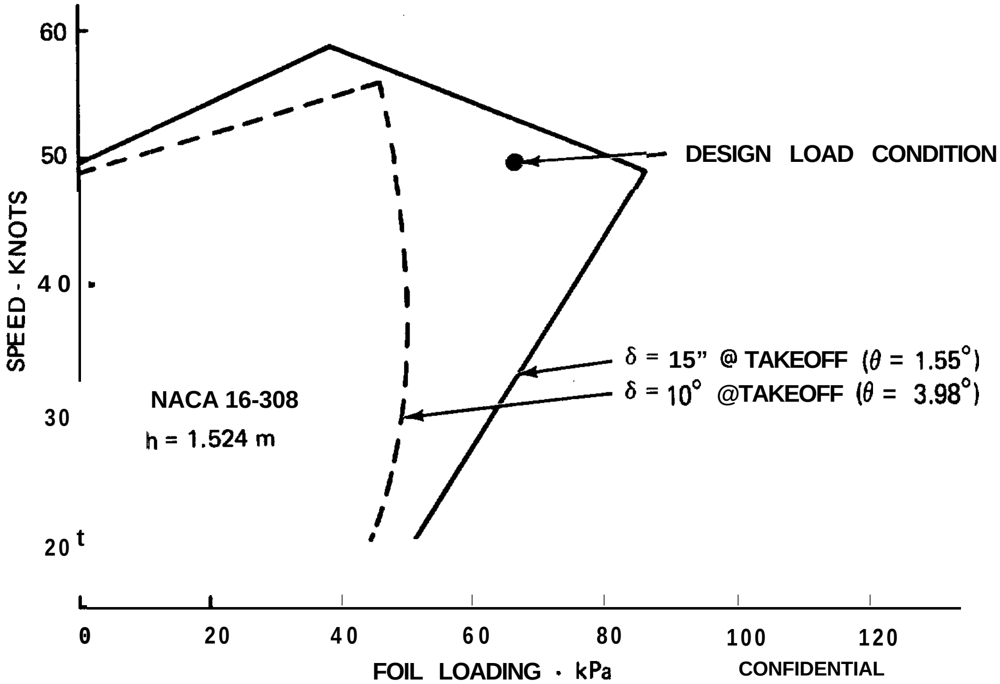

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Fig. 524 Forward Foil • Flap Lift Cavitation Buckets (U)

(U) The only change between the sections (other than the local velocity ratios which are obtained from Reference 6 for the NACA **64A-308**; a = 0.8 modified) is the relative section lift curve slope (K). Using a value of 0.96 for the relative section lift curve slope, the forward foil lift curve slopes for the NACA **64A-308** foil become:

$$C_{L_\alpha} = 0.0744/\text{deg}$$

$$C_{L_i} = 0.0677/\text{deg}$$

$$C_{L_\delta} = 0.0362/\text{deg}$$

$$C_{L_o} = 0.1537$$

(C) With these values the flap lift cavitation bucket for the forward foil with a NACA. **64A-308** section is plotted in Figure 5-25. Here again the two buckets represent the effect fo limiting the takeoff flap angle. As the figure demonstrates, the design load condition (50 knots; 66.071 **kPa)** is outside the cavitation buckets, indicating that the foil would be cavitated at the design speed.

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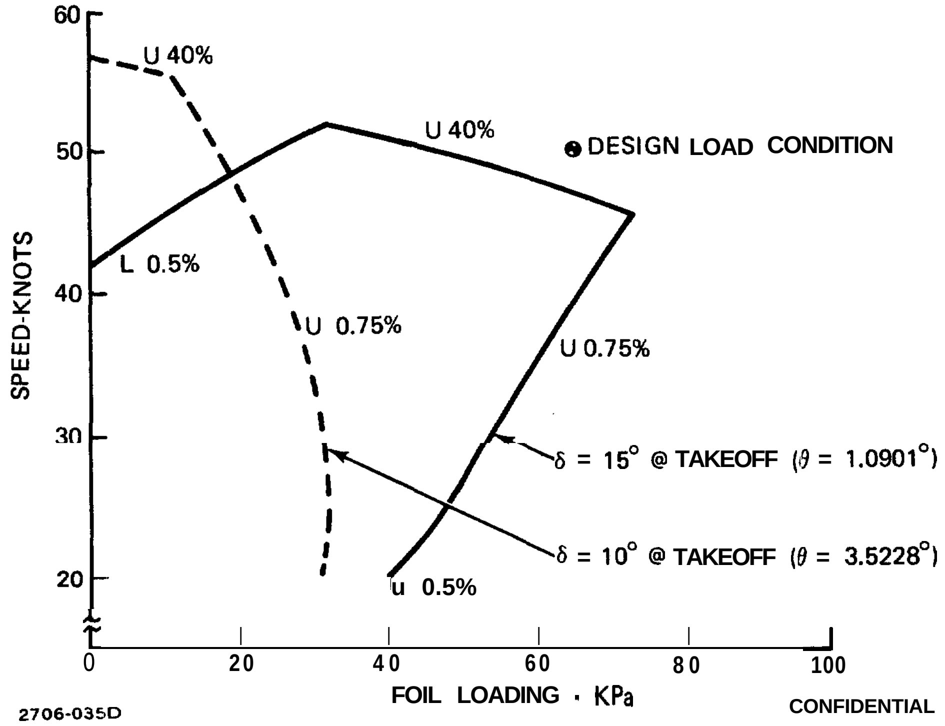

Fig. 5-25 Forward Foil - Flap Lift Cavitation Bucket, NACA 64A-308 (U)

(U) In general, the mid-chord incipient cavitation boundary (the upper boundary on Figure 5-24) is the effective boundary as well. The effective boundary is where cavitation produces a deleterious affect on. the foil performance. This commonality between the incipient and effective boundary is demonstrated in Reference 7 for the PCH-1 forward foil.

(U) Past design experience shows that reducing the foil thickness-to-chord ratio shifts the incipient cavitation bucket up and to the right on the speed versus loading scale. By examining various thickness-to-chord ratios for the NACA 64A section, Figure 5-26 displays that a 7 percent thickness-to-chord ratio puts the design load condition right on the incipient boundary. This is the maximum thickness-to-chord ratio that could be utilized on the forward foil if a NACA 64A section were to be used.

Structural Analvsis of NACA 64A and NACA 16 Section Foils

(U) The previous section limited itself to the cavitation restrictions placed on the foil section selections. The other restriction is a structural one which will be discussed in this section.

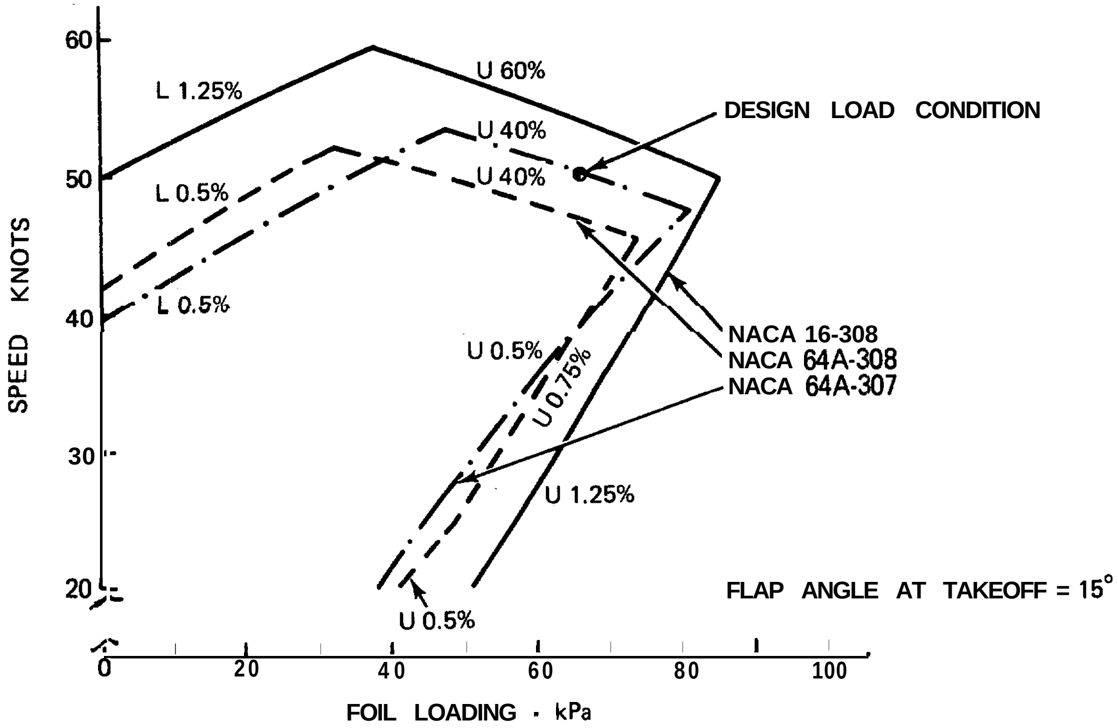

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Fig. 5-26 Forward Foil Configuration Cavitation Bucket Comparison (U)

(U) Using the same moment of inertia and ultimate shear curves presented in subsection 3.4 for the forward foil, a plot of ultimate stress at the root chord versus foil thickness-to-chord ratio is generated for the NACA 64A-3XX and the NACA 16-3XX foils (Figure 5-27). The two sets of curves represent those combinations of ultimate stress and foil thickness where the foils go solid from the 0 to the 70 percent chord station, and where the maximum plate thickness of the foil reaches a value of 38.1 mm. This plate thickness limit was assumed as the most feasible value from a fabrication and weight standpoint. The present design condition specified on Figure 5-27 is based on the use of a NACA 16-308 foil manufactured from HY 100 alloy steel. This condition is to the right of the maximum plate thickness line indicating that the forward foil maximum plate thickness would be less than 38.1 mm.

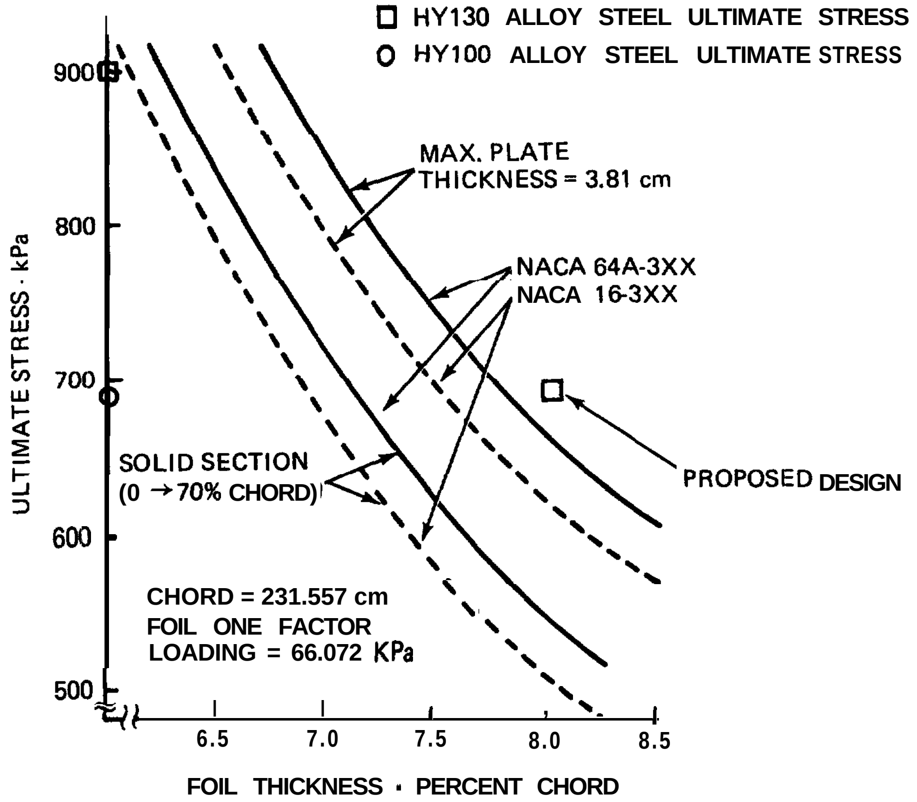

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Fig. 5-27 Root Stress vs Percent Foil Thickness - Forward Foil (U)

To use a NACA. 64A section, it has already been established that a 7 percent thickness-to-chord ratio must be used for cavitation free operation at the design speed. Moving horizontally from the present design condition (an 8 percent thickness-to-chord ratio) to a 7 percent value shows that the NACA 64A foil has gone solid at 7.3 percent, indicating that the forward foil cannot be a NACA 64A section if it is manufactured from HY 100 alloy steel.

If the foil were manufactured from HY 130 alloy steel one moves up to the ultimate stress of HY 130 (indicated by a square symbol on the ordinate) and the foil thickness limits for the NACA 64A section become 6.25 percent (solid section) and 6.8 percent (max. plate thickness limited to 38.1 mm). This change in material would allow the usage of a NACA 64A-307 for the proposed foil systems.

5.6 MATERIAL

As noted in the proposal for the development of the Advanced Technology Lift and Propulsion System, the material recommended for the fabrication of the struts and foils was HY 130 alloy steel. This recommendation was based upon extensive investigations over the past several years of the potential use of this material for lift system applications. As a result of these investigations, welding and manufacturing procedures for fabrication of HY 130 lift structure were developed. The applicability of these procedures was demonstrated by successfully manufacturing and delivering to the U. S. Navy an aft strut for the AG(EH)-1 PLAINVIEW in February 1976.

After preliminary discussions with Navy personnel it became evident that there were reservations on the usage of HY 130 for structures which are subjected to fatigue loadings, such as the struts and foils for this design. It was decided that the Preliminary Design would be based upon the use of HY 100 alloy steel in lieu of HY 130.

A comparison of the average properties (tensile stress, shear strength, elongation, etc.) is presented in Figure 5-28.

PROPERTY	HY 100 STEEL	HY 130 STEEL
TENSILE STRENGTH	830 MPa	1040 MPa
YIELD STRENGTH AT 0.2% OFFSET	723 MPa	992 MPa
SHEAR STRENGTH	588 MPa	592 MPa
ELONGATION IN 50.8mm · % MIN.	18%	14%
REDUCTION OF AREA · % · LONG'L	65%	57%

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Fig, 528 Strut and Foil Material (Average Properties) (U)

Fatigue

The decision to specify HY 100 steel for the struts and foils necessitated that a brief investigation be made to develop preliminary fatigue design curves for the base metal. This investigation was made primarily because of the lack of readily available information on the fatigue properties of HY 100 steel.

The preliminary fatigue properties and design curves derived for HY 100 steel apply to a base metal "in air." This is predicated on the assumption that the external strut and foil structure will be completely and effectively coated with a NAVSEA-approved coating system. The "Magna" system, as manufactured by the Midland Division of Dexter Corporation, which consists of a teflon-filled polyurethane topcoat over an epoxy primer, is a potential candidate coating. Internal surfaces would be protected by a corrosion preventive compound such as specified in MIL-C-16173,

Fatigue Design Curves

A fatigue analysis, presented in Reference 12, was used to derive preliminary design curves for notched HY 100 material subjected to constant-amplitude loading. The method utilizes Stowell's formula (References 13 and 14) in conjunction with the stabilized "cyclic" stress-strain curve for a material to obtain the local plastic stresses and strains at the base of notched parts subjected to an applied nominal net-section stress. This stabilized stress-strain curve more accurately represents the stress-strain relationship for a material subjected to cyclic loading than does the virgin tensile stress-strain curve. Moreover, a procedure is adopted to establish the local stress-strain (hysteretic) behavior during the loading and unloading phases of typical applied nominal stress-cycles $(0-f_{max}-f_{min}-f_{max}-\ldots)$.

The fatigue life of the notched part is calculated on the basic assumption that a part subjected to a given cyclic strain range at the base of the notch will fail in fatigue in the same number of cycles as a smooth specimen, subjected to the same strain range. In general, however, the calculated local strains at the base of the notch are not fully-reversed. Therefore, to use the generally available fully-reversed, unnotched strain-life curves, a mean-stress correction must be applied. This correction converts non-fully reversed notch loading to an equivalent fully-reversed notch strain amplitude with a corresponding number of cycles to failure.

The basic unnotched cyclic stress-strain and fully reversed strain-life curves for HY 100 were unavailable for this fatigue investigation. Therefore, these curves were estimated from available static tensile test data, using empirical equations originally derived by S.S. Manson in Reference 15. Figure 5-29 shows the virgin stress-strain and derived cyclic stress-strain curves for the HY 100 base material. Figure 5-30 shows the corresponding derived fully-reversed strain-life curve. These two curves were used with the fatigue method to calculate predicted fatigue life curves for notched material.

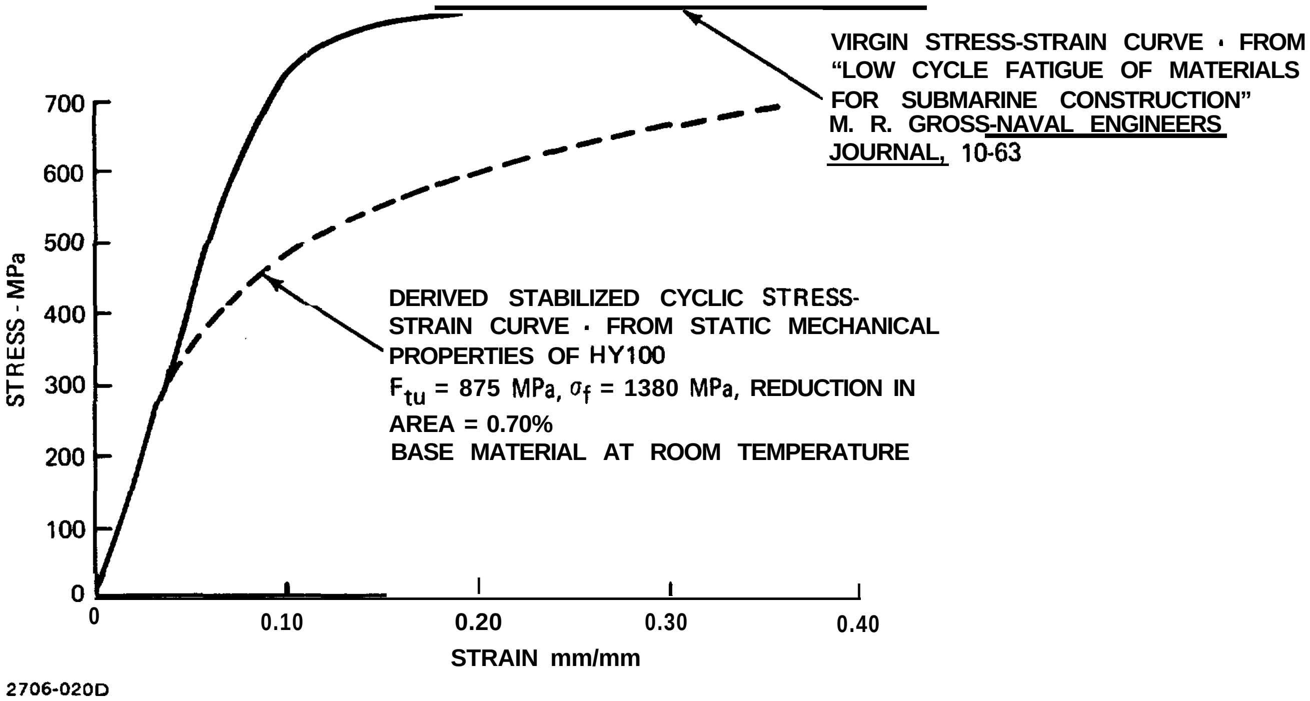


Fig. 5-29 Virgin and Derived Stabilized Cyclic Stress-Strain Curves for HY100 Steel (U)

Figures 5-31 through 5-33 present preliminary fatigue life design curves for notched HY 100 steel, at nominal stress ratios ($R = f_{min}/f_{max}$) of 0.3, 0.4 and 0.5. Each figure shows three constant-amplitude fatigue curves for elastic stress concentration factors, K_T, of 2, 3 and 4. The curves relate the maximum applied elastic notch stress, $K_T f_{max}$, to the fatigue life of a notched HY 100 steel part under constant-amplitude loading.

From the data presented in Figures 5-31 through 5-33, it was possible to tabulate the maximum stress versus cycles to failure based upon geometric stress concentration factors (K_T) of 2 .O and 3.0 at various stress ratios (R) This information is compiled in Figure 5-34. This data was then replotted as constant life diagrams for HY 100 alloy steel under the same conditions (Figures 5-35 and 5-36).

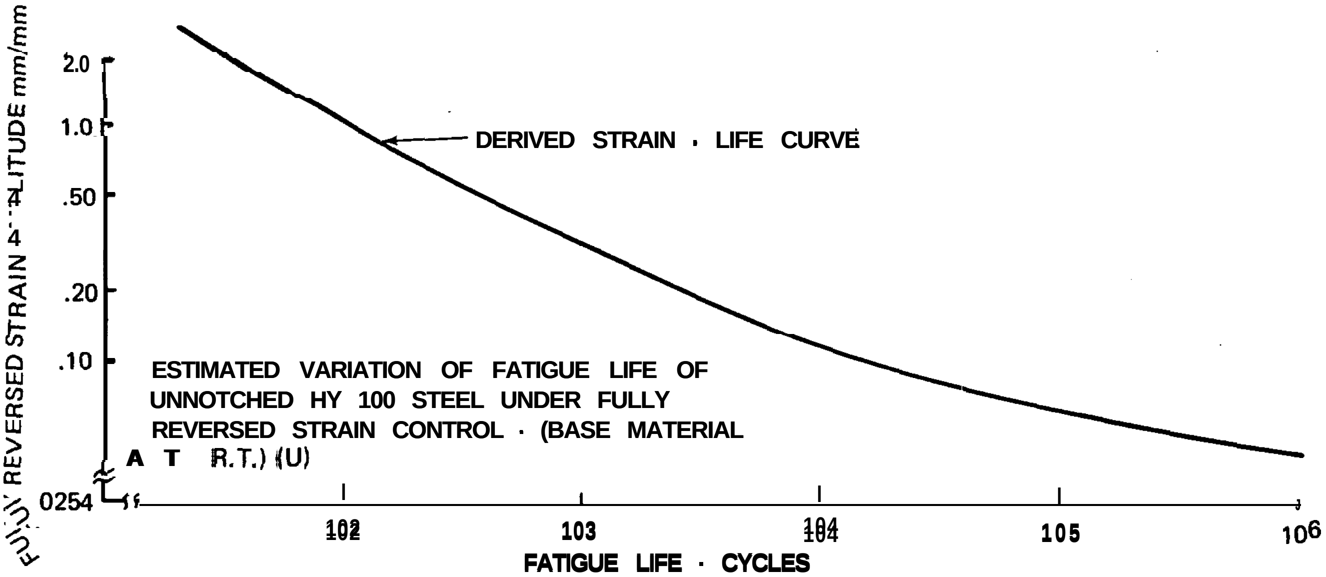


Fig. 5-30 Estimated Variation of Fatigue Life of Unnotched HY 100 Steel Under Fully Reversed Strain Control (Base Material at RT) (U)

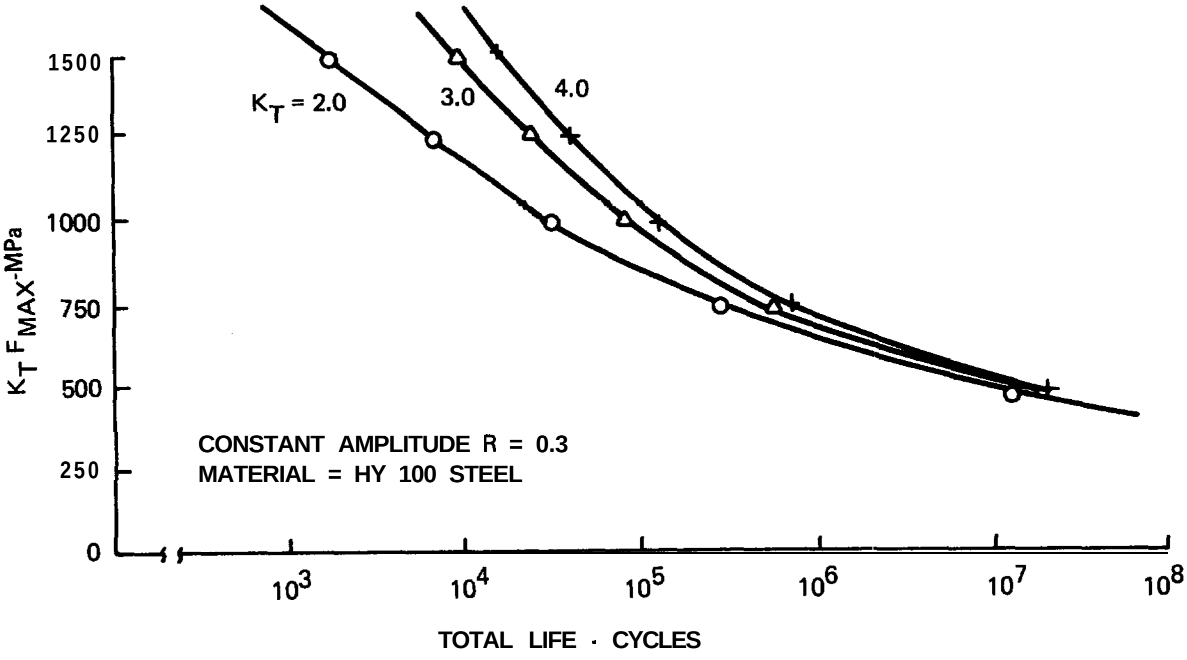


Fig. 531 Predicted fatigue For Notched HY 100 Steel Structure Under Constant-Amplitude Loading, R=0.3 (U)

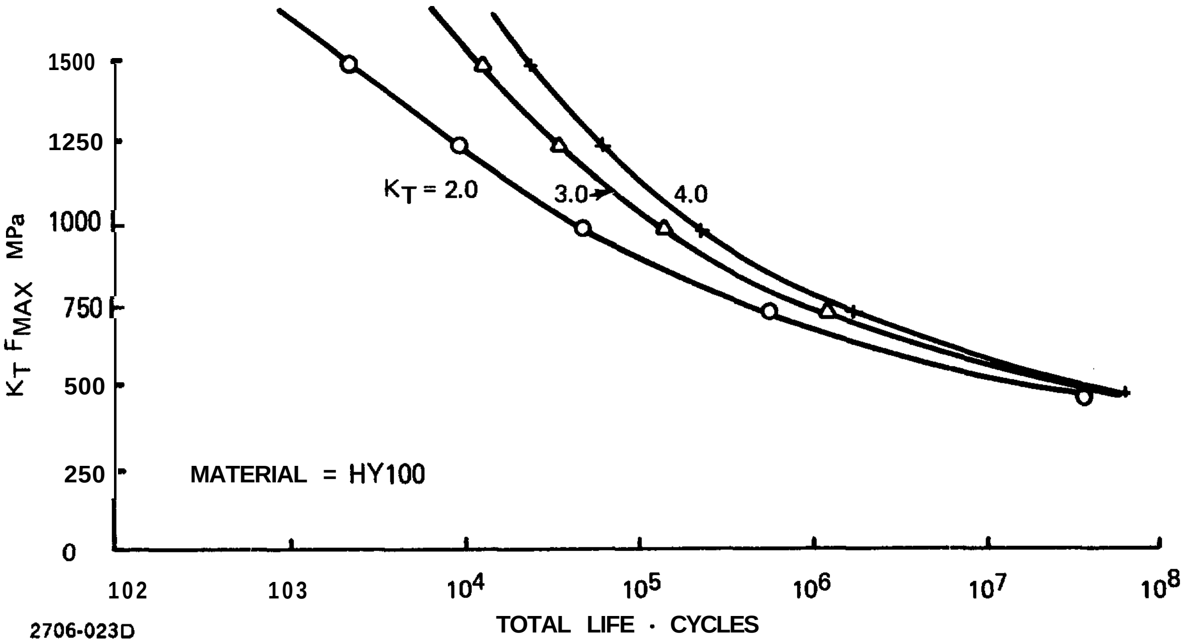


Fig. 5-32 Predicted Fatigue Life for Notched HY 100 Steel Structure Under Constant-Amplitude Loading, R = 0.4 (U)

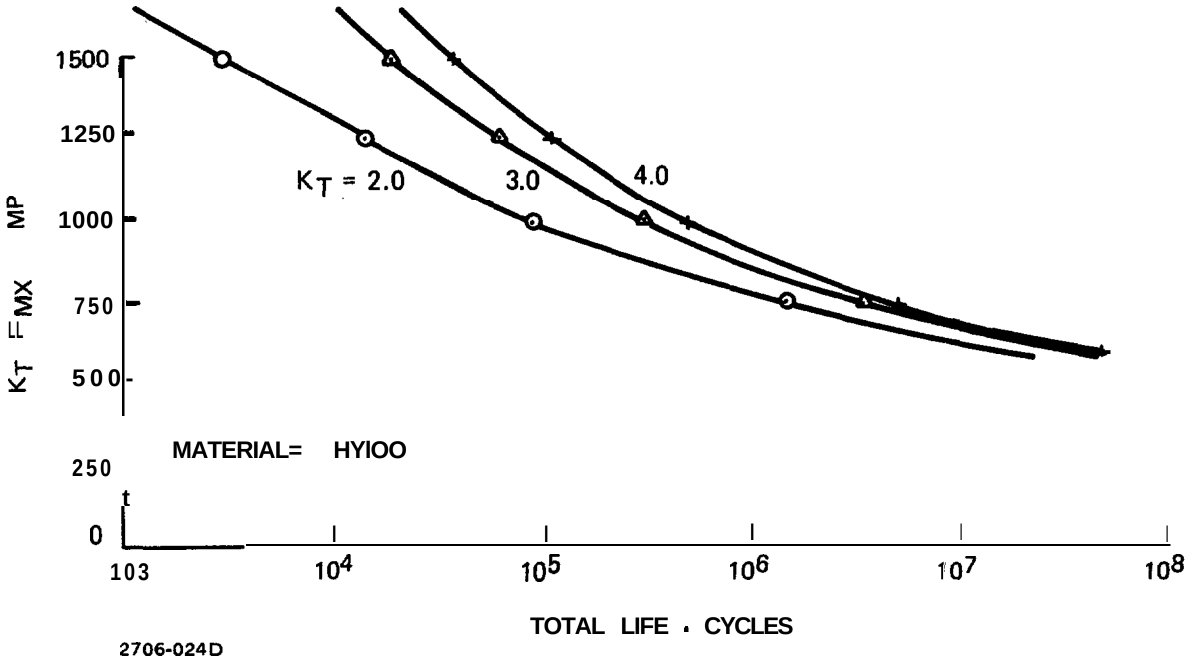


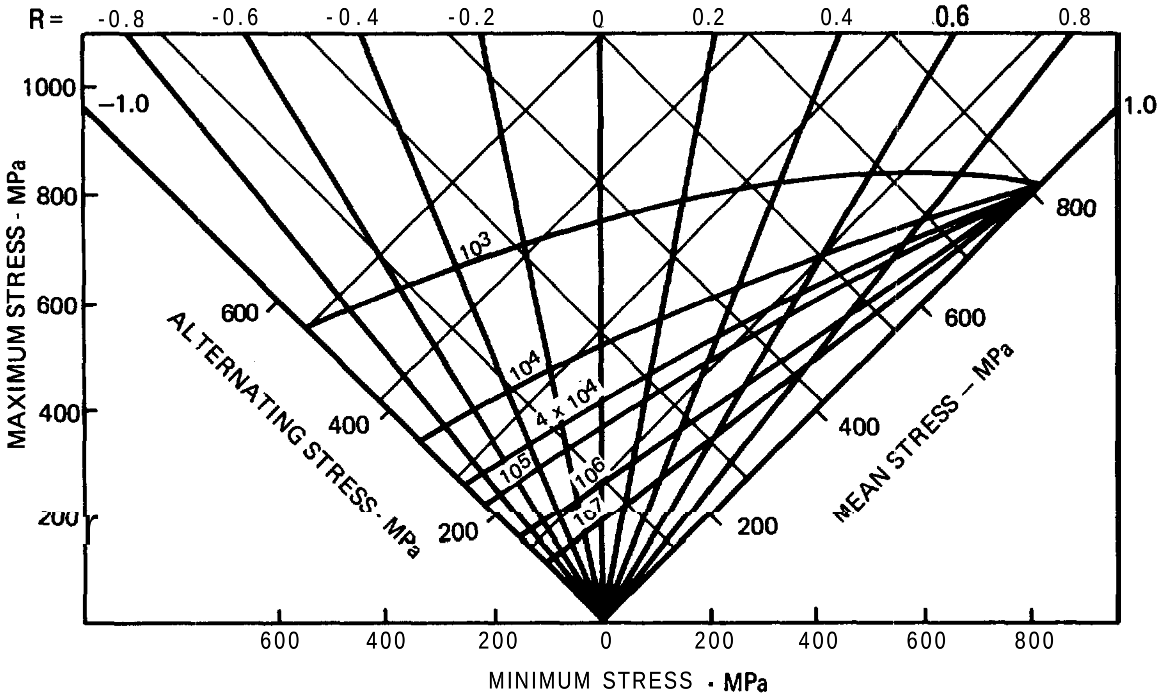
Fig. 5-33 Predicted Fatigue Life for Notched HY-100 Steel Structure Under Constant-Amplitude Loading, R = 0.5 (U)

MAX. STRESS MPa	K_T = 2.0					KT = 3.0				
R =	-1.0	0	0.3	0.4	0.5	-1.0	0	0.3	0.4	0.5
0	0	0	0	0	0	0	0	0	0	0
68.9	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞
137.9	5 x 10^5	∞	∞	∞	∞	1.6 x 10^5	8 x 10^6	lx 10^8	∞	∞
206.8	1.5 x 105	9 x 10^6	1 x 10^8	∞	∞	2.3 x 10^4	4 x 10^5	2.5 x 10^6	7x106	3x107
275.8	3x104	6 x 10^6	5x106	1.4 x 107	5x107	7x103	7.5x 10^4	3x105	5.5x 105	2x106
344.7	9 x 10^3	1.3x 105	5.5x 105	1.2x 106	3.5x 106	3x103	2.5 x 10^4	7 x 10^4	1.2x 105	4x105
413.7	4x103	4x104	1.3 x 10^5	2.5 x 10^5	5x105		1 x 104	2.5 x 10^4	3.7 x 104	1.2 x 106
482.6	2x103	1.5x 104	4 x 10^4	6.5 x 10^4	1.2 x 10^5		6 x 10^3	1.2x 104	1.6 x 10^4	5x104
551.6	1 x 10^3	7.2 x 10^3	1.6 x 10^4	2.5 x 10^4	3.7 x 10^4			6 x 10^3	8 x 10^3	2.5 x 10^4
620.5		3.6 x 10^3	7 x 10^3	1 x 10^4	1.5x 104					
689.5		2x103	3.5 x 103	5x103	6.5 x 10^3					

Determined from Figures 531through 5-33

2706-028D

Fig. 5-34 **HY100** Steel • Fatigue Properties • Cycles vs Stress (U)



2706-025D

Fig. 5-35 Constant Life Diagram • HY 100 Steel, K_T = 2.0 (U)

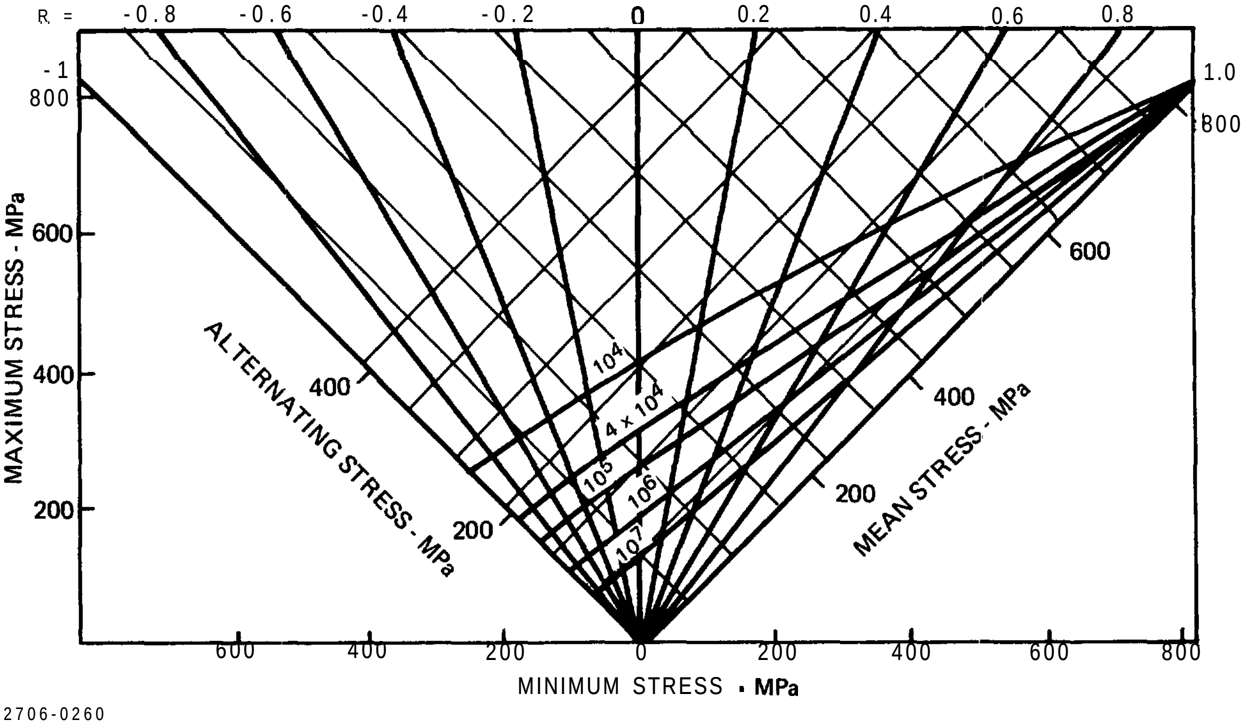


Fig. 5-36 Constant Life Diagram - HY100 Steel, K_T = 3.0 (U)

Fatigue Spectrum

A preliminary fatigue spectrum was developed based upon the criteria required by Rev. E of the NAVSEA "Foil System Life Assurance Requirements" dated 20 September 1976. The spectrum was developed using the procedure established for a similar analysis prepared for the Grumman Design M-151.

Excerpted from the Life Assurance Requirements document is the following life-cycle profile:

A. Annual Foilborne Hours:	800
B. Annual Hullborne Hours:	1240
C. Ship Life Expectancy:	15 years
D. Ship Weight:	Full load condition less 4% fuel

[redacted]

[redacted]. Turn Rate: 2 Degrees/Second - 6400 Occurrences/Year
4 **Degrees/Second** - 3200 Occurrences/Year
6 Degrees/Second - 800 Occurrences/Year
Maximum - 400 Occurrences/Year

F. Retraction and Extension: **Foil** system is retracted and extended 160 times per year.

G. **Headings** - Equally divided among:

Head
Port Bow
Port Beam
Port Stern Quartering
Following
Starboard Aft Quartering
Starboard Beam
Starboard Bow

H. Percent of Time in Various Sea States: Criteria - Atlantic **(62%),** Mediterranean (38%); Conservatively use Atlantic, -Area 9 (100%);

I. **Foilborne** Life: 12,000 Hours.

[redacted]

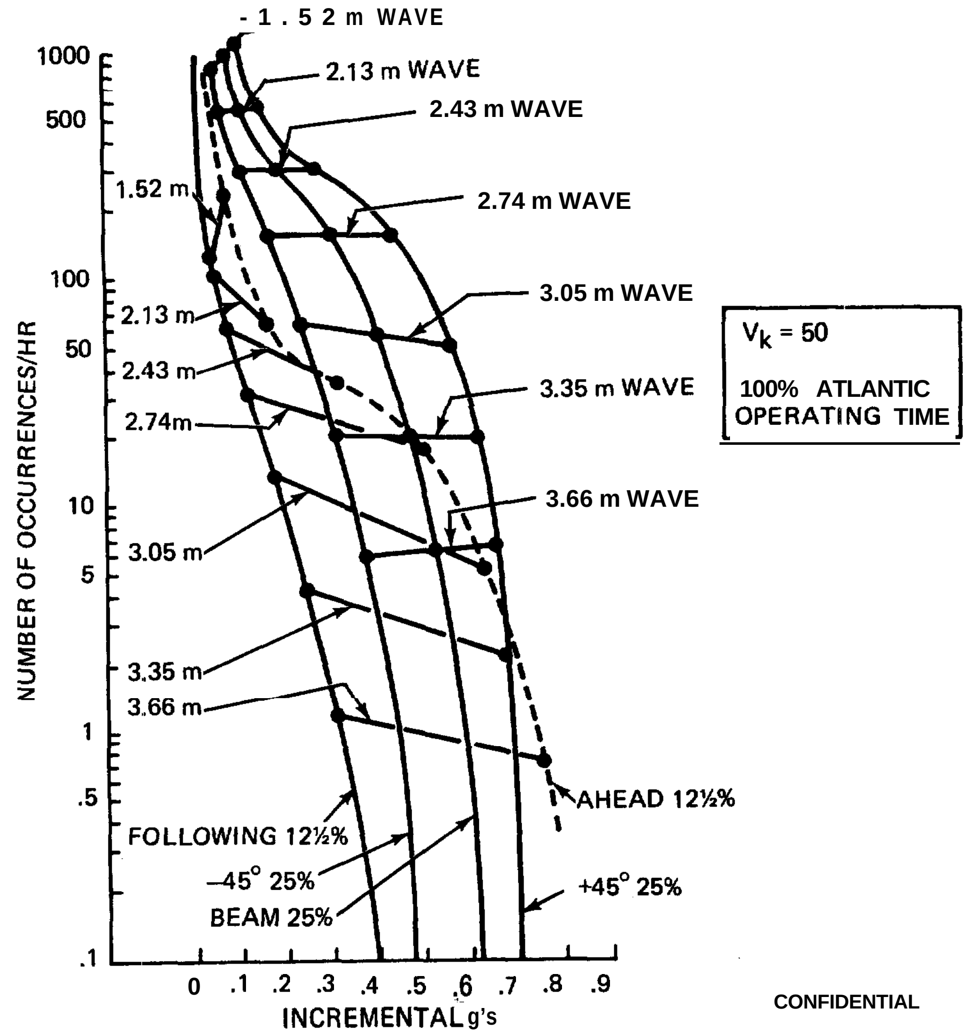
SEA STATE	MAX. WAVE HEIGHT **METRES**	% OF DAYS WAVE <MAX.	% OF TIME **IN** SEA STATE (ACTUAL)	% OF TIME IN SEA STATE **(WEIGHTED)**	HOURS
o-3	0.92	30	30	31.5	3780
3	1.53	60	30	31.5	3780
4	2.45	84	24	25	3000
5	3.67	95	11	12	1440
			95%	**100%**	12000

(U) Figure 5-37 presents the incremental **g's** as a function of the number of wave occurrences per hour. This information was generated from a similar analysis performed for Grumman Design M-151. From the information obtained in these curves, Figure 5-38 was developed to consolidate the total cycles for Sea States 4 and 5 in various headings and the corresponding g loadings which form the basis for the development of the allowable fatigue

[redacted]

[redacted]

stresses. Figure 5-38 presents Sea State 4 and 5 data inasmuch as it wa[illegible] determined that lower sea states do not contribute to the fatigue damage.



CONFIDENTIAL

2706-029D

Fig. 5-37 Incremental g's vs Wave Occurrences/HR (U)

Fatigue Loading Condition

(U) The baseline for the fatigue analysis as presented in the Life Assurance Requirements Document is the full load condition less 40 percent fuel. Based upon the data contained in Figure 5-38, a cumulative damage study has been made for HY 100 steel.

[redacted]

SEA HEADING	WAVE HEIGHT	SEA STATE 4	SEA STATE 5
		1.52m - 2.44m	2.44m - 3.66m
HEAD - 12½%	Average g's	0.095	0.509
	Average Occurrences Per Hour	121.1	11.7
	Total Hours	375	180
	Total Occurrences	45,400	2,100
+45° QUARTERING - 25%	Average g's	0.147	0.514
	Average Occurrences Per Hour	908.0	108.1
	Total Hours	750	360
	Total Occurrences	681,000	38.900
BEAM - 25%	Average g's	0.105	0.369
	Average Occurrences Per Hour	724.0	108.3
	Total Hours	750	360
	Total Occurrences	543,000	39,000
-45" QUARTERING - 25%	Average g's	0.062	0.233
	Average Occurrences Per Hour	582.7	111.1
	Total Hours	750	360
	Total Occurrences	437,000	40,000
FOLLOWING - 12½%	Average g's	0.048	0.181
	Average Occurrences Per Hour	98.7	22.3
	Total Hours	375	180
	Total Occurrences	37,000	4,020

2706-118D

Fig. 538 Wave Occurrences and 'g' Loadings (U)

The mean stress for fatigue was developed using the following assumptions and the results are tabulated on Figure 5-39.

$$\text{Fatigue mean stress} = \frac{\text{Fatigue Semi-Span Load}}{\text{Design Semi-Span Load}} = \frac{F_{ty}}{1.5}$$

where:

$$\text{Design Semi-Span Load} = L_{MFL_{fwd}} + L_{MFL_{aft}}$$

Fatigue Gross Weight (Displacement less 40% fuel) = 236.29 MT

Fatigue Semi-Span Load = 118.15 MT

Fatigue Mean Stress = 0.25 F_{ty}

[redacted]

MATERIAL	F_{tu}, MPa	F_{ty}, MPa	FATIGUE MEAN STRESS, MPa ($0.25 \times F_{ty}$)
HY 100	830	723	181
HY 130	1040	992	248
17-4 PH (H1100)	984	792	198

2706-032D

Fig. 5-39 Fatigue Mean Stress Comparison (U)

(U) To ascertain the maximum and minimum stress values and the stress ratio as a function of sea state the fatigue spectrum occurrences per hour are obtained from Figure 5-38 and corresponding 'g' loadings.

	SEA STATE 4, Occ/Hr	SEA STATE 5, Occ/Hr
Head Sea	121.1 (1.095 g's)	11.7 (1.509 g's)
+45° Quartering	908.0 (1.14 g's)	108.1 (1.514 g's)
Beam	724.0 (1.10 g's)	108.3 (1.369 g's)
-45° Quartering	582.7 (1.061 g's)	111.1 (1.233 g's)
Following Sea	98.7 (1.046 g's)	22.3 (1.181 g's)
AVERAGE:	467 (1.09 g's)	72.3 (1.36 g's)

[redacted] The fatigue spectrum is conservatively based on operation at 47 knots 100 percent of the time in the Atlantic. The major fatigue damage occurs for Sea State 5 for the head sea and the +45° quartering sea conditions. The other conditions fall below the endurance limit.

(U)

	HEAD SEA	+45° QUARTERING SEA
Sea State	5	5
Wave Ht. (m)	2.44-3.66	2.44-3.66
Avg. g's	0.509	0.514

[redacted]

Occurrences/Hr	11.7	108.1
Max. (%F_{ty})	37.7	37.9
Mean (%F_{ty})	25.0	25.0
Min. (%F_{ty})	12.3	12.2
Stress Ratio	0.326	0.322

Since these two cases are relatively similar they will be combined as follows to obtain the stress values.

Maximum A g's = 0.514

0 ccurrence/Hr = 119.8

Maximum Fatigue Stress = 37.9%F_{ty}

Minimum Fatigue Stress = 12.2%F_{ty}

Mean Fatigue Stress = 25. 0%F_{ty}

Stress Ratio (R) = 0.322

Figure 5-40 presents the life expectancy curve for HY 100 based on the Palmgren-Miner's hypothesis :

$$\frac{\eta 1}{N_1} + \frac{\eta 2}{N_2} + \ldots\ldots\ldots \frac{\eta i}{N_i} = 1.0$$

where η = actual cycles

N = failure cycles

For the critical condition of Sea State 5 operation:

$$\frac{\eta}{N} < 1.0$$

Letting η' denote occurrences/hr, the service life in hours is written as:

Service Life (hr) $= \frac{N}{\eta'}$

The plot of service life as a function of the stress concentration factor (K_T) is obtained for HY 100 alloy steel using the following procedure (example is for $K_T = 2.0$).

$F_{ref} = f_{max} = 274$ MPa = Fatigue Mean Stress x A g

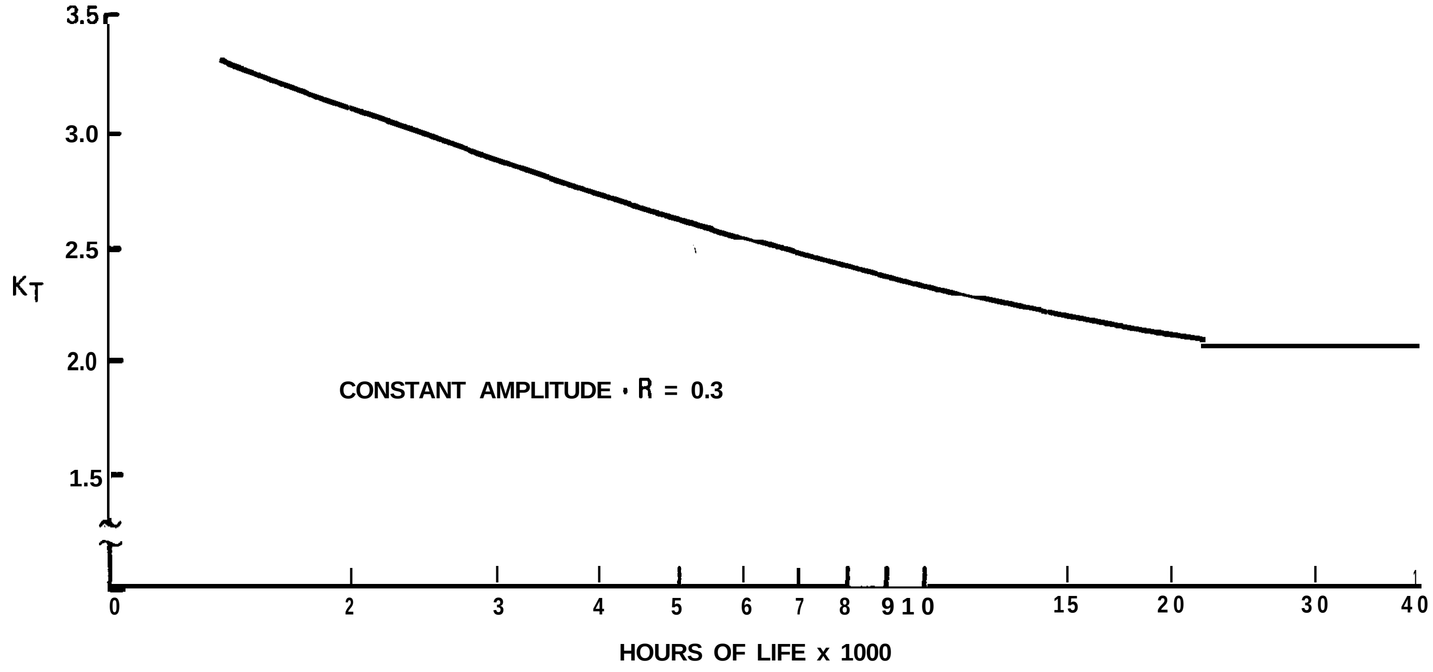
$K_T F_{ref} = 2 \times 274 = 548$ MPa

$R = 0.32$

$N \approx 5 \times 10^6$ cycles - From Figure 5-32

Service Life $= \frac{N}{\eta'} = 41{,}700$ hr

Reviewing the KT values of Figure 5-40 it is apparent that a K_T value of 2.36 or less will satisfy the life expectancy requirement of 112,000 hours. This value appears conservative but will require verification prior to initiation of the detail design.



2706-031D

Fig. 5-40 K_T Factor vs Life Expectancy - HY100 Steel (U)

Weight Consideration

The utilization of HY 130 alloy steel in lieu of HY 100 would present a weight saving due to the higher allowable stresses of HY 130. The skins on the struts and foils are particularly suitable for HY 130 because of their bending characteristics. The ratio of allowables can affect a weight saving of approximately 23 percent in this area.

The total weight of the strut and foil skins is 17.75 metric tons based on HY 100 alloy steel. If the foil/strut systems were manufactured from HY 130 a savings of 4.68 metric tons would be obtained (Figure 5-41). This savings includes a 15 percent margin on the materials.

ITEM	WEIGHT (MT)	
	HY 100	HY 130
FORWARD FOIL	2.13	1.64
AFT FOIL	5.76	4.44
FORWARD STRUT	3.00	2.31
AFT STRUTS	6.86	5.28
TOTALS	17.75 MT	13.67 MT

2706-1170

Fig. 541 HY 100 VS HY 130 Skin Weight Comparison (U)

SECTION 6

HYDRODYNAMIC TEST PROGRAM

6 - HYDRODYNAMIC TEST. PROGRAM

6.1 HYDRODYNAMIC TEST PROGRAM

It is recommended that, for further Navy development of the Hydrofoil Advanced Technology Lift and Propulsion System, a three-part comprehensive hydrodynamic test program be conducted. To keep costs at a minimum, the test program would be performed at existing test facilities at the Grumman Aerospace Corporation and the David W. Taylor Naval Ship Research and Development Center.

6.2 TEST OBJECTIVES

The primary objective of the test program is to reduce the hydrodynamic risk associated with future development to a minimum. The four basic objectives of the test program are categorized as follows:

- Validate cavitation characteristics
- Validate stability and control characteristics
- Validate flap effectiveness
- Validate lift characteristics.

These four characteristics must be validated to ensure that there are no unanticipated qualitative effects on performance and to quantitatively confirm the lift and side force characteristics of the design.

6.3 TEST FACILITIES

To perform a cost-effective, comprehensive test program, the test has been decomposed into three individual tests conducted at the Rotating Arm Facility at the David W. Taylor Naval Ship Research and Development Center, the Whirling Tank and the Low Speed Wind Tunnel located within the Grumman Aerospace Corporation. A brief description of each facility is presented in this subsection.

Rotating-Arm Facility

The Rotating-Arm Facility at David W. Taylor Naval Ship Research and Development Center consists of a basin and a rotating arm carriage. The reinforced concrete basin is 80 meters in diameter and 6.4 meters deep. Models are towed through it in circular paths. Steady-state speeds up to 30 knots can be obtained in one-half revolution at a radius of 36 meters; speeds up to 50 knots at the same radius can be obtained in a little more than one full turn. Model attachments to the arm and adjustments during tests are facilitated by a movable drydock.

The rotating arm is pivoted from a pedestal in the center of the basin and is driven by wheels mounted on its outboard end, which ride on a rail laid on a raised portion of the side wall. The arm is a bridge-like structure of aluminum tubing 39 meters in span, 6 meters wide and 6 meters high. The total weight of the arm is 196 kN, and its natural vibration frequency is 3.3 cycles per second in the vertical and horizontal modes and 4 cycles per second in the torsional mode.

To utilize this facility for testing the one-eighth scale model, some modifications will have to be made to handle the maximum anticipated loads which will be generated by the model. The mounting bracket for the Aerojet dynamometer and the pitch angulator will be reviewed structurally before any testing is performed.

Whirling Tank Facilitv

This unique hydrodynamic tool, located in Grumman's High-Speed Hydrodynamic Laboratory at Bethpage, New York, is the only facility where tests can be conducted at full scale values of Froude number, cavitation number and speed. This capability is made possible by testing in a rotating channel or toroid created by an artificial gravity field of 30 to 200 g's. During operation, the model is held stationary, as in wind tunnel practice, and the water rotates about a vertical axis. Friction between the channel and the water produces the driving force for the water, and centrifugal force holds the water in the channel.

The Whirling Tank can be used for hydrodynamic force model tests on any submerged body designed to operate near the surface. Grumman has used this facility primarily for prototype development of hydrofoil and hydrofoil systems. Prototype foil systems developed in this facility include those for the H.S. DENISON, AG(EH)-1 PLAINVIEW, H. S. DOLPHIN and PG(H)-1 FLAGSTAFF. A "transiting" foil system and an 80-kt foil system for AG (EH)- 1 PLAINVIEW were also developed in this facility.

Test models, mounted on a balance arm, can be automatically controlled in pitch, yaw, depth, and roll. Model attitude is displayed at the operator's console and can be fed to a data acquisition system. Since the tank is a continuous flow facility, data acquisition time is 50 to 100 times faster than conventional towing tanks. This feature makes the Whirling Tank an extremely economical test facility.

Wind Tunnel Facility

The Grumman subsonic wind tunnel is a continuous flow, open return circuit tunnel having a 2.0 x 3.0 m test section. Velocity is variable from 0 to 61 m/s. Turbulence factor is 1.34.

Comprehensive aerodynamic, propulsion, flutter, and loads testing. can be accomplished on conventional three-dimensional models or on floor-mounted reflection plane models; two-dimensional models can be tested utilizing inserts that form a test section. A ground board is available for simulated ground effects testing.

Powered model testing can be accomplished using variable-frequency electric motors for propellers or an auxiliary air supply for nozzles or ejectors. We have in operational readiness four motor channels of variable frequency drive with a range of O-600 Hertz with a maximum power capacity of 100 kW. Similarly, air supply lines and meters provide air flows up to 0.68 kg/s.

The Grumman subsonic wind tunnel has a dedicated IBM 1800 digital computer system located at the tunnel. In addition to the mechanical balance digital outputs and tunnel operating parameters, the system can handle 32 channels of analog data: 24 strain gage measurements, 7 channels of Scanivalve data, and one reference. Thirty-two additional channels exist for peripheral equipment such as tape recorders, multiplexers, etc. Auxiliary analog data acquistion (oscillographs and tape recorders) can be provided as necessary.

The IBM system provides final, corrected, tabulated data on-line in coefficient form. Automatic plotting on a drum-type plotter takes five minutes and is usually made at the end of each test run, but can be made on-line with some reduction of operating efficiency.

Two 50-tube manometer boards are available for visual pressure indications. Photographic equipment is available as necessary.

High resolution closed-circuit TV with video recorders and instant playback is available for tufts and oil flow visualization.

6.4 TEST MODELS

Preliminary test planning indicates the need for two test models. A one-eighth scale model would be used for those tests conducted in the rotating arm facility and the low speed wind tunnel. A one-ninetieth scale model would be used for the whirling tank test. Preliminary model design indicates that the one-eighth scale model would require some modification to fit the existing wind tunnel test stand.

The one-eigth scale model would have a 1.78 meter span and a 29.6 centimeter root chord. The foil would be fabricated from steel and the planform and contours would be identical to those shown in Figure 2-13. The model would be equipped with four remotely driven flap segments adding a third degree of freedom to the rotating arm tests (present facility has two degrees of freedom-pitch and yaw).

Special angle attachment fittings wo uld be necessary to support the entire one-eighth scale model assembly by the struts on the existing trunnions in the low speed wind tunnel. Approximately 15 foil surface static pressure taps would be installed for measuring the spanwise and chordwise pressure distributions.

The one-ninetieth scale model would have a 15.24 cm span and a 2.54 cm root chord. The foil would be fabricated from steel and the contours and planform would be identical to those shown in Figure 2-l.

The flap settings would not be remotely controlled like the one-eighth scale model. Ten hand set flap angles would be manufactured for the one-ninetieth scale model.

6.5 TEST PROGRAM

The hydrodynamic test program for the aft lift system is presently envisioned as three separate programs. Lift, side load and cavitation characteristics would be investigated in the rotating arm facility on the one-eighth scale model. Lift, side load, cavitation, roll and ventilation characteristics would be investigated in the whirling tank facility. Drag and spanwise and chordwise pressure distributions would be studied in the low speed wind tunnel facility.

For completeness, there would be some duplication in those tests run in the rotating arm and the whirling tank. The preliminary test plans for each facility are outlined below and a preliminary schedule is presented in Section 7 of this report. Included with each test is a brief summary of the purpose of the test.

ROTATING ARM FACILITY

Strut Side Load - No Foil or Pod - determine the effect of foil on side force slope and closure angle.

Speed: 45 knots

Depths: 1.52 m, 4.0 m

0 to 3 vented points ($\sim 8^{\circ}$) at 1.0° increments

Return to reattachment point at 1.0° increments and repeat for opposite yaw.

Strut Tares - No Foil - determine drag tares and pod effects on side-force slope and closure angle.

Speeds: 25, 30, 35, 40, 45, 50 knots

Depths: 1.52 m, 2.74 m, 4.0 m

0 to 3 vented points ($\sim 8^{\circ}$) at 1.0° increments

Return to reattachment point at 1.0° increments

Lift Curves - Zero Flap - determine lift, drag, moments (flap & foil) and cavitation boundaries.

Speeds: 25, 30, 35, 40, 45, 48, 50 knots

Depths: 1.52 m, 4.0 m

-3.0’ to 12° pitch or higher (to bracket $C_{L_{max}}$) at 1.0° increments, back at 2.0° increments

Flap Lift Curve Slopes - Inboard and Outboard - determine lift, drag, moments (flap & foil) and cavitation boundaries.

Speed: 40 knots

Depths: 4.0 m

Ten inboard flap angles: -15.0°, -10.0°, -5.0°, -2.0°, 2.0°, 4.0°, 6.0°, 8.0°, 10.0°, 15.0’

Ten outboard flap angles: -15.0°, -10.0°, -5.0°, -2.0°, 2.0°, 4.0° 6.0°, 8.0°, 10.0°, 15.0’

Pitch angles: -4. 0°, -2. 0°, 0.0°, 2.0°, 4.0°, 6.0°, 8.0°, 10.0°, 12.0’ (bracket CL_{max})

Side Load Curves - Zero Foil Flap - determine zero lift angle, drag, side force slope and closure angle for zero lift.

Speeds: 25, 30, 35, 40, 45, 48, 50 knots

Depths: 1.52 m, 2.74 m, 4.0 m

0 to 3 vented points (~ 8°) at 1.0° increments

Return to reattachment point at 1.0° increment and repeat for opposite yaw.

Side Load Curves - 0.25g Foil Flaps - effect of lift on zero lift angle, drag, side force slope and closure angle.

Speeds: 25, 30, 35, 40, 45, 48, 50 knots

Depths: 1.52 m, 2.74 m, 4.0 m

-2.0 to 3 vented points (~ 8°) at 1.0 increments

Return to reattachment point at 1.0° increments

WHIRLING TANK FACILITY

Lift curves - Zero Flap - determine lift, drag, moments (flap & foil) and cavitation boundaries.

Speeds: 25, 30, 35, 40, 45, 48, 50 knots

Depths: 1.52 m, 4.0 m

-3.0° to 12° pitch or higher (to bracket $C_{L_{max}}$)

at 1.0° increments, back at 2.0° increments .

Flap Lift Curve Slopes - Inboard and Outboard - determine lift, drag, moments (flap & foil) and cavitation boundaries.

Speed: 40, 45 knots

Depths: 4.0 m

Ten inboard flap angles: -15.0°, -10.0°, -5.0°, -2.0°, 2.0°, 4.0°, 6.0°, 8.0°, 10.0°, 15.0’

Ten outboard flap angles: -15.0°, -10.0°, -5.0°, -2.0°, 2.0°, 4.0°, 6.0°, 8.0°, 10.0°, 15.0’

Pitchangles: -4.0°, -2.0°, 0.0°, 2.0°, 4.0°, 6.0°, 8.0°, 10.0°, 12.0° (to bracket $C_{L_{max}}$)

Side Load Curves - Zero Foil Flap - determine zero lift angle, drag, side force slope and closure angle for zero lift.

Speeds: 25, 30, 35, 40, 45, 48, 50 knots

Depths: 1.52 m, 2.74 m, 4.0 m

0 to 3 vented points ($\sim$ 8.0’) at 1.0° increments

Return to reattachment point at 1.0° increment and repeat for opposite yaw.

Side Load Curves - 0.25g Foil Flaps - effect of lift on zero lift angle, drag, side force slope and closure angle.

Speeds: 25, 30, 35, 40, 45, 46, 50 knots

Depths: 1.52 m, 2.74 m, 4.0 m

-2.0° to 3 vented points (~ 8°) at 1.0° increments

Return to reattachment point at 1.0° increments

Roll Control - determine roll moment characteristics and maximum moment boundary for power and authority.

Speeds: 25, 40, 45, 48, 50 knots

Depths: 1.52 m, 4.0 m

Flap Angles: -2.0°, 0.0°, 2.0°, 5.0°, 10.0°, 15.0°, 20.0’

Seven differential outboard flap angles: -2.0°, O.Oo, 2.0°, 4. 0°, 6.0°, 8.0°, 10.0’

Ventilation Characteristics - Flat Foil - to ensure lift requirements are met without ventilating.

Depths: 1.52 m, 4.0 m

Pitch Angles: 0.0°, 3.0°, 6.0°, 9.0°, 12.0°, + ventilation angles + 2 vented points.

Return to reattachment angle.

Speeds:	25 KNOTS	40 KNOTS	50 KNOTS
Flap Angles:	-2.0’ Flap	- 10.0’ Flap	-10.0’ Flap
	0.0°	- 6.0°	- 6.0°
	2.0°	- 2.0°	- 2.0°
	10.0°	0.0°	0.0°
	15.0°	2.0°	2.0°
	20.0°	10. 0°	10.0°
	25.0’	20.0°	15.0°
		25.0’	

Ventilation Characteristics - Rolled - Low Speed - determine minimum flight depth for 1 g lift and axisymmetric lift conditions.

Roll angles: 10.0’ and 25.0’

Speeds: 25, 40, 45, 50 knots

Flap Angles: -10.0°, -5.0°, 0.0°, 5.0°, 10.0°, 15.0°, 20.0’

Depths: 0.3 m, 0.15 m, 0.0, Strut/Foil Intersection

Pitch Angles: -3.0°, 0.0°, 3.0°, 6.0°, 9.0°, 12. 0°, + vent angle + 2 vented points

Return to reattachment angle

Coordinated Turns - determine turning performance characteristics.

Speeds: 25, 40, 45, 50 knots

Roll Angles: 5.0°, 10.0°, 15.0°, 20.0°, 25.0’ (with appropriate flap settings)

Depths: 1.52 m, 4 m, 13.0 m

Yaw Angles: -3.0°, -2.0°, -1.0°, 0.0°, 1.0°, 2.0°, 3.0° which should bracket the closure angle

WIND TUNNEL FACILITY

Drag Polars - With Flaps - verify drag polar and Reynolds number effects.

High Reynolds Number

Flap Angles: -10.0°, -5.0°, -2.0°, 0.0°, 2.0°, 5.0°, 10.0°, 15.0°, 20.0°, 25.0’

Pitch Angles: -3.0°, -2.0°, 0.0°, 2.0°, 4.0°, 6.0°, 8.0°, 10.0°, 12.0°

Chordwise/Spanwise Pressure Distributions - verify pressure distribution for cavitation conditions.

High Reynolds Number

Flap Angles: -10.0°, -5.0°, 0.0°, 5.0°, 10.0°, 15.0°, 20.0’

Various differential flap segments.

These test programs are of a preliminary nature and will be revised during the pre-test planning phase.

SECTION 7

SCHEDULES

7- SCHEDULES

7.1 RECOMMENDED DEVELOPMENT SCHEDULE

The recommended development schedule for the Advanced Technology Lift and Propulsion System is shown in Figure 7-l. As shown, these recommendations are divided into the sequential phases, as follows:

- Phase I - Design Studies
- Phase II - Design Verification and Preparation
- Phase III - Detail Design and Hardware Fabrication..

The phases are further subdivided into major tasks within each individual phase. Prime consideration in the formulation of the recommended development schedule was emphasis on careful considerations of associated risks and minimum costs. The schedule targets for complete verification of the design and identification of cost elements by 1 July 1980 in sufficient detail to proceed with a firm-fixed price contract for hardware fabrication and installation. Target data for completion of installation of all hardware on an evaluation platform ready for Navy trials is 1 December 1982.

Phase I - Design Studies

Phase I consists of three tasks, of which the first, Preliminary Design, is being completed with this report. Two additional tasks, Lift System Structures Definition and Test Planning and Model Design, are recommended.

The Lift System Structural Definition will develop the structural scantlings for the lift system using computer-aided design capabilities. Lift system hydrodynamic contours are defined in this report, with structural guidance provided by existing Grumman drawings **M167-56701** and **M167-56702.** Task output will include engineering drawings showing the final structural configuration in sufficient detail, to serve as guidance drawings for the initiation of Detail Design. Typical joint fabrication, scantlings, components, and method of fabrication and assembly will be shown.

Associated output will include a weight statement of the lift system including associated non-structural components, a final report, and a draft design specification for detail design and fabrication of the structural components of the Advanced Technology Lift System.

Test planning and model design will develop the detail test requirements for a comprehensive hydrodynamic test program considering the acquisition of data relative to:

- Strut Side Load
- Strut Surface Effects
- Strut Tares
- Lift Curves (zero flap)
- Flap Lift Curve Slopes (inboard and outboard)
- Side Load Curves (zero flap)
- Side Load Curves (0.25g foil flaps)
- Roll Control
- Ventilation Characteristics (flap foil)
- Ventilation Characteristics (rolled)
- Coordinated Turns
- Drag Polar Verification
- Spanwise/Chordwise Pressure Distributions.

Due consideration will be directed to the most cost-effective utilization of existing test facilities at both Grumman and the David W. Taylor *Naval* Ship R & D Center. Dual use of test models will be given prime consideration. Model designs will be developed to suitable test scales for the basic models with adjustable flaps and mechanisms, fittings, and for instrumentation for implementation of the test program. Structural adequacy of the test models will be verified. Engineering drawings of the models will be provided in sufficient detail for fabrication costing.

The final report of the task will include detail definition of the test program and schedule.

Also identified as reference in Figure 7-1 is a section test data correlation task. This task is a completion of a review and the formulation of a final report on the section test data received during the development of the preliminary design analysis in this report. This task is not directly necessary for the continuation of the development of the Advanced Technology Lift System, but should be completed and documented for future developments in other areas and activities.

Phase II - Design Verification and Preparation

Phase II contains five tasks, the first three consisting of hydrodynamic test programs, a propeller design review and the preparation of a design package for the alterations required on the test platform. The principal objective of these tasks is to verify the hydrodynamic performance predictions contained in this report for the lift system and propeller and the preparation of the ship alteration package.

Preliminary scoping of the model test requirements completed to date indicate that the most advisable program should consist of a three-part program consisting of a rotating arm test using the facilities at the David W. Taylor Naval Ship R & D Center, and whirling tank and wind tunnel tests at Grumman. The rotating arm and wind tunnel tests would use an identical 1/8 scale model, while the whirling tank tests would use a 1/90 scale model. Model preparation time for the larger 1/8 scale model is estimated to be four months, while the smaller model will require approximately three months to build.

Actual testing times have been estimated to be three weeks in the rotating arm facility, three weeks in the whirling tank, and six days in the wind tunnel. A one month period in the schedule has been allocated in each case for these tests. Three months of data reduction, post test analysis, and report preparation has also been allocated in each case for a total combined hydrodynamic program time of nine months.

The propeller design review is estimated to be a limited scope activity conducted in conjunction with the potential propeller supplier to verify estimated propeller performance, design, and manufacturing schedules.

The final task included in Phase II, preparation of the ship alterations design package, will require approximately five months to complete. Identification of the actual test platform is required for initiation with a completion date of approximately two months prior to establishment of a firm-fixed price position for hardware fabrication and installation in Phase III. Actual period of accomplishment thus is flexible within these constraints.

Phase III -- Detail Design and Hardware Fabrication

Phase III consists of initial activities under anticipated cost plus fixed fee type contracting followed by anticipated firm fixed price activities for actual hardware development and ship installation. The initial activities include a six month initial detail design phase both in support of the firm pricing objectives and preparation for lift system fabrication.

Figure 7-1 illustrates lead time requirements! from release of purchase orders to delivery of hardware for all major equipment components of the Advanced Technology Lift and Propulsion System. Also illustrated are the estimated times required to purchase minor components and material, make ship alterations, and install major systems.

SECTION 8

REFERENCES

REFERENCES

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SECTION 9

SYMBOLS

SYMBOL	DEFINITION
A	Aspect Ratio
b	Span
$\overline{BM}$	Distance From Center of Buoyancy to Metacenter
BP	Brake Power
Cave	Average Chord
C_D	Drag Coefficient
C_d	Derating Factor For Contact Stress Allowables Profile Drag Coefficient
C_{Di}	Induced Drag Coefficient.
$C_{D_{MAXR}}$	Drag Coefficient for Maximum Range
$C_{D_{SEP}}$	Separation Drag Coefficient
$C_{D_{SURF}}$	Surface Image Drag Coefficient
C_{D_W}	Wave Drag Coefficient
CL	Foil Lift Coefficient
C_{L_α}	Foil Lift Curve Slope
C_{L_δ}	Flap Lift Curve Slope
C_{L_i}	Incidence Lift Curve Slope
C_{ℓ_i}	Section Lift Coefficient
$C_{\ell_{i_{eff}}}$	Effective Ideal Lift Coefficient
$C_{L_{MAXR}}$	Foil Lift Coefficient for Maximum Range
C_{L_o}	Residual Lift Coefficient (CL for $\alpha = i = \delta = 0^\circ$)
C_f	Friction Drag Coefficient
C_r	Friction Drag Coefficient Allowance
c sfc	Specific Fuel Consumption Parameter

SYMBOL	DEFINITION
C_0, C_1, C_2	Drag Polar Coefficients
D	Drag
D_0	Overall Propeller Diameter
d_h	Propeller Hub Diameter
DP	Delivered Power
δ	Circulation Distribution Factor or Flap Angle
F_h	Depth Froude Number
f_{max}	Maximum Stress
f_{min}	Minimum Stress
FS	Free Surface
F_{tu}	Ultimate Tensile Stress
F_{ty}	Yield Tensile Stress
G	Non-Dimensional Circulation Distribution
g	Acceleration of Gravity
$\overline{GM}$	Distance from Center of Gravity to Metacenter
h	Depth of Submergence
I	Moment of Inertia
i	Incidence Angle
J	Advance Ratio
K	Relative Section Lift Curve Slope
$\overline{KB}$	Distance from Keel to Center of Buoyancy
K_d	Derating Factor for Bending Stress Allowables
KG	Distance from Keel to Center of Gravity
K_{sep}	Separation Drag Coefficient $dC_d/d(C_\ell - C_{\ell_{i_{eff}}})^2$
K_T	Elastic Stress Concentration Factor

SYMBOL	DEFINITION
L	Dynamic Lift
ζ	Flap Load Distribution Parameter
ℓ/d	Length-to-Diameter Ratio
LMFL	Maximum Foil Lift,
L_{MOM}	Longitudinal Moment
M	Moment
M	Thrust **Margin**
M_{RR}	Relative Rotative Efficiency
MULT	Ultimate Bending Moment
P_A	Atmospheric Pressure
P.C.	Overall Propulsive Coefficient
PV	Vapor Pressure
P/D	Propeller Pitch-to-Diameter Ratio
P_o	Ambient Pressure
$P_{.7}/D$	Propeller Pitch at 0.7 Radius to Diameter Ratio
4	Dynamic Pressure
R	Nominal Stress Ratio **(f min/f max)**
R'_{MAX}	Range Indicator (max)
$R'_{S_{MAX}}$	Specific Range Indicator (max)
S	Foil area or cavitation parameter $(1 + \sigma)$
T	Thrust Available
t	Shin Thickness or Foil Thickness
T_{T_5}	Turbine Inlet Temperature
t/c	Foil Thickness-to-Chord Ratio

SYMBOL	DEFINITION
VCB	Vertical Center of Buoyancy
V_{MAX_R}	Speed for Maximum Range
V_{MOM}	Vertical Moment
WF	Fuel Weight Factor
W/S	Foil Loading
x/c	Chord Section on Station
θ	Pitch Angle
Γ	Circulation
$d\alpha/d\delta$	Flap Effectiveness
$1-\omega$	Taylor Wake Fraction
1-t	Thrust Deduction Factor
α	Angle of Attack
Δ	Displacement
η	Nondimensional **Spanwise** Distance
λ	Taper Ratio
η_p	Propeller Efficiency
Λ	Sweep Angle
ρ	Density
ψ	Cavitation Parameter
a	Cavitation No.
w	Cavitation Parameter
ξ_i	$\left[C_\ell/C_L)_i \,/\, C_\ell/C_L)_\delta \right]^{-1}$
ξ_α	$\left[C_\ell/C_L)_\alpha \,/\, C_\ell/C_L)_\delta \right]^{-1}$
v	Local Velocity

SUBSCRIPTS

SYMBOL	DEFINITION
α	Angle of Attack
i	Angle of Incidence
δ	Flap Angle
0	Residual
D	Design Speed
To	Takeoff Speed

APPENDIX D

COMPOSITE WEIGHT AND CENTER-OF-GRAVITY STATEMENT

APPENDIX A

A complete weight and center-of-gravity summary is presented in the following tables. Weight changes over the PHM-3 occur in the Hull Structure (Group 1), Propulsion (Group 2) and Lift Systems (Account Number 567 of Group 5).

Structural. changes are primarily in the aft superstructure, Main Deck and engine compartment, to accommodate the new foilborne propulsion configuration.

The strut and foil system is a complete redesign in HY 100 alloy steel.

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ESTIMATE OF WEIGHT FOR SHIPS. SUMMARY SHEET
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HULL STRUCTURE - GROUP 1

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ACCT. NO.	DESCRIPTION	WEIGHT kg	CENTER OF GRAVITY										
			ABOVE BASE	MOMENTS	REFERRED TO FRAME NO FP				REFERRED TO ¢			
					FWD	MOMENTS	AFT	MOMENTS	PORT	MOMENTS	ST'BD	MOMENTS
110	SHELL AND SUPPORTING STRUCTURE	18045	1.78	32141			19.83	357781			.01	268
111	SHELL PLATING, SURF. SHIP AND SUB. PRESS. HULL											
112	SHELL PLATING, SUBMARINE NON-PRESSURE HULL											
113	INNER BOTTOM											
114	SHELL APPENDAGES											
115	STANCHIONS											
116	LONGIT. FRAMING, SURF. SHIP AND SUB. PRESS. HULL											
117	TRANSV. FRAMING, SURF. SHIP AND SUB. PRESS. HULL											
118	LONGIT. AND TRANSV. FRAMING, SUB. NON-PRESS. HULL											
120	HULL STRUCTURAL BULKHEADS	8167	2.84	23233			19.34	157900	.05	379		
121	LONGITUDINAL STRUCTURAL BULKHEADS											
122	TRANSVERSE STRUCTURAL BULKHEADS											
123	TRUNKS AND ENCLOSURES											
124	BULKHEADS IN TORPEDO PROTECTION SYSTEM											
125	SUBMARINE HARD TANKS											
126	SUBMARINE SOFT TANKS											
130	HULL DECKS	7004	4.27	29899			19.11	133861			.00	0
131	MAIN DECK											
132	2ND DECK											
133	3RD DECK											
134	4TH DECK											
135	5TH DECK AND DECKS BELOW											
136	01 HULL DECK (FORECASTLE AND POOP DECKS)											
137	02 HULL DECK											
138	03 HULL DECK											
139	04 HULL DECK AND HULL DECKS ABOVE											
	Sub Total Group I Sheet 1. kg	33216	2.57	85273			19.56	649542	●	111		

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HULL STRUCTURE - GROUP 1 - SUMMARY

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ACCT. NO.	DESCRIPTION	WEIGHT kg	CENTER OF GRAVITY ABOVE BASE	MOMENTS	REFERRED TO FRAME NO FP FWD	MOMENTS	AFT	MOMENTS	REFERRED TO ℄ PORT	MOMENTS	ST'BD	MOMENTS
140	HULL PLATFORMS AND FLATS	3091	1.80	5579			17.08	52793			.00	0
141	1ST PLATFORM											
142	2ND PLATFORM											
143	3RD PLATFORM											
144	4TH PLATFORM											
145	5TH PLATFORM											
149	FLATS											
150	DECKHOUSE STRUCTURE	4831	6.15	29701			17.37	83933	.02	86		
151	DECKHOUSE STRUCTURE TO FIRST LEVEL											
152	1ST DECKHOUSE LEVEL											
153	2ND DECKHOUSE LEVEL											
154	3RD DECKHOUSE LEVEL											
155	4TH DECKHOUSE LEVEL											
156	5TH DECKHOUSE LEVEL											
157	6TH DECKHOUSE LEVEL											
158	7TH DECKHOUSE LEVEL											
159	8TH DECKHOUSE LEVEL AND ABOVE											
160	SPECIAL STRUCTURES	172	1.58	272			34.46	5931			.02	3
161	STRUCTURAL CASTINGS, FORGINGS, AND EQUIV. WELDMENTS											
162	STACKS AND MACKS (COMBINED STACK AND MAST)											
163	SEA CHESTS											
164	BALLISTIC PLATING											
165	SONAR DOMES											
166	SPONSONS											
167	HULL STRUCTURAL CLOSURES											
168	DECKHOUSE STRUCTURAL CLOSURES											
169	SPECIAL PURPOSE CLOSURES AND STRUCTURES											
	Sub Total Group I - Sheet 2. kg-	8094	4.39	35552			17.63	142657	.01	83		

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ACCT. NO.	DESCRIPTION	WEIGHT kg	CENTER OF GRAVITY									
			ABOVE BASE	MOMENTS	REFERRED TO FRAME NO FP				REFERRED TO ¢			
					FWD	MOMENTS	AFT	MOMENTS	PORT	MOMENTS	ST'BD	MOMENTS
170	MASTS, KINGPOSTS, AND SERVICE PLATFORMS	1062	12.12	12877			19.95	21196			.00	0
171	MASTS, TOWERS, TETRAPODS											
172	KINGPOSTS AND SUPPORT FRAMES											
179	SERVICE PLATFORMS											
180	FOUNDATIONS	6581	3.51	23069			18.50	121532			.04	263
181	HULL STRUCTURE FOUNDATIONS											
182	PROPULSION PLANT FOUNDATIONS											
183	ELECTRIC PLANT FOUNDATIONS											
184	COMMAND AND SURVEILLANCE FOUNDATIONS											
185	AUXILIARY SYSTEMS FOUNDATIONS											
186	OUTFIT AND FURNISHINGS FOUNDATIONS											
187	ARMAMENT FOUNDATIONS											
190	SPECIAL PURPOSE SYSTEMS	1313	2.27	2983			22.15	29077			.00	0
191	BALLAST, FIXED OR FLUID, AND BUOYANCY UNITS											
192	COMPARTMENT TESTING											
195	ERECTION OF SUBSECTIONS(PROGRESS REPORT ONLY)											
198	FREE FLOODING LIQUIDS											
199	HULL REPAIR PARTS AND SPECIAL TOOLS											
	Sub Total **Group 1 - Sheet 3** [redacted]	8956 [redacted]	4.35 [redacted]	38929	[redacted]		1 [redacted]	.18	171805		.04	263
	Sub Total Group 1 - **Sheet 1**	33216	2.57	85273			19.56	649542	.00	111		
	Sub Total Group 1 - Sheet 2	8094	4.39	35552			17.63	142657	.01	83		
	TOTAL - GROUP 1. **kg**	50266	3.18	159754			19.18	964004		.00		69

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HULL STRUCTURE - GROUP 1 - **SUMMARY**

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	DESCRIPTION	WEIGHT kg	ABOVE BASE	MOMENTS	CENTER OF GRAVITY REFERRED TO FRAME NO FP FWD	MOMENTS	AFT	MOMENTS	REFERRED TO ¢ PORT	MOMENTS	STBD	MOMENTS
210	ENERGY GENERATING SYSTEM (NUCLEAR)											
211	(RESERVED)											
212	NUCLEAR STEAM GENERATOR											
213	REACTORS											
214	RECATOR COOLANT SYSTEM											
215	REACTOR COOLANT SERVICE SYSTEM											
216	REACTOR PLANT AUXILIARY SYSTEMS											
217	NUCLEAR POWER CONTROL AND INSTRUMENTATION											
218	RADIATION SHIELDING (PRIMARY)											
219	RADIATION SHIELDING (SECONDARY)											
220	ENERGY GENERATING SYSTEM (NON-NUCLEAR)											
221	PROPULSION BOILERS											
222	GAS GENERATORS											
223	MAIN PROPULSION BATTERIES											
224	MAIN PROPULSION FUEL CELLS											
230	PROPULSION UNITS	5883	2.43	14267			30.93	181959			.00	16
231	PROPULSION STEAM TURBINES											
232	PROPULSION STEAM ENGINES											
233	PROPULSION INTERNAL COMBUSTION ENGINES											
234	PROPULSION GAS TURBINES											
235	ELECTRIC PROPULSION											
236	SELF-CONTAINED PROPULSION SYSTEMS											
237	AUXILIARY PROPULSION DEVICES											
238	SECONDARY PROPULSION (SUBMARINES)											
239	EMERGENCY PROPULSION (SUBMARINES)											
	Sub Total Group 2 Sheet I, kg	5883	2.43	14267			30.93	181959			.00	

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ESTIMATE OF WEIGHT FOR SHIPS, **SUMMARY** SHEET
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ACCT NO	DESCRIPTION	WEIGHT kg	CENTER OF GRAVITY									
			ABOVE BASE	MOMENTS	REFERRED TO FRAME NO FT				REFERRED TO ℄			
					FWD	MOMENTS	AFT	MOMENTS	PORT	MOMENTS	ST'BD	MOMENTS
240	TRANSMISSION AND PROPULSOR SYSTEMS	9596	-.23	-2220			30.92	296702			.00	8
241	PROPULSION REDUCTION GEARS											
242	PROPULSION CLUTCHES AND COUPLINGS											
243	PROPULSION SHAFTING											
244	PROPULSION SHAFT BEARINGS											
245	PROPULSORS											
246	PROPULSOR SHROUDS AND DUCTS											
247	WATER JET PROPULSORS											
250	PROPULSION SUPPORT SYS. (EXCEPT FUEL AND LUBE OIL)	2532	4.72	11945			25.82	65390	.62	1561		
251	COMBUSTION AIR SYSTEM											
252	PROPULSION CONTROL SYSTEM											
253	MAIN STEAM PIPING SYSTEM											
254	CONDENSERS AND AIR EJECTORS											
255	FEED AND CONDENSATE SYSTEM											
256	CIRCULATING AND COOLING SEA WATER SYSTEM											
259	UPTAKES (INNER CASING)											
260	PROPULSION SUPPORT SYSTEMS (FUEL AND LUBE OIL)	382	2.57	981			30.05	11488			.00	0
261	FUEL SERVICE SYSTEM											
262	MAIN PROPULSION LUBE OIL SYSTEM											
263	SHAFT LUBE OIL SYSTEM (SUBMARINES)											
264	LUBE OIL FILL. TRANSFER. AND PURIFICATION											
290	SPECIAL PURPOSE SYSTEMS	2597	2.46	6389			27.43	71251			.35	900
298	PROPULSION PLANT OPERATING FLUIDS											
299	PROPULSION PLANT REPAIR PARTS AND SPECIAL TOOLS											
	Sub Total Group 2 • **Sheet** 2	15107	1.13	17095			29.45'	444831	.04	653		
	sub Total Group 2 • Sheet 1	5883	2.41	14267			30.93	181959			.00	16
	TOTAL • GROUP 2 kg	20990	1.49	31362			29.86	626790	.03	637		

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PROPULSION - GROUP 2 - SUMMARY

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ELECTRIC PLANT - GROUP 3

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ACCT. NO.	DESCRIPTION	WEIGHT kg	CENTER OF GRAVITY									
			ABOVE BASE	MOMENTS	REFERRED TO FRAME NO. F.P.				REFERRED TO			
					FWD	MOMENTS	AFT	MOMENTS	PORT	MOMENTS	ST'BD	MOMENTS
310	ELECTRIC POWER GENERATION	4108	2.84	11680			26.86	110339	.02	71		
311	SHIP SERVICE POWER GENERATION											
312	EMERGENCY GENERATORS											
313	BATTERIES AND SERVICE FACILITIES											
314	POWER CONVERSION EQUIPMENT											
320	POWER DISTRIBUTION SYSTEMS	2386	4.14	9881			23.28	55554	.58	1376		
321	SHIP SERVICE POWER CABLE											
322	EMERGENCY POWER CABLE SYSTEM											
323	CASUALTY POWER CABLE SYSTEM											
324	SWITCHGEAR AND PANELS											
330	LIGHTING SYSTEM	923	4.52	4175			18.15	16762	.10	90		
331	LIGHTING DISTRIBUTION											
332	LIGHTING FIXTURES											
340	POWER GENERATION SUPPORT SYSTEMS											
341	SSTG LUBE OIL											
342	DIESEL SUPPORT SYSTEMS											
343	TURBINE SUPPORT SYSTEMS											
390	SPECIAL PURPOSE SYSTEMS	109	4.10	447			23.27	2535	.00	0		
398	ELECTRIC PLANT OPERATING FLUIDS											
399	ELECTRIC PLANT REPAIR PARTS AND SPECIAL TOOLS											
	TOTAL - GROUP 3. kg	7526	3.48	26183			24.61	185190	.20	1537		

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ELECTRIC PLANT - GROUP 3 - SUMMARY

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COMMUNICATION AND CONTROL - GROUP 4

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ACCT. NO.	DESCRIPTION	WEIGHT kg	CENTER OF GRAVITY									
			ABOVE BASE	MOMENTS	REFERRED TO FRAME NO. F.P.				REFERRED TO ℄			
					FWD	MOMENTS	AFT	MOMENTS	PORT	MOMENTS	ST'BD	MOMENTS
410	COMMAND AND CONTROL SYSTEMS	418	5.21	2177			12.24	5117			.11	45
411	DATA DISPLAY GROUP											
412	DATA PROCESSING GROUP											
413	DIGITAL DATA SWITCHBOARDS											
414	INTERFACE EQUIPMENT											
415	DIGITAL DATA COMMUNICATIONS											
416	COMMAND AND CONTROL TESTING											
417	COMMAND AND CONTROL ANALOG SWITCHBOARDS											
420	NAVIGATION SYSTEMS	1099	6.35	6979			14.03	15428			.62	684
421	NON-ELECTRICAL/ELECTRONIC NAVIGATION AIDS											
422	ELECTRICAL NAVIGATION AIDS(INCL NAVIG.LIGHTS)											
423	ELECTRONIC NAVIGATION SYSTEMS, RADIO											
424	ELECTRONIC NAVIGATION SYSTEMS, ACOUSTICAL											
425	PERISCOPES											
426	ELECTRICAL NAVIGATION SYSTEMS											
427	INERTIAL NAVIGATION SYSTEMS											
430	INTERIOR COMMUNICATIONS	1071	5.58	5977			14.84	15896	.58	642		
431	SWITCHBOARDS FOR I.C. SYSTEMS											
432	TELEPHONE SYSTEMS											
433	ANNOUNCING SYSTEMS											
434	ENTERTAINMENT AND TRAINING SYSTEMS											
435	VOICE TUBES AND MESSAGE PASSING SYSTEMS											
436	ALARM, SAFETY, AND WARNING SYSTEMS											
437	INDICATING, ORDER, AND METERING SYSTEMS											
438	INTEGRATED CONTROL SYSTEMS											
439	RECORDING AND TELEVISION SYSTEMS											
	Sub Total Group 4 - Sheet 1, kg	2588	5.85	15133			14.08	36441			.03	87

COMPUTING BY

COMPUTING CHECKED

COMMUNICATION AND CONTROL GROUP 4 - SUMMARY

UNCLASSIFIED

ESTIMATE OF WEIGHT FOR SHIPS, **SUMMARY** SHEET
COMMUNICATION AND CONTROL GROUP 4. Sheet 2 of 3
NAVSHIPS 9291/14 (7-73)

U.S.S. M-167

COMMUNICATION AND CONTROL GROUP 4

PAGE

DATE 10/19/78

ACCT NO.	DESCRIPTION	WEIGHT kg	REFERRED TO ABOVE BASE	REFERRED TO MOMENTS	CENTER OF GRAVITY REFERRED TO FRAME NO. F.P. FWD	MOMENTS	AFT	MOMENTS	REFERRED TO ℄ PORT	MOMENTS	ST'BD	MOMENTS
440	EXTERIOR COMMUNICATIONS	1660	6.07	10083			15.80	26224	.89	1473		
441	RADIO SYSTEMS											
442	UNDERWATER SYSTEMS											
443	VISUAL AND AUDIBLE SYSTEMS											
444	TELEMETRY SYSTEMS											
445	TTY AND FACSIMILE SYSTEMS											
446	SECURITY EQUIPMENT											
450	SURVEILLANCE SYSTEMS (SURFACE)	345	5.24	1807			18.30	6311	.89	307		
451	SURFACE SEARCH RADAR											
452	AIR SEARCH RADAR (2D)											
453	AIR SEARCH RADAR (3D)											
454	AIRCRAFT CONTROL APPROACH RADAR											
455	IDENTIFICATION SYSTEMS (IFF)											
459	SPACE VEHICLE ELECTRONIC TRACKING											
460	SURVEILLANCE SYSTEMS (UNDERWATER)											
461	ACTIVE SONAR											
462	PASSIVE SONAR											
463	ACTIVE/PASSIVE (MULTIPLE MODE) SONAR											
~~464~~	~~CLASSIFICATION SONAR~~											
~~465~~	~~BATHYTHERMOGRAPH~~											
	Sub Total Group 4 - Sheet 2. kg	2005	5.93	11890				2535	.89	1780		

COMPUTING BY

COMPUTING CHECKED

UNCLASSIFIED

ESTIMATE OF WEIGHT FOR SHIPS, SUMMARY SHEET
COMMUNICATION AND CONTROL GROUP 4. Sheet 3 of 3
NAVSHIPS 9291/14 (7-73)

U.S.S. M-167

COMMUNICATION AND
CONTROL • GROUP 4

PAGE
DATE 10/19/78

ACCT NO.	DESCRIPTION	WEIGHT kg	ABOVE BASE	MOMENTS	CENTER OF GRAVITY REFERRED TO FRAME NO. F.P. FWD	MOMENTS	AFT	MOMENTS	REFERRED TO ℄ PORT	MOMENTS	ST'BD	MOMENTS
470	COUNTERMEASURES	303	7.76	2348			. 9	4629	.17	51		
471	ACTIVE ECM (INCL COMB ACTIVE/PASSIVE)											
472	PASSIVE EM											
473	TORPEDO DECOYS											
474	DECOYS (OTHER)											
475	DEGAUSSING											
476	MINE COUNTERMEASURES											
480	FIRE CONTROL SYSTEMS	3799	6.26	23797			16.51	62740	.56	2141		
481	GUN FIRE CONTROL SYSTEMS											
482	FIRE CONTROL SYSTEMS (NON-SONAR DATA BASE)											
483	FIRE CONTROL SYSTEMS (SONAR DATA BASE)											
489	FIRE CONTROL SYSTEMS SWITCHBOARDS											
490	SPECIAL PURPOSE SYSTEMS	1831	6.46	11829			15.81	28951	.62	1135		
491	ELECTRONIC TEST, CHECKOUT, AND MONITORING EQUIPMENT											
492	FLIGHT CONTROL AND INSTRUMENT LANDING SYSTEMS											
493	NON COMBAT DATA PROCESSING SYSTEMS											
494	METEOROLOGICAL SYSTEMS											
495	INTEGRATED OPERATIONAL INTELLIGENCE SYSTEMS											
498	COMMAND AND SURVEILLANCE OPERATING FLUIDS											
499	COMMAND AND SURV. REPAIR PARTS AND SPEC. TOOLS											
	Sub Total Group 4 - Sheet 3	5933	6.40	37974			16.23	96320	.56	3327		
	Sub Total Group 4 - Sheet 1	2588	5.85	15133			14.08	36441			.03	87
	Sub Total Group 4 - Sheet 2	2005	5.93	11890			16.23	32535	.89	1780		
	TOTAL - GROUP 4, kg	10526	6.17	64997			15.70	165296	.48	5020		

COMPUTING BY

COMPUTING CHECKED

ESTIMATE OF WEIGHT FOR SHIPS, **SUMMARY** SHEET
AUXILIARY SYSTEMS - GROUP 6. **Sheet 1 of 3**
NAVSHIPS 9291/14 (7-73)

U.S.S. M-167

AUXILIARY SYSTEMS - GROUP 5

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UNCLASSIFIED

ACCT NO.	DESCRIPTION	WEIGHT kg	ABOVE BASE	MOMENTS	CENTER OF GRAVITY REFERRED TO FRAME NO. F.P. FWD	MOMENTS	AFT	MOMENTS	REFERRED TO ℄ PORT	MOMENTS	ST'BD	MOMENTS
510	CLIMATE CONTROL	3265	. 7	15234			20.96	68431	1.01	3313		
511	COMPARTMENT HEATING SYSTEM											
512	VENTILATION SYSTEM											
513	MACHINERY SPACE VENTILATION SYSTEM											
514	AIR CONDITIONING SYSTEM											
515	AIR REVITALIZATION SYSTEMS (SUBMARINES)											
516	REFRIGERATION SYSTEM											
517	AUXILIARY BOILERS AND OTHER HEAT SOURCES											
520	SEA WATER SYSTEMS	2735	2.19	2976			27.59	75460			.33	890
521	FIREMAIN AND FLUSHING (SEA WATER) SYSTEM											
522	SPRINKLER SYSTEM											
523	WASHDOWN SYSTEM											
524	AUXILIARY SEA WATER SYSTEM											
526	SCUPPERS AND DECK DRAINS											
527	FIREMAIN ACTUATED SERVICES - OTHER											
528	PLUMBING DRAINAGE											
529	DRAINAGE AND BALLASTING SYSTEM											
530	FRESH WATER SYSTEMS	1817	2.61	4749			23.58	42865			2.10	3822
531	DISTILLING PLANT											
532	COOLING WATER											
533	POTABLE WATER											
534	AUX. STEAM AND DRAINS WITHIN MACHINERY BOX											
535	AUX. STEAM AND DRAINS OUTSIDE MACHINERY BOX											
436	AUXILIARY FRESH WATER COOLING											
	Sub Total Group 5 - Sheet 1, kg	7817	3.32	25959			23.89	186756			.18	3199

COMPUTING BY

COMPUTING CHECKED

AUXILIARY SYSTEMS - GROUP 5 - SUMMARY

UNCLASSIFIED

ESTIMATE OF WEIGHT FOR SHIPS, SUMMARY SHEET
~~AUXILIARY SYSTEMS~~ - GROUP 5, Sheet 2 of 3
NAVSHIPS 9291/14 (7-73)

U.S.S. M-107

AUXILIARY SYSTEMS - GROUP 5

PAGE

DATE 10/19/78

ACCT. NO.	DESCRIPTION	WEIGHT kg	CENTER OF GRAVITY									
			ABOVE BASE	MOMENTS	REFERRED TO FRAME NO. F.P.				REFERRED TO ℄			
					FWD	MOMENTS	AFT	MOMENTS	PORT	MOMENTS	ST'BD	MOMENTS
540	FUELS AND LUBRICANTS, HANDLING AND STORAGE	1188	1.93	2294			22.71	26987			.01	12
541	SHIP FUEL AND FUEL COMPENSATING SYSTEM											
542	AVIATION AND GENERAL PURPOSE FUELS											
543	AVIATION AND GENERAL PURPOSE LUBRICATING OIL											
544	LIQUID CARGO											
545	TANK HEATING											
550	AIR, GAS, AND MISC. FLUID SYSTEMS	3905	3.74	14619			24.04	93869	.38	1472		
551	COMPRESSED AIR SYSTEMS											
552	COMPRESSED GASES											
553	O2 N2 SYSTEM											
554	LP BLOW											
555	FIRE EXTINGUISHING SYSTEM											
556	HYDRAULIC FLUID SYSTEM											
557	LIQUID GASES, CARGO											
558	SPECIAL PIPING SYSTEMS											
560	SHIP CONTROL SYSTEMS	591	2.57	1524			22.99	13587			.00	14
561	STEERING AND DIVING CONTROL SYSTEMS											
562	RUDDER											
563	BUOYANCY AND HOVERING (SUBMARINES)											
564	TRIM SYSTEM (SUBMARINES)											
565	TRIM AND HEEL (ROLL STABILIZATION)											
566	DIVING PLANES AND STABILIZING FINS											
567	LIFT SYSTEMS											
568	MANEUVERING SYSTEMS											
	Sub Total Group 5 - Sheet 2, kg	5684	3.24	18437			23.65	134443	.25	1446		

COMPUTING BY

COMPUTING CHECKED

AUXILIARY SYSTEMS - GROUP 5 - SUMMARY

ESTIMATE OF WEIGHT FOR SHIPS, SUMMARY SHEET
AUXILIARY SYSTEMS - GROUP 5, Sheet 3 of 3
NAVSHIPS 9291/14 (7-73)

U.S.S. M-167

AUXILIARY SYSTEMS - GROUP 5

PAGE

DATE 10/19/78

ACCT. NO.	DESCRIPTION	WEIGHT kg	ABOVE BASE	MOMENTS	REFERRED TO FRAME NO. F.P. FWD	MOMENTS	AFT	MOMENTS	REFERRED TO PORT	MOMENTS	ST'BD	MOMENTS
570	UNDERWAY REPLENISHMENT SYSTEMS	218	6.06	1321			20.58	4486	.30	65		
571	REPLENISHMENT-AT-SEA											
572	SHIP STORES AND PERSONNEL AND EQUIP. HANDLING											
573	CARGO HANDLING											
580	MECHANICAL HANDLING SYSTEM	3897	3.94	15366			16.43	64016			.33	1292
581	ANCHOR HANDLING AND STOWAGE SYSTEMS											
582	MOORING AND TOWING SYSTEMS											
583	BOAT HANDLING AND STOWAGE SYSTEMS											
584	MECHANICALLY OPERATED DOOR, GATE, RAMP, TURNTABLE SYS.											
585	ELEVATING AND RETRACTING GEAR											
586	AIRCRAFT RECOVERY SUPPORT SYSTEMS											
587	AIRCRAFT LAUNCH SUPPORT SYSTEMS											
588	AIRCRAFT HANDLING, SERVICING AND STOWAGE											
589	MISCELLANEOUS MECHANICAL HANDLING SYSTEMS											
590	SPECIAL PURPOSE SYSTEMS	2229	3.31	7385			22.21	49522	.44	977		
591	SCIENTIFIC AND OCEAN ENGINEERING SYSTEMS											
592	SWIMMER AND DIVER SUPPORT AND PROTECT. SYSTMS.											
593	ENVIRONMENTAL POLLUTION CONTROL SYSTEMS											
594	SUB. RESCUE, SALVAGE, AND SURVIVAL SYSTEMS											
595	TOWING, LAUNCHING AND HANDLING FOR UNDERWATER SYS.											
596	HANDLING SYS. FOR DIVER AND SUBMERSIBLE VEHS.											
597	SALVAGE SUPPORT SYSTEMS											
598	AUXILIARY SYSTEMS OPERATING FLUIDS											
599	AUXILIARY SYSTEMS REPAIR PARTS AND TOOLS											
	Sub Total Group 5 - Sheet 3	6344	3.79	24072			18.60	118024			.04	250
	Sub Total Group 5 - Sheet 1	7817	3.32	25959			23.89	186756			.18	1399
	Sub Total Group 5 - Sheet 2	5684	3.24	18437			23.65	134443	.25	1446		
	TOTAL - GROUP 5, kg	19845	3.45	68468			22.13	439223			.01	203

COMPUTING BY

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UNCLASSIFIED

ESTIMATE OF WEIGHT FOR SHIPS, SUMMARY SHEET
OUTFIT AND FURNISHINGS - GROUP 6, Sheet 1 of 2
NAVSHIPS 9291/14 (7-73)

U.S.S. M-167

OUTFIT AND FURNISHINGS -
GROUP 6

PAGE

DATE 10/12/78

ACCT. NO.	DESCRIPTION	WEIGHT kg	ABOVE BASE	MOMENTS	CENTER OF GRAVITY REFERRED TO FRAME NO. F.P. FWD	MOMENTS	AFT	MOMENTS	REFERRED TO ℄ PORT	MOMENTS	ST'BD	MOMENTS
610	SHIP FITTINGS	1349	5.26	7092			18.92	25521			.04	48
611	HULL FITTINGS											
612	RAILS, STANCHIONS, AND LIFELINES											
613	RIGGING AND CANVAS											
620	HULL COMPARTMENTATION	1992	3.74	7451			20.43	40692			.00	8
621	NON-STRUCTURAL BULKHEADS											
622	FLOOR PLATES AND GRATINGS											
623	LADDERS											
624	NON-STRUCTURAL CLOSURES											
625	AIRPORTS, FIXED PORTLIGHTS, AND WINDOWS											
630	PRESERVATIVES AND COVERINGS	3501	3.80	13294			17.99	62973	.02	68		
631	PAINTING											
632	ZINC COATING											
633	CATHODIC PROTECTION											
634	DECK COVERING											
635	HULL INSULATION											
636	HULL DAMPING											
637	SHEATHING											
638	REFRIGERATED SPACES											
639	RADIATION SHIELDING											
640	LIVING SPACES	2939	2.951	8662			16.72	49127			1.08	3168
641	OFFICER BERTHING AND MESSING SPACES											
642	NONCOM. OFFICER BERTHING AND MESSING SPACES											
643	ENLISTED PERSONNEL BERTHING AND MESSING SPACES											
644	SANITARY SPACES AND FIXTURES											
645	LEISURE AND COMMUNITY SPACES											
	Sub Total Group 6 - Sheet 1, kg :	9781	3.73	36499			18.23	178313			.32	3156

COMPUTING BY

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UNCLASSIFIED

ESTIMATE OF WEIGHT FOR SHIPS, **SUMMARY** SHEET
OUTFIT AND FURNISHINGS - GROUP 6, Sheet 2 of 2
NAVSHIPS 9291/14 (7-73)

U.S.S. M-167

OUTFIT AND FURNISHINGS - GROUP 6

PAGE

DATE 10/12/78

ACCT. NO.	DESCRIPTION	WEIGHT kg	ABOVE BASE	MOMENTS	CENTER OF GRAVITY REFERRED TO FRAME NO. F.P. FWD	MOMENTS	AFT	MOMENTS	REFERRED TO PORT	MOMENTS	ST'BD	MOMENTS
650	SERVICE SPACES	1857	2.81	5222			10.64	19764			.68	1262
651	COMMISSARY SPACES											
652	MEDICAL SPACE											
653	DENTAL SPACES											
654	UTILITY SPACES											
655	LAUNDRY SPACES											
656	TRASH DISPOSAL SPACES											
660	WORKING SPACES	1532	4.78	7319			14.45	22147			.02	31
661	OFFICES											
662	MACHINERY CONTROL CENTERS FURNISHINGS											
663	ELECTRONICS CONTROL CENTERS FURNISHINGS											
664	DAMAGE CONTROL STATIONS											
665	WORKSHOPS, LABS, TEST AREAS (INCL. PORTABLE TOOLS, EQUIPMENT)											
670	STOWAGE SPACES	1434	3.55	5089			17.21	24672			.82	1176
671	LOCKERS AND SPECIAL STOWAGE											
672	STOREROOMS AND ISSUE ROOMS											
673	CARGO STOWAGE											
690	SPECIAL PURPOSE SYSTEMS											
698	OUTFIT AND FURNISHINGS OPERATING FLUIDS											
699	OUTFIT AND FURNISH. REPAIR PARTS AND SPECIAL TOOLS											
	Sub Total Group 6 - Sheet 2	4823	3.66	17630			13.81	66583			.51	2469
	Sub Total Group 6 - Sheet 1	9781	3.73	36499			18.23	178313			.32	3156
	TOTAL - GROUP 6, kg	14604	3.71	54129			16.77	244896			.39	5625

COMPUTING BY

COMPUTING CHECKED

ESTIMATE OF WEIGHT FOR SHIPS, **SUMMARY** SHEET
ARMAMENT GROUP 7. Sheet 1 of 2
NAVSHIPS 9291/14 (7-73)

U.S.S. M-167 ARMAMENT - GROUP 7

PAGE

DATE 10/12/78

ACCT. NO.	DESCRIPTION	WEIGHT kg	ABOVE BASE	MOMENTS	CENTER OF GRAVITY REFERRED TO FRAME NO. F.P.				REFERRED TO ℄			
					FWD	MOMENTS	AFT	MOMENTS	PORT	MOMENTS	ST'BD	MOMENTS
710	GUNS AND AMMUNITION	8500	5.19	44131			.92	41844				622
711	GUNS											
712	AMMUNITION HANDLING											
713	AMMUNITION STOWAGE											
720	MISSILES AND ROCKETS	715	5.08	3630			31.02	22171			.00	0
721	LAUNCHING DEVICES (MISSILES AND ROCKETS)											
722	MISSILE, ROCKET, AND GUIDANCE CAPSULE HANDLING SYS.											
723	MISSILE AND ROCKET STOWAGE											
724	MISSILE HYDRAULICS											
725	MISSILE GAS											
726	MISSILE COMPENSATING											
727	MISSILE ENVIRONMENTAL MONITORING AND LAUNCHER CONTR.											
728	MISSILE HEATING, COOLING, TEMPERATURE CONTROL											
730	MINES											
731	MINE LAUNCHING DEVICES											
732	MINE HANDLING											
733	MINE STOWAGE											
740	DEPTH CHARGES											
741	DEPTH CHARGE LAUNCHING DEVICES											
742	DEPTH CHARGE HANDLING											
743	DEPTH CHARGE STOWAGE											
750	TORPEDOES											
751	TORPEDO TUBES											
752	TORPEDO HANDLING											
753	TORPEDO STOWAGE											
754	SUBMARINE TORPEDO EJECTION											
	Sub Total Group 7 - Sheet 1, kg.	9215	5.18	47761			6.95	64015			.07	622

COMPUTING BY

COMPUTING CHECKED

UNCLASSIFIED

ESTIMATE OF WEIGHT FOR SHIPS, SUMMARY SHEET
ARMAMENT - GROUP 7, Sheet 2 of 2
NAVSHIPS 9291/14 (7-73)

U.S.S. M-167

ARMAMENT - GROUP 7

PAGE

DATE 10/12/78

ACCT. NO.	DESCRIPTION	WEIGHT kg	CENTER OF GRAVITY ABOVE BASE	MOMENTS	REFERRED TO FRAME NO. F.P. FWD	MOMENTS	AFT	MOMENTS	REFERRED TO ℄ PORT	MOMENTS	ST'BD	MOMENTS
760	SMALL ARMS AND PYROTECHNICS	149	5.93	884			9.36	1395	2.14	319		
761	SMALL ARMS AND PYROTECHNIC LAUNCHING DEVICES											
762	SMALL ARMS AND PYROTECHNIC HANDLING											
763	SMALL ARMS AND PYROTECHNIC STOWAGE											
770	CARGO MUNITIONS											
772	CARGO MUNITIONS HANDLING											
773	CARGO MUNITIONS STOWAGE											
780	AIRCRAFT RELATED WEAPONS											
782	AIRCRAFT RELATED WEAPONS HANDLING											
783	AIRCRAFT RELATED WEAPONS STOWAGE											
790	SPECIAL PURPOSE SYSTEMS	164	3.04	499			12.07	1983	.90	148		
792	SPECIAL WEAPONS HANDLING											
793	SPECIAL WEAPONS STOWAGE											
797	MISC. ORDNANCE SPACES											
798	ARMAMENT OPERATING FLUIDS											
799	ARMAMENT REPAIR PARTS AND SPECIAL TOOLS											
	Sub Total Group 7 - Sheet 2	313	4.42	1383			10.79	3378	1.49	467		
	Sub Total Group 7 - Sheet 1	9215	5.18	47761			6.95	64015			07	622
	TOTAL - GROUP 7. kg	9528	5.16	49144			7.07	67393			.02	155

COMPUTING BY

COMPUTING CHECKED

ARMAMENT GROUP 7 - SUMMARY

UNCLASSIFIED

ESTIMATE OF WEIGHT FOR SHIPS, WORK SHEET
NAVSHIPS 4616A-2 (REV. 6-65)

PAGE

U.S.S. M-167

GROUP NO.

DATE 10/19/73

DESCRIPTION	WEIGHT kg	CENTER OF GRAVITY									
		ABOVE BASE	MOMENTS	REFERRED TO FRAME NO. F.P.				REFERRED TO ℄			
				FWD	MOMENTS	AFT	MOMENTS	PORT	MOMENTS	STBD	MOMENTS
567 Hydrofoil Lift System											
567.1A Aft Strut	11300	4.82	54466			34.30	387590			.00	0
567.1F Fwd. Strut	6370	4.00	25480			-1.50	-9555			.00	0
567.2A Aft Pod/Nacelles	2770	5.52	15290			37.30	103321			.00	0
567.2F Fwd. Pod/Nacelles	375	4.55	1706			-4.70	-1763			.00	0
567.3A Aft Foil	9180	4.87	44707			37.50	344250			.00	0
567.3F Fwd. Foil	4390	4.65	20414			-5.00	-21950			.00	0
Foils Up TOTALS kg	34385	4.71	162063			23.32	801893			.00	0

COMPUTING BY

COMPUTING CHECKED

ESTIMATE OF WEIGHT FOR SHIPS. WORK SHEET
NAVSHIPS 4616A-2 (REV. S-65)

PAGE

U.S.S. M-167 GROUP NO.

DATE 10/15/73

DESCRIPTION	WEIGHT kg	ABOVE BASE	MOMENTS	CENTER OF GRAVITY REFERRED TO FRAME NO. FP				REFERRED TO ¢			
				FWD	MOMENTS	AFT	MOMENTS	PORT	MOMENTS	ST'BD	MOMENTS
567 Hydrofoil Lift System											
567.1A Aft Strut	11300	-.50	-5650			29.50	333350			.00	0
567.1F Fwd. Strut	6370	-.10	-637			2.10	13377			.00	0
567.2A Aft Pod/Nacelles	2770	-3.84	-10637			30.00	83100			.00	0
567.2F Fwd. Pod/Nacelles	375	-3.30	-1238			2.90	1088			.00	0
567.3A Aft Foil	9180	-4.23	-38831			29.34	269341			.00	0
567.3F Fwd. Foil	4390	-3.65	-16024			2.70	11853			.00	0
Foils Down TOTALS kg	34385	-2.12	-73017			20.71	712109			.00	0

COMPUTING BY

COMPUTING CHECKED

UNCLASSIFIED

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

U.S.S. M-167

PAGE

DATE 10/20/78

DESCRIPTION	WEIGHT kg	ABOVE BASE	MOMENTS	CENTER OF GRAVITY REFERRED TO FRAME NO. FP				REFERRED TO ℄			
				FWD	MOMENTS	AFT	MOMENTS	PORT	MOMENTS	ST'BD	MOMENTS
SHIP IN LIGHT CONDITION	183189	2.27	416154			20.54	3763184	.01	1360		
LOADS (FROM PAGE 15) PHM-3 Report	65871	1.86	122786			17.94	1181656			.02	1348
Extra Fuel	17070	1.13	19241			26.70	455970			.00	0
Foils Extended **SHIP IN** FULL LOAD CONDITION kg-m	266130	2.10	558181			20.29	5400810	.00	12		
BASE ABOVE/BELOW BOTTOM OF KEEL - ΔM			280858				126498		0		
Foils Retracted CENTER OF GRAVITY ABOVE BOTTOM OF KEEL -kg-m	266130	3.15	839039			20.76	5527308	.00	12		

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 FEET

C.G. ABOVE BOTTOM OF KEEL FEET

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

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

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

COMPUTING BY	COMPUTING CHECKED

B-26801

UNCLASSIFIED

ESTIMATE OF **WEIGHT** FOR SHIPS
SHIP III LIGHT CONDITION
NAVSHIPS 9291/6 (REV. 3-67) (Formerly NAVSHIPS 4616A-4) SHEET 1 **U.S.S.** M-167

PAGE ______
DATE 10/19/78

GROUP	DESCRIPTION	WEIGHT kg	ABOVE BASE M	MOMENTS	CENTER OF GRAVITY REFERRED 6."	TO FRAME No. MOMENTS	FP AFT	MOMENTS	REFERRED PORT	TO MOMENTS	ST'BD	MOMENTS
1	HULL STRUCTURE	50266	3.10	139734			19.18	964004			.00	69
2	PROPULSION	20990	1.49	31362			29.86	626790	.03	637		
3	ELECTRIC PLANT	7526	3.48	26183			24.61	185190	.20	1537		
4	COMMUNICATION AND CONTROL	10526	6.17	64997			15.70	165296	.48	5020		
											.01	203
5 6	AUXILIARY SYSTEMS OUTFIT AND FURNISHINGS	[illegible] 14604	1.45 1.71	68468 94429			[illegible]	[illegible] 244896			.02	5625
7	ARMAMENT	9528	5.16	49144			.07	67393				155
[illegible]	567 - Hydrofoil Lift Sys.	34385	-2.12	-73017			20.71	712109			.00	0
	Margin - Design & Constr.	2458	2.87	360332			20.69	50856			.00	0
	Navsea	6453	5.58	-79433			20.74	133852	.03	218		
	100, 200, 567 Changes 15%	6608	-1.20				26.27	133575			.00	0
	SHIP IN LIGHT CONDITION kg-m	183189	2.27	416154			20.54	3763184	.01	1360		
	BASE ABOVE/BELOW BOTTOM OF KEEL -											
	CENTER OF GRAVITY ABOVE BOTTOM OF KEEL -											

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.

- ba.d.

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

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

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

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

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

COMPUTING BY ______ | COMPUTING CHECKED ______

UNCLASSIFIED

UNCLASSIFIED

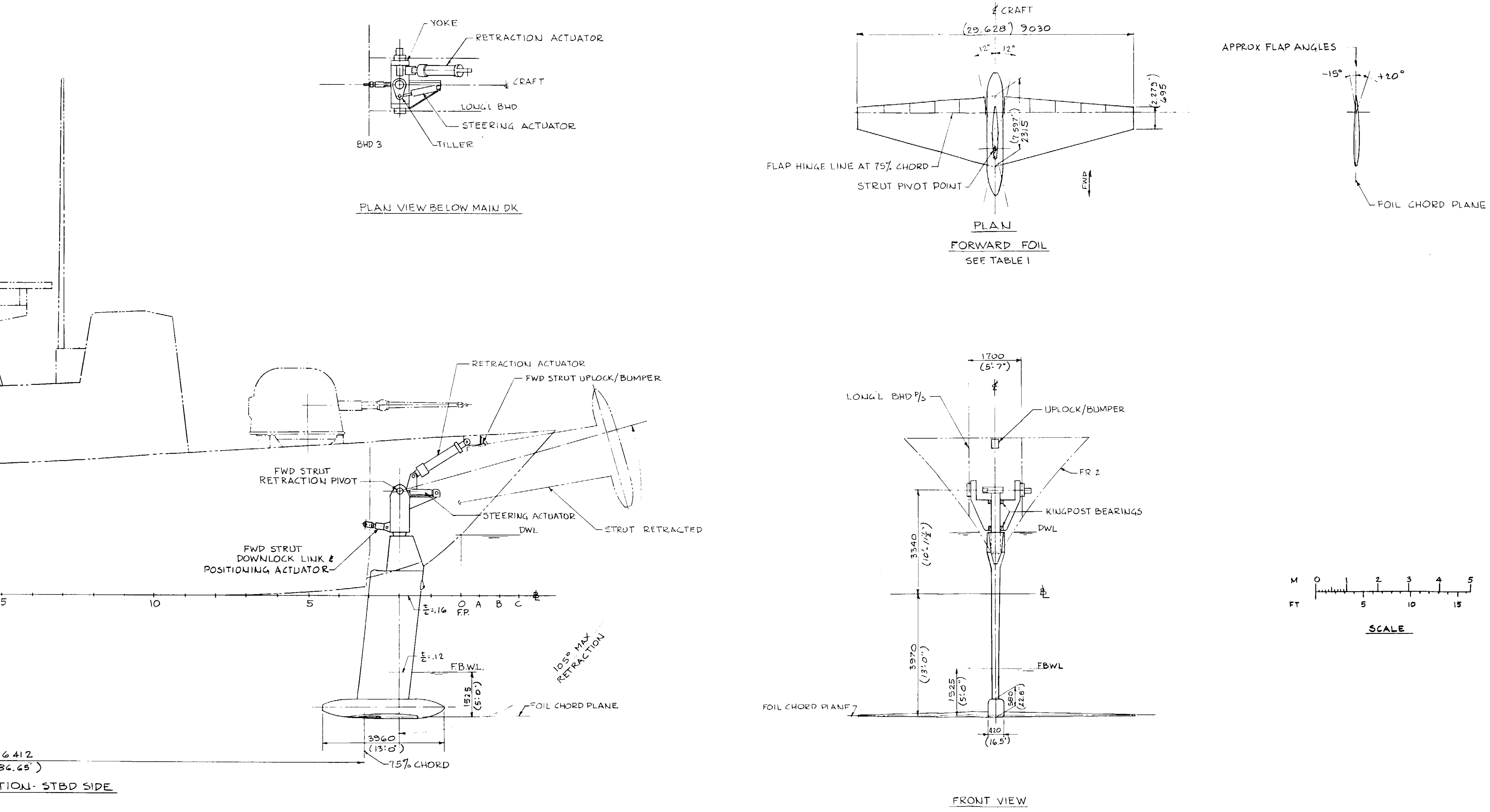
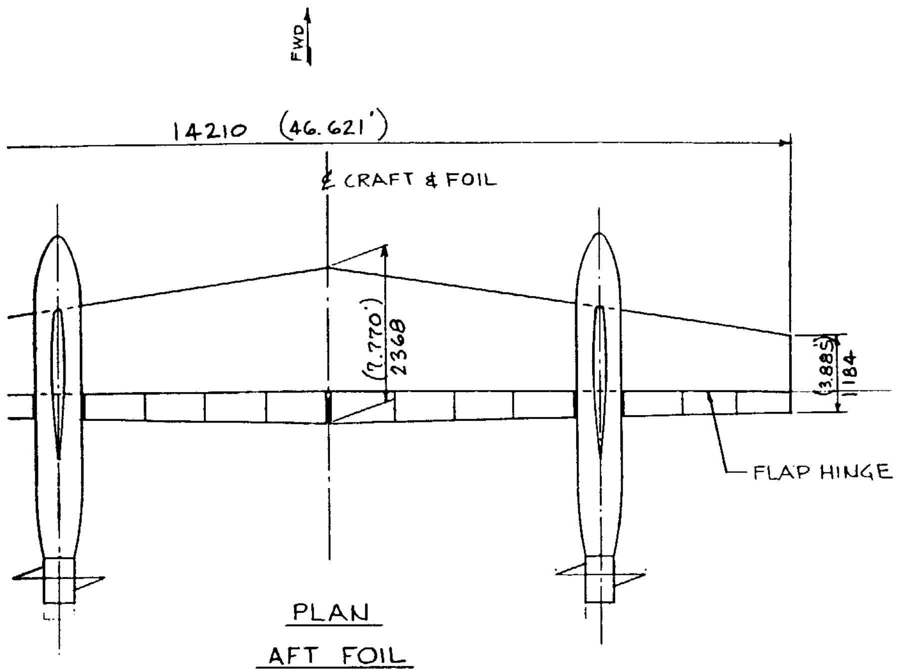


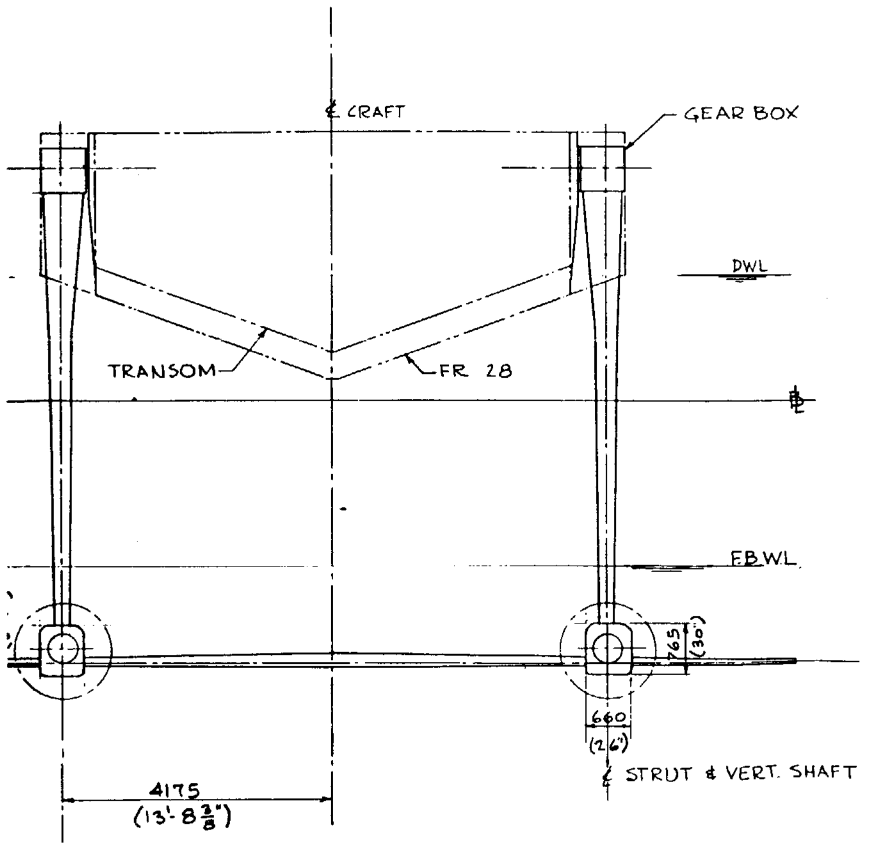
Fig. 2-1 Craft Geometry (U)



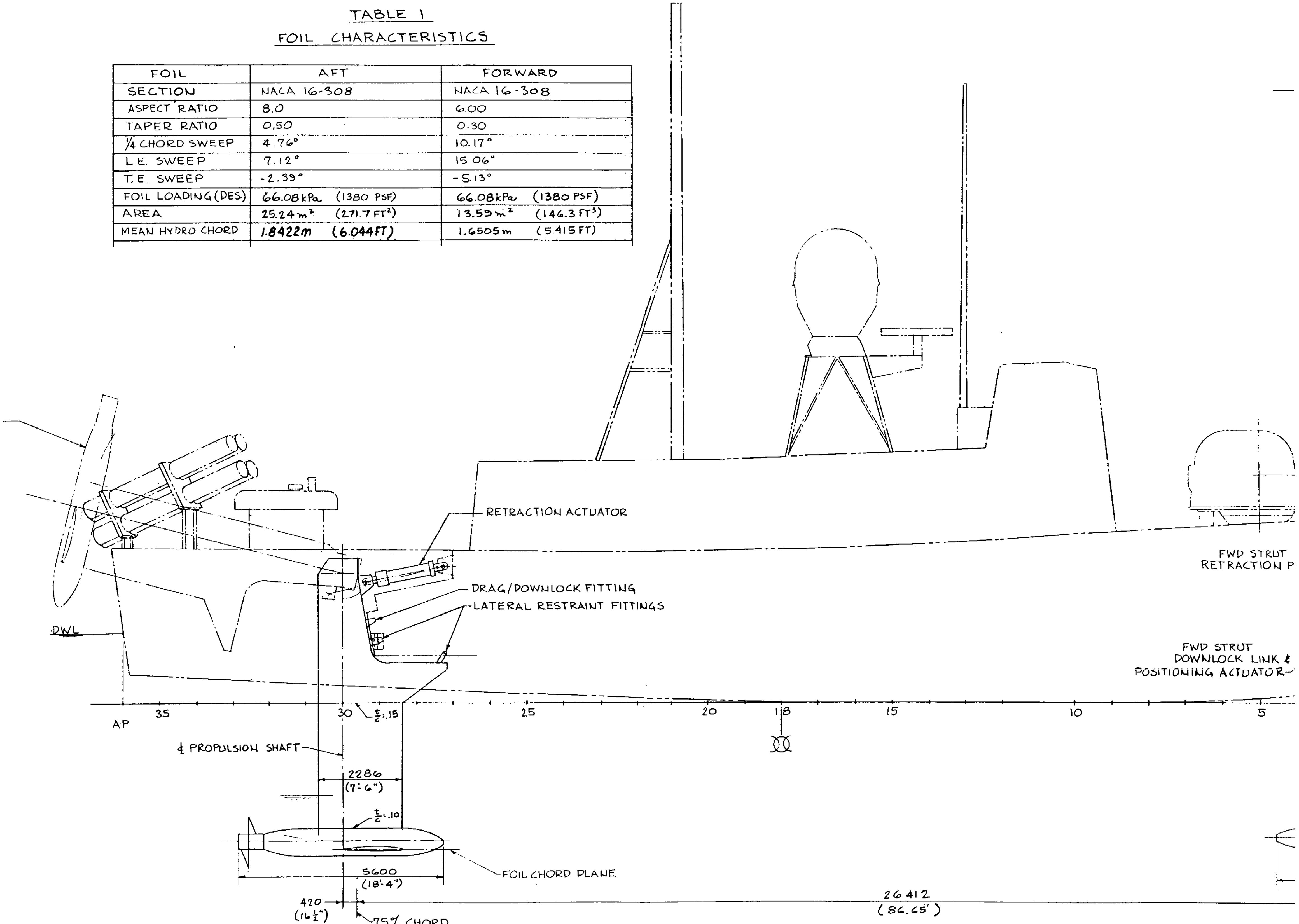
PLAN
AFT FOIL
SEE TABLE 1

TABLE 1
FOIL CHARACTERISTICS

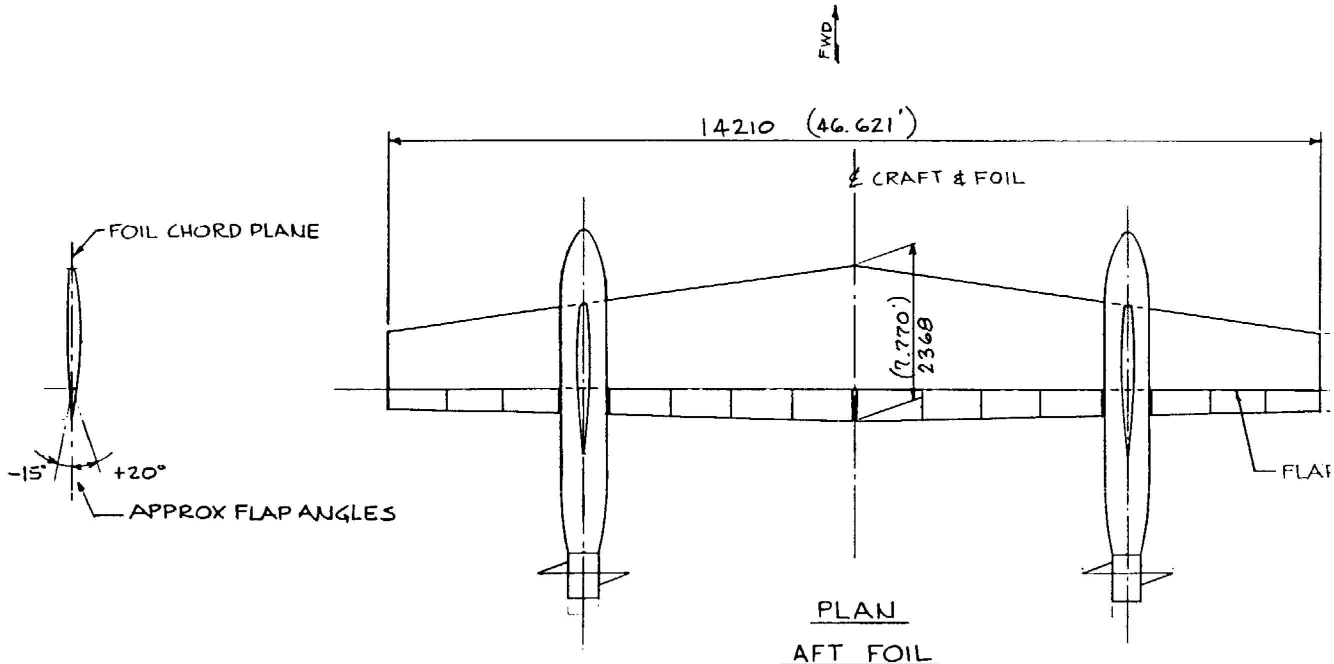
FOIL	AFT	FORWARD
SECTION	NACA 16-308	NACA 16-308
ASPECT RATIO	8.0	6.00
TAPER RATIO	0.50	0.30
1/4 CHORD SWEEP	4.76°	10.17°
L.E. SWEEP	7.12°	15.06°
T.E. SWEEP	-2.39°	-5.13°
FOIL LOADING (DES)	66.08 kPa (1380 PSF)	66.08 kPa (1380 PSF)
AREA	25.24 m² (271.7 FT²)	13.59 m² (146.3 FT³)
MEAN HYDRO CHORD	1.8422m (6.044FT)	1.6505m (5.415FT)



STERN VIEW



ELEVATION - STBD SIDE

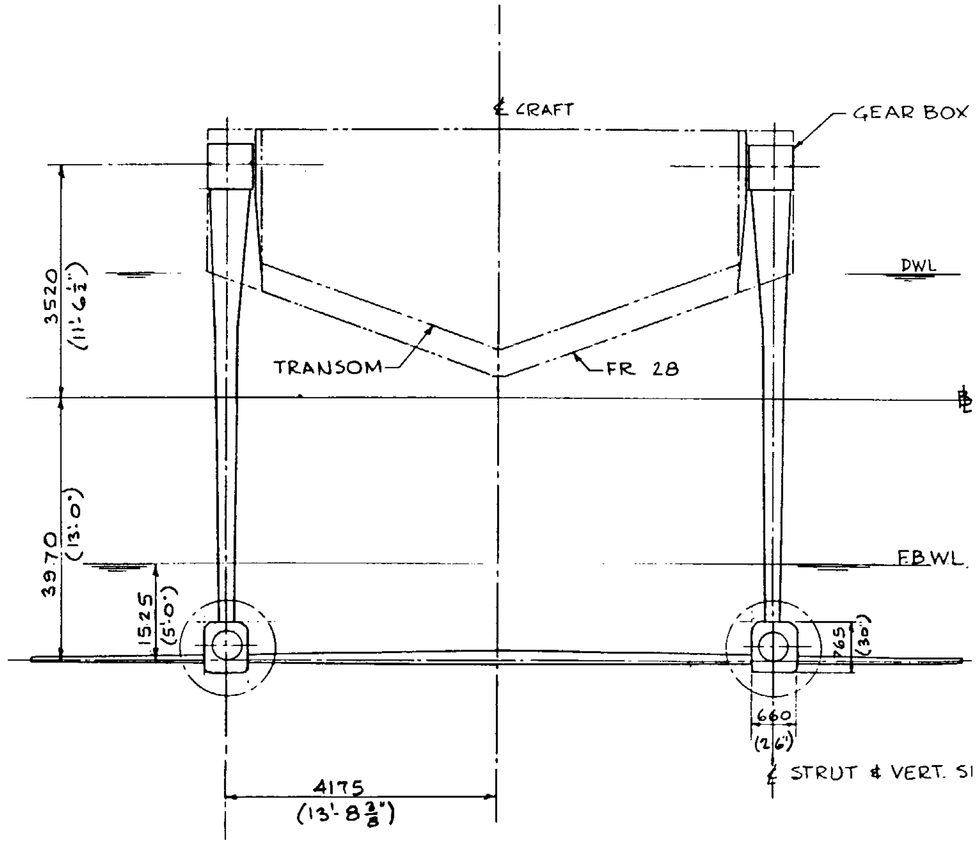


PLAN

AFT FOIL

SEE TABLE 1

STRUT RET



STERN VIEW

ABBREVIATIONS

CIC	COMBAT INFORMATION CENTER
CO	COMMANDING OFFICER
DWL	DESIGN WATER LINE
FBWL	FOILBORNE WATERLINE
LKR	LOCKER
OFF'S	OFFICERS
SR	STATEROOM
T&S	TOILET & SHOWER

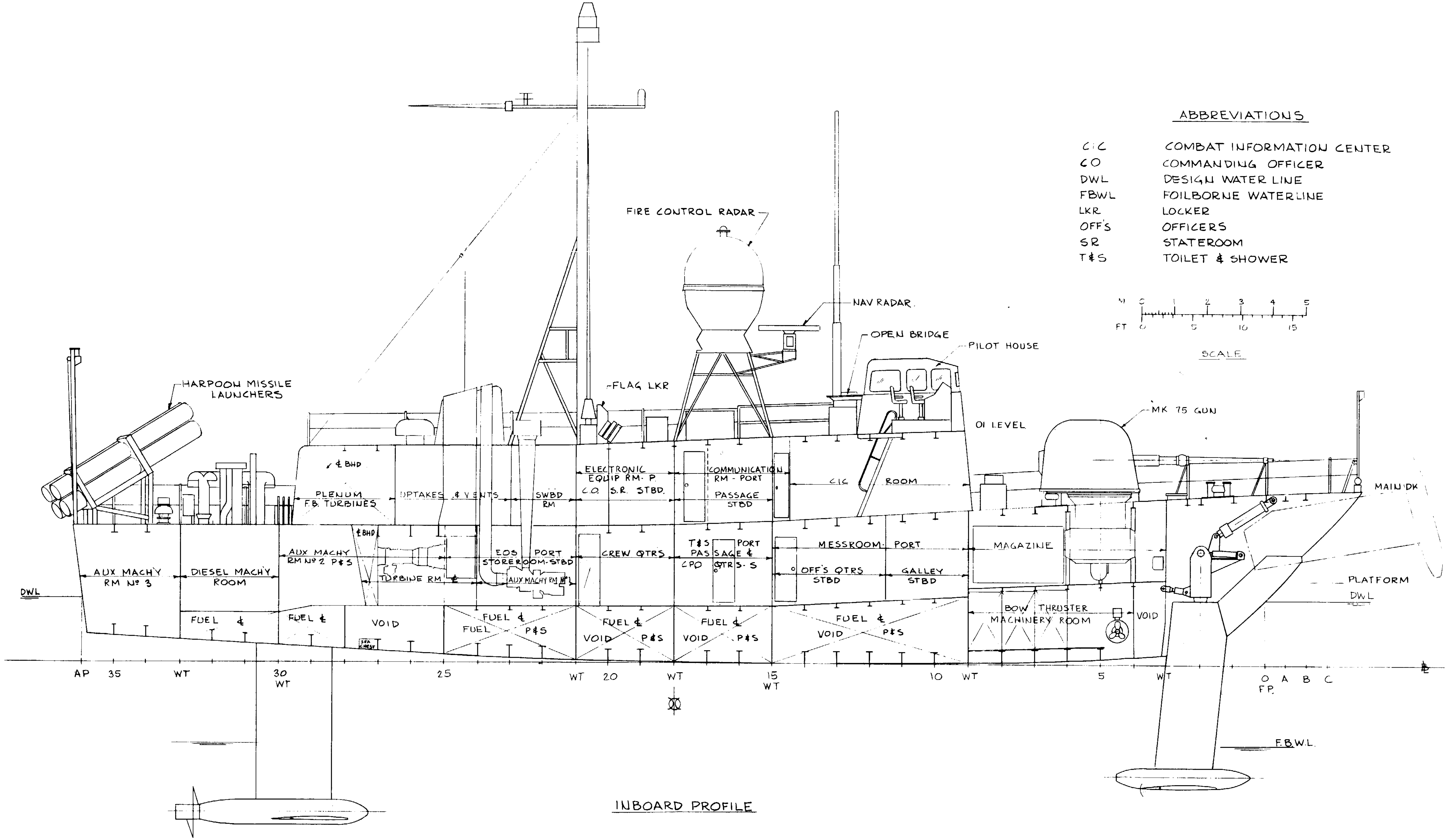


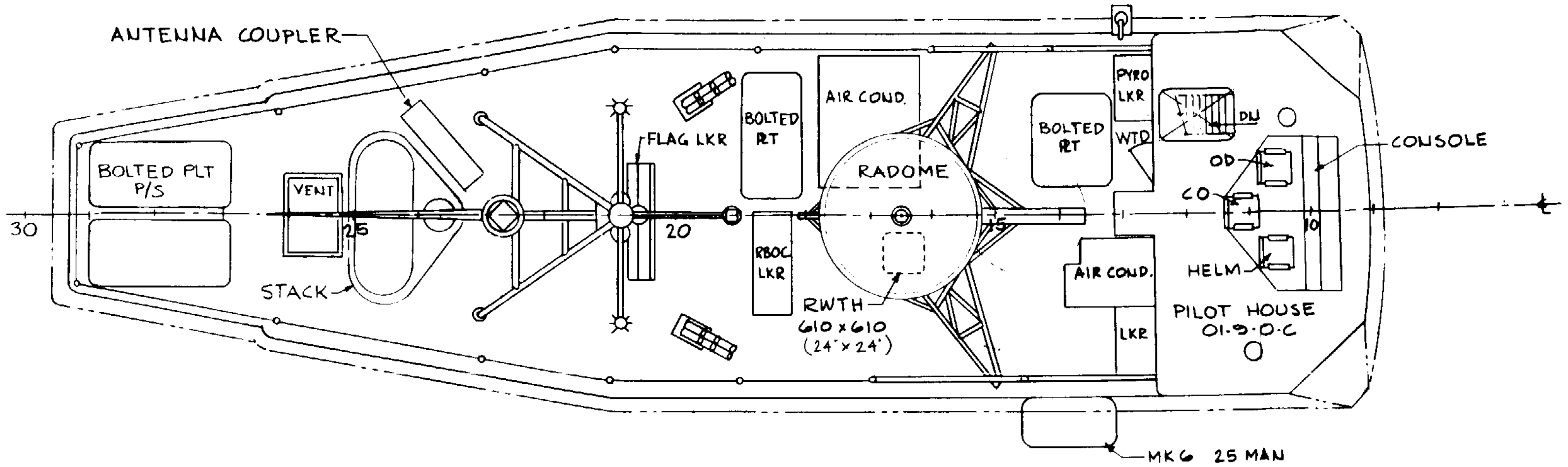
Fig. 2-2 General Arrangement - Inboard Profile (U)

GENERAL NOTES

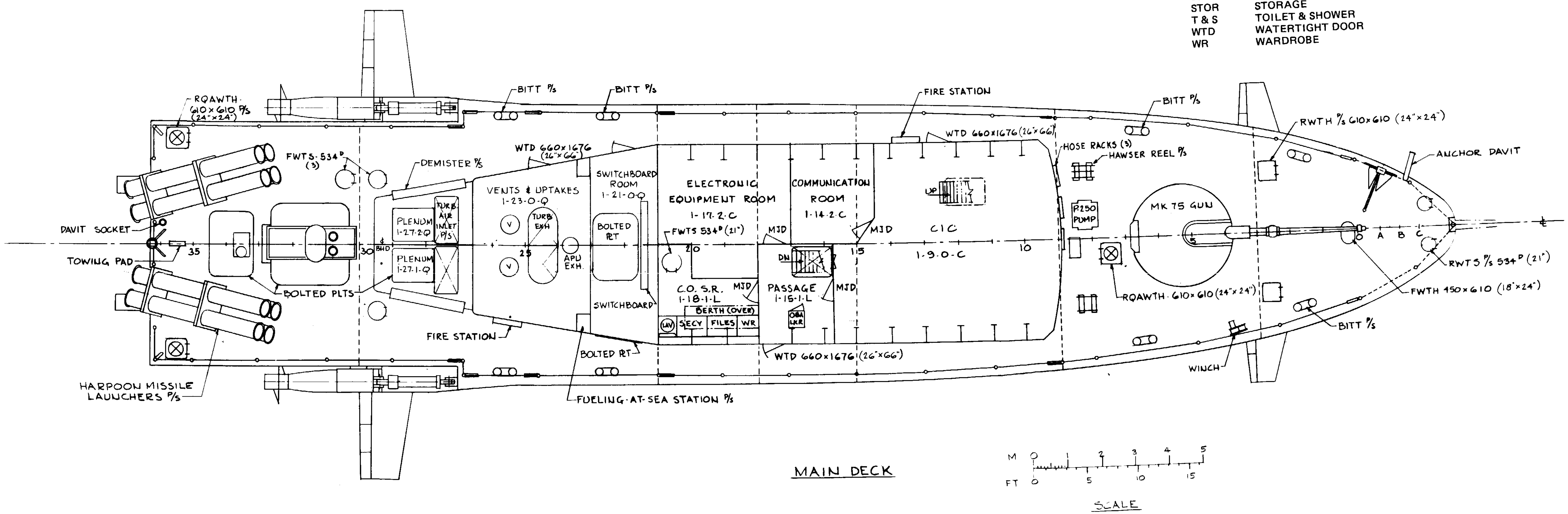
1. ALL DIMENSIONS SHOWN ARE IN MILLIMETERS.
2. BOLTED PLATE ACCESS TO TANKS & VOIDS NOT SHOWN.
3. ALL JOINER DOOR CLEAR OPENINGS TO BE 660 X 1905 (26" X 75").

ABBREVIATIONS

A/C	AIR CONDITIONING UNIT
CG	CLEANING GEAR
CIC	COMBAT INFORMATION CENTER
CO	COMMANDING OFFICER
DC	DAMAGE CONTROL
EOS	ENGINEER'S OPERATING STATION
FWTH	FLUSH WATER TIGHT HATCH
FWTS	FLUSH WATER TIGHT SCUTTLE
LKR	LOCKER
MED	MEDICAL LOCKER
MJD	METAL JOINER DOOR
MU	MODULAR UNIT
OD	OFFICER OF THE DAY
RBOC	RAPID BLOOM OFFBOARD CHAFF
RQAWTH	RAISED QUICK-ACTING WATERTIGHT HATCH
RWTH	RAISED WATERTIGHT HATCH
RWTS	RAISED WATERTIGHT SCUTTLE
SR	STATEROOM
SSPU	SHIP'S SERVICE POWER UNIT
STOR	STORAGE
T & S	TOILET & SHOWER
WTD	WATERTIGHT DOOR
WR	WARDROBE

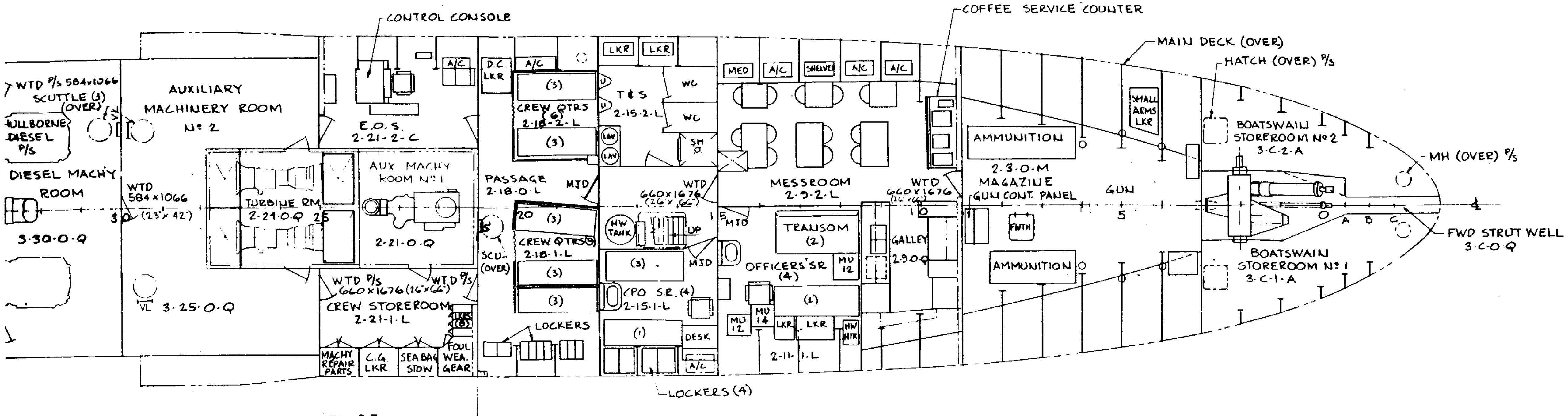


01 LEVEL



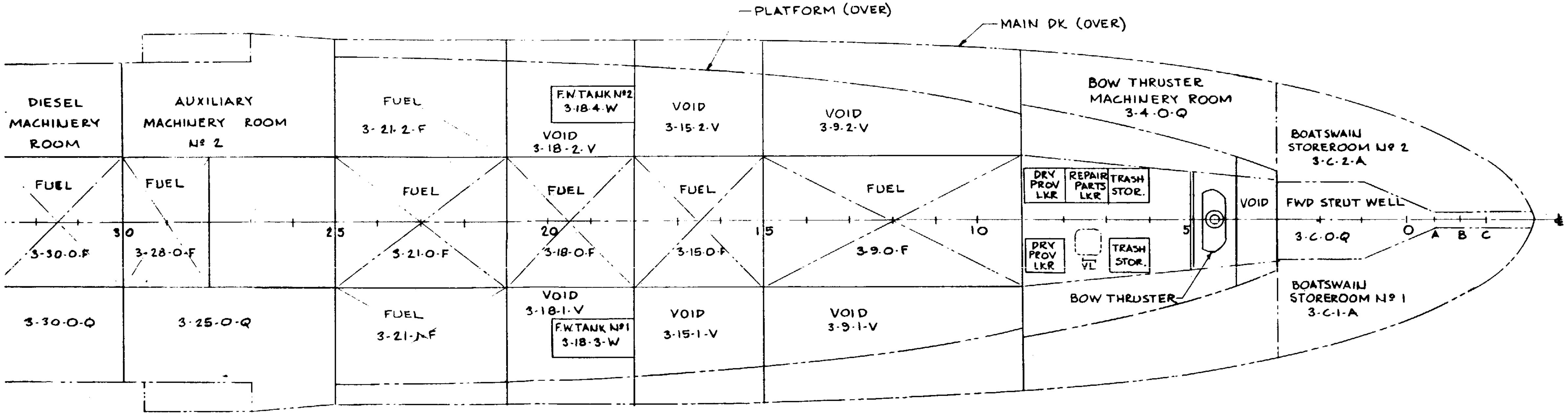
MAIN DECK

Fig. 2-3 General Arrangement - Deck Plans (U)



...NGEMENT OF MACHINERY SPACES SEE Fig. 2-5

PLATFORM



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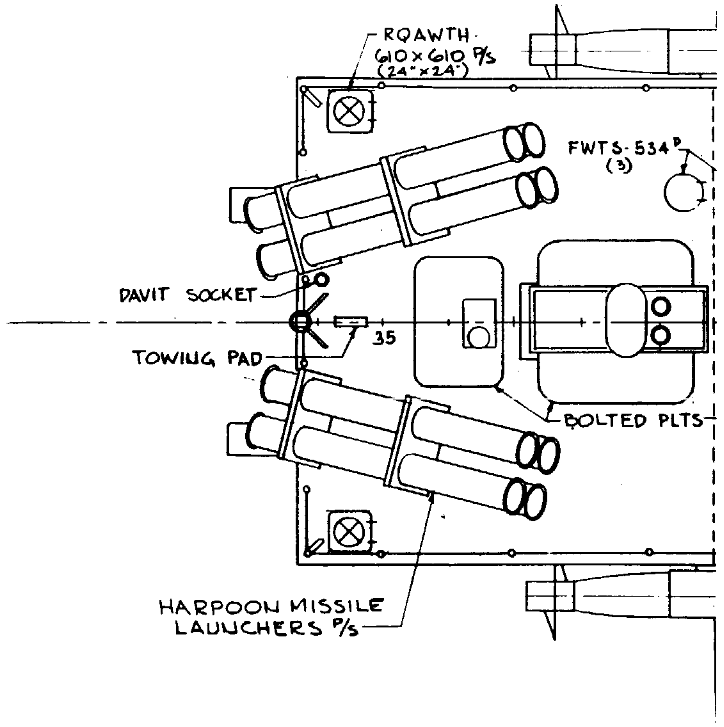
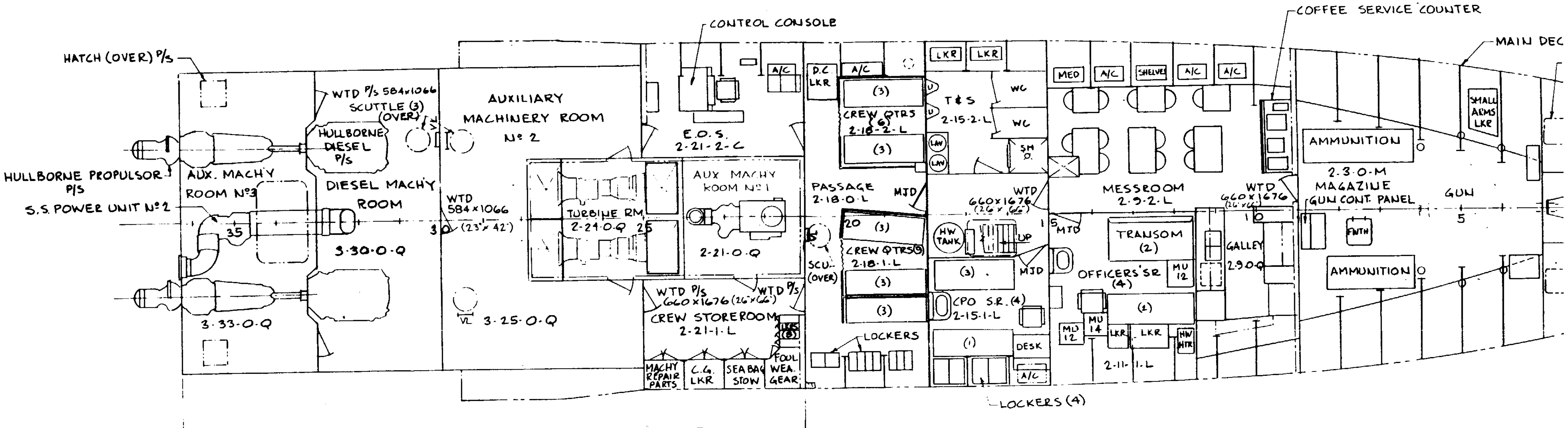
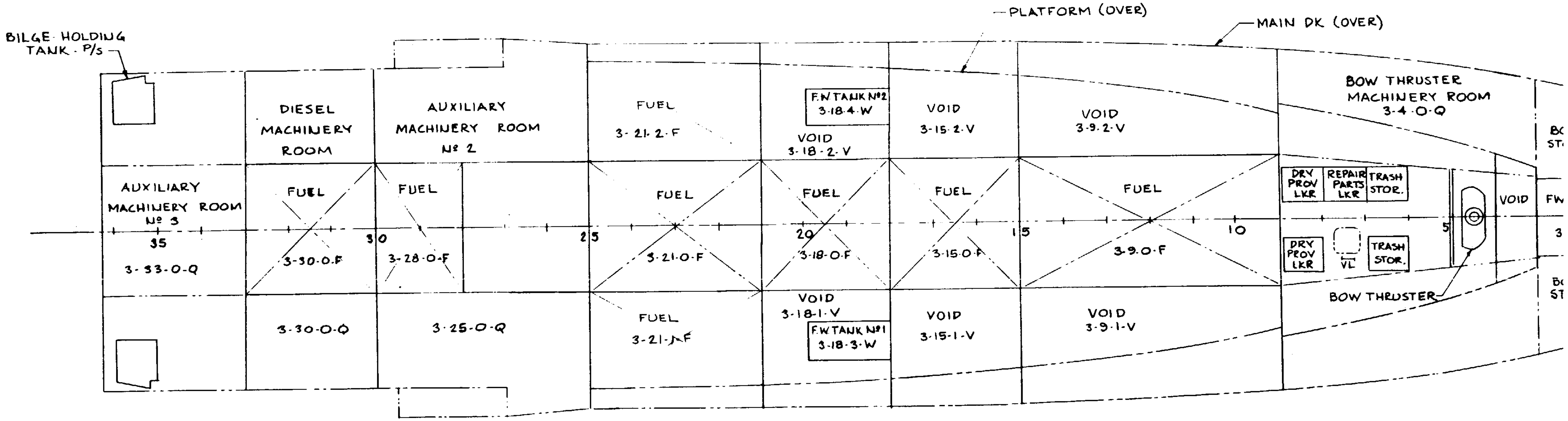




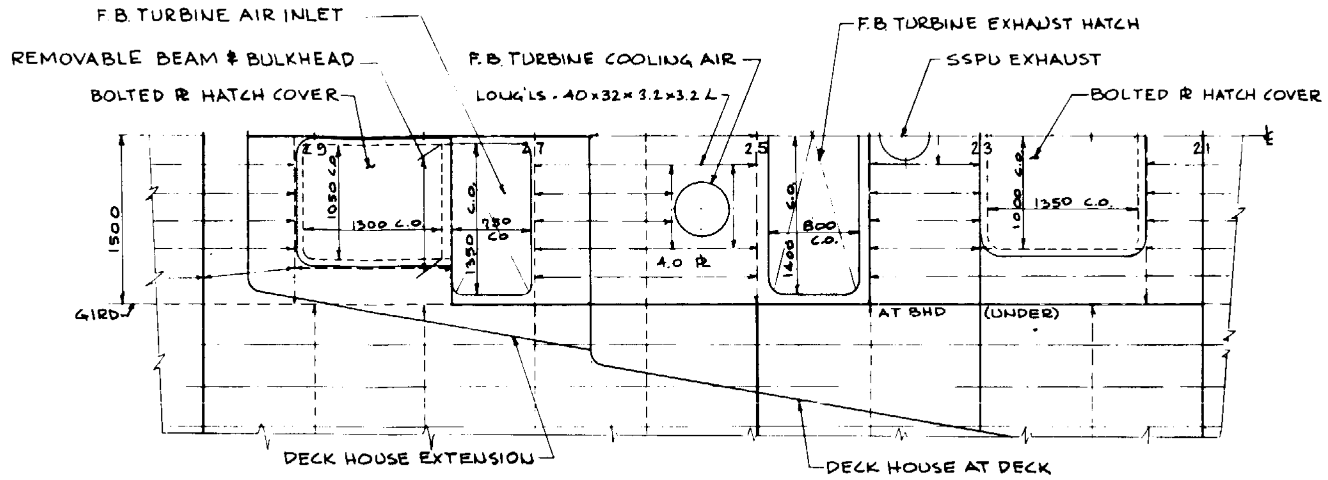
FOR ARRANGEMENT OF MACHINERY SPACES SEE Fig. 2-5

PLATFORM



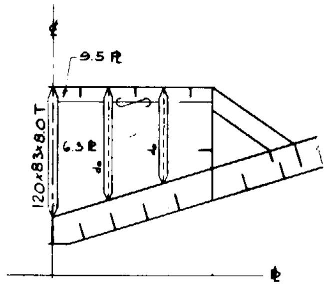
HOLD

2835-003D



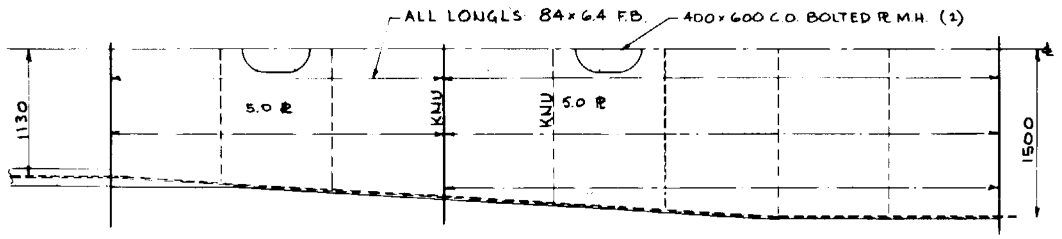
DETAIL 5B

MAIN DECK MODIFICATIONS

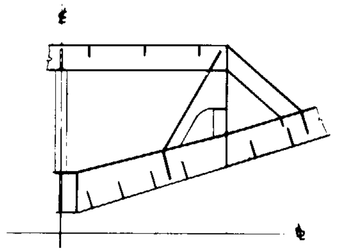


SEC 6B

OT FLR FR 28

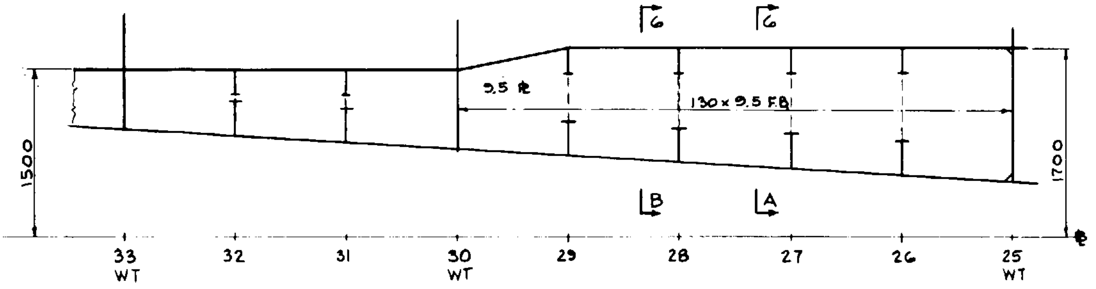


PLAN- PLATFORM



SEC 6A

TYP. OPEN FLOOR

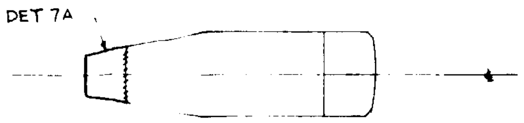


ELEV. STBD KEELSON

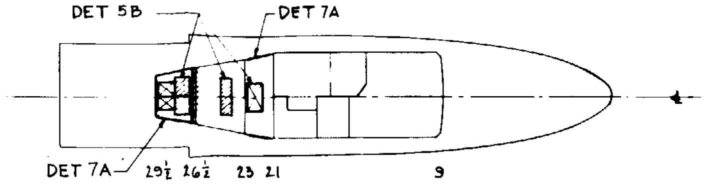
PORT SIM TO OPP HAND

DETAIL 5A

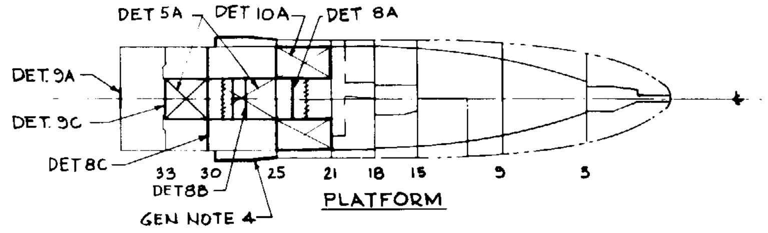
PLATFORM & KEELSONS IN WAY OF ADDED FUEL TANKAGE



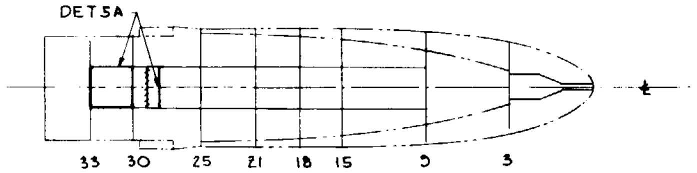
01 LEVEL



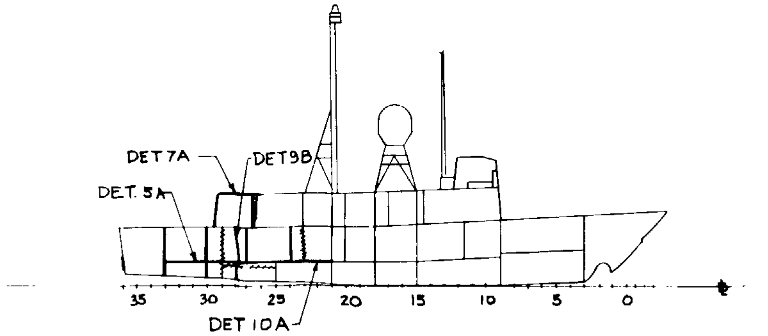
MAIN DECK



PLATFORM



HOLD

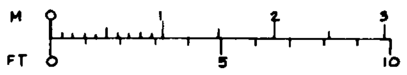


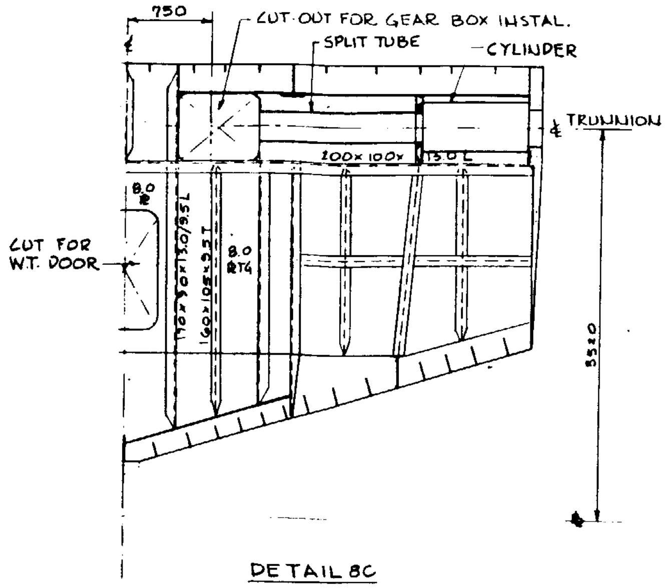
KEY PLAN

MAJOR STRUCTURAL MODIFICATIONS

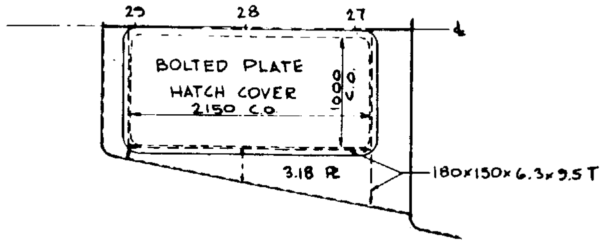
GENERAL NOTES

1. MATERIAL: PLATE-ALUM ALLOY 5456-H116/H117
   SPEC QQ-A-250/20
   SHAPES-ALUM ALLOY 5456-H111
   SPEC QQ-A-200/7
2. SCANTLINGS SHOWN ARE PRELIMINARY - FOR INFORMATION & WEIGHT ESTIMATION ONLY.
3. ALL DIMENSIONS IN MILLIMETERS.
4. HULL FAIRINGS IN WAY OF AFT STRUTS TO BE MODIFIED AS NECESSARY TO SUIT NEW STRUTS. BASIC STRUCTURE TO BE SIMILAR TO PHM-3.

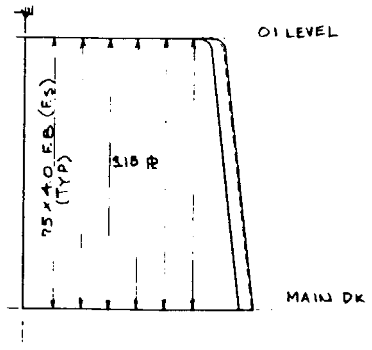
~~~ REMOVALS
—— ADDITIONS



SCALE

Fig. 2-4 Structural Modifications to PHM-3 Series (U)
~~~



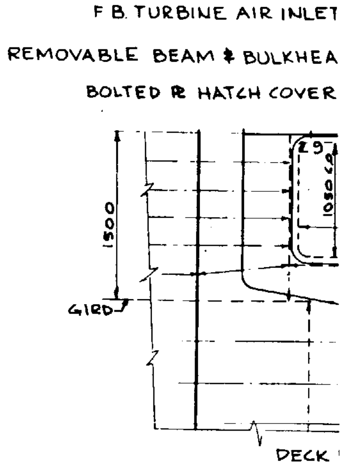
DETAIL 8C
W.T. BULKHEAD 30
PORT LKG AFT



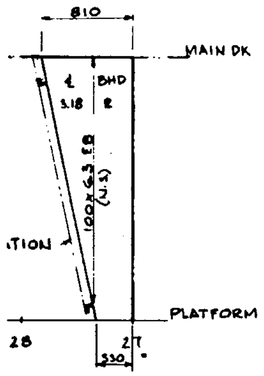
PLAN AT 01 LEVEL



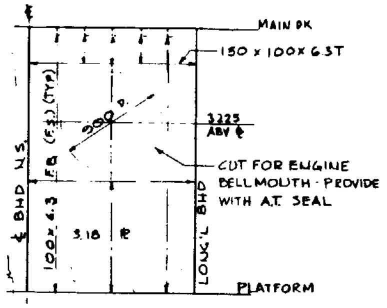
TRANS BHD 26½
STBD LKG FWD



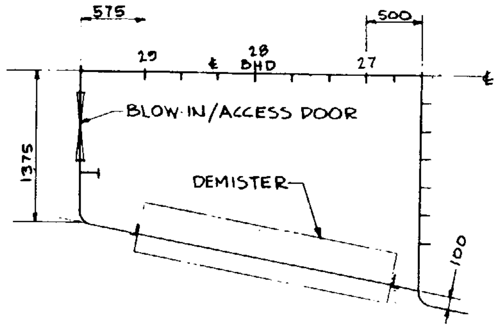
ILS



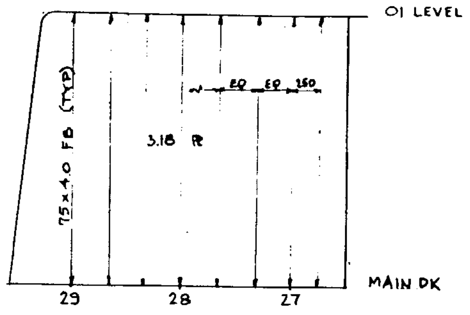
ET
3



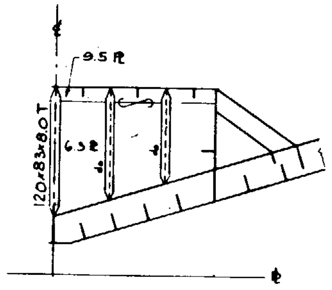
DET 8B
TRANS BHD FR 27
STBD LKG FWD



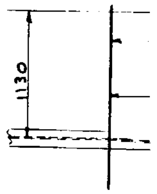
PLAN AT MAIN DK

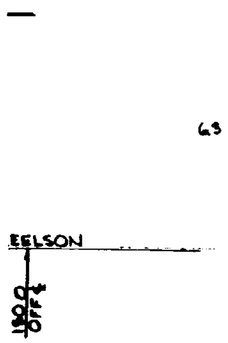


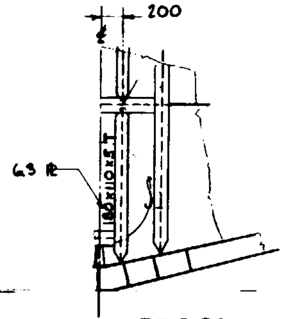
ELEV ℄ BHD



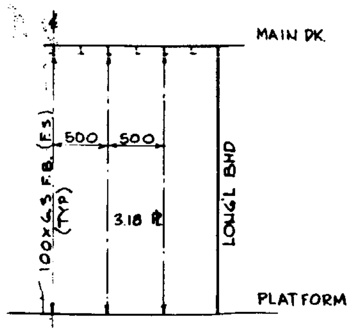
SEC 6B
OT FLR FR 28



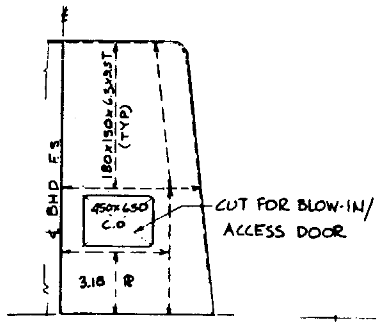




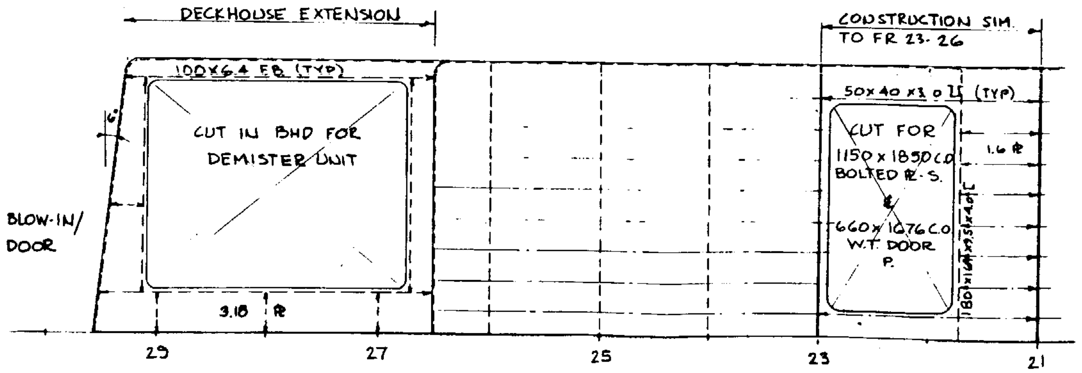
DET. 9A
TRANSOM
PORT LKG AFT



DET. 8A
TRANS. BHD FR 24
STBD LKG FWD

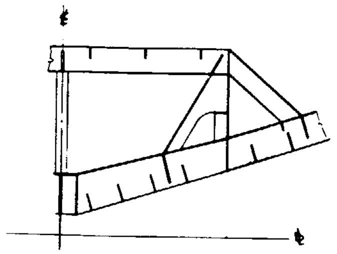


AFT BHD

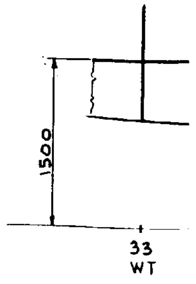


ELEVATION STBD BHD
PORT SIDE TO OPP. HAND

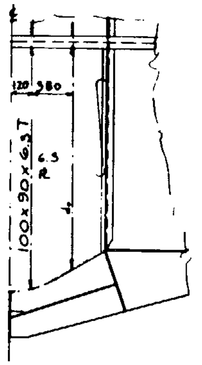
DETAIL 7A
DECK HOUSE & 01 LEVEL EXTENSION



SEC 6A
TYP. OPEN FLOOR



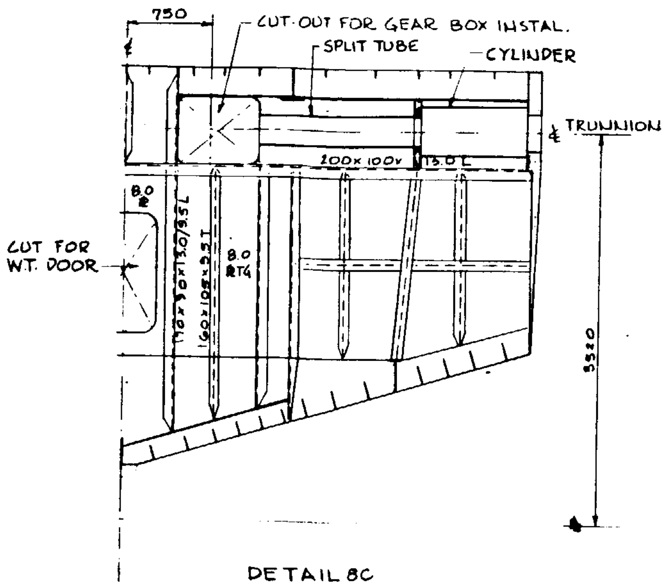
PLATFOR
AD



DET. 9C

W.T. BHD 33

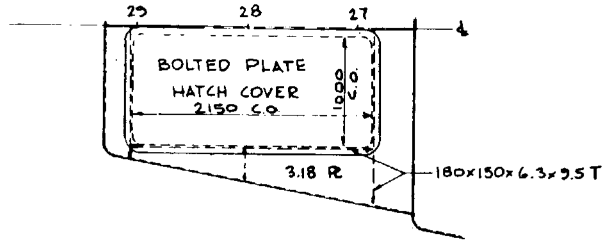
STBD LKG FWD



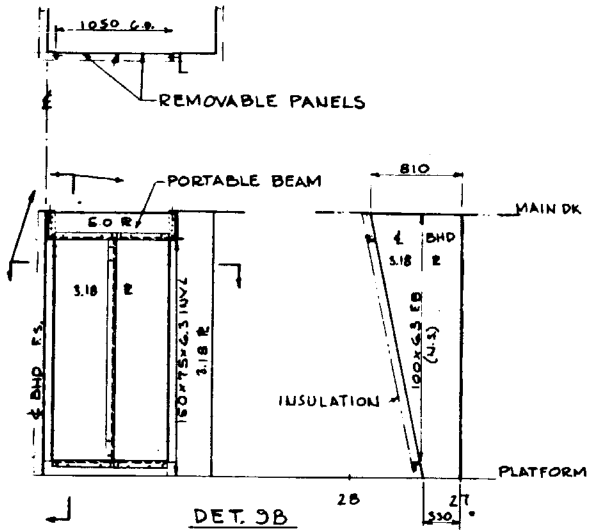
DETAIL 8C

W.T. BULKHEAD 30

PORT LKG AFT



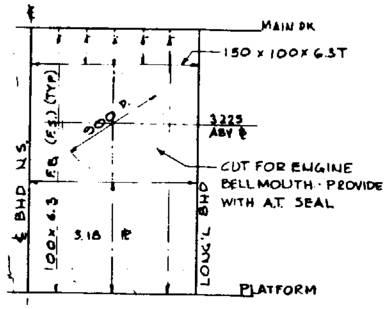
PLAN AT 01 LEVEL



DET. 9B

TURBINE AIR INLET

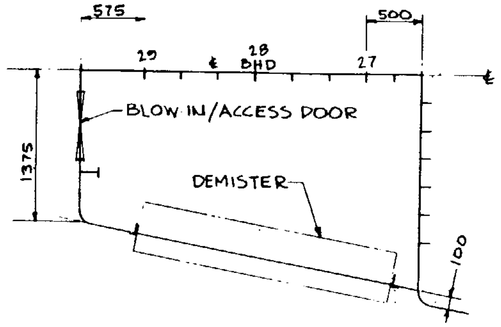
BHD - FR 27-28



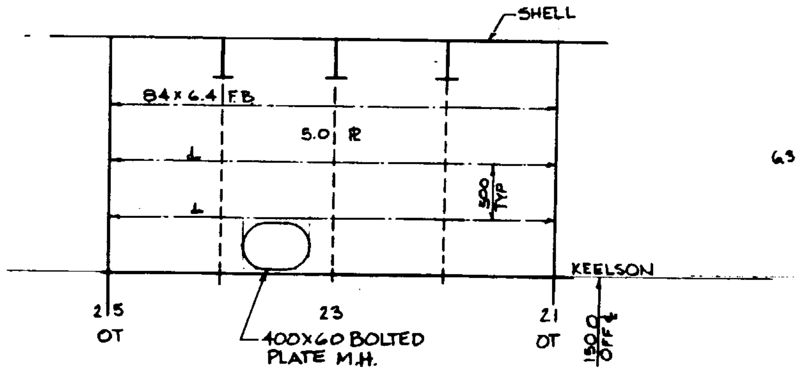
DET 8B

TRANS BHD FR 27

STBD LKG FWD

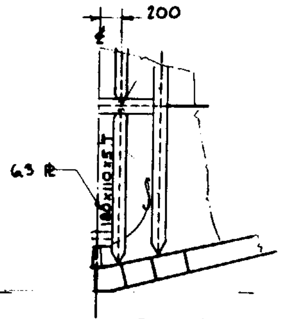


PLAN AT MAIN DK



DET. 10A

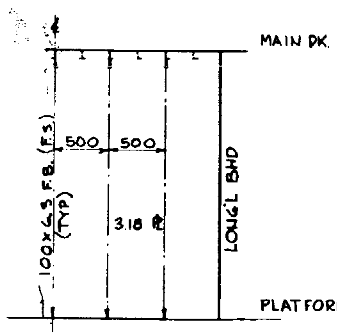
PLATFORM IN WAY OF ADDED FUEL TANKS



DET. 9A

TRANSOM

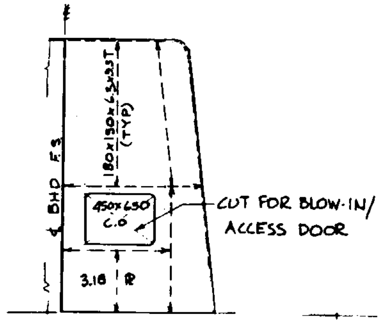
PORT LKG AFT



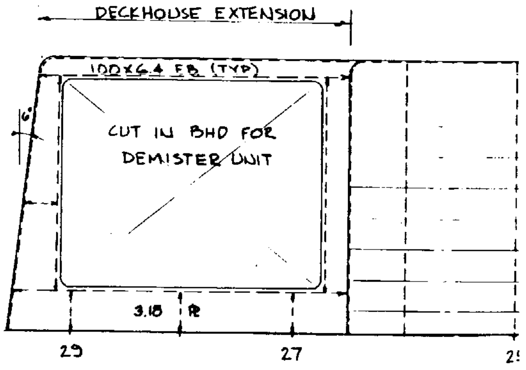
DET. 8A

TRANS. BHD FR 24

STBD LKG FWD



AFT BHD



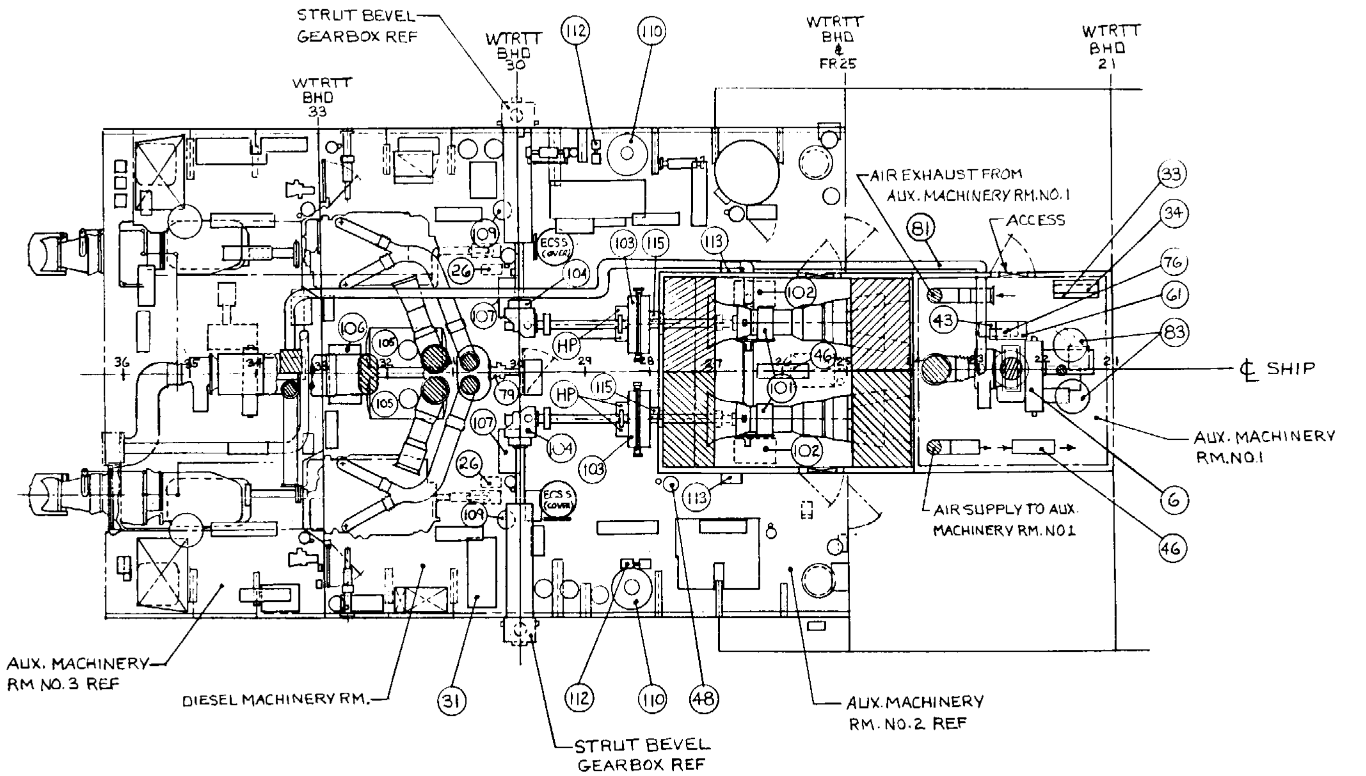
ELEVATIO

PORT SIDE

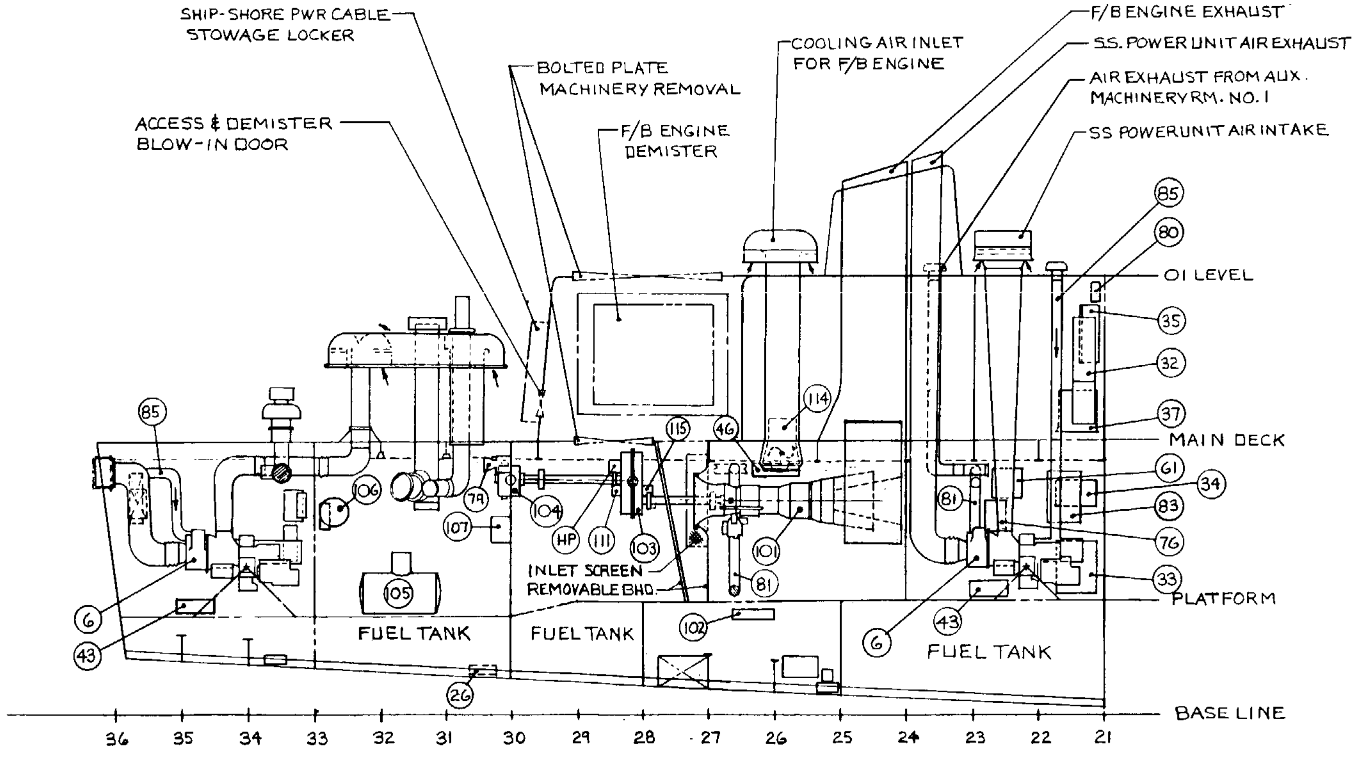
DETAIL 7

DECK HOUSE & 01 LEVE

2835-004D



PLAN VIEW
(BELOW MAIN DECK)



CENTER ELEVATION

REF: NAVSEA DWG. NO. 82-5000459 REV D, PATROL COMBATANT MISSILE (HYDROFOIL) PHM 3 SERIES GEN. ARRANGEMENT MACHINERY ROOM

- THE FOLLOWING PC NO'S ARE ADDITIONS TO THE REF. DWG AND ARE IDENTIFIED BY THE 100 SERIES NUMBERS ON THIS DWG.

	PC NO.	NO. REQD	DESCRIPTION	G/T RM	DIES. RM	AMR NO1	AMR NO2	AMR NO3	SWBD RM
	101	2	FOILBORNE ENGINE	2					
	102	2	FOILBORNE ENGINE FUEL HEATER/L.O. COOLER	2					
	103	2	HULL MOUNTED GEARBOX				2		
	104	2	HULL BEVEL GEARBOX				2		
	105	2	TRANSMISSION L.O. RESERVOIR		2				
	106	1	TRANSMISSION L.O. REPLENISHMENT TANK		1				
	107	2	TRANSMISSION L.O. HEAT EXCHANGER		2				
	108	2	TRANSMISSION L.O. SUPPLY PUMP				2		
	109	2	POD SEAL OIL TANK		2				
	110	2	PROP. PITCH CONTROL HYDRAULIC TANK				2		
	111	2	PROP. PITCH CONTROL PRIMARY HYDRAULIC PUMP				2		
	112	2	PROP. PITCH CONTROL ZERO PITCH HYDRAULIC PUMP				2		
	113	2	PROP. PITCH CONTROL/ENGINE ELEC. PANEL				2		
	114	2	G/T RM AIR SUPPLY FAN	2					
	115	2	TRANSMISSION L.O. SCAVENGE PUMP				2		1
*	46	1	SPACE HEATER WITH FAN						1
*	26	1	BILGE PUMP		1				

*INCREASE IN QUANTITY FROM REF. DWG.

- THE FOLLOWING PC NO'S HAVE BEEN RELOCATED ON THIS DWG. WITH RESPECT TO THE REF. DWG.

	PC NO.	NO. EFFTD	DESCRIPTION	G/T RM	DIES. RM	AMR NO1	AMR NO2	AMR NO3	SWBD RM
	6	2	SS POWER UNITS NOS 1 & 2			1		1	
	31	1	LP AIR COMPRESSOR		1				
	32	1	SWITCHBOARD NO. 1						1
	33	1	BATTERY SET NO.1			1			
	34	1	BATTERY CHARGER NO. 1			1			
	35	1	DC POWER PANEL NO.1						1
	37	2	FREQUENCY CONVERTER						2
	43	2	SS POWER UNIT LUBE COOLER			1		1	
	46	2	SPACE HEATER WITH FAN	1		1			
	48	1	DRY CHEMICAL UNIT				1		
	61	1	SSPU JUNCTION & EMERGENCY			1			
	76	1	CT BOX			1			
	80	1	BACK UP CONVERTER BOX						1
	83	2	HYDRAULIC RESERVOIR			2			
	85	2	GENERATOR COOLING AIR EXHAUST			1		1	
	26	1	BILGE PUMP		1				
	79	1	INTERCOM SPEAKER		1				
	81		AIR START DUCTING	✓		✓	✓		
**	HP	4	HYDRAULIC PUMP				4		

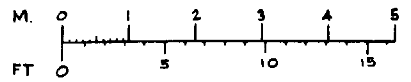
** ITEMS SHOWN ON REDUCTION GEARBOX ON REF. DWG. BUT NOT IDENTIFIED BY PC NO.

- THE FOLLOWING PC NO'S & INDICATED QUANTITIES ( ) REMAIN THE SAME AS SHOWN ON THE REF. DWG.

4(2), 5(2), 7(4), 8(1), 9(2), 10(2), 11(1), 12(1), 13(1), 14(1), 16(1), 22(1), 24(1), 25(2), 26(2), 27(1), 28(2), 29(2), 36(2), 37(1), 38(1), 39(1), 40(1), 41(1), 43(1), 44(1), 45(1), 46(6), 47(4), 48(4), 49(3), 50(1), 51(1), 52(4), 53(1), 54(2), 55(1), 56(1), 59(3), 60(1), 61(1), 63(2), 70(1), 71(1), 73(3), 74(1), 75(1), 76(1), 77(4), 78(4), 79(2), 81, 83(2), 84(2), 86, 88(1).

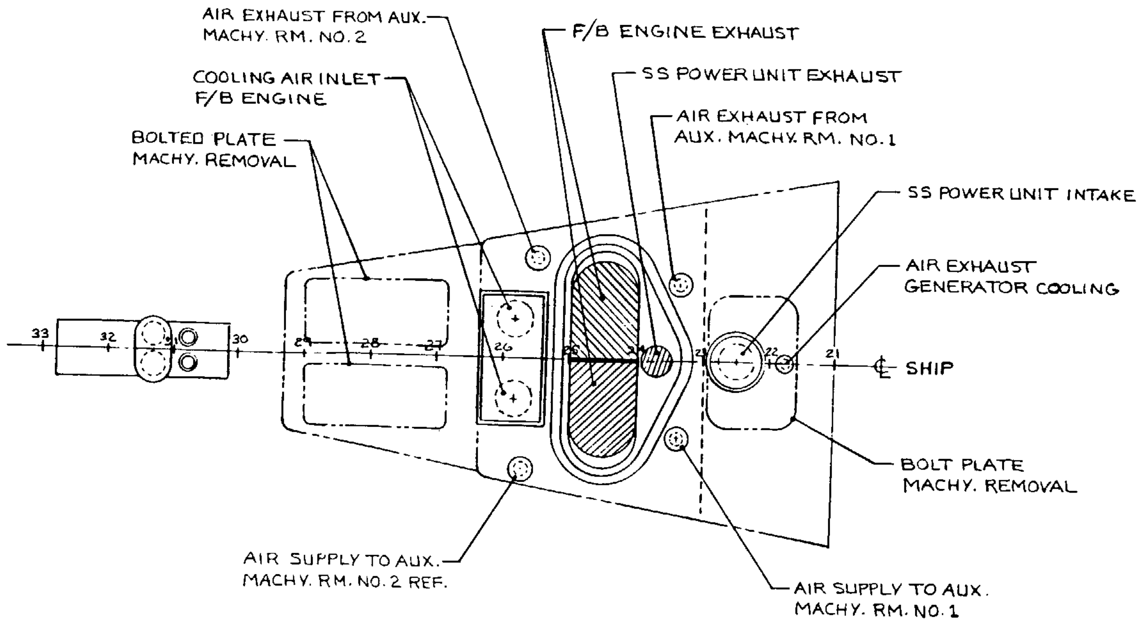
- THE FOLLOWING PC NO'S & INDICATED QUANTITIES( ) SHOWN ON THE REF DWG. HAVE BEEN DELETED FROM THIS DWG.

1(1), 2(1), 3(1), 17(1), 18(1), 19(1), 20(1), 21(1), 30(2), 42(1), 62(1), 66(1), 68(1), 69(2), 87(1).

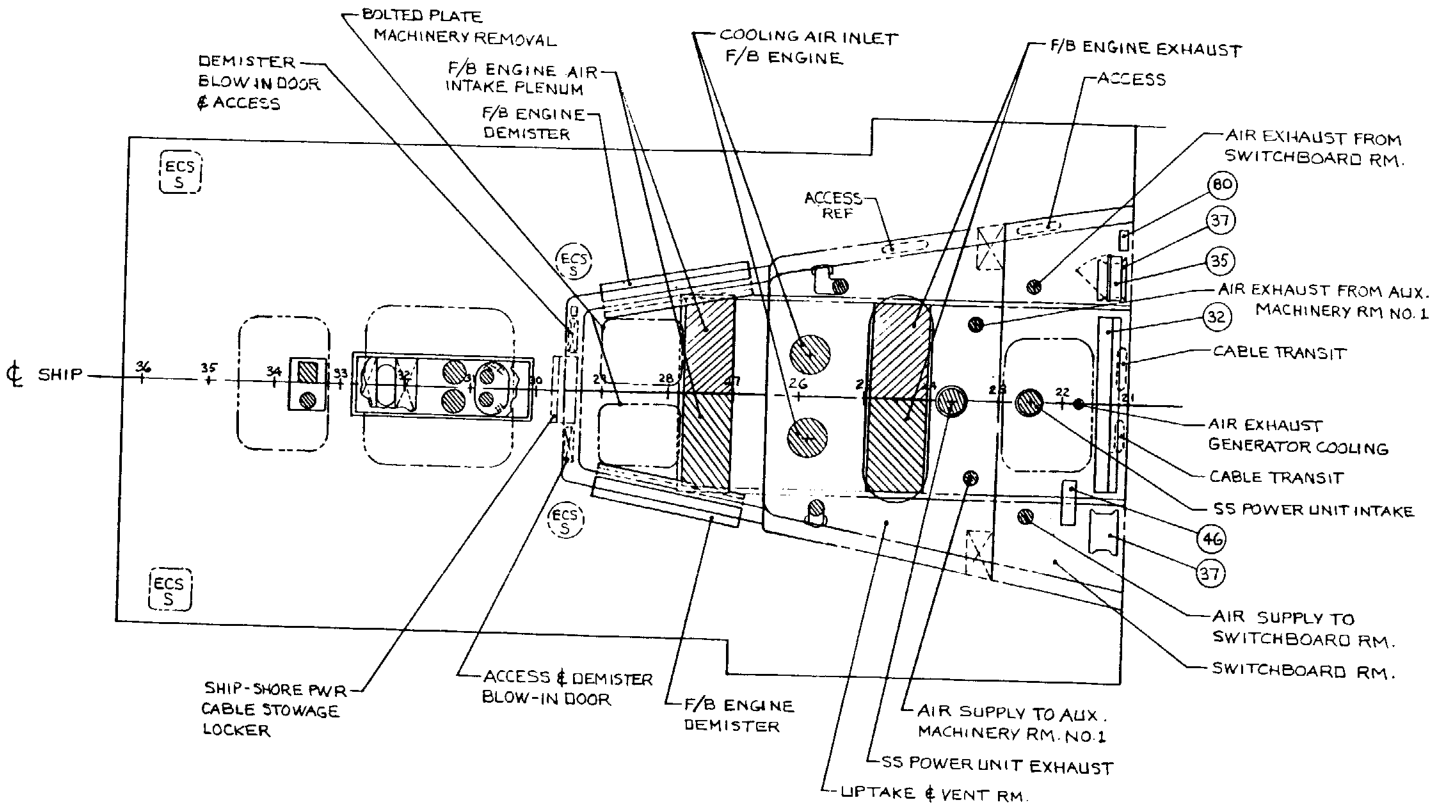


SCALE

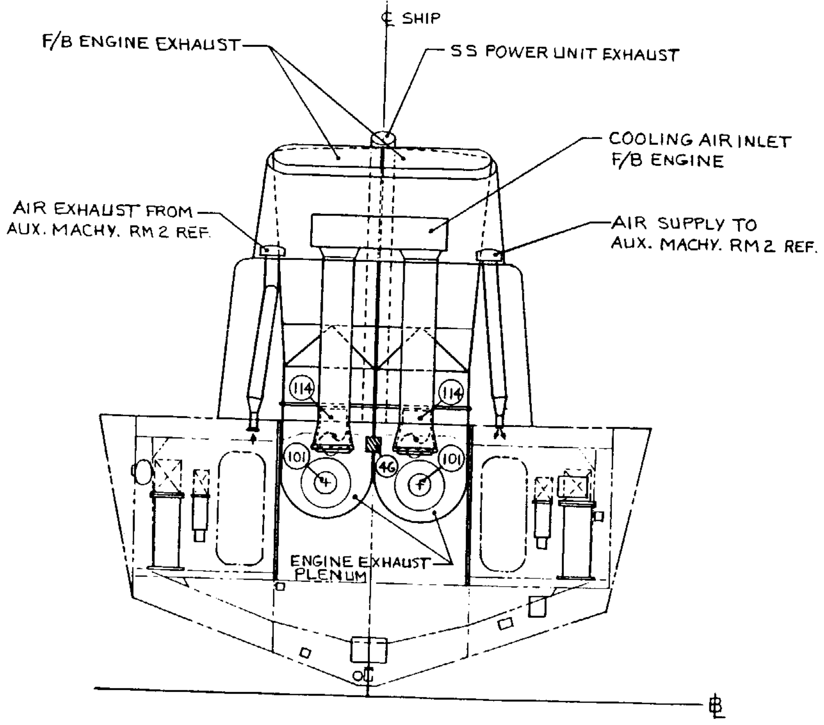
Fig. 2-5 General Arrangement - Machinery Spaces (U)



PLAN VIEW
(01 LEVEL)

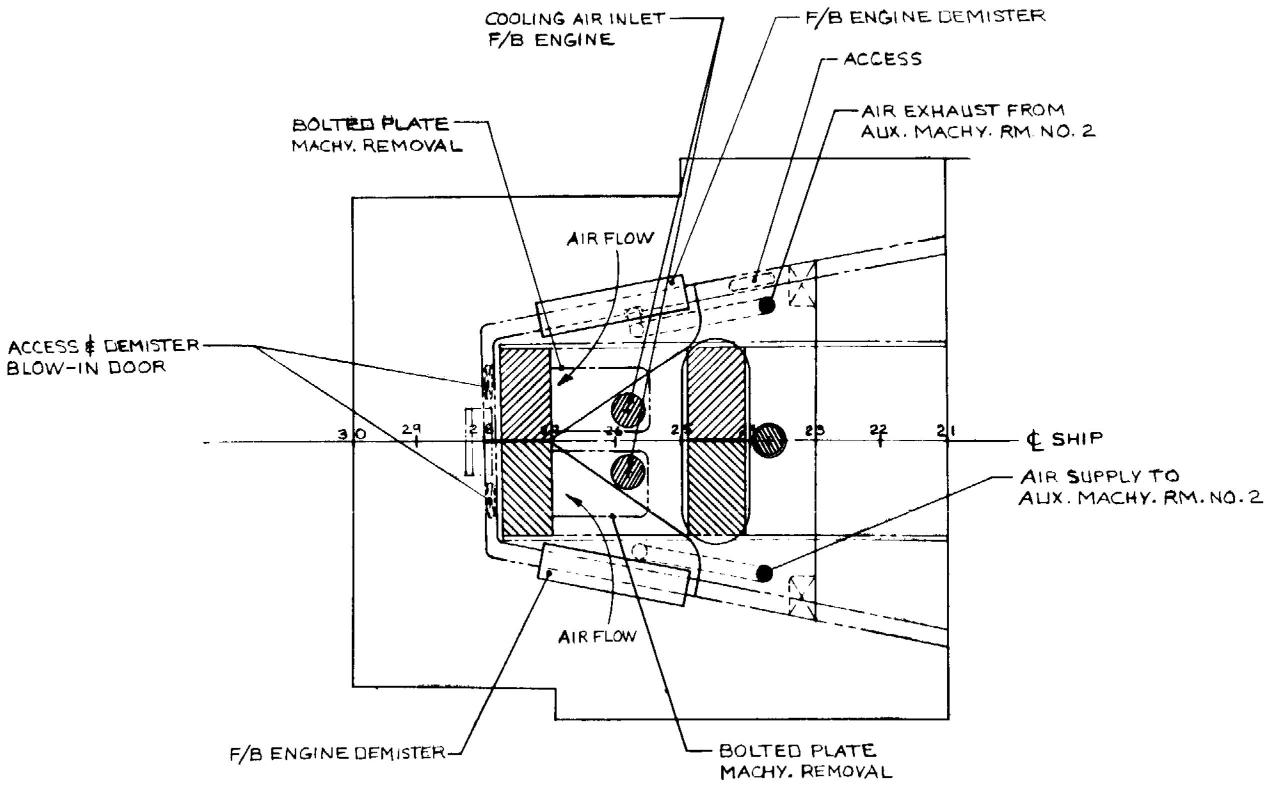


PLAN VIEW
(MAIN DECK)

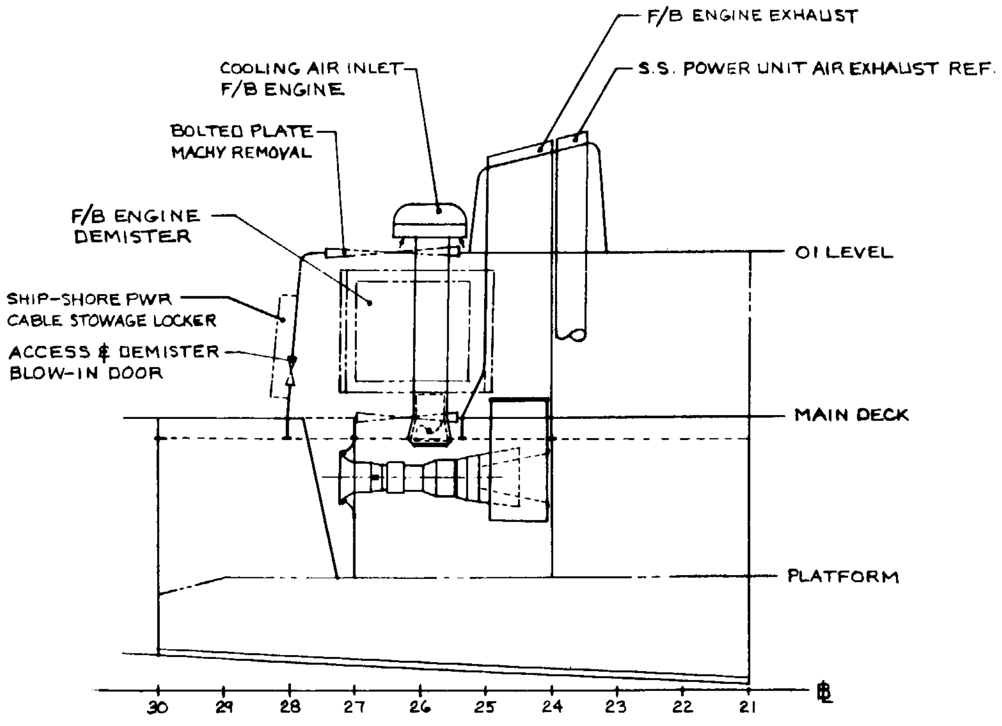


SECTION AT FR 26 LKG FWD

2835-005D



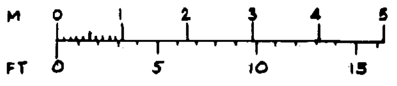
PLAN VIEW
(MAIN DECK)



CENTER ELEVATION

NOTES

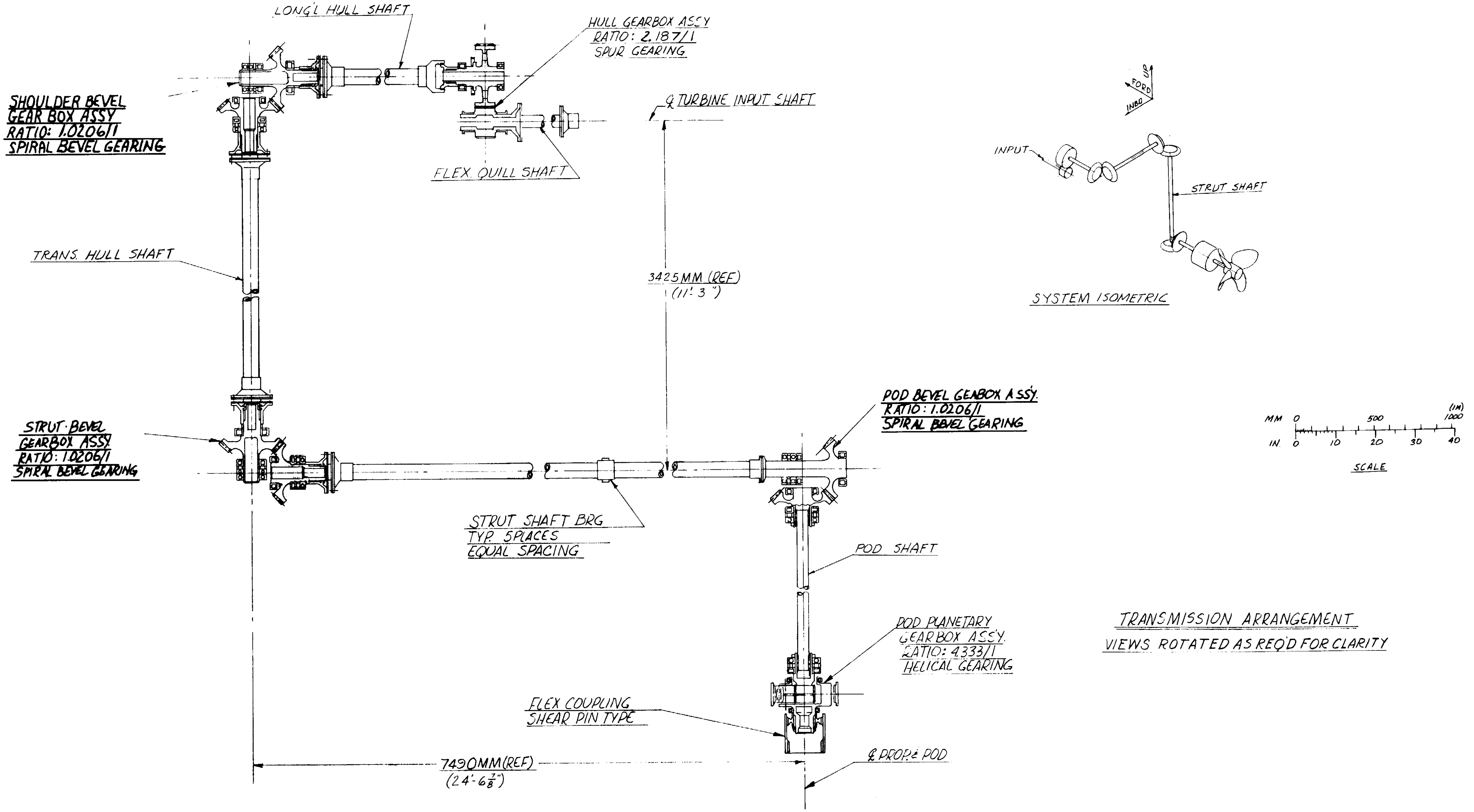
1. FOR REMAINDER OF ARRANGEMENT NOT SHOWN AND FOR COMPONENT IDENTIFICATION SEE FIG. 2-5.



SCALE

2835-006D

Fig. 2-6 General Arrangement - Machinery (Alternate) (U)

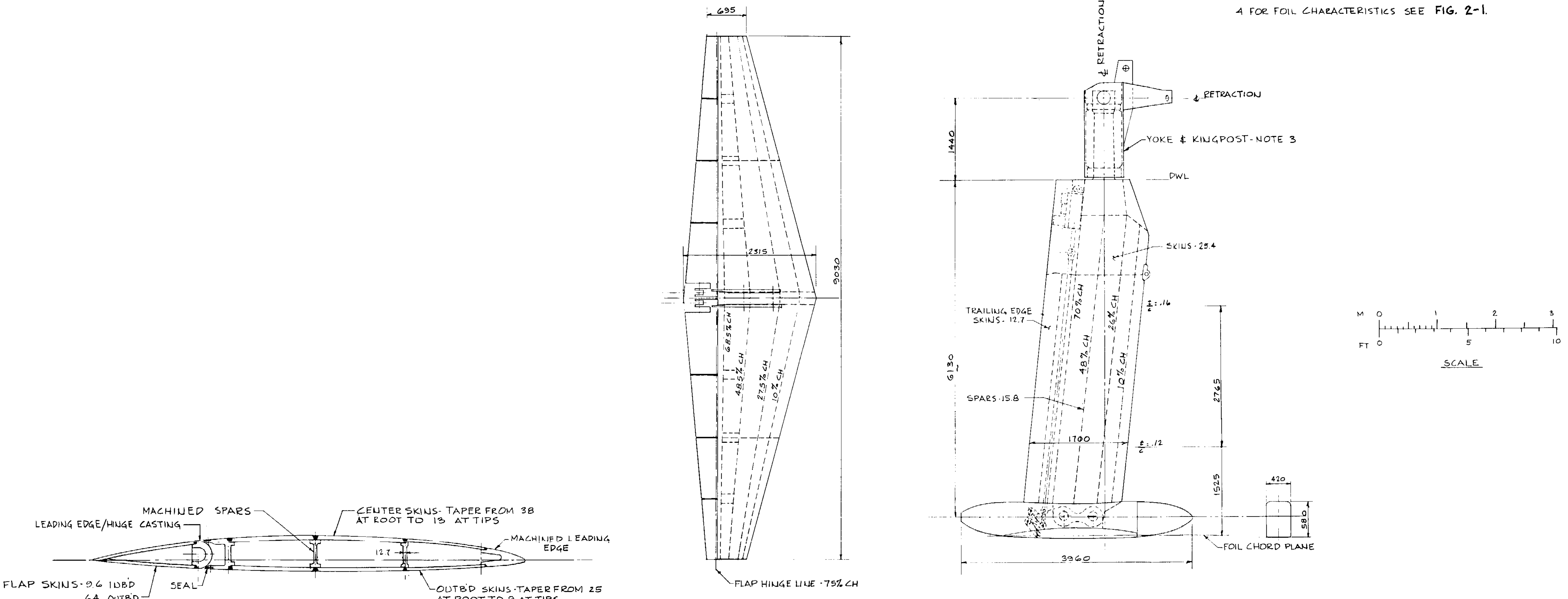


2835-007D

Fig. 3-4 Transmission Arrangement (U)

GENERAL NOTES

1. ALL DIMENSIONS ARE GIVEN IN MILLIMETERS.
2. MATERIAL FOR STRUT & FOIL TO BE HY100 STEEL.
3. STRUT, YOKE, & KINGPOST TO BE DIMENSIONALLY SIMILAR TO PHM-3, BUT WITH SCANTLINGS MODIFIED AS NECESSARY TO SUIT HY-100 MATERIAL
4. FOR FOIL CHARACTERISTICS SEE FIG. 2-1.



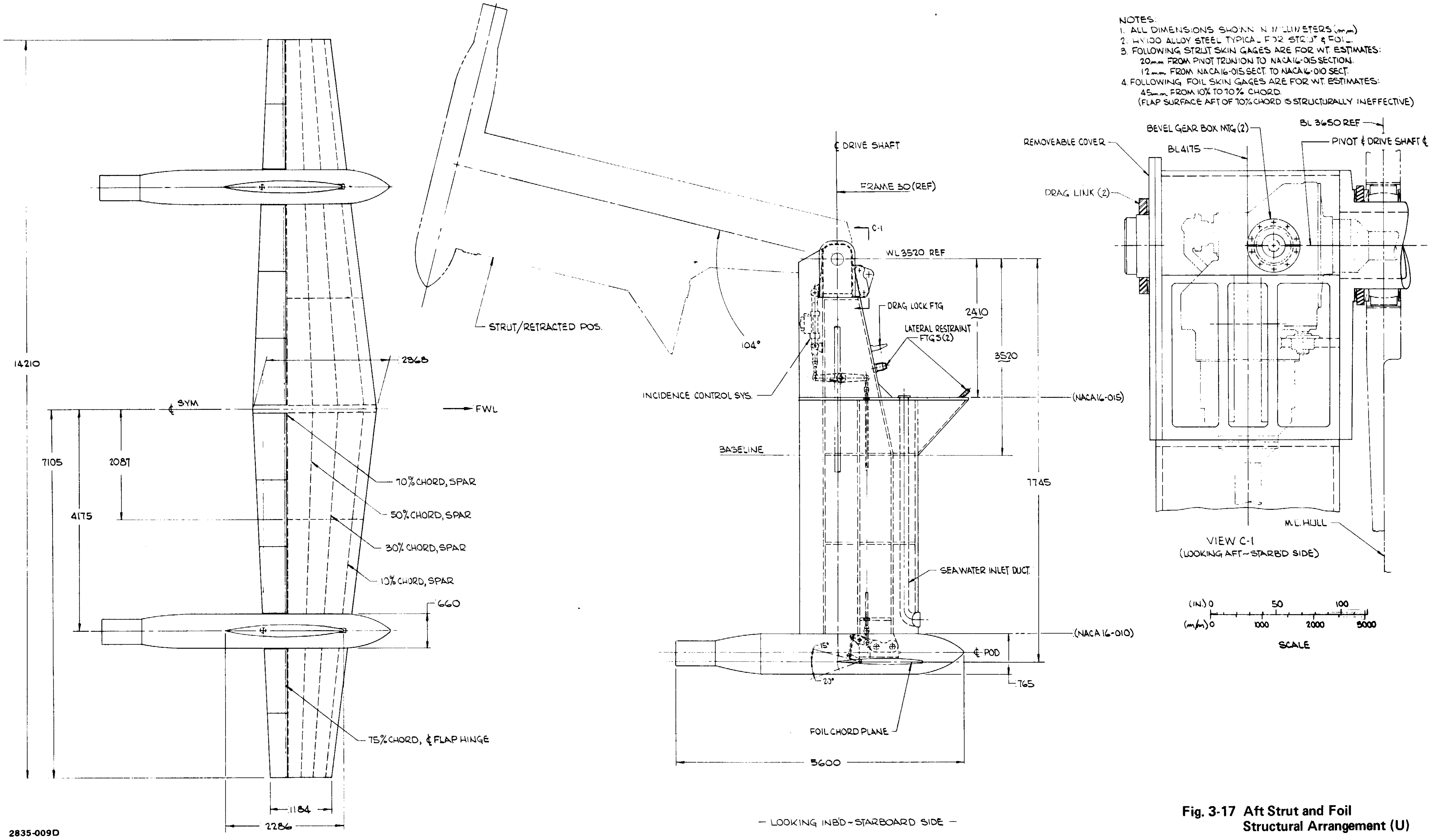
TYP. SECTION THRU FOIL

PLAN
FORWARD FOIL

ELEVATION
FORWARD STRUT

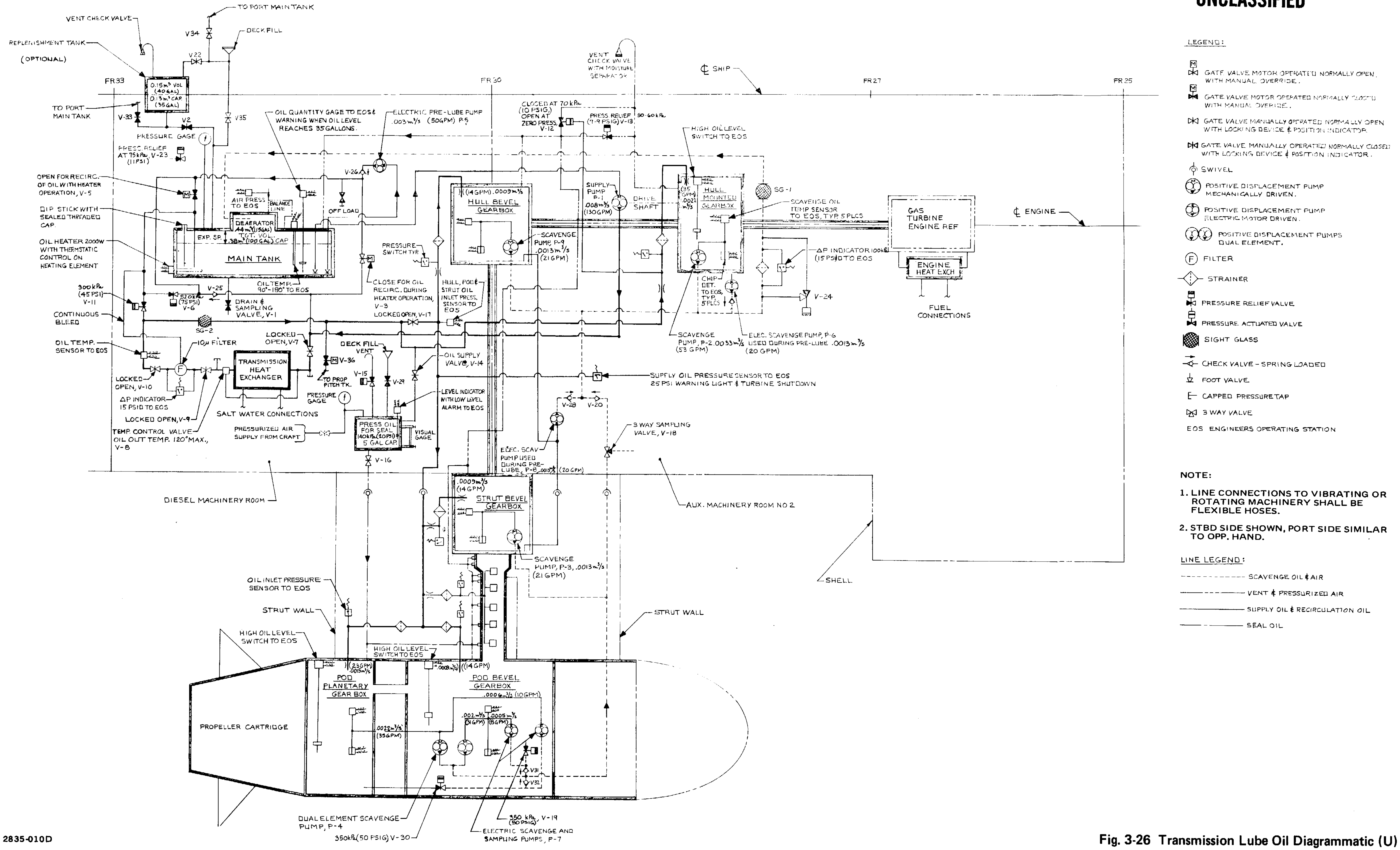
2835-008D

Fig. 3-13 Forward Strut and Foil Structural Arrangement (U)



NOTES:
1. ALL DIMENSIONS SHOWN IN MILLIMETERS (mm)
2. HY100 ALLOY STEEL TYPICAL FOR STRUT & FOIL.
3. FOLLOWING STRUT SKIN GAGES ARE FOR WT. ESTIMATES:
20mm FROM PIVOT TRUNION TO NACA16-015 SECTION.
12mm FROM NACA16-015 SECT. TO NACA16-010 SECT.
4. FOLLOWING FOIL SKIN GAGES ARE FOR WT. ESTIMATES:
45mm FROM 10% TO 70% CHORD.
(FLAP SURFACE AFT OF 70% CHORD IS STRUCTURALLY INEFFECTIVE)

Fig. 3-17 Aft Strut and Foil Structural Arrangement (U)

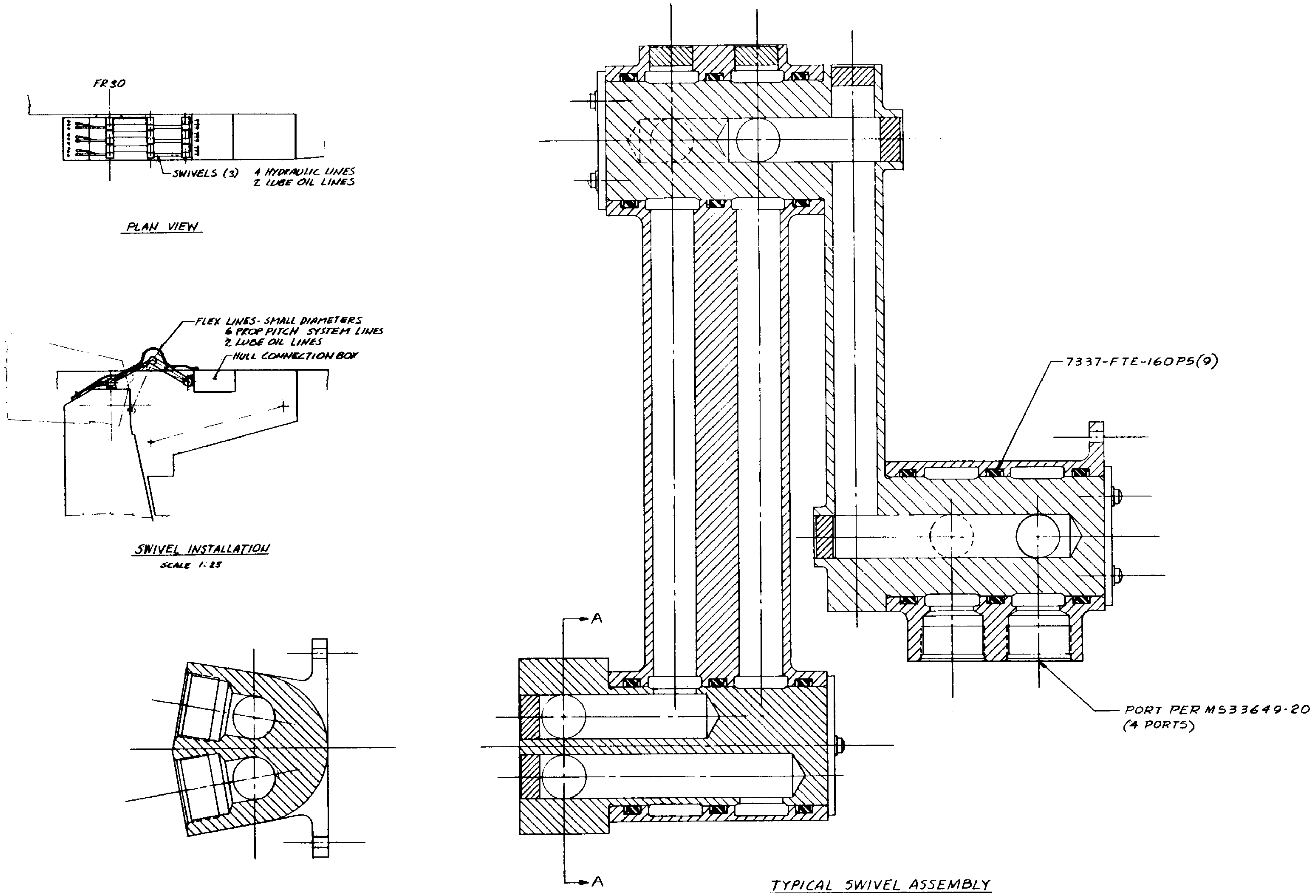


NOTE:

1. LINE CONNECTIONS TO VIBRATING OR ROTATING MACHINERY SHALL BE FLEXIBLE HOSES.
2. STBD SIDE SHOWN, PORT SIDE SIMILAR TO OPP. HAND.

2835-010D

Fig. 3-26 Transmission Lube Oil Diagrammatic (U)



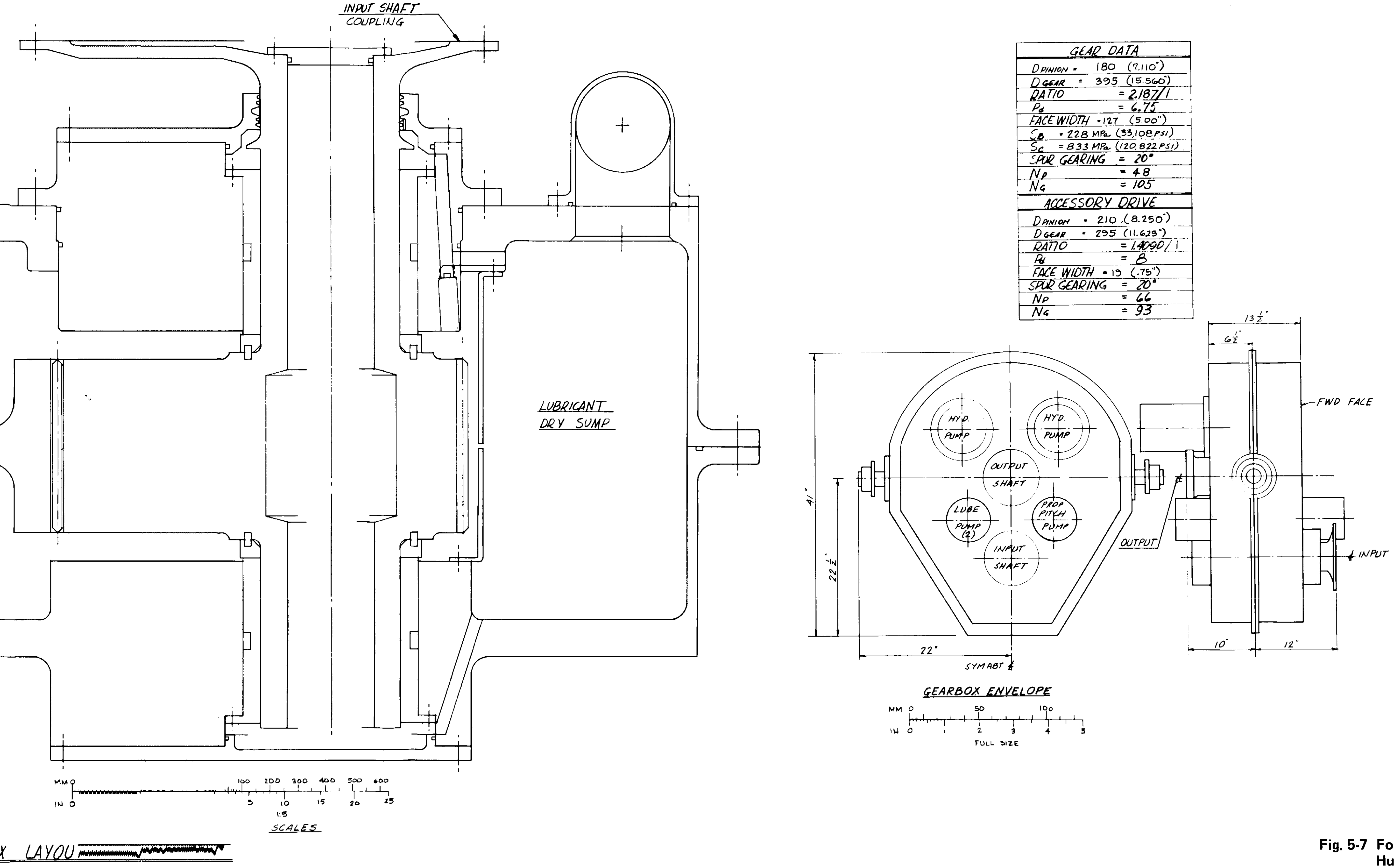
PLAN VIEW

SWIVEL INSTALLATION
SCALE 1:25

TYPICAL SWIVEL ASSEMBLY

SECTION A-A

Fig. 3-29 Hydraulic Swivel -
Aft Strut Installation (U)



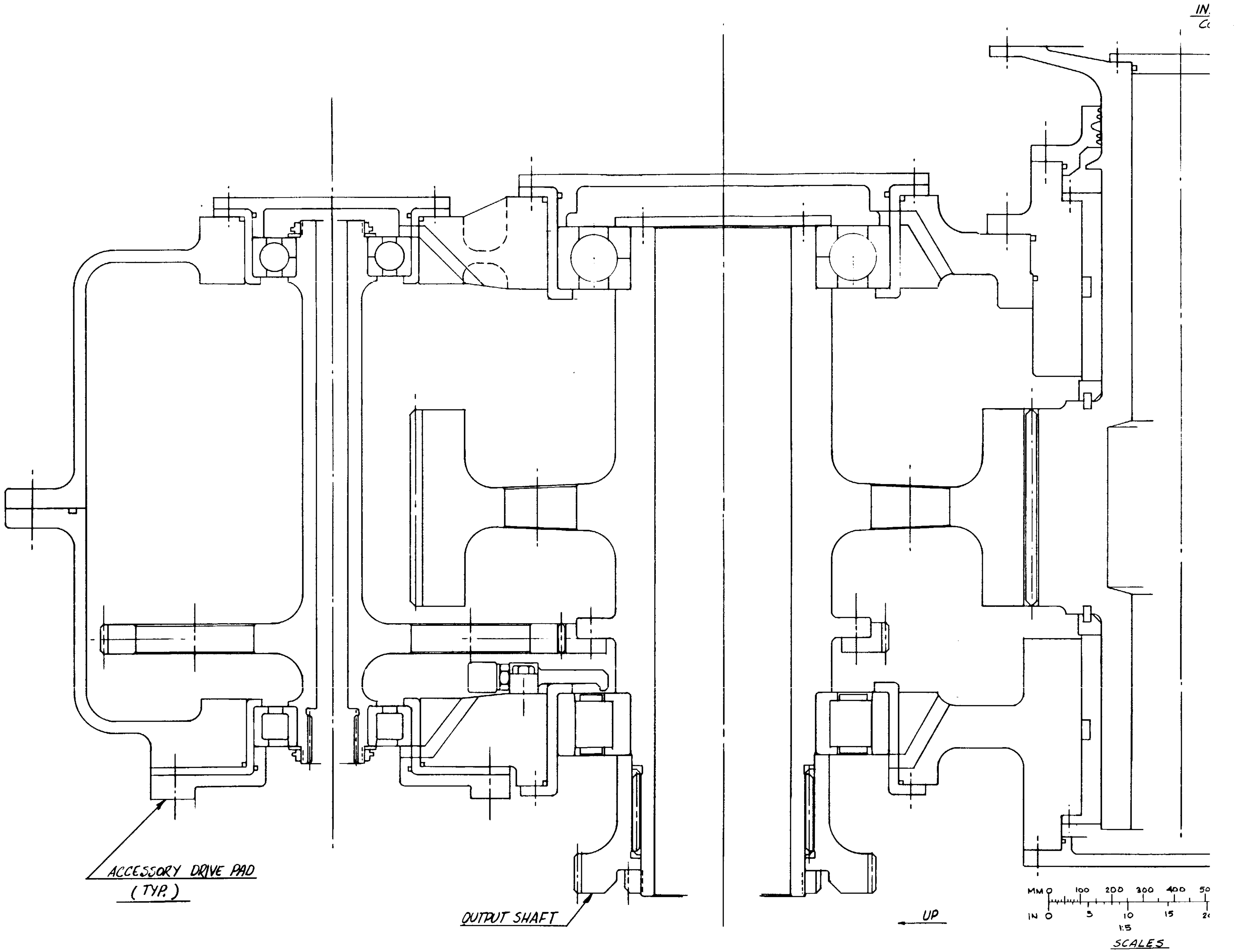
GEAR DATA

D_{PINION} = 180 (7.110")
D_{GEAR} = 395 (15.560")
RATIO = 2.187/1
P_d = 6.75
FACE WIDTH = 127 (5.00")
S_B = 228 MPa (33,108 PSI)
S_c = 833 MPa (120,822 PSI)
SPUR GEARING = 20°
N_P = 48
N_G = 105

ACCESSORY DRIVE

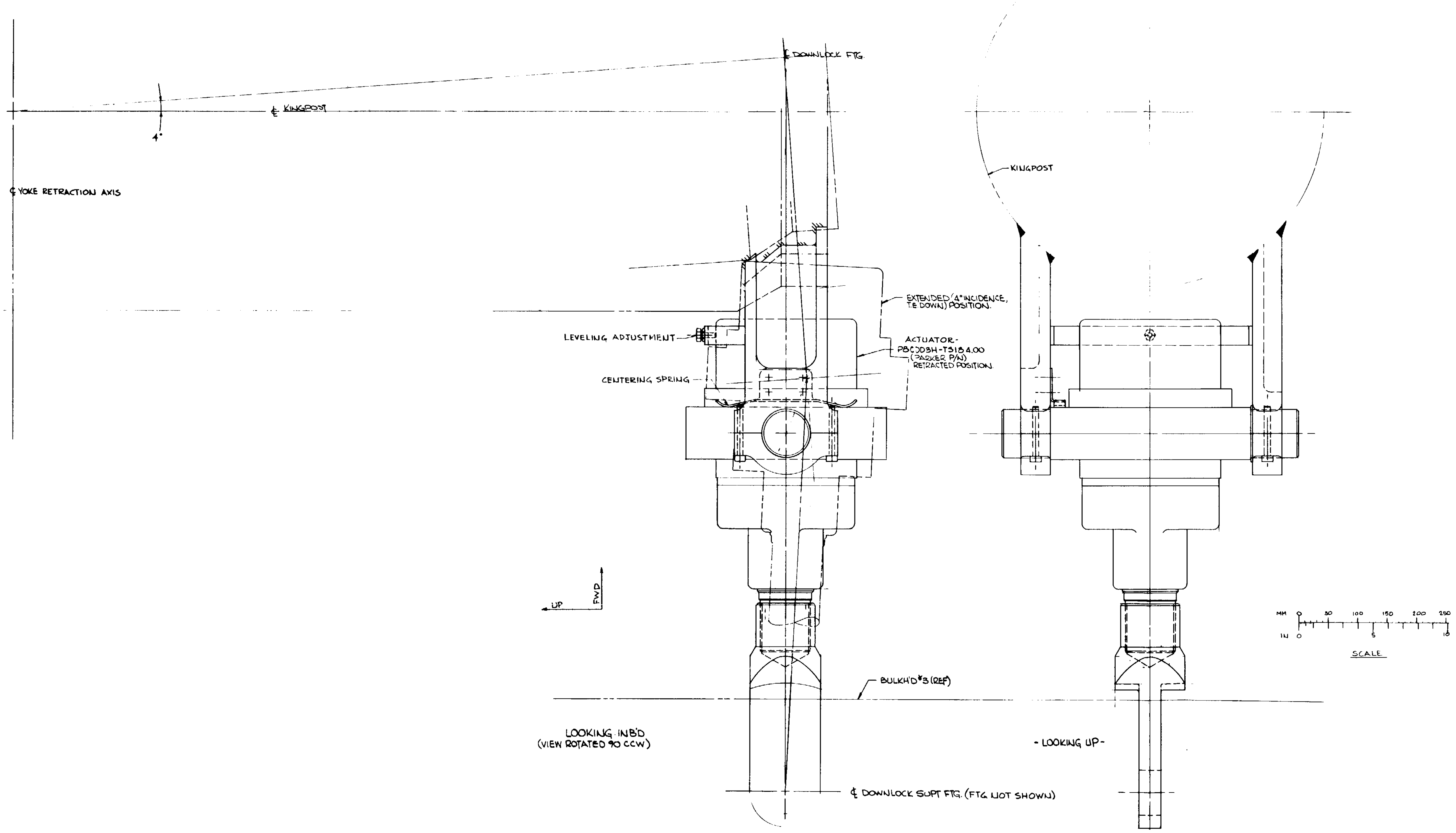
D_{PINION} = 210 (8.250")
D_{GEAR} = 295 (11.625")
RATIO = 1.4090/1
P_d = 8
FACE WIDTH = 19 (.75")
SPUR GEARING = 20°
N_P = 66
N_G = 93

Fig. 5-7 Foilborne Transmission Arrangement - Hull Gearbox (U)



HULL MOUNTED GEAR BOX LAYOUT

2835-013D



2835-015D

Fig. 5-19 Forward Strut - Two Position Actuator Installation (U)

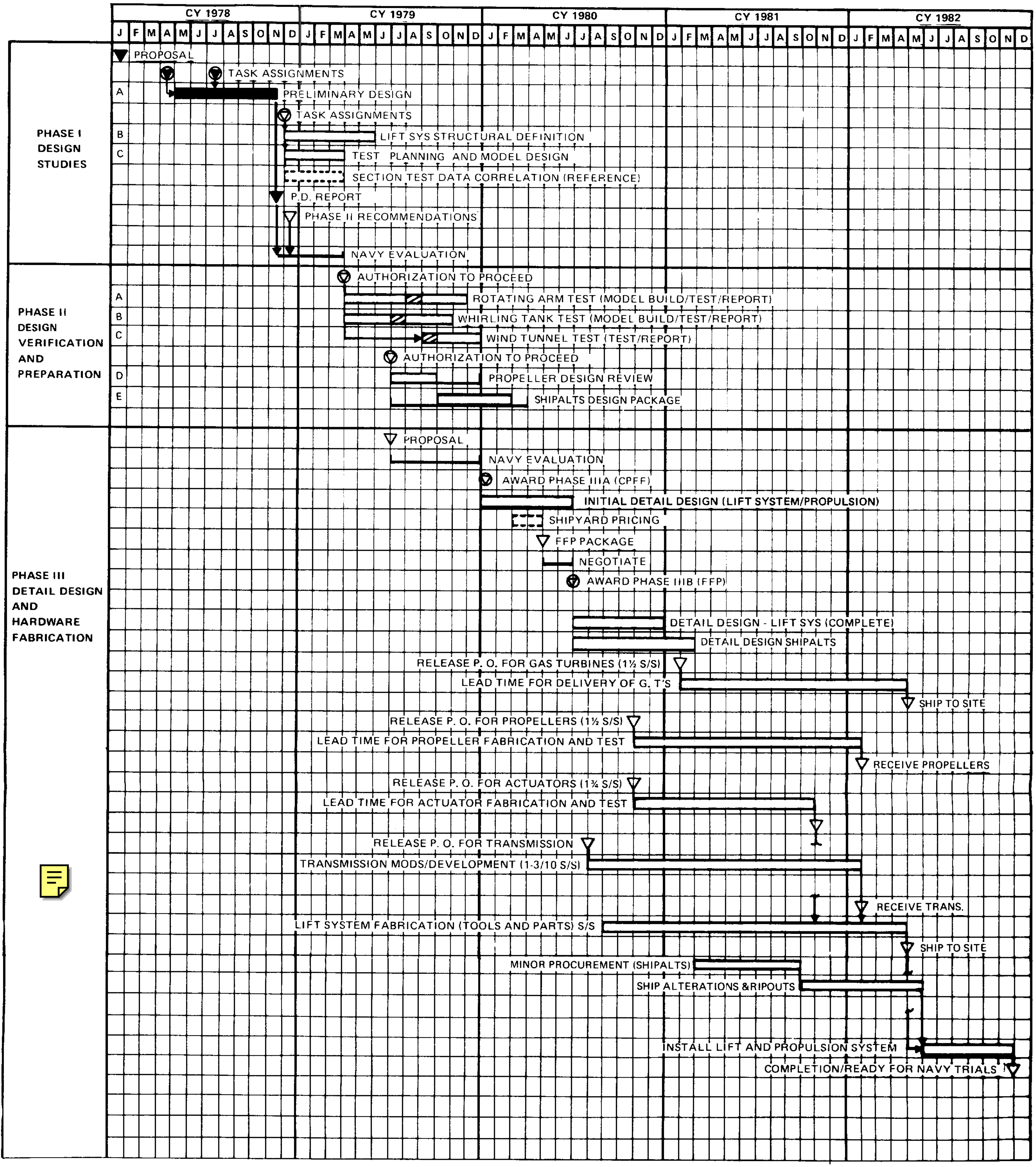


Fig. 7-1 Advanced Technology Lift and Propulsion System - Recommended Development Schedule (U)