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ABSTRACT

A physical description, weights, arrangements and performance characteristics for a large advanced Dash-capable open ocean hydrofoil of 986 metric tons (970 long tons) displacement are presented. The combat suite has been selected as suitable for a wide range of ocean escort missions, projected into the 1995 time frame. The material is organized in accordance with standard format requirements set forth by the ANVCE project office.

KEY WORDS

Advanced Naval Vehicles Concept Evaluation
Boeing Model 1026-010
Dash Operation
HYD 7

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NOMENCLATURE

ANVCE - Advanced Naval Vehicles Concept Evaluation

COGOG - Combined Gas Turbine Or Gas Turbine Propulsion Machinery Arrangement

HOC - Hydrofoil Ocean Combatant - Previous Boeing designated study for 1400 M. ton hydrofoil Model 1026-009

SWBS - Ship's Work Breakdown Structure per NAVSHIPS 0900-039-9010

1.0 INTRODUCTION (U)

(C) The drawings and data presented herein are in response to the task, guidelines and procedures set forth by the various working papers and guidance documentation invoked under Contract N00600-75-C-1107. The task addresses a requirement for data input to the ANVCE program, for a hydrofoil ship with a dash speed of 70 knots. A set of top level requirements formed the basis for the design and required that the Gross Vehicle Weight not exceed 1,000 metric tons, within a framework of specified performance, crew size, combat suite and static ship protection features. This point design has been designated "HYD-7".

(C) One may note, in connection with this study, that for the last 10 years there has been little interest in Naval applications for 70 knot hydrofoils, at least to the extent that R&D activity is an indicator. In the period 1964-1966 the Boeing Company constructed FRESH-l for the Navy, which was a small turbojet powered craft specifically designed as a test bed for high speed foil systems. The craft operated at speeds in excess of 80 knots, employing blunt-based foils and fixed struts in both canard and airplane configuration. Subsequently, all Navy sponsored research and development for "supercavitating" hydrofoils was curtailed except for a limited continuation of foil system investigations at the laboratory level. The FRESH-l experience did stimulate the Boeing Company to pursue a rigorous general analytical attack on the foilborne dynamic control problem which has been of great benefit to the subcavitating ship design programs and produced execellent engineered systems for those ships operating within a subcavitating flow regime.

(U) For these reasons the Boeing Model 1026-010 "Point Design" data presented has been built on a technology base that is less well developed than for subcavitating systems but which nonetheless responds to the ANVCE request for "best available" material as a practical means of extrapolating into the 1995 time frame.

(U) The design procedure has also departed considerably from a normal approach in that the effort to achieve a high degree of uniformity of the combat suite

(U) between point designs foreclosed on the customary dialogue between ship designer and those involved in combat suite selection.

(U) Finally, in an effort to forecast the existence of compatible combat system components twenty years downstream, armament concepts have been employed which are somewhat notional and for which installation data and environmental requirements are yet to be developed.

(C) The resulting ship design, for the above reasons, is not a demonstratably feasible ship definition. It should be considered as a "conditioned estimate" of the physical and performance characteristics of a 70 knot hydrofoil ship constrained to the top level requirements set forth for this study.

2.0 VEHICLE GENERAL DESCRIPTION

2.1 PRINCIPAL CHARACTERISTICS

Drawing 315-11006, sheets 1 and 2 (Figures 2.1-1 and 2.1-2) set forth the general arrangements as developed for this study. Figures 2.1-3 and 2.1-4 indicate the possibilities for converting the aft main deck area to alternate mine-warfare tasks.

The overall arrangement seeks to provide the maximum amount of enclosed deck area by carrying the ship sides up to the 01 level between frames 6-25. It is desirable in a hydrofoil to arrange for protected traffic routes and minimum open deck personnel exposure.

The ship control functions are vested in a navigation bridge at the 01 level for extended hullborne operations, with a conventional open wing arrangement for maneuvering alongside, and foilborne control station at the 02½ level wherein a small conning crew with 360" visibility will operate the ship foilborne. The combat operations center is conveniently adjacent to the bridge. While engine throttle control will be available at the foilborne and bridge stations, all machinery set-up, monitoring and electric plant control will be provided for in the Engineering Operating Station located on the second deck aft. A secondary conning station suitable for hullborne operations is on the 02 level at frame 19.

The ASMD vertical launchers as well as the Harpoon SSW missiles are arranged aft in a compact cluster specifically to minimize fraqmentation exposure and reduce vulnerability. It was not possible to arrange the ship to accommodate the MK-48 torpedoes in a fixed below-decks reloading launcher because of insufficient length aft of the machinery box. A functional helicopter replenishment area is available although the somewhat crowded stern arrangement would make it necessary to erect a portable mast for conventional replenishment at sea.

Six deployed linear array canisters are shown on the port side aft. If considerably more deck area and handling equipment is ultimately required for

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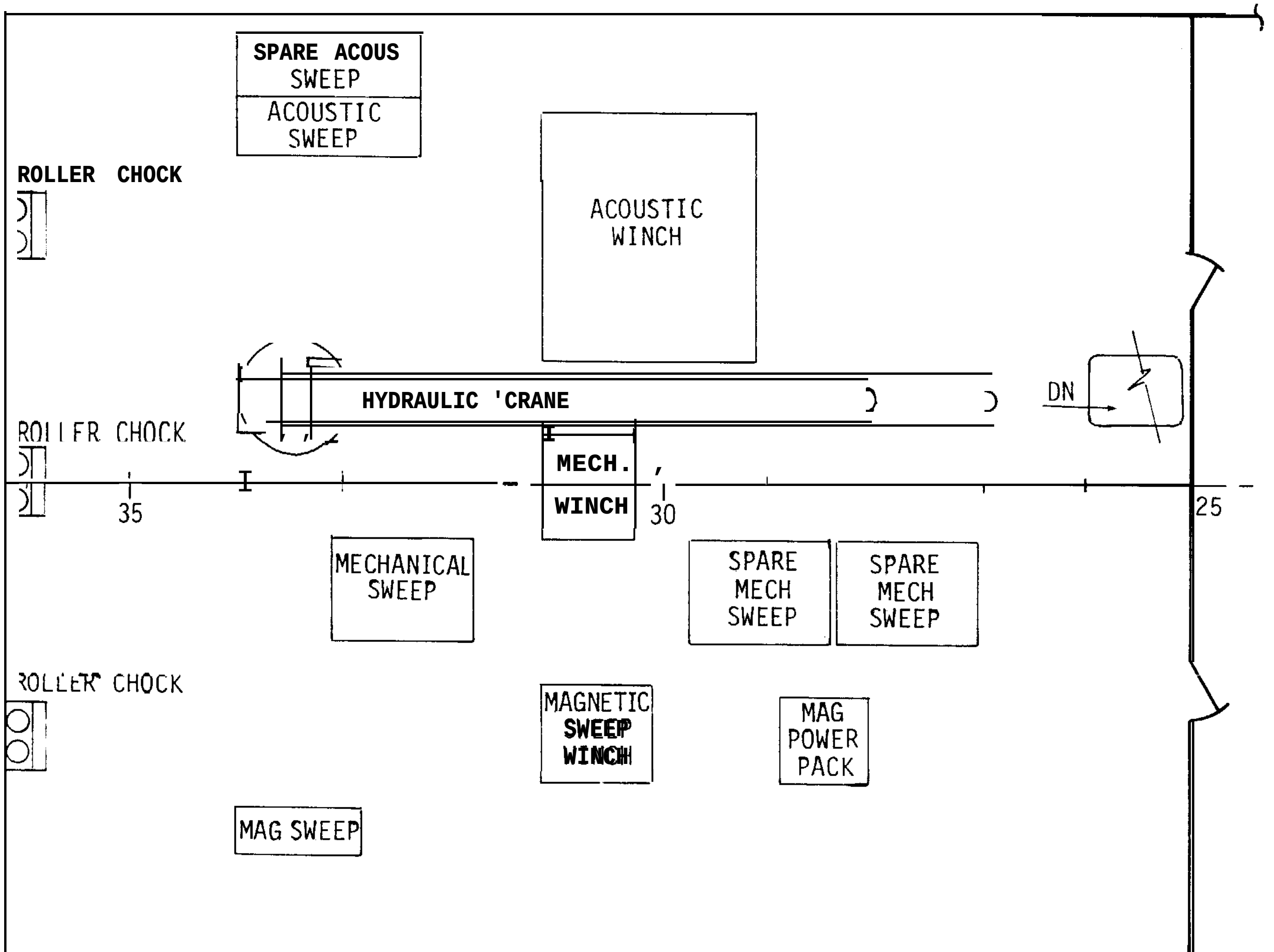
ALTERNATE STERN ARRANGEMENT - MINELAYING OPTION

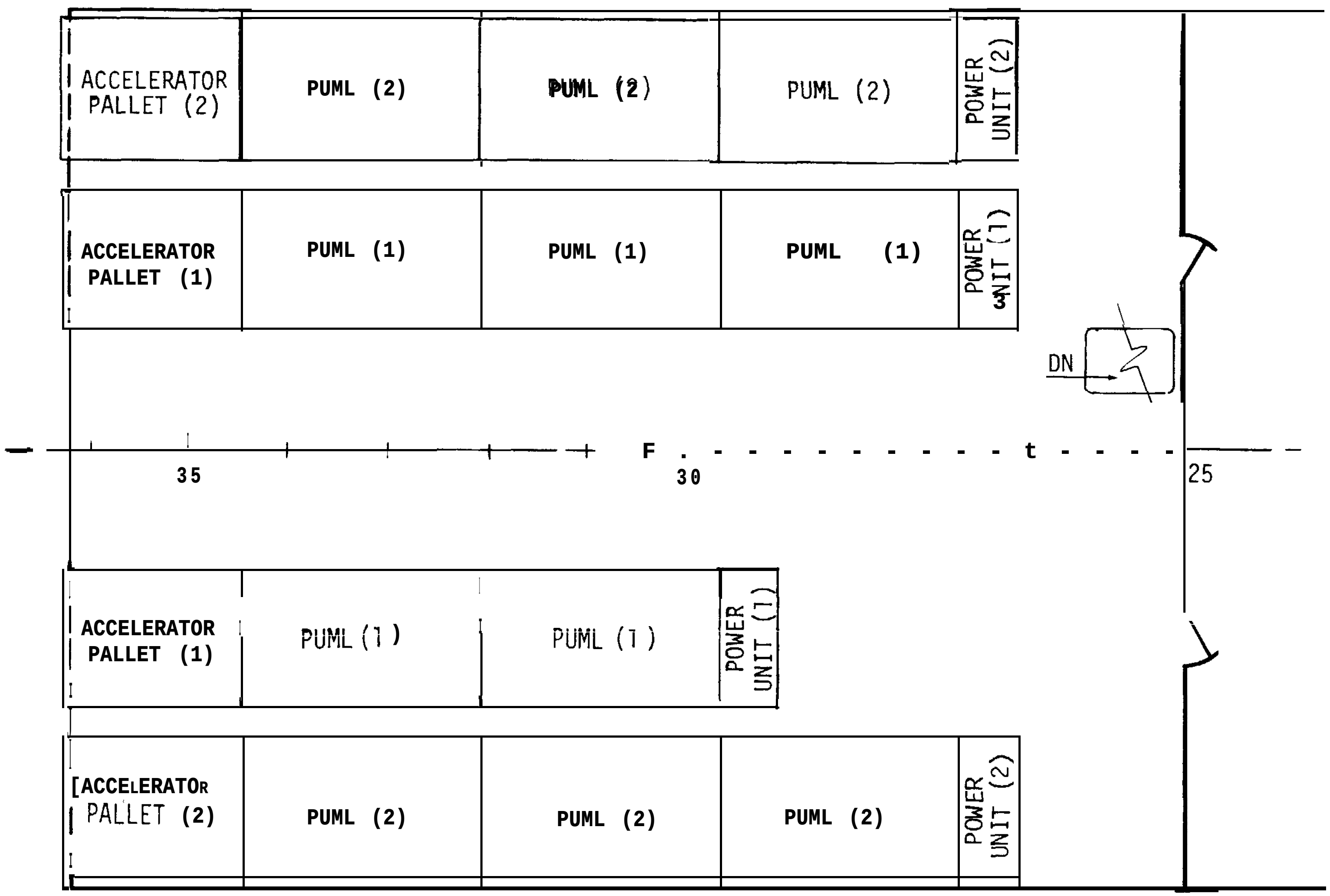


MAIN DECK AFT - MINELAYING ARRANGEMENT

FIGURE 2.1-3

BOEING MODEL 1026-010

ALTERNATE STERN ARRANGEMENT - MINE COUNTERMEASURES OPTION



MAIN DECK AFT - MINE'COUNTERMEASURES ARRANGEMENT

FIGURE 2.1-4

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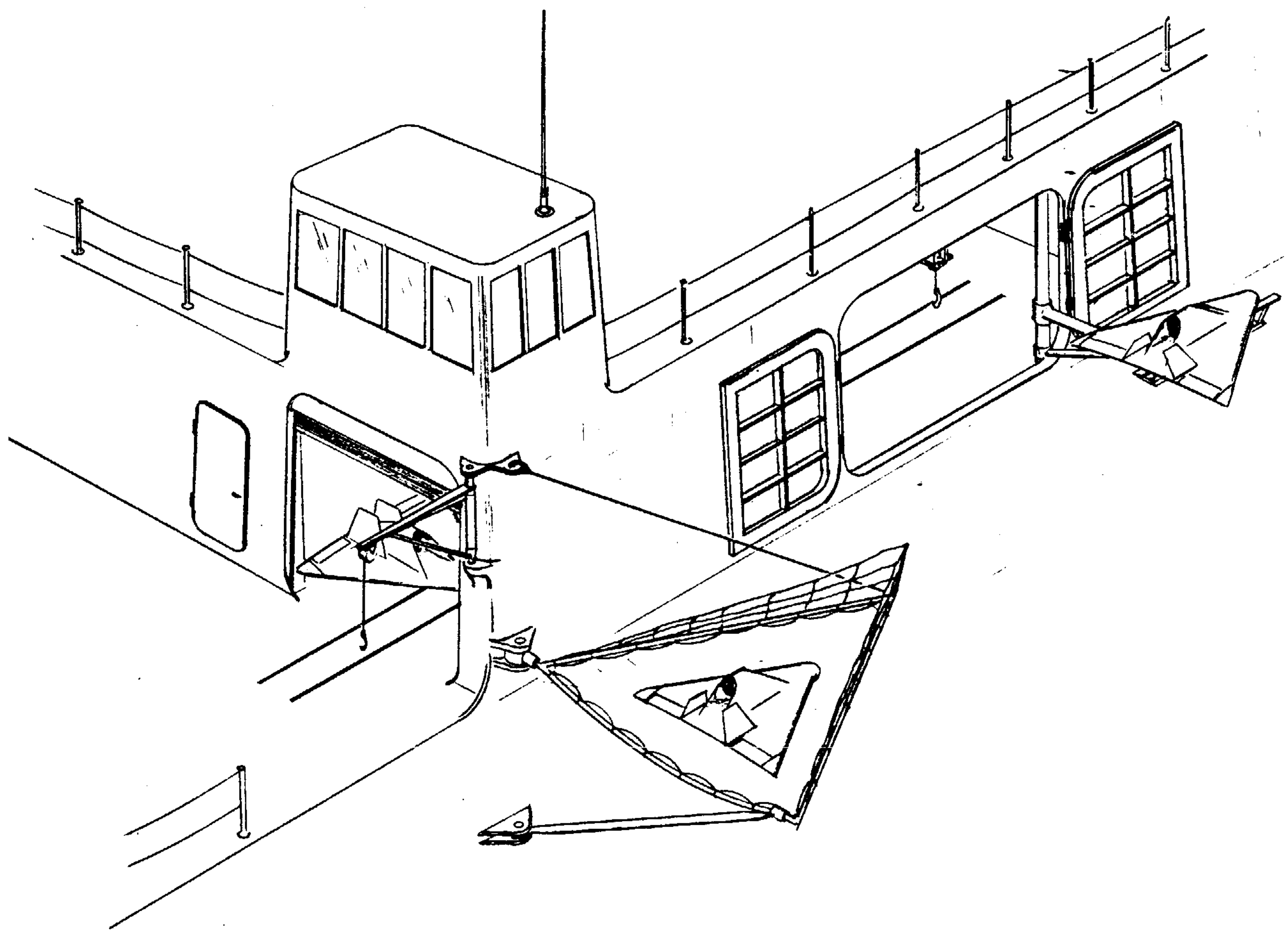
this function, mission priorities would suggest that this particular component be deleted.

The requirement to carry 12 remote piloted vehicles (RPV) stimulated some innovative thought. No firm policy or standards as regards handling, launching and retrieving exists. Available guidance material indicates a concept employing a pneumatic launching rail and a "butterfly" net retrieval. This would ordinarily lead to some kind of 01 level platform at the stern to carry out these functions, and attendant competion with an already cramped array of weapons suite components. Figure 2.1-5 is a new concept which reduces to an absolute minimum the amount of ship real estate required to support the function, mechanizes the handling of the 250 pound vehicles, and allows a retrieval aim point which is parallel to but not directly at the ship, substantially enhancing the inherent safety of this operation. Although not conclusively defined, the operational philosophy involves bringing the ship into the foilborne speed range to achieve low relative approach velocity on retrieval. Returned RPV's are fed into the aft hanger door and tracked through to the launch handling system for refueling and service.

The second deck is designated the damage control deck, serving as the main fore and aft traffic flow. Crew habitability spaces are divided between fore and aft locations. All sanitary functions are on the second deck to eliminate the need for pumped drainage systems. A general purpose repair facility of modest size is located aft on the second deck, as well as a combined electronics repair and parts storage adjacent to the COC on the 02 deck level.

The stern area on the 2nd deck is compartmented to permit working a RAPS type sonar through a stern door. While the VDS is handled entirely from the main deck, the total support commitment for auxiliary machinery, sonar cabinets and support components is not well defined but an effort has been made to allocate a generous amount of below deck area for sonar functions.

FIGURE 2.1-5



RPV LAUNCH AND RECOVERY CONCEPT

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The overall arrangement is compact but reasonably sets forth a minimum size configuration which could, at least from the physical point of view, support the HYD-7 characteristics, given the available level of component and system support knowledge.

TABLE 2.1

PRINCIPAL CHARACTERISTICS (U)

(C) OPERATION: General Purpose Advanced Technology Ocean Escort with Sprint (50 knot)/Drift and High Speed (70 knot) Dash Capability

(U) DIMENSIONS:

	ENGLISH (FT)	METRIC (METERS)
Length Overall	198.0	60.4
Length Between Perpendiculars	180.0	54.9
Hull Beam (Max.)	42.9	13.1
Hull Beam (at WL)	37.5	11.4
Foil Span (maximum)	81.88	24.96
Hull Draft	11.00	3.35
Nav. Draft	31.00	9.45
Hull Depth at ℄	24.80	7.56

(U) POWER PLANTS:

Propulsion Engines:

Foilborne: Two 50,000 BHP Gas Turbines - GE LM-5000 or P&W FT9A-4

Hullborne: Same as foilborne engines

Low Speed (to 16 knots) and Maneuvering: Two 4000 BHP Gas Turbines - Advanced AVCO Super TF-40 or equivalent (typical)

Propulsors:

Foilborne: Dual, 8 ft. diameter controllable, reversible pitch (CRP) KaMeWa Model 398B propellers

Hullborne: Same power train and propellers as foilborne

Lift Engines: None Required

Lift Fans: None Required

TABLE 2.1 (Cont'd)

(U) SYSTEMS:

	Complement	Accommodations
Number:	5 Officers	6 Officers
	4 CPO	4 CPO
	70 Other Enlisted Men	70 Enlisted
Total	79	80

(U) FUEL:

Diesel or JP-5

Design full load - 184 M. Tons (181 L. Tons) Gross, 179 M. Tons (177 L. Tons) Net Usable (Excess Capacity Available)

(U) ELECTRICAL:

Prime power generation - 400 Hz, 440 volts, 0.8 Power Factor, lagging

Prime movers - (2) diesel engines rated at 1000 BHP each

Total connected load estimate - 1380 KW

Total generator capacity - Two 500 KW Primary
- One 150 KW Emergency

(U) HYDRAULICS:

Ship Control Hydraulic System (SCHS):

Variable Volume, Dual Range 27.58/55.16 MN/m^2 (4000/8000 psig) constant pressure, redundant multiple pump supply system with surge accumulators.

Total of 1480 gpm driven from COGOG propulsion train accessory drive PTO and auxiiary SS diesels

Ships Service Hydraulic System (SSHS)

Same type as SCHS except constant pressure of 55.16 MN/m^2 (8000 psig)

Total of 80 GPM driven by SS diesels

(u) 510 - CLIMATE CONTROL:

Hot and chilled water distribution system. Central heating and cooling source in auxiliary machinery spaces.

TABLE 2.1 (Cont'd)

(U) 520 - SEAWATER SYSTEMS:

Non-Propulsion - Conventional except inlet source from aft struts and use of non-metallic (green thread GRP) distribution piping. Includes firemain, flushing and auxiliary machinery cooling.

(u) 530 - FRESH WATER SYSTEMS:

Conventional except for non-metallic distribution piping. Pressure tank in machinery space serves as storage reservoir.

(u) 531 - DISTILLING PLANT:

Dual units rated at 1100 gallons per day each. Heat source from auxiliary boilers, electrical heaters and/or diesel generator jacket heaters.

(U) 533 - POTABLE WATER:

Stowage capacity 3200 gallons. Pneumatic pressure tank in engine room near distiller. Distributed zone hot water heaters (electrical) supply hot water system meeting requirements of MIL-H-965 (Ships).

(U) 541 - FUEL OIL TRANSFER SYSTEM:

Fore and aft flanged main deck fill connection on fill and transfer main. Fill, transfer, and suction manifolds at fore and aft ends of machinery box. Aluminum piping in mains and tanks except in machinery spaces where stainless tubing used. Tanks and transfer system instrumented and mechanized to provide efficient management of fuel from EOS. All ballasting is to separate clean ballast tanks.

(u) 551 - COMPRESSED AIR SYSTEM:

One (1) 125 psig service air compressor and accumulator for ships service.

One (1) 3000 psig low capacity compressor for torpedo impulse air.

TABLE 2.1 (Cont'd)

(u) 555 - FIRE PROTECTION SYSTEM:

Fixed Halon System for machinery spaces and inside of turbine enclosures. Foam and portable CO_2 canisters as part of damage control outfit. Standard sea water fire main outlets, hose connections, fog and foam equipment. Dual path firemain-sprinkler system.

(U) 561 - AUTOMATIC CONTROL SYSTEMS:

Computer control of high speed hullborne (optional), takeoff, landing and all foilborne operation will be performed by the ACS through automatic control of the hydraulic actuation of dynamic control surfaces which will provide attitude control, stability, and ride smoothing in rough water.

(U) 562 - STEERING:

Foilborne: Coordinated banked turns utilizing automatic control system. Heading hold via steerable forward strut.

High Speed Hullborne: Forward strut steering appurtenances

Low Speed Hullborne: Forward strut steering appurtenances

(U) 567 - LIFT SYSTEMS:

Submerged foil - Canard; T-foil forward, bent foil aft. All foils and struts have supercavitating mode spoilers on both sides of section. Forward foil is incidence variable. Aft foil has control tipperons and trailing edge flaps. Foil area ratio - 80% aft, 20 % forward. Nominal loading 1448 psf. Strut/foil assemblies are non-retracting. Forward T-foil is steerable.

(U) 568 - MANEUVERING SYSTEMS:

4000 (each) BHP maneuvering turbines drive through main downshaft and CRP propeller system.

(U) 570 - UNDERWAY REPLENISHMENT SYSTEMS:

Fixed padeyes forward and portable masts aft to receive standard lightweight

TABLE 2.1 (Cont'd)

(U) whip for hose rigs and fleet freight transfer. Illuminated drop area aft for VERTREP.

(U) 581 - ANCHOR HANDLING AND STOWAGE SYSTEMS:
Lightweight (Danforth type) anchor-nylon line system.

(U) 583 - BOAT HANDLING AND STOWAGE:
Aluminum davit system for 18 foot personnel boat. Inflatable rafts to suit complement.

(U) 593 - ENVIRONMENTAL POLLUTION CONTROL SYSTEMS:
GATX type (or similar) waste system evaporator. Clean ballast tanks provided.

(U) WEIGHTS:

	Long Tons	Short Tons	Metric Tons
Full Load Displacement	970.0	1086.4	985.6
Foilborne Cruise Dynamic Lift	803.0	899.4	815.9
Lightship (with Margins)	711.0	796.0	722.4
Fuel (Dry Pipe)	181.0	202. 7	183.9
Other Loads	78.0	87.4	79.3

(C) PERFORMANCE SUMMARY:

	English	Metric
Max. Speed (1.4 Meter significant sea)	70 knots	130 KM/Hr
Drag Hump Thrust Margin:		
(a) 'Takeoff Hump (Calm Water, 50,000 BHP Total)	46%	46%
(b) Transition Hump (Calm Water, 115,000 BHP Total)	14%	14%
Best Range Speed (Calm Water)	43 Knots	79.6 KM/hr.

TABLE 2.1 (Cont'd)

(C)	ENGLISH	METRIC
Takeoff Distance (Calm Water)	700 Feet (from 10 Kts)	213.4 Meters
Takeoff Distance (Rough Water)	To Be Determined	
Range (Calm Water)	(N.MI.)	(Km)
Foilborne at 45 knots	1400	2560
Hullborne at 16 knots on Main Turbines	1512	2765
16 knots on Maneuvering Turbines	2025	3700
Endurance (Calm Water)		
Foilborne at 45 knots	31.0 Hours	
Hullborne at 16 knots	94.5 Hours	
16 knots with Maneuvering Turbine	126.0 Hours	

(C) COMBAT SYSTEM:

AAW

- TAS Radar (1)
- Advanced Lightweight TWS FCS (1)
- ASMD EW (1)

SSW

- APS-116 (4)
- Harpoon (8)

ASW

- Active Passive Towed Array (1)
- APRAP (1)
- Deployed Linear Array (2)
- ERAP (20)
- ERAPS Launcher (6 Cells)
- MK 48 Improved Torpedo (6)
- Ejection Launch Container for MK 48 (6)
- Standoff Weapon/ALWT with launcher (12)

Sub Vehicles

- Standard Ship Launched RPV (12)

2.2 VEHICLE PERFORMANCE (U)

(U) Various curves and tables which describe Model 1026-010 performance are presented in this section in the order and format recommended in ANVCE WP-005.

2.2.1 THRUST AND DRAG (U)

(C) Figure 2.2.1-1 is a plot of both thrust to weight ratio and drag to weight ratio as a function of speed. This figure was derived from Figure 2.2.1-2 by nondimensionalizing the thrust and drag estimates by the full load weight. Since the speed regime of zero to seventy knots is so large several modes of ship operation must be considered. The modes may be characterized as hullborne, from zero to about 28 knots; foilborne subcavitating, from 28 knots to about 54 knots; and foilborne supercavitating, at speeds to 72 knots.

(U) The hullborne drag has been calculated based on PHM model test data Froude scaled to the size of Model -010. Foil system lift and drag forces are included as they become significant as the ship approaches takeoff speed, approximately 25 to 28 knots.

(U) The subcavitating foilborne drag has been calculated using a computer program. Given the geometry of the strut/foil system and the speed, depth, and trim angle of the ship, the program calculates the forces acting on the foils and struts and adjusts the control surfaces to null the sum of the moments about the center of gravity. The foil/strut system forces are calculated using well established theoretical or empirical expressions for each component of the system.

(U) The peak drag of the takeoff hump was also found using this computer program. In the takeoff mode the program functions essentially the same as when it is in the foilborne mode with the exception that forces and moments due to the hull are also considered. The hull forces and moments are derived from model test data.

FIGURE 2.2.1-1

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BOEING MODEL 1026-010

THRUST/WEIGHT AND DRAG/WEIGHT VS SPEED

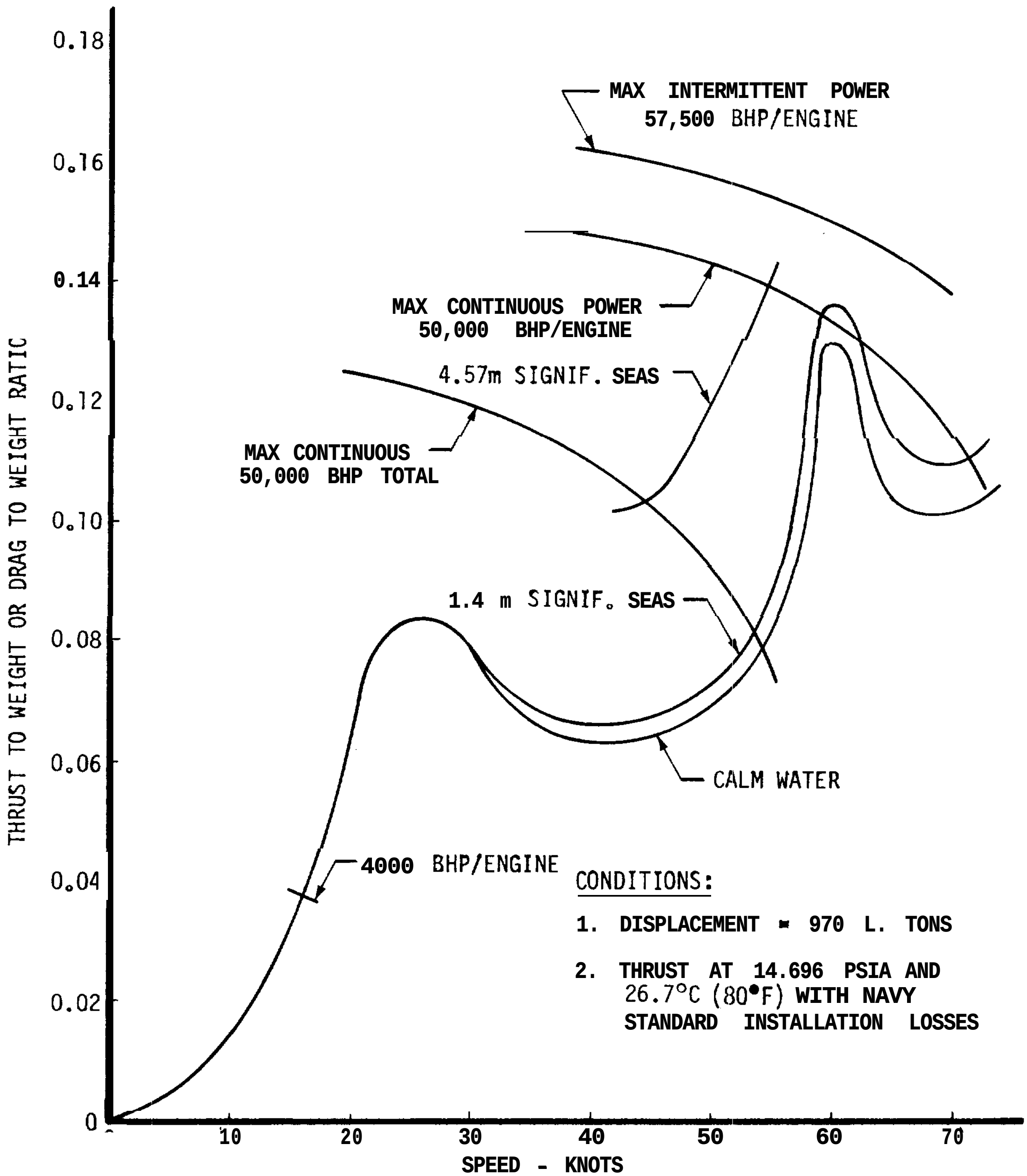
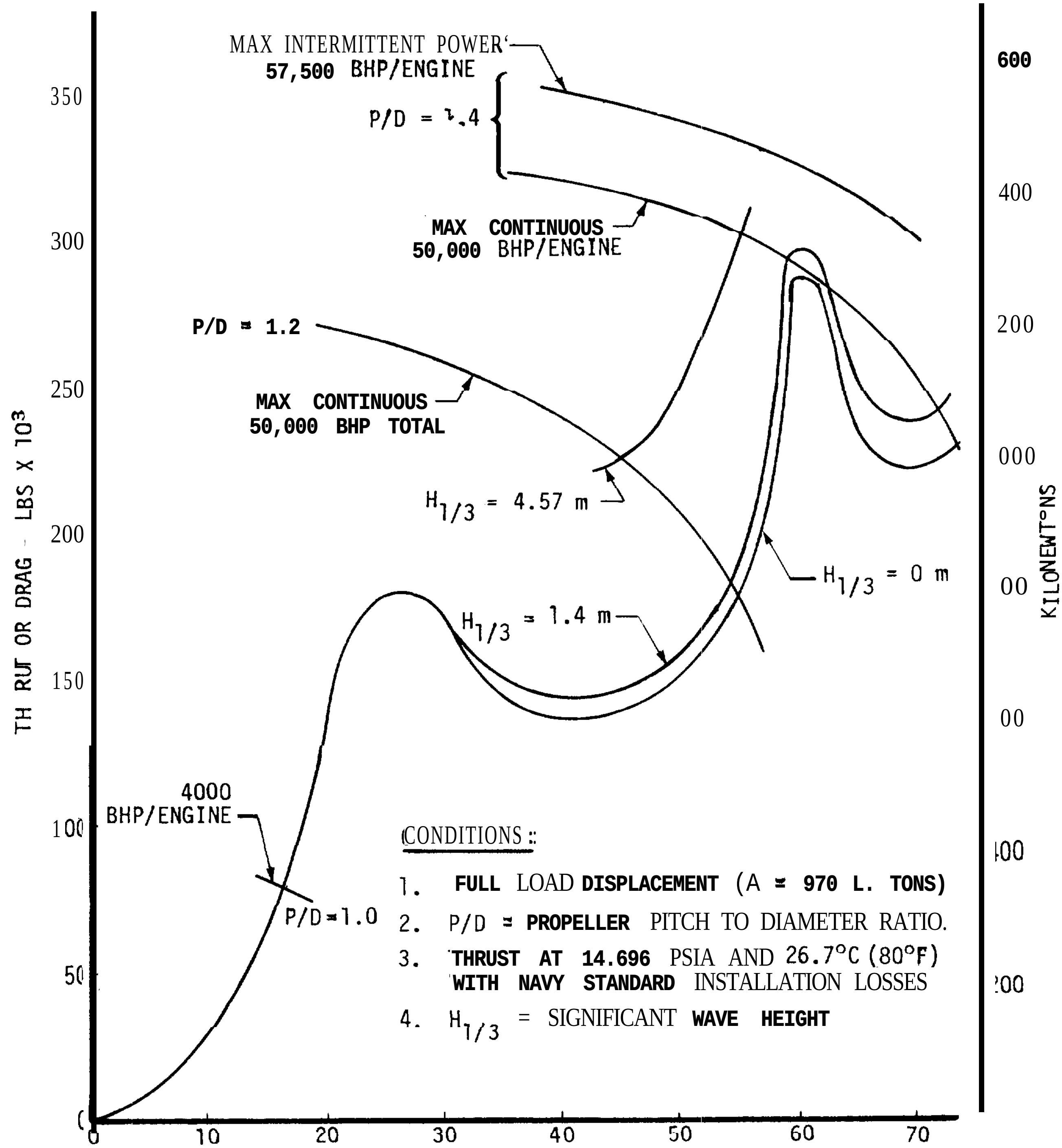


FIGURE 2.2.1-2

BOEING MODEL 1026-010

THRUST AND DRAG VS SPEED



(C) The calculation of drag for a foil intended to operate efficiently in the speed regime from 30 to 70 knots is a difficult task since the foil must be capable of operating under both subcavitating and supercavitating flow conditions. A theoretical approach to performance prediction compatible with the scope of the ANVCE study for these so-called mixed foils is lacking and model tests to date have not been conclusive. In order to overcome this problem, the Hydrofoil Project Office, Code 115, of DTNSRDC provided an interpretation of recent model test data, Reference 2.2. 1-1.

(U) The foil section concept recommended by DTNSRDC consists essentially of a thin subcavitating section - for this study the NACA 16-207 section was used - which for higher speed operation deploys two control devices (see Fiqure 2.3.5.2-2). A small spoiler-like device will be deployed from the upper surface near the leading edge to stabilize a cavity over the upper foil surface. Another control surface will be deployed from the lower surface about 60 percent aft of the leading edge to reduce the wetted area and increase the foil loading.

(C) The data supplied by DTNSRDC consisted of plots of lift to drag ratio as a function of speed for the unappended strut/foil system. Figure 2.2.1-3 is typical of this data. The relatively low lift to drag ratio around 60 knots is presumably due to operation of the foils in a partly cavitating regime - far from the subcavitating or supercavitating design points. The low L/D in this region is responsible for the high secondary hump shown on Figures 2.2.1-1 and 2.2.1-2. The use of maximum intermittent power will be required to get over this hump with an acceptable margin.

(U) The total ship drag was determined by adding the drag of the several pods plus aerodynamic drag to the strut/foil system drag. Pod drag was based on previous work by Hydronautics, Reference 2.2.1-2 and the aerodynamic drag was based on PHM trials data scaled up to Model -010's size.

(U) Figure 2.2.1-l and 2.2.1-2 also contain estimates of the added drag in seas of 1.4 and 4.57 meters significant wave height. These estimates were based on analysis of existing hydrofoil trials data as described in the discussion of Figures 2.2.1-9 and 2.2.1-10.

FIGURE 2.2.1-3

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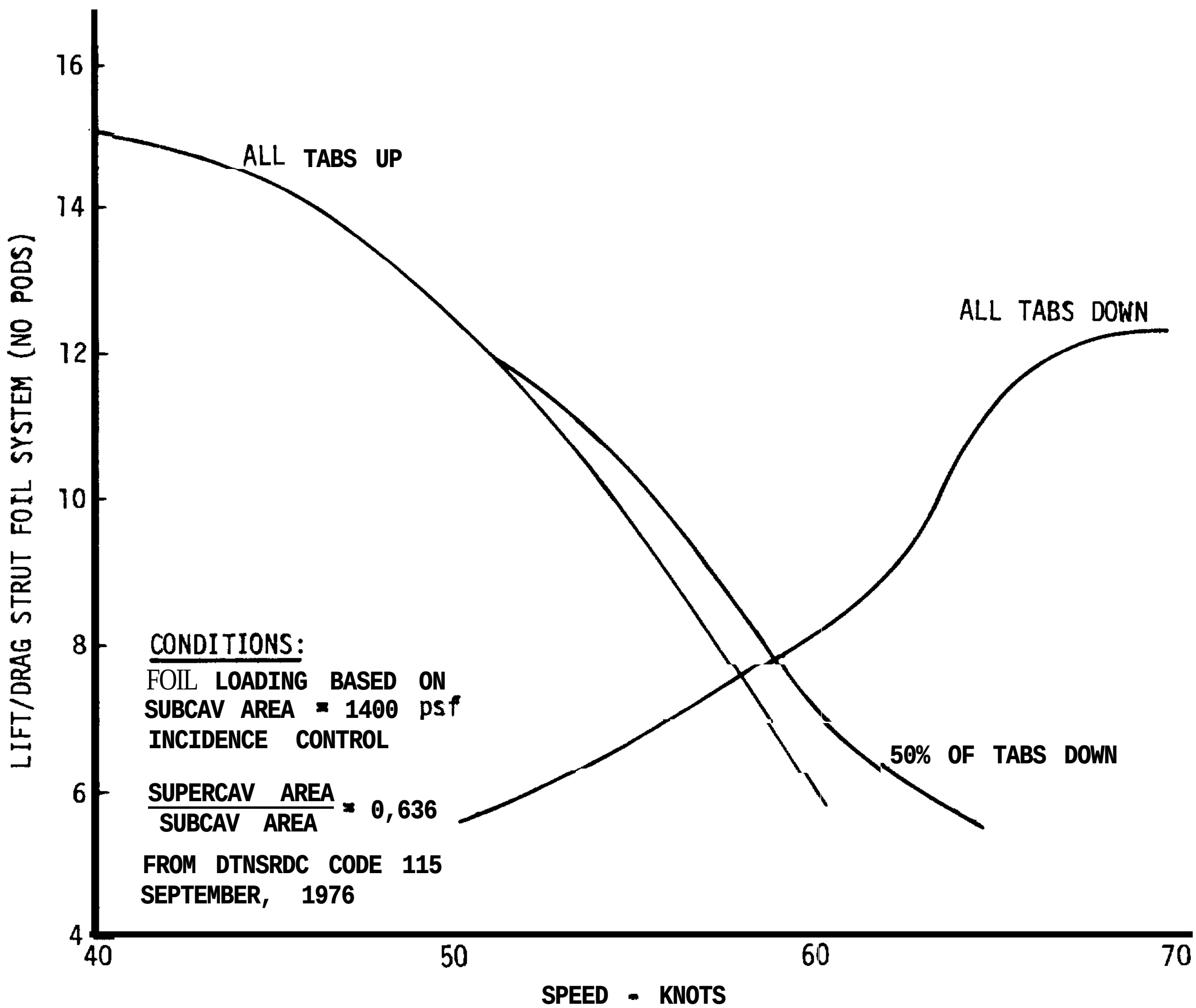
MIXED FOIL PERFORMANCE



(U) A breakdown by components of the calm water hullborne drag is shown in Figure 2.2.1-4. Figure 2.2.1-5 is a similar breakdown for foilborne drag.

(U) Four thrust lines are shown in Figures 2.2.1-1 and 2.2.1-2. The thrust lines correspond to (1) full power operation of the maneuvering engines, 4000 BHP per engine; (2) maximum continuous power of one foilborne engine, 50,000 BHP; (3) maximum continuous operation of both foilborne engines, 100,000 BHP; and (4) maximum intermittent operation of both foilborne engines, 115,000 BHP. Engine power levels are at 80°F with standard losses. Power levels at lower temperatures were not calculated since adequate power is available at 80°F.

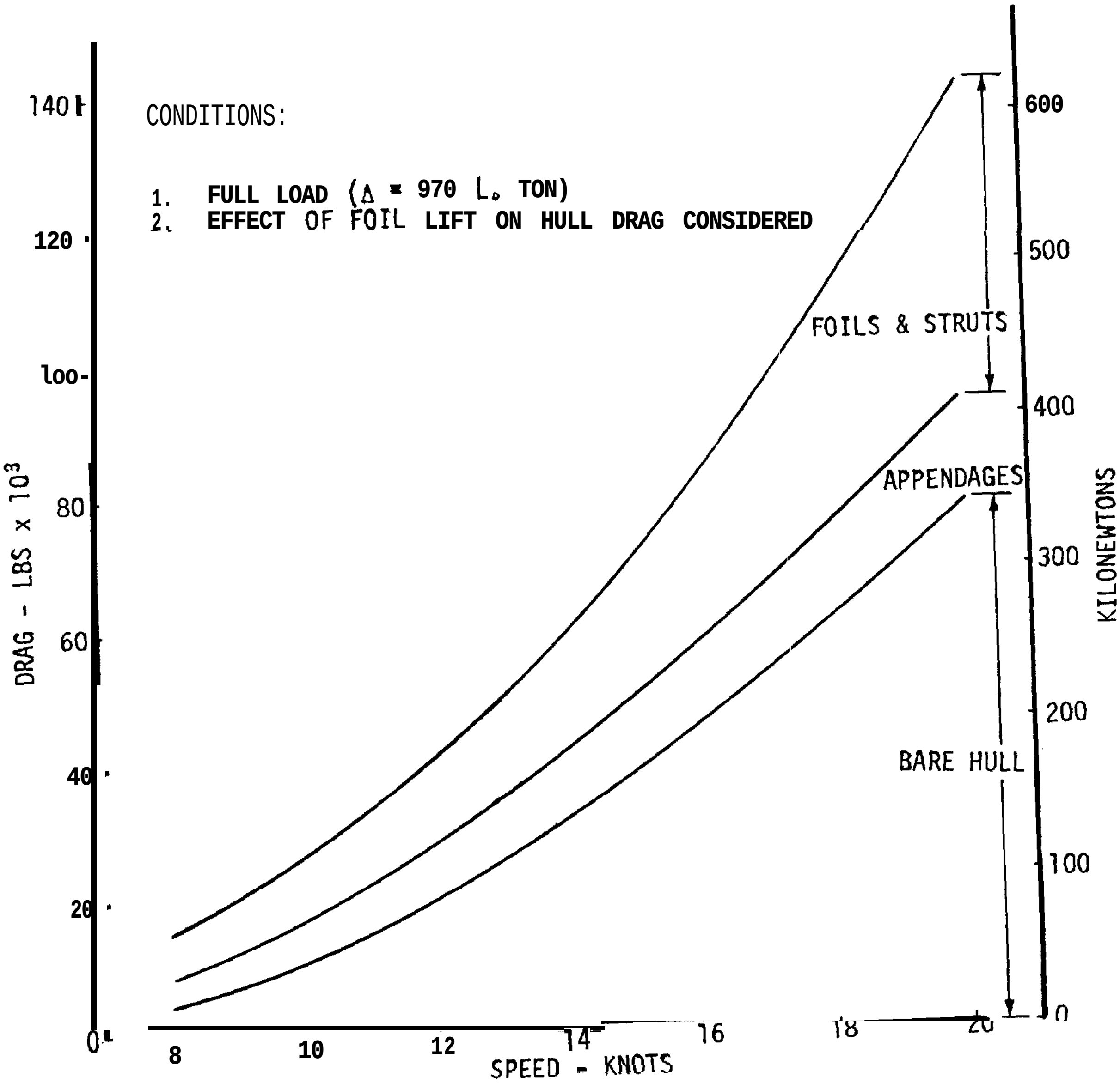
(U) Thrust available curves were obtained from propeller model test data supplied by KaMeWa for their Model 398B propeller. Due to the wide speed regime in which the propeller must operate efficiently a controllable-reversible pitch (CRP) propeller was chosen. The controllable pitch capability and the "transcavitating" type of propeller design allow the propeller to obtain good efficiency over a wide operating range. A brief study indicated that an 8.0 foot diameter propeller will provide near optimum performance from this type of propeller while keeping propeller blade loadings reasonably low and propeller RPM reasonably high. As an independent check on the propeller estimates Figure 2.2.1-6 was prepared. The upper graph was taken from Reference 2.2.1-3 and indicates that the selected propeller compares favorably with optimum four bladed supercavitating propellers in terms of size, efficiency and RPM at the required power level. The lower graph on Figure 2.2.1-6 indicates that even though the selected propeller will absorb significantly more power than previous hydrofoil propellers, the nominal disc loading will be well within present experience. Figure 2.2.1-7 is a plot of propulsive efficiency (EHP/BHP) as a function of speed. Note that the transmission efficiency of 0.95 is included in the definition and therefore propeller efficiencies are about five percent higher than shown.

(U) The rather unconventional use of the propellers in the tractor position was motivated by the desire to operate the propellers in the most favorable flow

FIGURE 2.2.1-4

BOEING MODEL 1026-010

HULLBORNE DRAG COMPONENTS



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DRAG COMPONENT BREAKDOWN
FOILBORNE

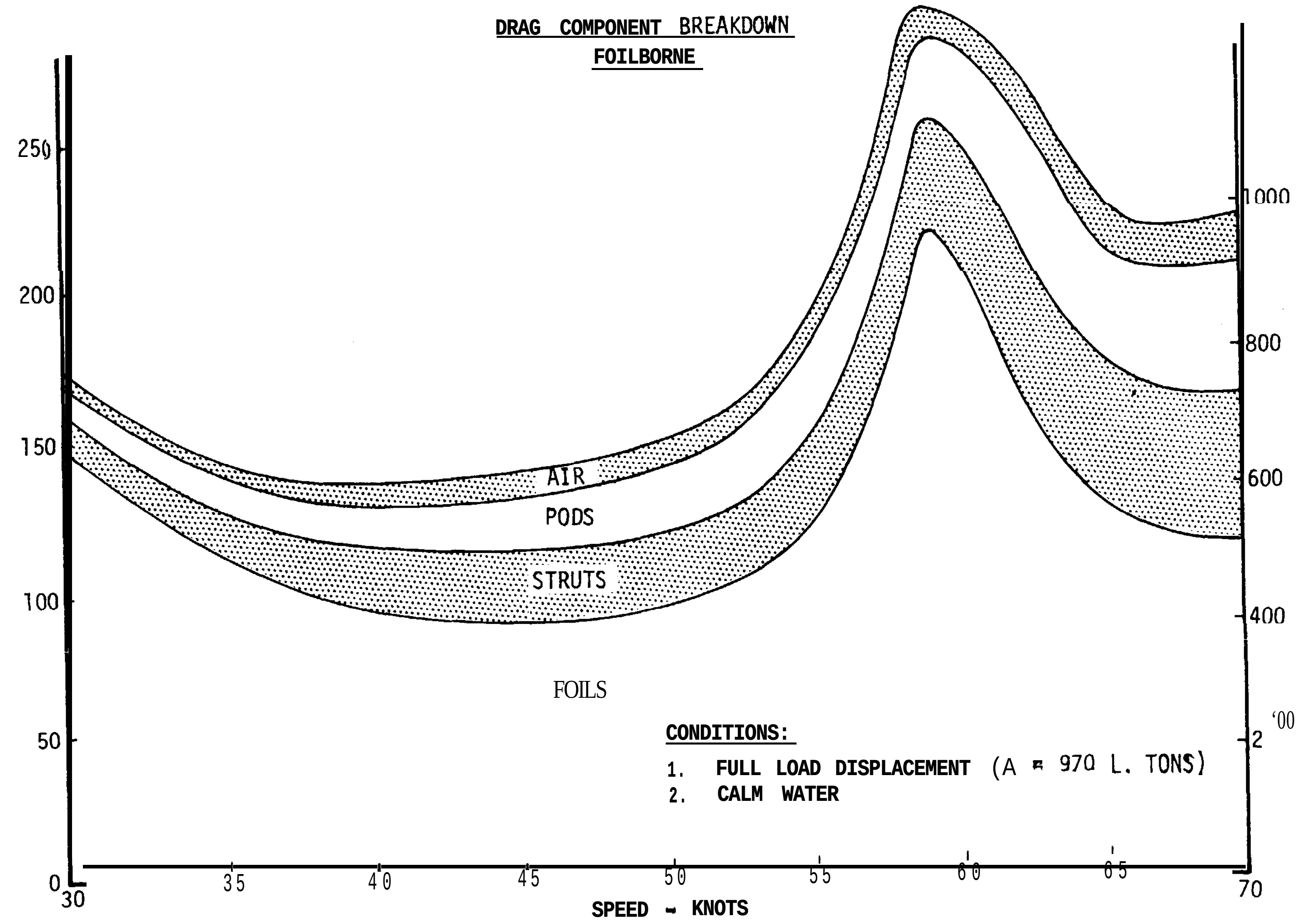

FIGURE 2.2.1-5

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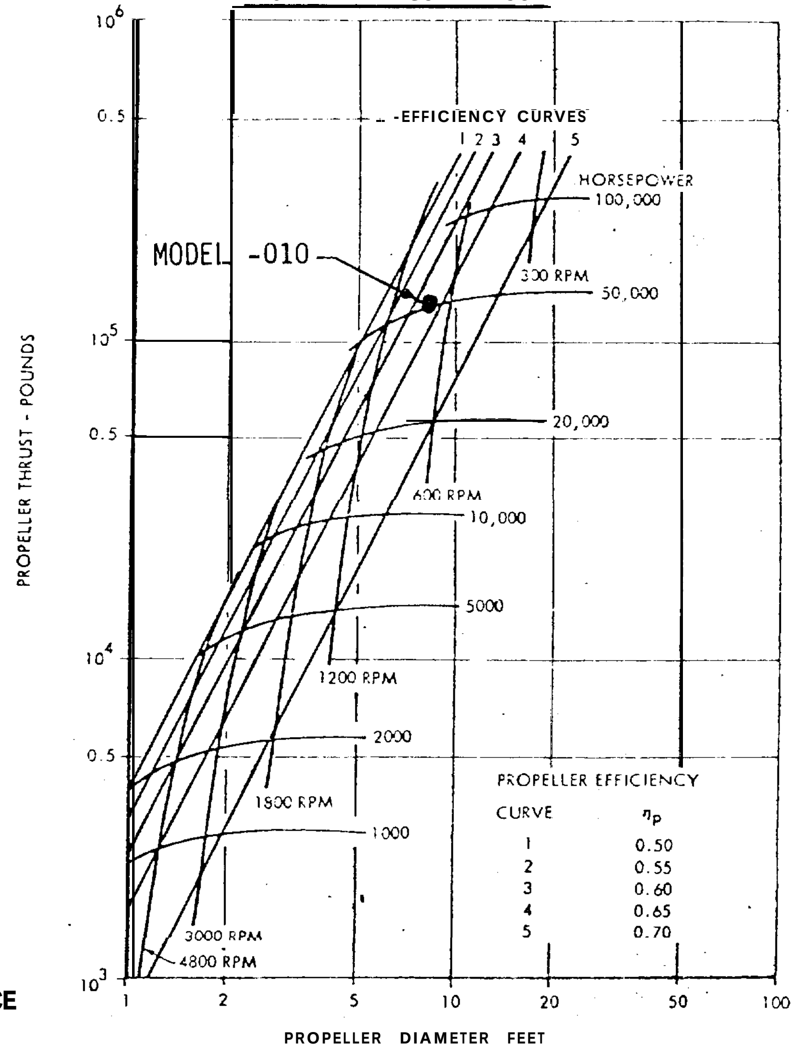
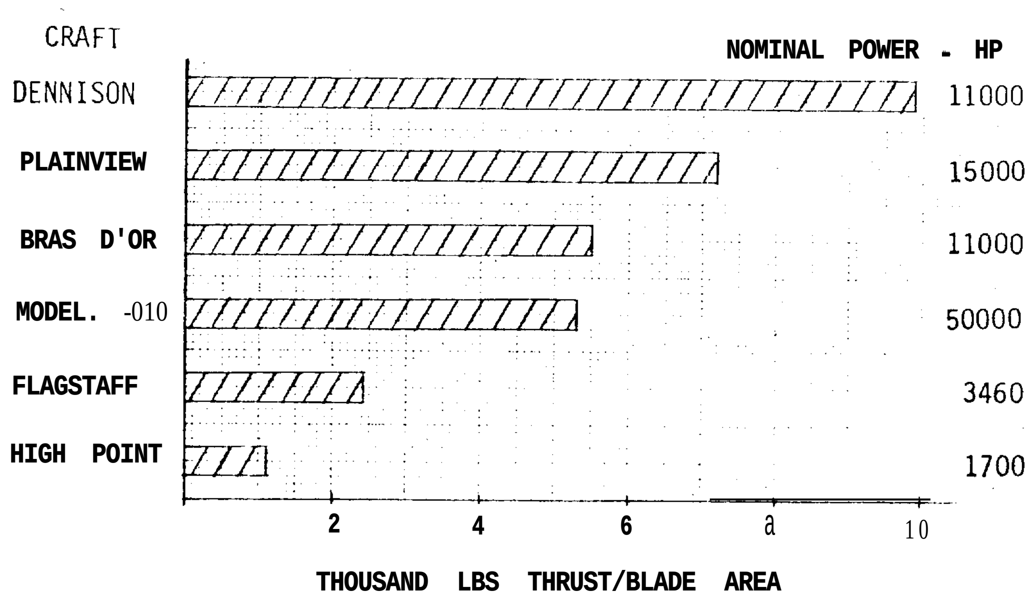
FIGURE 2.2.1-6

PROPELLER COMPARISON



SOURCE: **REFERENCE** 2.2.1-3

Performance curves for optimum, four-bladed, supercavitating propellers at 80 knots, with 25,000.psi design stress



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PROPULSIVE EFFICIENCY VS SPEED

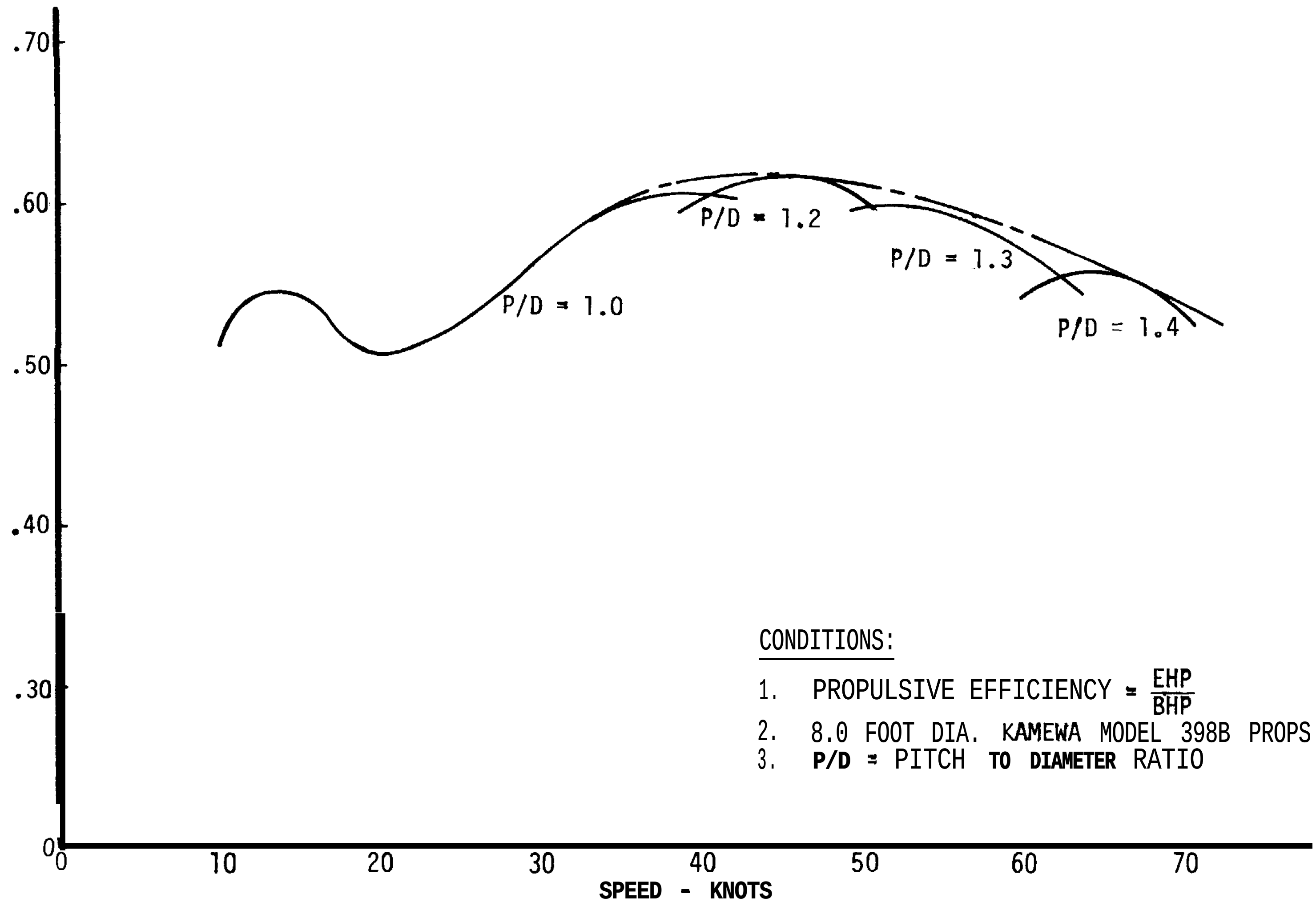

FIGURE 2.2.1-7

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(U) field possible. Conventional pusher propellers would halve to operate in the highly confused ventilated wake of the foil and strut at high speeds, inducing probable propeller structural and performance problems. However, there are also some areas of concern for the tractor propeller installation. For instance, the problem of the tractor propellers' tip vortices impinging on the strut/foil structure will require additional investigation. The other significant problem of tractor propeller installations - induced drag due to operation of the foils and struts in the high velocity wake of the propeller - will be minimized by the drop pod arrangement (see Figure 2.3.5.2-5).

(U) Figure 2.2.1-8 is a plot of "transport efficiency", which is defined as vehicle weight times velocity divided by power required, as a function of speed. It can be shown that the following equation holds for hydrofoils:

$$\frac{WV}{P} \sim (PC)\,\frac{L}{D} = \frac{PC}{D/W}$$

Therefore Figures 2.2.1-1 and 2.2.1-7 complement this figure.

(U) Vessels tend to be slowed in a seaway for a variety of reasons. The subcavitating hydrofoil tends to be slowed by:

a) added drag due to wind,
b) added strut drag due to operation at a deeper depth,
c) added drag due to wave induced angles of attack and control surface reactions,
d) added drag due to hull contact with waves (cresting), and
e) reduction in propulsor efficiency as wave motion causes variations in propeller or inlet cavitation number.

(U) Although very sophisticated computer programs are available for motion simulation analysis, none is presently capable of calculating the speed loss due to sea state. Therefore, to assess the problem of speed reduction, trials data from contemporary propeller driven hydrofoils were plotted interpreting the overall speed degradation as a function of significant wave

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BOEING MODEL 1026-010

TRANSPORT EFFICIENCY VS SPEED

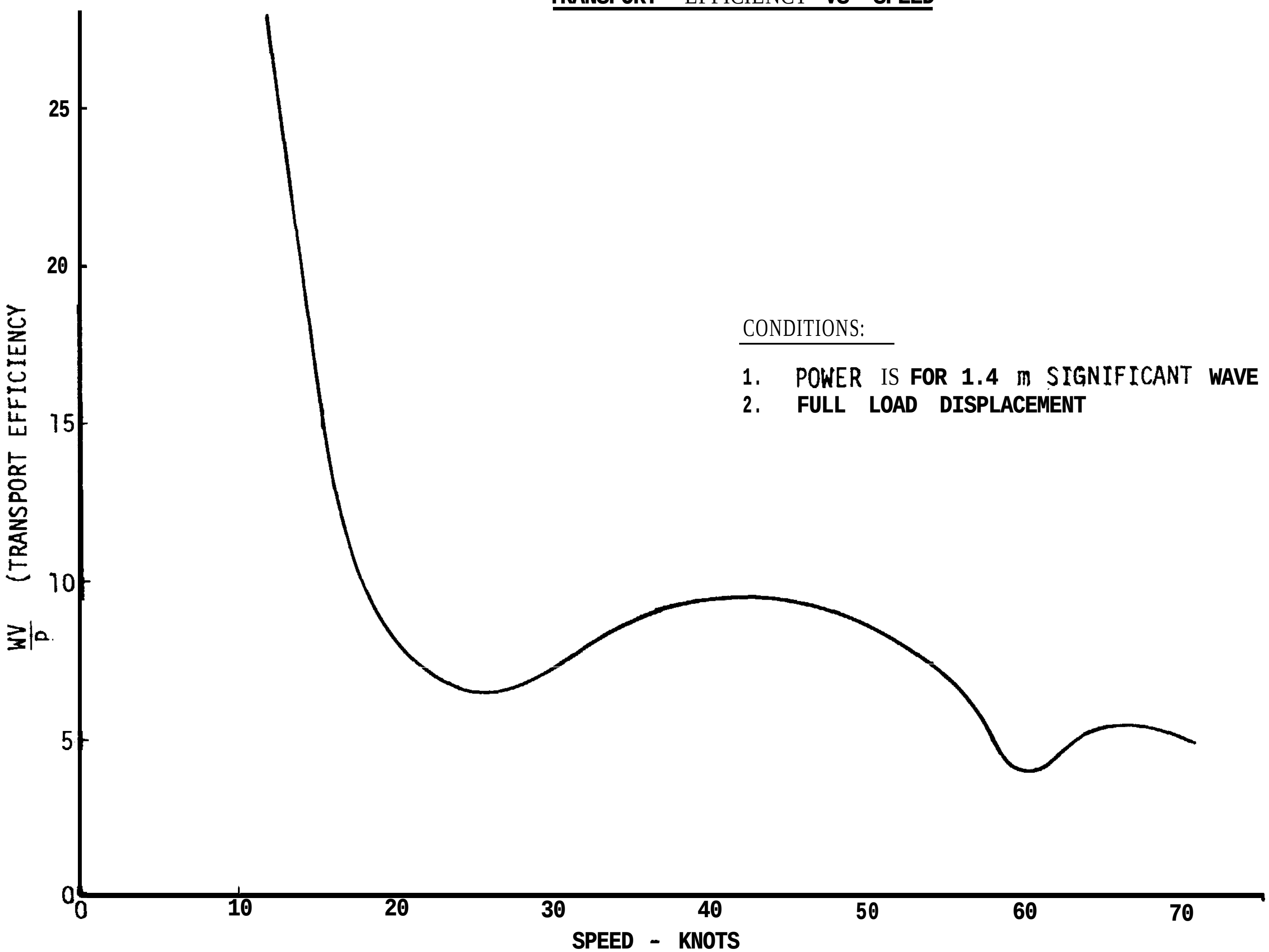

FIGURE 2.2.1-8

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(U) height, Figure 2.2.1-9. This figure also indicates that current hydrofoils experience an approximate four percent speed loss due to a change in depth setting needed to optimize rough water performance.

(U) On the basis of the above data and the physical characteristics of Model -010, the projected speed reduction due to sea state, for single engine operation, is shown on Figure 2.2.1-9. This curve was arrived at as follows:

1. The depth setting is not changed for rough water operation due to the low nominal keel-water clearance.

2. For low wave heights the slope of the curves is the same as trials data.

3. In higher sea states, an additional decrement is added to account for more frequent wave cresting and deeper hull immersion. The speed loss due to hull drag caused by wave cresting has been estimated qualitatively, since quantitative analytic procedures were not available.

(U) Figure 2.2.1-10 has been prepared from Figure 2.2.1-9. The curves shown correspond to: (1) supercavitating operation with both engines, (2) subcavitating operation with both engines, and (3) subcavitating operation with one engine.

(U) For the high speed supercavitating regime, operating capabilities into seas beyond the 1.4 meter seas addressed in the TLR is considered possible, and is so indicated. However, the total lack of real hydrofoil experience at these speeds preclude accurate identification of the limiting factors or the estimation of the upper sea state capability with any degree of precision. It is considered probable that the upper sea state limit for supercavitating will occur when wave induced angle of attack variation on the foil and struts become sufficiently large that portions of the foils will tend to rewet frequently. Such rewetting will tend to create difficulties in accomplishing

BOEING MODEL 1026-010

SPEED LOSS VS SIGNIFICANT WAVE HEIGHT

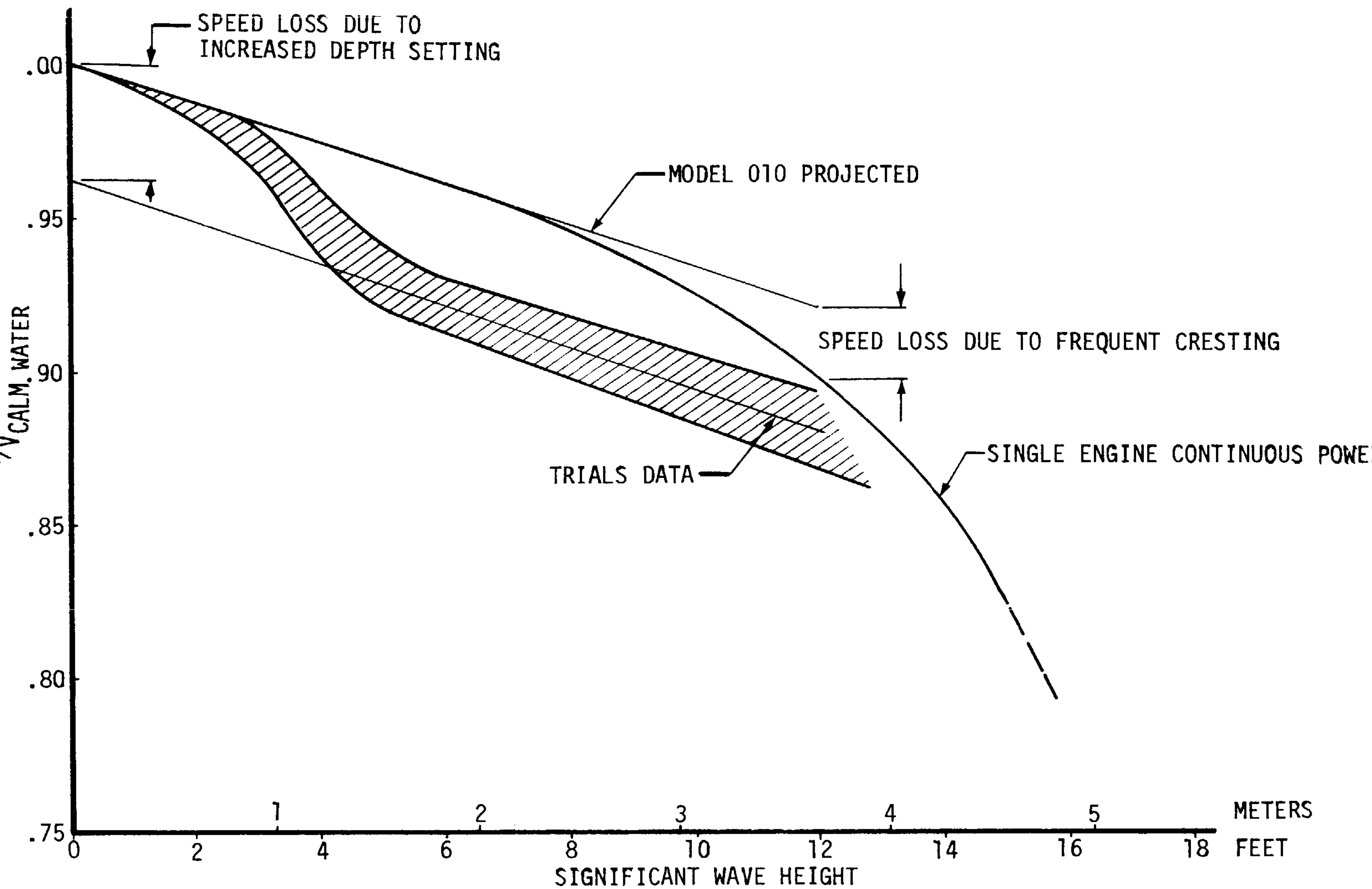

FIGURE 2.2.1-9

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SPEED VS SIGNIFICANT WAVE HEIGHT

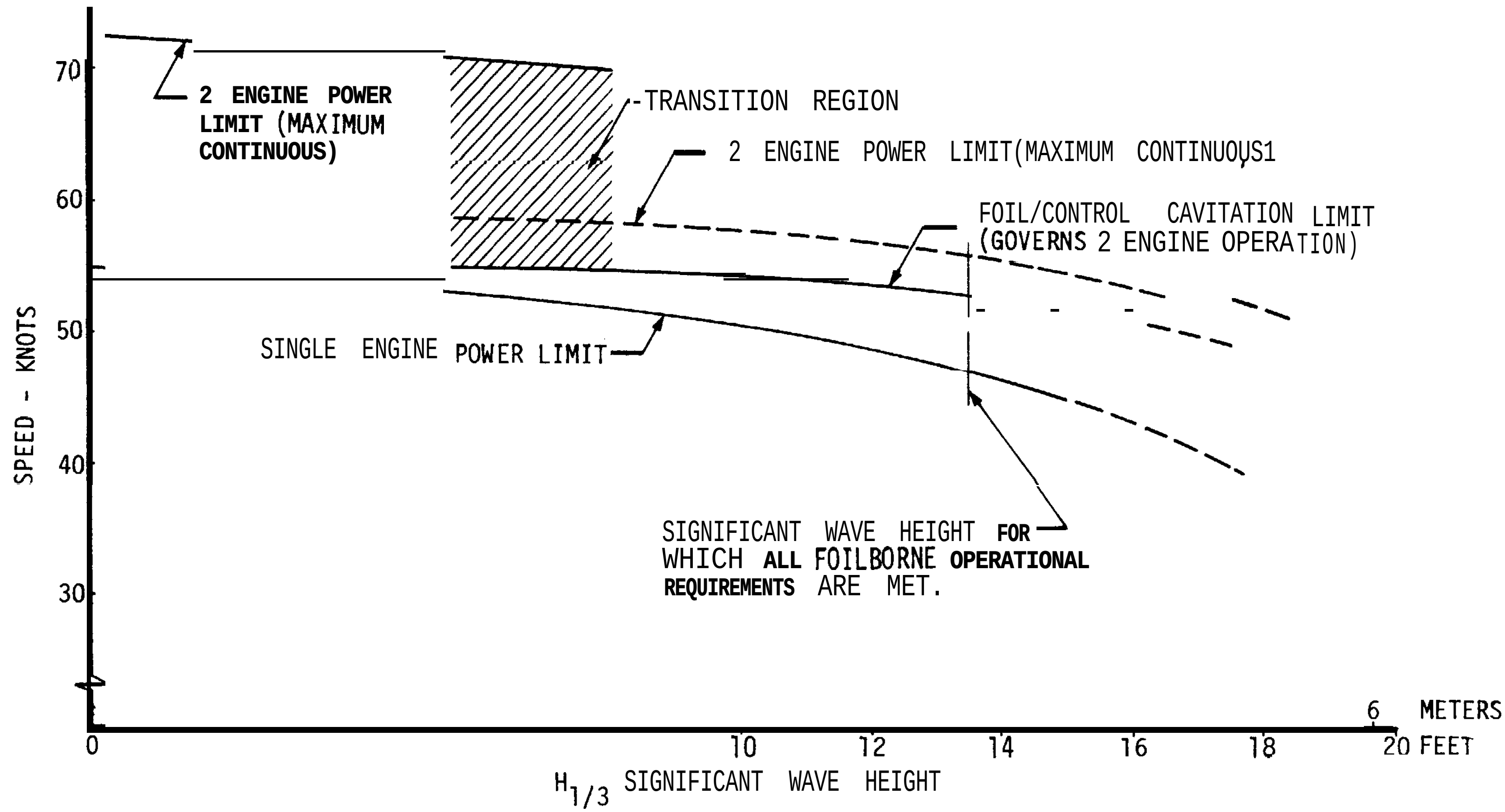

FIGURE 2.2.1-10

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(U) necessary control on the vehicle and will also create added drag increments either or both of which could limit high speed supercavitating operation in larger seas. Propeller efficiency may also be reduced as discussed previously.

(U) Thus the high speed (supercavitating operation) envelope shown in Figure 2.2.1-10 indicates a grey area where the ship will have to transition back to subcavitating operation somewhere between about 1.8 and 2.4 meter seas. Note that the transition is considered to be an operating mode transition, not a power limited transition and as such the transition is a vertical drop downward to the subcavitating regime.

(U) The upper speed for subcavitating operation is less than the two engine power limit. It is anticipated that the max speed in the subcavitating regime will be governed by foil system and/or control surface cavitation boundaries. As noted, the two engines will have sufficient power to drive the ship at speeds above the foil cavitation boundaries.

(U) For one engine the upper speed capability in seas is established by the single engine power limit as indicated.

(U) Also indicated on Figure 2.2.1-10 is the significant wave height (4.1 meters) for which the ship can meet all foilborne operational requirements. In seas greater than this height, foilborne operation is judged possible, but with some degradation in ride quality and maneuverability to be expected.

REFERENCES

2.2.1-1 AIAA Paper No. 76-851, "Recent Studies of Struts and Foils for High-Speed Application", by Young T. Shen and Raymond Wermter, October 1976

2.2.1-2 Hydronautics, Inc. Technical Report 816-2, "Studies of Stepped- Pod Propulsion Units for Surface Effect Ships (U)", by R. Altmann, June 1969, ASTIC Document No. 822 589L

2.2.1-3 Barr, R. A., "Supercavitating and Superventilated Propellers", Transactions of the Society of Naval Architects and Marine Engineers, 1970

2.2.2 MANEUVERING (U)

2.2.2.1 TURNING RATE AND RADIUS VERSUS SPEED (U)

(U) Turning rate and turning radius as a function of speed are presented in Figures 2.2.2-1 and 2.2.2-2. The effects of seaway wave height are provided in Figures 2.2.2-3 and 2.2.2-4. Tactical turning capabilities are shown in Figure 2.2.2-5. Turning radius specified in paragraph 2.3.4 of the TLR is, "tactical diameter less than 750 meters".

(U) Turning radius was calculated from turn rate and speed as:

$$\text{TURN RADIUS (METERS)} = 29.5 \frac{\text{SPEED (KNOTS)}}{\text{TURN RATE (DEG/SEC)}}$$

(C) Turn rate limits are established primarily by the geometric configuration of the foils and struts and from foil lift limits. The basic method of turning is the banked (or fully coordinated) turn where the ship is rolled such that the total acceleration vector on the craft is acting along the craft vertical axis. In this mode, the forward strut is rotated as the ship rolls to maintain zero angle of attack on the struts. Thus a typical limitation on turn rate arises from geometrical constraints necessary to keep the after foil tips in the water. The geometry of the Model 1026-010 is such that it can bank in excess of 20° without either broaching a foil tip or dragging the hull in the water, which would allow fully cordinated turns of up to 10°/sec at 40 knots and up to 13°/sec at 55 knots.

(C) Another possible constraint on turning is the limitation on available foil lift. A 0.4g lateral turn would increase the foil lift requirement both forward and aft by only 8%, and a 0.4g turn corresponds to greater than 8 degrees per second turning capabilities up to 55 knots. Thus added foil lift should not pose any constraint on turning, and since the forward foil is incidence controlled there should not be any large build up in forward foil drag in a turn such as experienced by fixed foil systems..

BOEING MODEL 1026-010

FIGURE 2.2.2-1

TURNING RADIUS VS SPEED

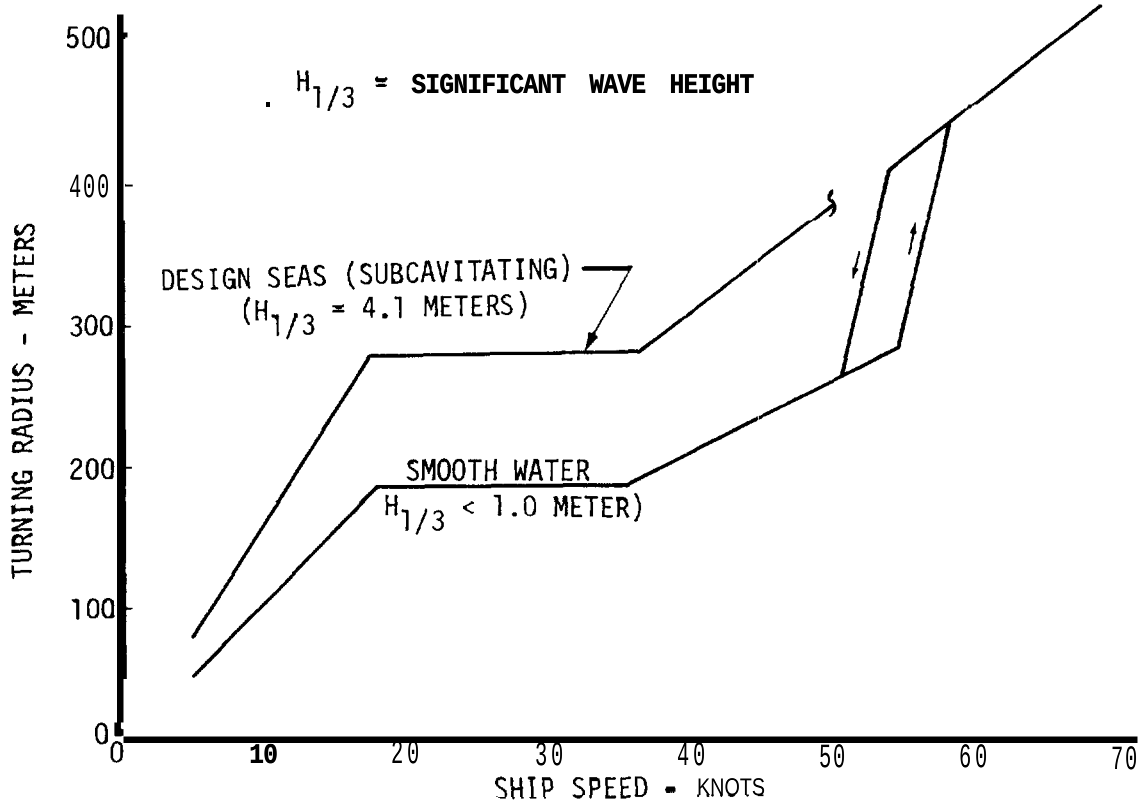
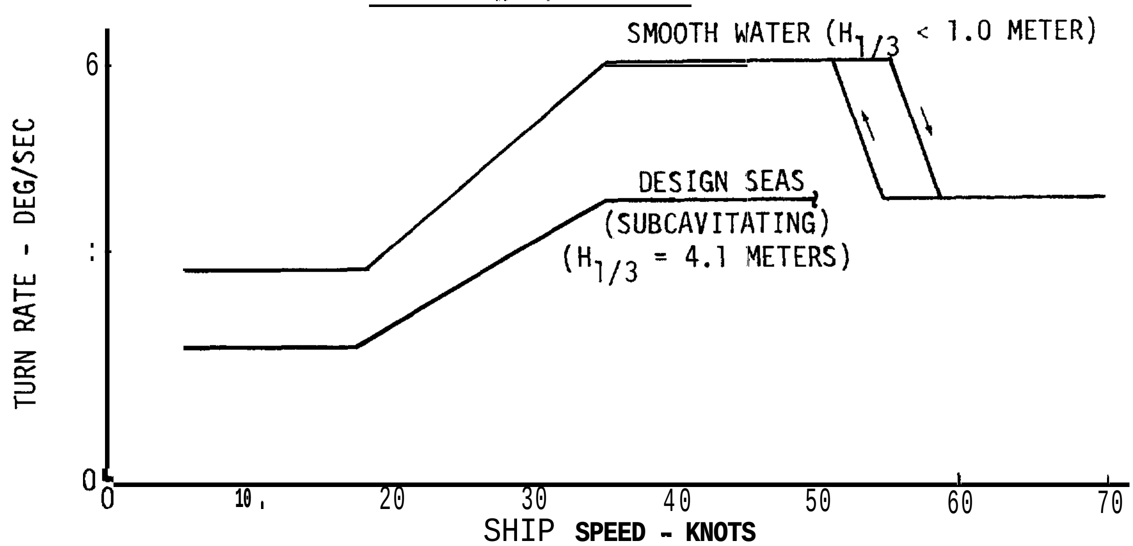


FIGURE 2.2.2-2

TURNING RATE VS SPEED



BOEING MODEL 1026-010

FIGURE 2.2.2-3

TURN RADIUS VERSUS SIGNIFICANT WAVE HEIGHT

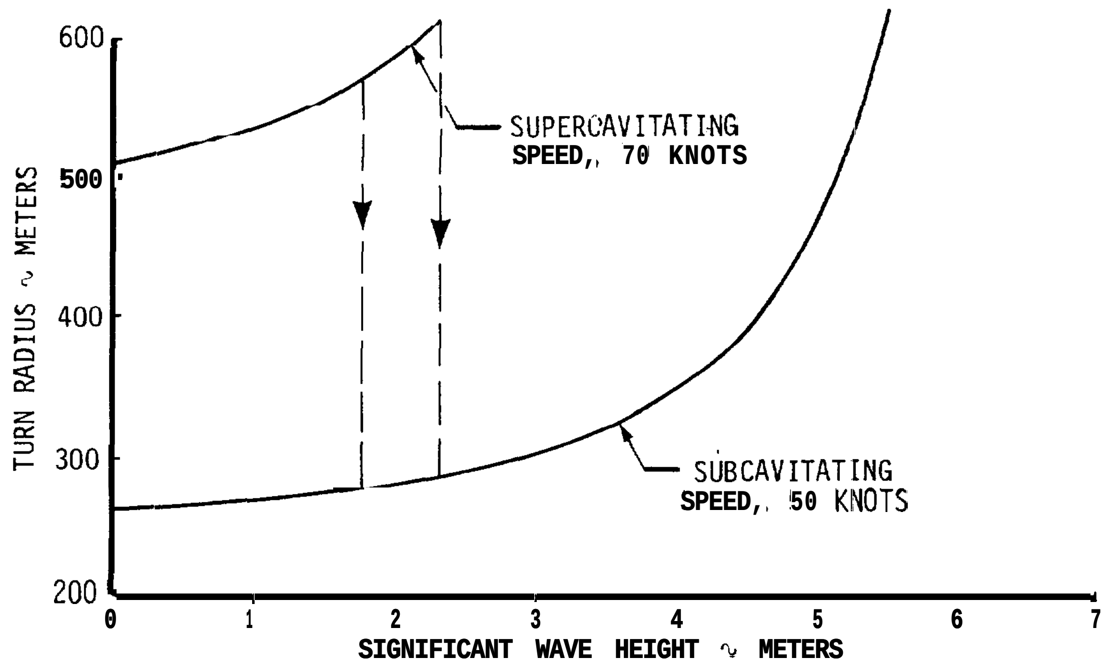


FIGURE 2.2.2-4

TURN RATE VERSUS SIGNIFICANT WAVE HEIGHT

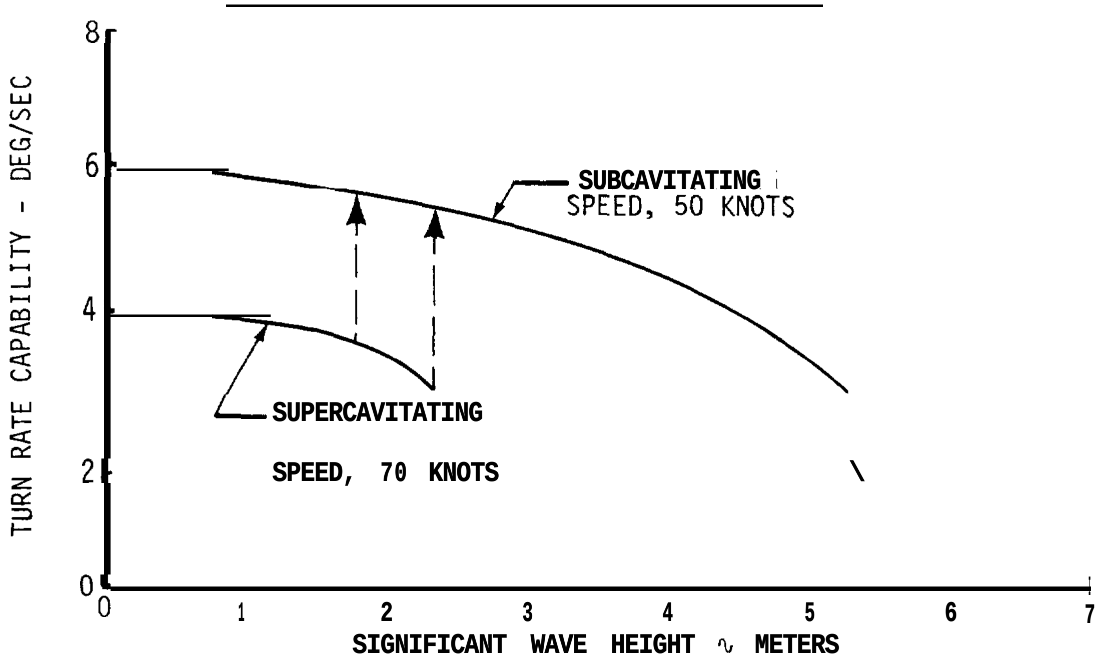


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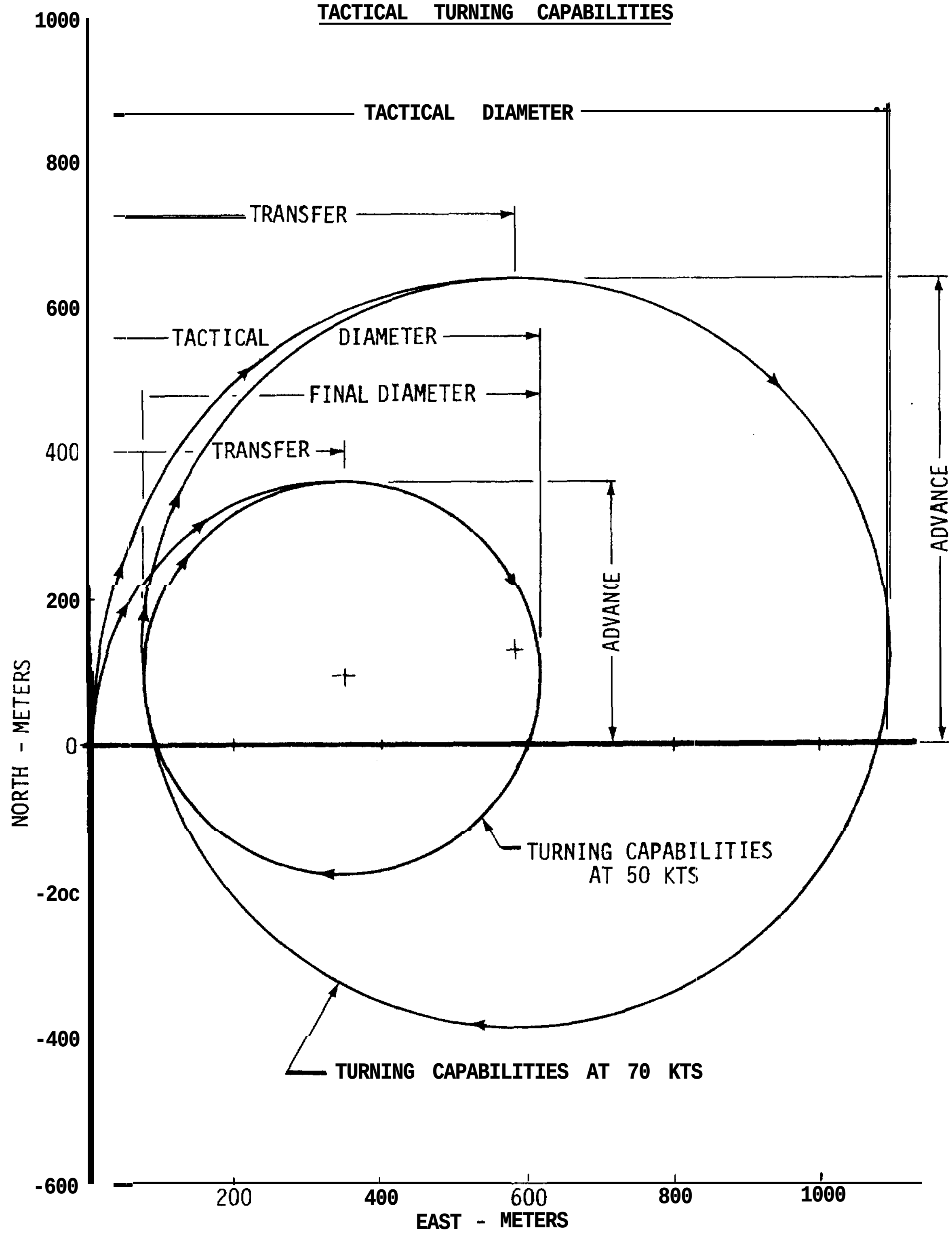
FIGURE 2.2.2-5

TACTICAL TURNING CAPABILITIES



Thus there are no physical properties that pose any significant limitation to turning. It was felt prudent on a ship of this size to design for turn rates only up the levels shown in Figure 2.2.2-Z as these levels are sufficient to meet all known requirements, and they do not impose any significant design compromises on other ship subsystems.

A hysteresis-like effect is shown in the transition between the subcavitating and supercavitating regimes. This hysteresis-like box is intended to show the reality that there is not just one specific speed where the ship will or must transition. Instead, there is an over-lapping between the upper speed for subcavitating operation and the lower speed for super-cavitating operation. The overall point being that while the ship would not be designed to operate continuously in the transition region, some discretion is allowed in selecting the speed(s) at which the transition(s) would be programmed.

2.2.2.2 ACCELERATION/DECELERATION CAPABILITY

The method used to calculate the time to accelerate between two specified speeds is found by a straight forward application of Newton's second law:

$$t = m \int_{V_1}^{V_2} (T - D)^{-1} \, dV$$

where:
- t = time (sec)
- V = velocity (ft/sec)
- m = mass (slugs)
- T = thrust (pounds)
- D = drag (pounds)

This equation was solved using Simpson's rule to calculate the appropriate area under the curve of $(T - D)^{-1}$ versus V. The thrust was calculated for one and two engine operation as indicated on Figure 2.2.2-6.

Deceleration capability is shown for two conditions on Figure 2.2.2-6. A "normal" landing consists of the reduction of engine power back to idle

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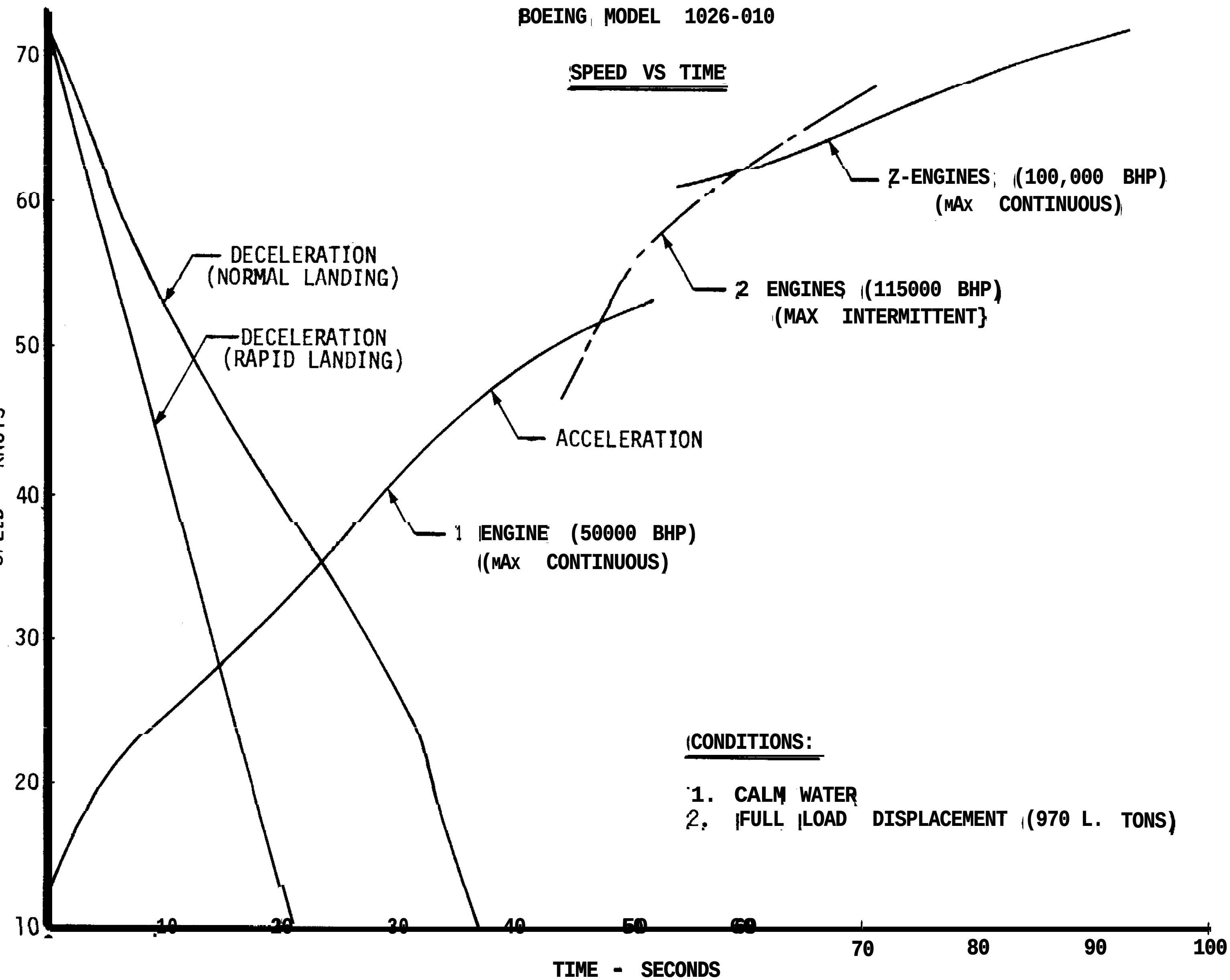

FIGURE 2.2.2-6

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allowing the ship to glide to a landing. A "rapid" landing occurs when the throttles are reduced to idle and the depth controller is set to a value corresponding to normal hullborne operation. This procedure will cause the hull to rapidly touch the water thereby significantly increasing drag and the deceleration rate.

The time to decelerate between two specified speeds for a "normal" landing is found from the following equation:

$$t = m \int_{V_1}^{V_2} D^{-1}\, dV$$

This equation was also solved numerically. Due to the complicated hull/foil/water interactions which occur during a "rapid" landing the results of a PHM computer simulation were used to estimate the "rapid" landing characteristics of Model -010.

The reversing ability of the CRP propellers was not utilized in the present study. Their use would, of course, further decrease the stopping time.

2.2.2.3 STOPPING AND TAKEOFF DISTANCE

The appropriate equation for calculating distance is:

$$S = \int_{t_1}^{t_2} V\, dt$$

where: S = distance (feet)

The solution to this equation was obtained numerically using Figure 2.2.2-6 and is shown in Figure 2.2.2-7. Note that the reversible ability of the propellers has not been considered and stopping distance could be reduced utilizing this capability.

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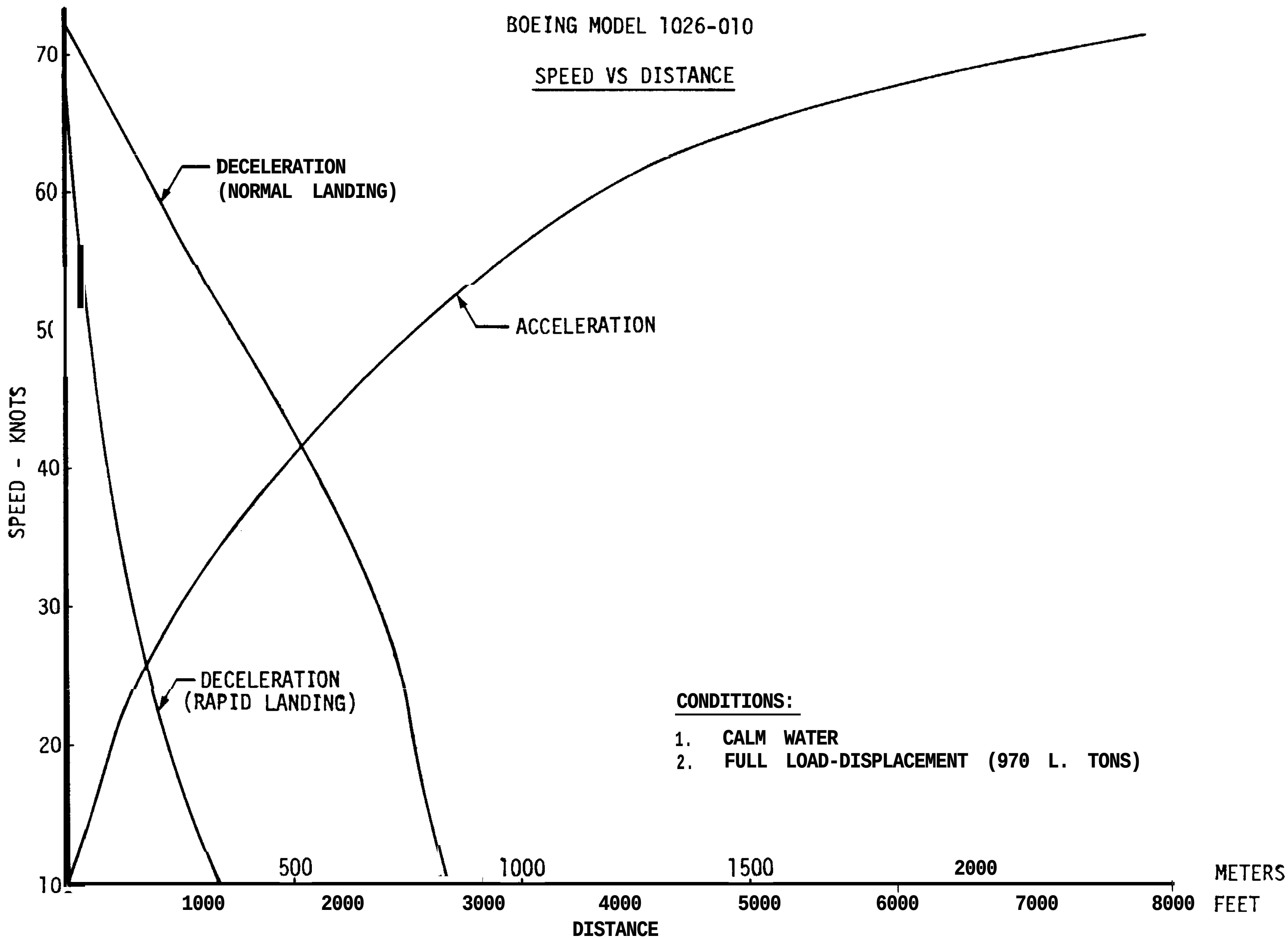

FIGURE 2.2.2-7

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2.2.3 RANGE AND PAYLOAD (U)

(U) Figure 2.2.3-l is a graph of fuel consumption in terms of nautical miles per ton of fuel plotted as a function of speed and Figure 2.2.3-2 is a graph of range as a function of speed. All range calculations were done based on the TLR methodology. The specific fuel consumption at 50,000 BHP was taken as 0.364 pounds per brake horsepower hour based on data in ANVCE Working Paper 011. The auxiliary fuel flow was taken as 500 pounds per hour foilborne and 225 pounds per hour hullborne.

(C) The range performance is compared with the TLR goals and requirements in the following summary:

	RANGE - N.M.		
SPEED/MODE	REQUIREMENT	GOAL	PERFORMANCE (ENGINE)
20 Knot Hullborne	--	2000	1150 (1 LM 5000 - typical)
16 Knot Hullborne	1500	--	1512 (1 LM 5000 - typical)
			2025 (2 TF 40's - typical)
45 Knots	1000	--	1400 (1 LM 5000 - typical)
50 Knots	--	1300	1330 (1 LM 5000 - typical)

The summary indicates that all TLR requirements and goals are met except the 20 knot goal which appears impractical (see Section A4.2.7). Fuel tankage is available for additional fuel, however, for structural and hydrostatic reasons the maximum takeoff displacement should not exceed 970 long tons.

(C) The range curve and fuel consumption curves are somewhat novel in appearance and therefore will be briefly discussed. The low point in the curves at approximately 25 knots corresponds to the takeoff drag hump, The hump in the curves around 42 knots are indicative of the speed for maximum range. The low point in the curves at 60 knots is due to the high speed transition drag hump shown on Figures 2.2.1-1 and 2.2.1-2.

(U) Figure 2.2.3-3 is a graph of endurance in hours as a function of speed for a 1.4 meter significant wave height.

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NAUTICAL MILES/TON OF FUEL

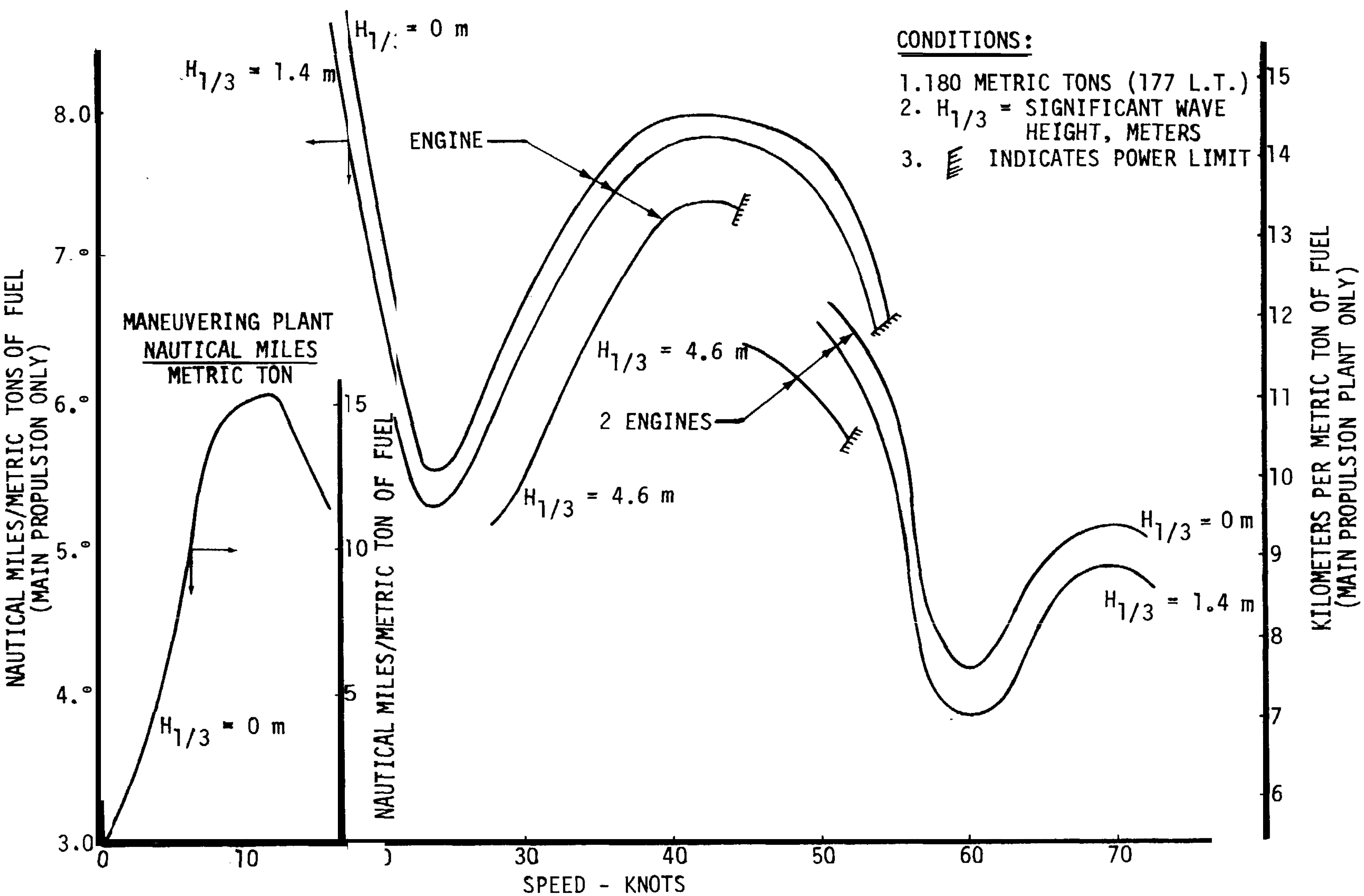

FIGURE 2.2.3-1

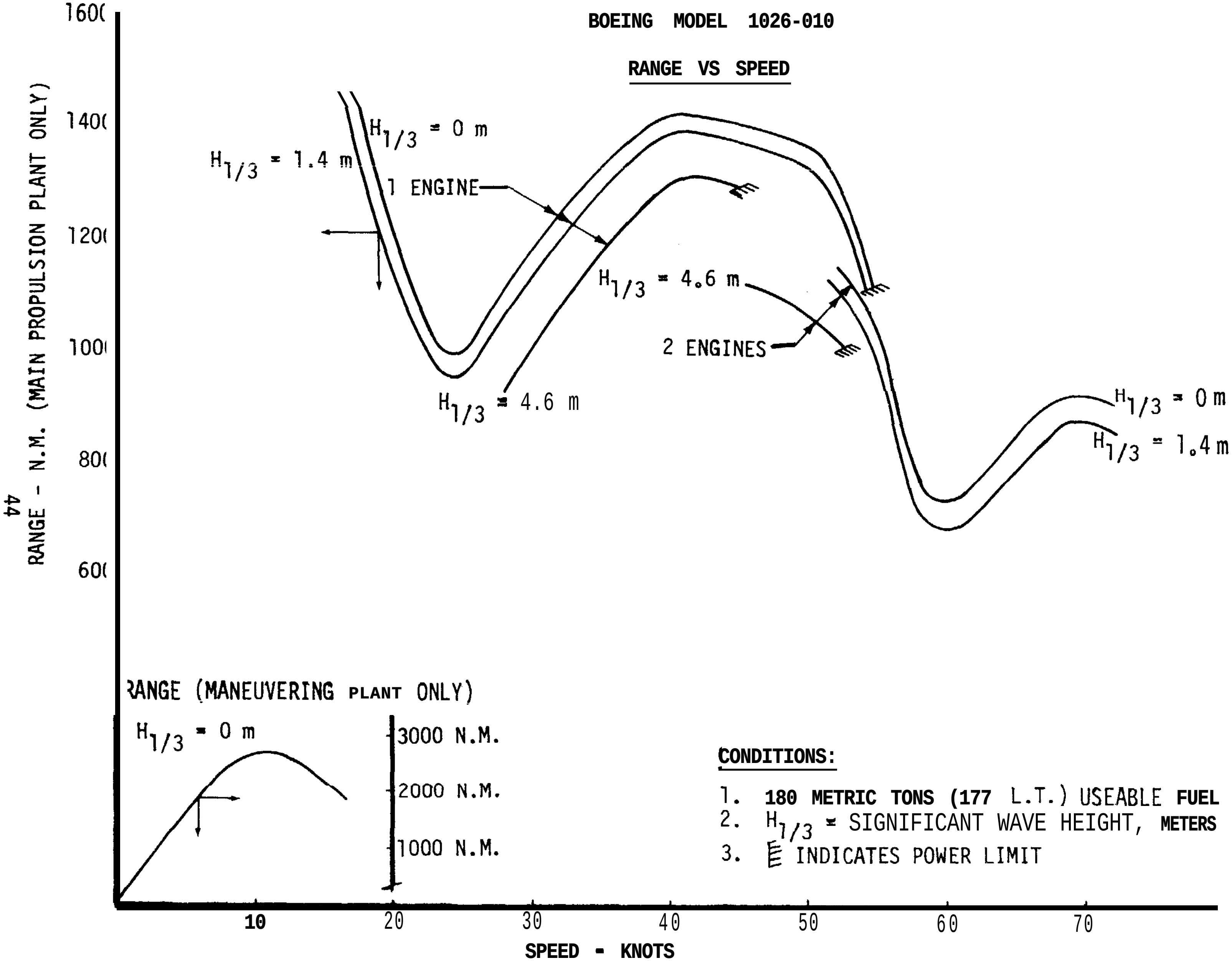

FIGURE 2.2.3-2

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ENDURANCE VS SPEED

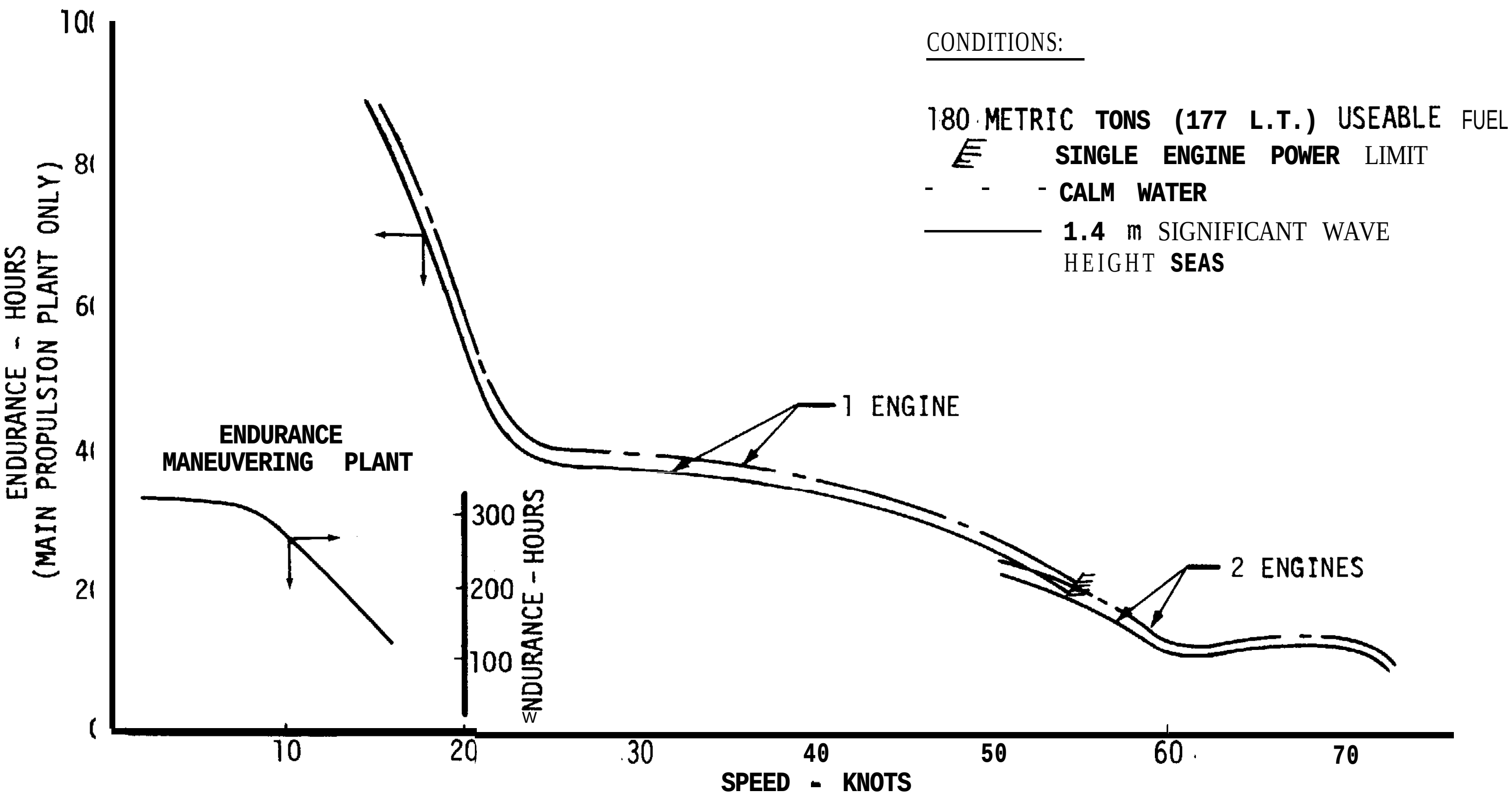

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FIGURE 2.2.3-3

(C) The payload versus range graph, Figure 2.2.3-4, has been prepared for speeds of 15, 20, 45 and 70 knots.

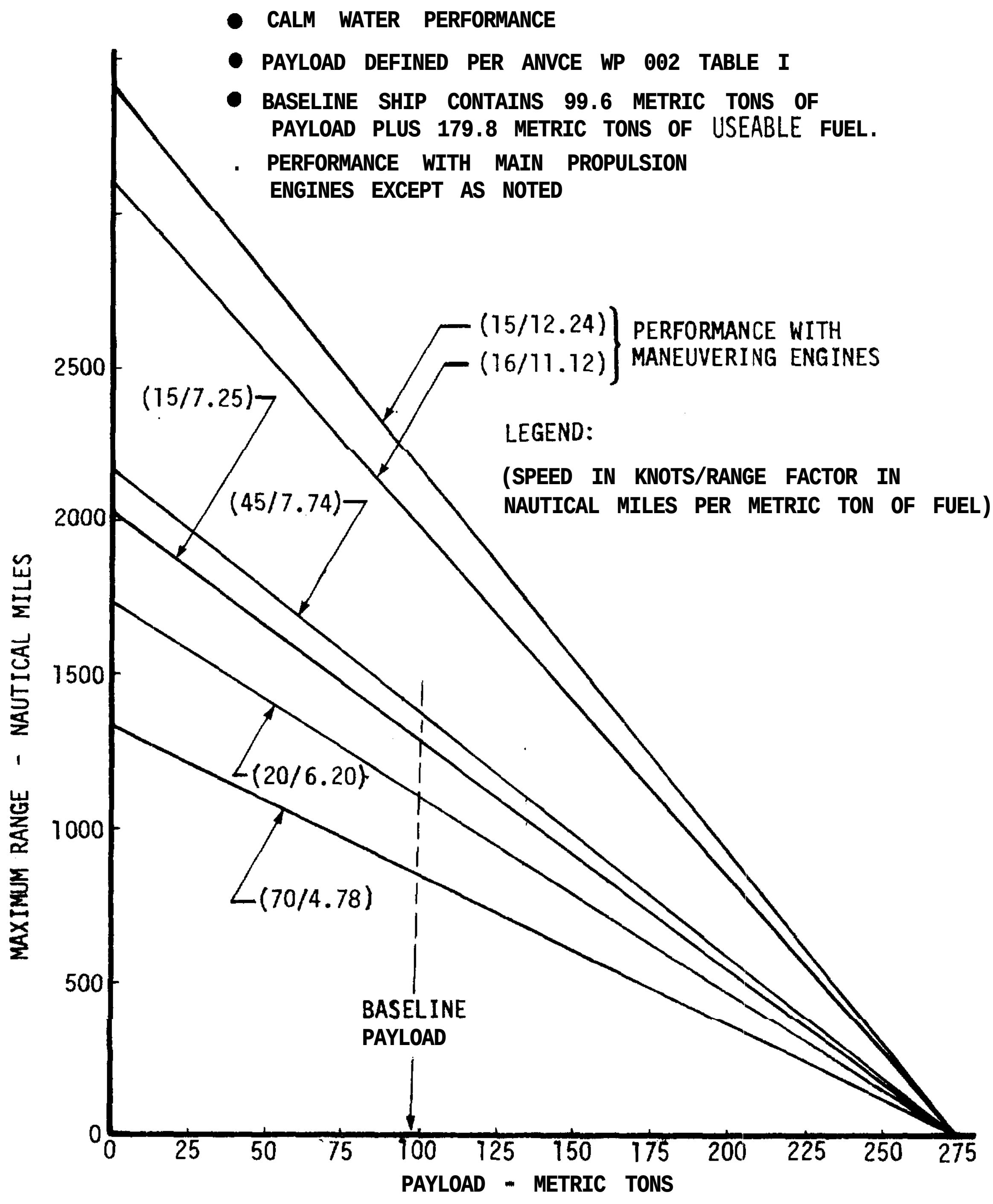
(U) For any other speeds the maximum (zero payload) range can be found by referring to the range versus speed curve of Figure 2.2.3-2 to obtain the range value corresponding to the baseline 99.6 metric tons (98 long tons) payload case. then dividing that value by 179.8 metric tons (177 long tons) of useful fuel and multiplying the resulting range factor by (99.6 + 179.8) = 279.4 metric tons. The straight line then constructed between that zero payload range point on the ordinate and 279 metric tons (275 long tons) of payload on the abscissa of Figure 2.2.3-4 provides the desired direct weight tradeoff between weight and payload.

(U) The definition of payload has been taken from ANVCE WP-002, Table I.

FIGURE 2.2.3-4

BOEING MODEL 1026-010

AVAILABLE RANGE/PAYLOAD TRADEOFF!-



2.2.4 WEIGHT AND VOLUME SUMMARY (U)

(U) The weight summary resulting from the HYD-7 studies are set forth in Table 2.2.4-l.

(U) Weights for the various SWBS groups were derived as follows

--- Group 100 - Hull Structure - Ratiocination from an analytical 1400 ton hull development, verified by HANDE program data.

--- Group 200 - Component build up and synthesis.

--- Group 300 - Ratiocination except for diesel generator weights

--- Group 400 - Synthesis

--- Group 500 - Non-Strut/Foils - Ratiocination using data from PHM, 1400 ton HOC, FFG-7 and other sources.

--- Group 567 - Struts/Foils-Analytically derived (basic structure)

--- Group 600 - Ratiocination, insulation calculated

--- Group 700 - Synthesis

(C) There are no deviations from the standard Navy SWBS in the weight statement. Allocations are consistent with other designs although there are no closely comparable designs (70 knots) to compare with. Some judgment was exercised in certain groups to include a small long term technology improvement factor. All specified margins are included in weight and stability studies. Although modest spares allotted weights are included, in appropriate weight groups, it is neither customary nor appropriate to identify these items further in a limited feasibility study.

(U) Although a deck area summary was not required by WP-005, Table 2.2.4-Z is included as a normally useful item of design data. The 'volume breakdown is shown in Table 2.2.4-3.

(U) Deck heights in habitability spaces are 7.5 to 8 feet. Internal volume for habitability purposes is related to habitability standards. Main propulsion volumes stem from direct layouts. CIC allocation reflects both experience

)

TABLE 2.2.4-1

HYD-7/ MODEL 1026-010 - WEIGHT SUMMARY

SWBS	WEIGHT Long Tons	WEIGHT Short Tons	WEIGHT Metric Tons
GROUP 100: STRUCTURAL SYSTEM[1]	196	220	199
GROUP ZOO: PROPULSION SYSTEM[2]	130	146	132
GROUP 300: ELECTRICAL SYSTEM	37	41	38
GROUP 400: COMMAND AND SURVEILLANCE	43	48	44
GROUP 500: AUXILIARY SYSTEM	143	160	145
(567: Lift System)	(80)	(90)	(81)
GROUP 600: OUTFIT AND FURNISHINGS[3]	57	64	58
GROUP 700: ARMAMENT	12	13	12
DESIGN AND BUILDERS MARGIN	93	104	94
EMPTY WEIGHT (LIGHTSHIP)	711	796	722
GROUP F00: FULL LOADS	259	290	263
Group F10: Crew and Effects	9	10	9
Group F21: Ordnance	46	52	47
Group F23: Secondary Vehicle (RPVs)	2	2	2
Group F31: Provisions	4	4	4
Group F32: General Stores	1	1	1
Group F41-F42: Fuel/98% Usable	181/177	203/198	184/180
Group F46: Lube Oil	3	3	3
Group F52: Fresh Water - Potable, Washdown	12	13	12
Group F54: Hydraulic Fluid	1	1	1
FULL LOAD WEIGHT	970	1086	986

NOTES:
1 - Includes 21 Long tons for ballistic protection of vital spaces.
2 - Includes 4 long tons for high impact shock protection of Group 200 equipment.
3 - Includes 20 long tons for special passive fire protection insulation.

TABLE 2.2.4-2

MODEL 1026-010 DECK AREA COMPARISON

SPACE	All Areas in Square Feet MODEL 010	NAVSEC RECOMMENDED	NAVSEC ACCEPTABLE
Main Propulsion, Auxiliary and Electrical	2710	--	--
Personnel	3670		
Officer Berthing	477	445	402
Officer Bath	154	140	115
Wardroom and Pantry	240	219	209
CPO Berthing and Lounge	135	140	100
CPO Washroom, Water Closet and Shr	97	56	56
Crew Berthing	1385	1400	1050
Crew Washroom, WC and Showers	357	350	231
CPO and Crew Mess	400	556	436
Medical Space	186	195	140
Galley and Scullery	350	400	400
Recreation Room - Crew	0	35	0
Laundry	95	128	120
Provisions	264		
Stores	520		
Ships Store, Supply Office	310		
Payload			
Ship Control Station	160	--	--
Bridge	310	--	--
CIC, CIC Equipment, Electronics	1230	--	--
Radio Room	187	--	--
Sonar Equipment	810	--	--
Other			
Passages and Stairways	1433		
Shops	400		

TABLE 2.2.4-3

MODEL 1026-010 VOLUME SUMMARY

FUNCTION	INTERNAL VOLUME CUBIC FEET	INTERNAL VOLUME CUBIC METERS
Main Propulsion	23,835	675
Auxiliary and Electrical	5,525	156
Personnel		
Officer Berthing	4,293	122
Officer Washroom, Water Closet & Shower	1,386	39
Wardroom and Pantry	2,160	61
CPO Berthing and Lounge	1,333	38
CPO Washroom, Water Closet and Shower	862	24
Crew Berthing	11,911.	338
Crew Washroom, Water Closet and Shower	2,856	81
CPO and Crew Mess	4,000	113
Medical Space	1,674	47
Galley and Scullery	3,500	99
Laundry	760	22
Provisions	2,112	60
Store's	4,160	118
Ship's Store and Supply Office	3,104	88
Subtotal	44,107	1250
Payload		
Ship Control Station	1,280	36
Bridge	2,480	70
CIC, CIC Equipment and Electronics	9,840	279
Radio Room	1,496	42
Sonar Equipment	8,114	230
Subtotal	23,206	658
Other		
Passages and Stairways	11,464,	325
Shops	3,200	91
Fuel Tanks	8,300	235
Miscellaneous	60,234	1707
TOTAL ENCLOSED VOLUME (Hull and Superstructure)	179,871	5097

(U) and suggested standards set forth by ANVCE memo Serial 107 establishing combat system support standards.

(U) The ship is weight-limited and also essentially volume limited except for some excess tank volumes as best as can be determined at this stage of definition.

(U) In general DDS 079-l standards with a 15% Kg margin were acceptable and did not involve any special design measures. The GM_T and GML are as follows:

	Minimum Operating	Full Load
GM_T	2.65m (8.68 feet)	2.41m (7.89 feet)
GM_L	106.1m (348.0 feet)	93.5m (306.7 feet)

2.2.5 STABILITY

The hydrostatic stability of Model 010 was evaluated following the applicable stability and buoyancy criteria as defined in NAVSEC DDS 079-1, "Stability and Buoyancy of U.S. Naval Surface Ships," (Reference A.2-12), Part III. The Boeing version of NAVSEC's Ship's Hull Characteristics Program (SHCP) was the primary tool used in this evaluation. The program has been modified to account for the effects of strut/foil buoyancy, complex hull shapes, free surface effects of tanks, and uses improved numerical procedures.

The intact and damaged hydrostatic stability of Model 010 is concisely defined by Figure 2.2.5-1, which plots actual and limiting values of KG as a function of displacement. The figure indicates that the intact ship wind heel limiting KG heights exceed the calculated KG height including the 15 percent light ship (L.S.) KG margin for both 80 and 100 knot beam winds. Intact stability is not anticipated to be a problem.

Figure 2.2.5-l also allows assessment of the damaged stability requirements, using the same format. The limiting KG values are plotted for the worst case of damage at both full load and minimum operating conditions. The worst case of damage was found to be damage to the bulkhead at frame 28. The limiting KG values are in excess of the calculated KG including the 15 percent light-ship KG margin. The worst case damaged condition at minimum operating condition is seen to provide the lowest KG margin. Clean ballast tankage is available, if it should be required by future increases in KG height.

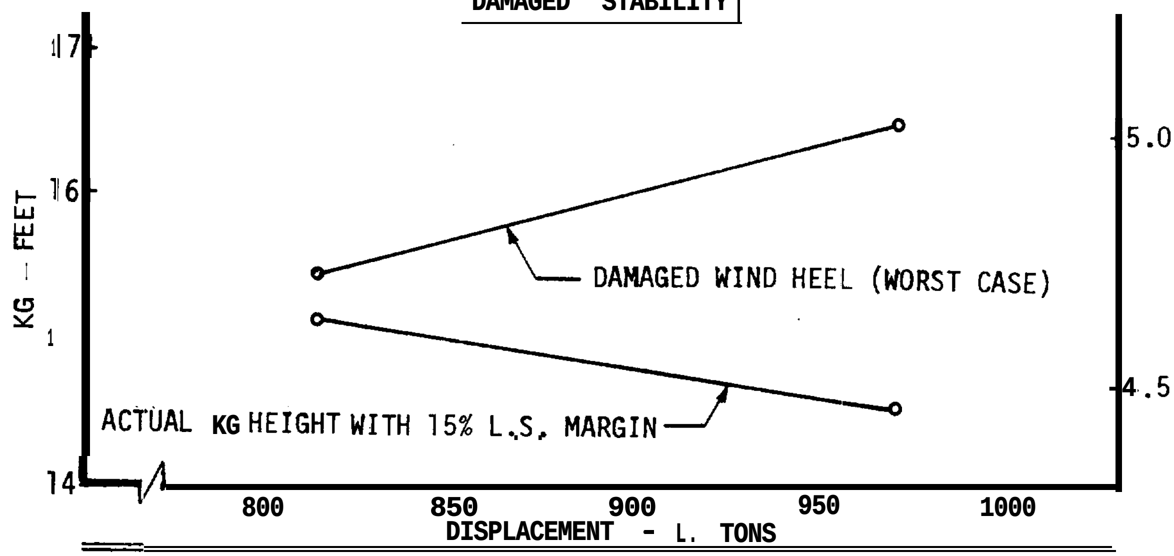
The ability of Model 010 to meet NAVSEC DDS 079-l stability and buoyancy requirements is due to several factors, For instance,, the bulkhead spacing is seen in Figure 2.2.5-2 to result in a conservative floodable length curve and the fixed foil system insures a relatively low value of KG.

Plots of heeling and righting moments versus angle are available from the SHCP output. Such plots are not included since Figure 2.2.5-l provides a clear summary and verification of the design's ability to meet the stability and buoyancy requirements.

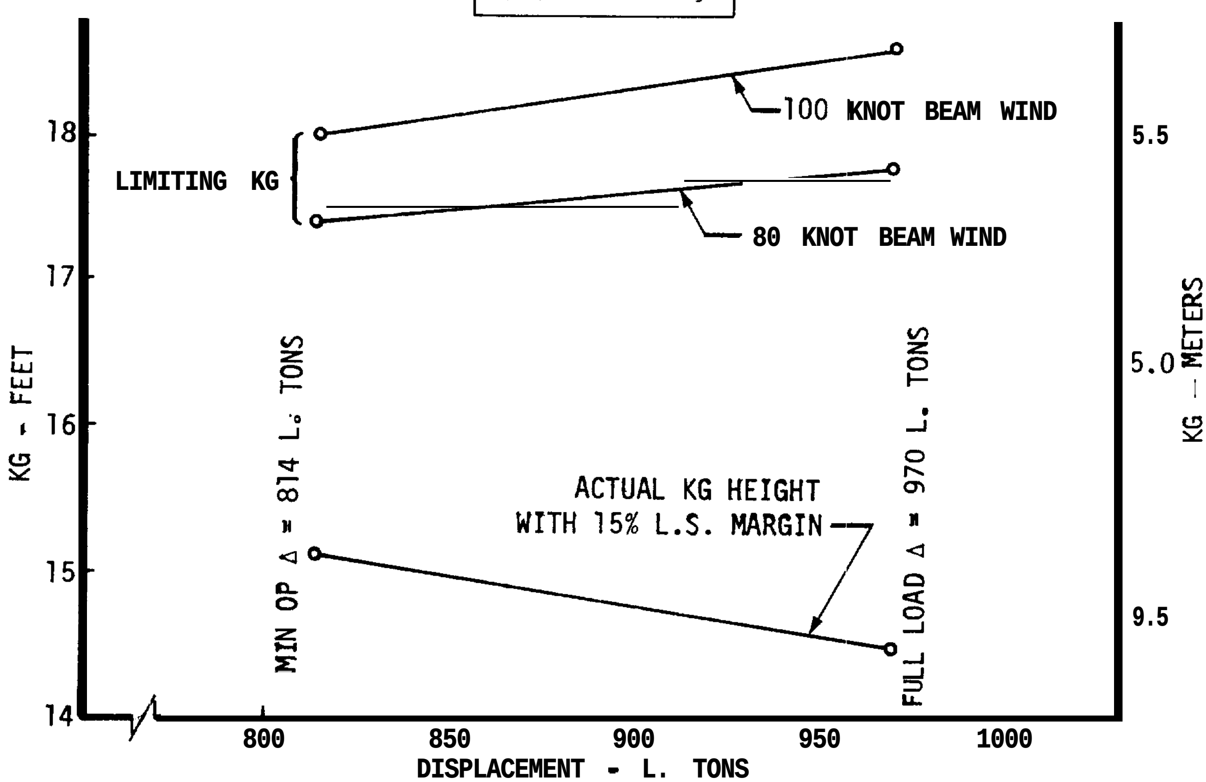
FIGURE 2.2.5-1

HYDROSTATIC STABILITY

DAMAGED STABILITY



INTACT STABILITY



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55

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FLOODABLE LENGTH

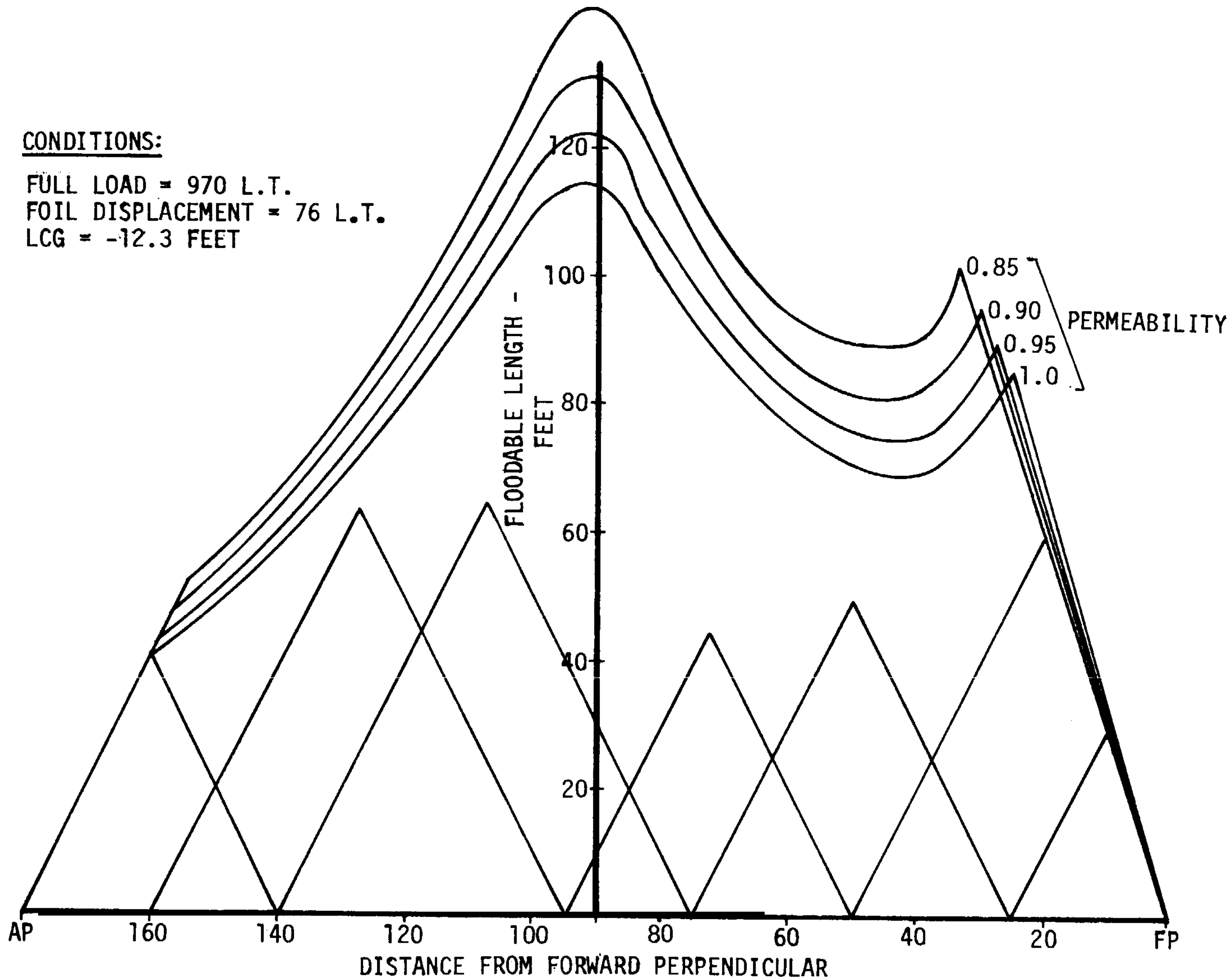


FIGURE 2.2.5-2

UNCLASSIFIED

THE BOEING COMPANY

(U) Figures 2.2.5-3 and 2.2.5-4 show predicted roll and pitch motions as a function of significant wave height. The ordinate value is given as 1σ which is the standard deviation. (The standard deviation is the same as the RMS value for zero mean).

(C) In both the subcavitating regime and the supercavitating regime (70 knots) the worst case heading for pitch motions is a quartering sea (45 degrees off a following sea) while the worst case heading for roll motions is beam sea operation.

(C) Roll and pitch motions are quite small for all cases (a $<1^{\circ}$). An increase in both pitch and roll motions is indicated for the 70 knot (supercavitating) case. These increased motions resulted not because of the speed change, but because of the control configuration chosen for supercavitating operation. As discussed in detail in Section 2.3.5.2 the after foil system does not employ incidence control (which is needed for effective control in the supercavitating regime). Thus in supercavitating operation the major part of the aft foil system is passive (no active control); hence pitch and roll motions are not controlled as tightly as they are in the subcavitating regime where active control of both pitch and roll motions are accomplished though the trailing edge flaps. The tipperons are providing some active roll control at supercavitating speeds which tends to keep the 70 knot roll curve closer to the 50 knot curve than is shown for pitch.

BOEING MODEL 1026-010

FIGURE 2.2.5-3

PITCH DEVIATION

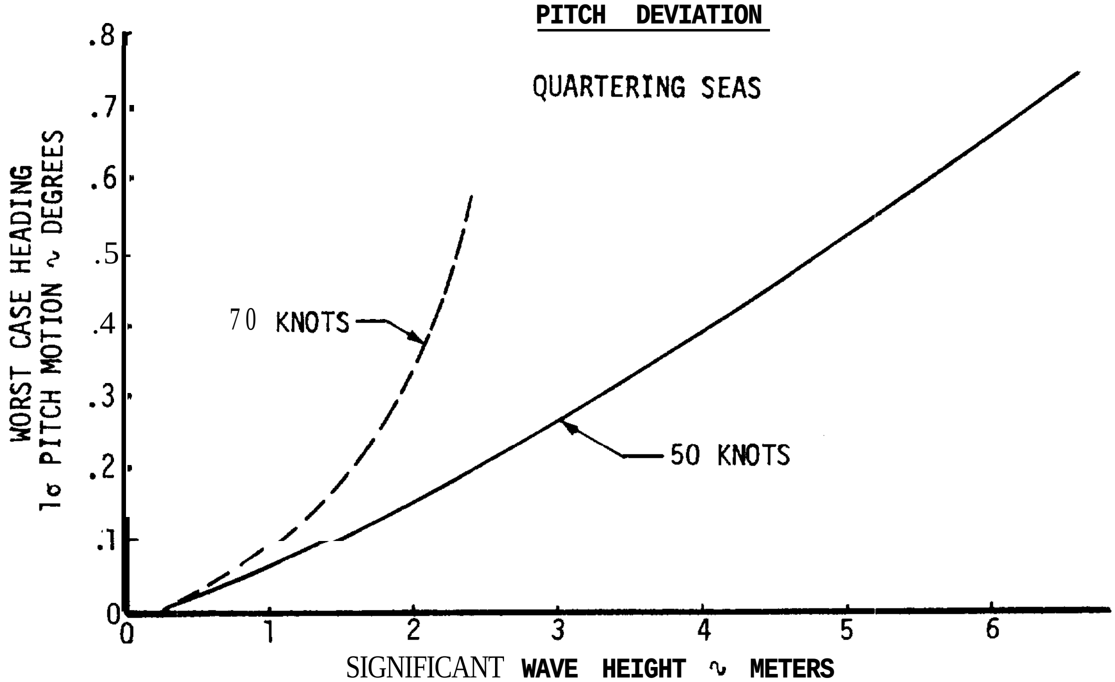
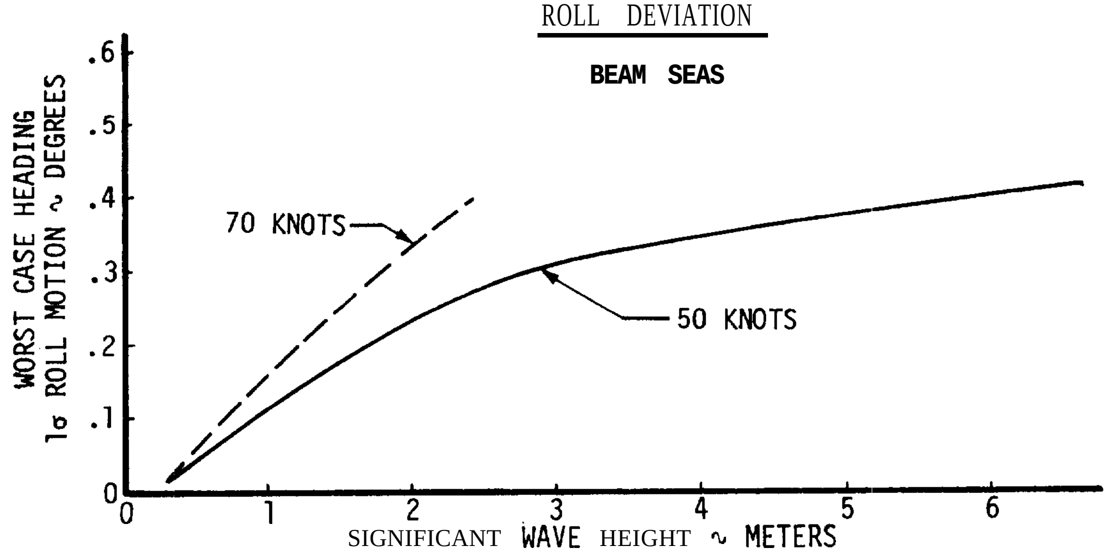


FIGURE 2.2.5-4

ROLL DEVIATION



2.2.6 HULL LINES AND OFFSETS

HYD-7 hull lines and offsets were derived from the PHM hull lines and offsets by increasing the longitudinal dimensions by a factor of 1.524, the transverse dimensions by a factor of 1.557, and the vertical dimensions by a factor of 1.804. The PHM hull lines are shown on Figure 2.2.6-l with three dimensions boxed in to provide scaling for the HYD-7. The aft strut retraction hull notches are not included in the HYD-7 hull.

The length between perpendiculars is 180 feet (54.864 m), the beam at sheer at midship is 42.90 feet (13.076 m), and at that point the sheer is 24.83 feet (7.568 m) above the baseline.

The HYD-7 has 36 frames at 5 feet spacing (1.524 m) as compared to the PHM's 36 frames at 1.00 m spacing.

TABLE 2.2.6-1

HULL CHARACTERISTICS

(HYDRODYNAMIC PARAMETER LISTING)

	English	Metric
DISPLACEMENT (Δ)	970 L. Tons	988 M. Tons
CRUISE DYNAMIC LIFT (CDL)	803 L. Tons	816 M. Tons
LENGTH OVERALL (LOA)	198.0 Feet	60.4 Meters
LENGTH BETWEEN PERPENDICULARS (LBP)	180.0 Feet	54.9 Meters
MAXIMUM BEAM AT DWL	37.5 Feet	11.4 Meters
DRAFT TO DWL	11.0 Feet	3.35 Meters
LCG, AFT OF MIDSHIP	12.3 Feet	3.76 Meters
C_B, BLOCK COEFFICIENT	.456	.456
C_M, MAXIMUM SECTION COEFFICIENT	.617	.617
C_P, PRISMATIC COEFFICIENT	.739	.739
C_{WP}, WATERPLANE COEFFICIENT	.804	.804
WETTED SURFACE AREA	6722 $Feet^2$	592 $Meters^2$
$\Delta/(L/100)^3$	166	166
$L/\nabla^{1/3}$	5.56	5.56
LCB, AFT OF MIDSHIP	12.30	12.30
L/D	7.26	7.26
L/B	4.80	4.80
HULL FORM - HARD CHINE		

See Table 2.3.5.2-1 for foil/strut system characteristics.

2.2.7 RIDE QUALITY (U)

(C) Riding qualities have been analized for the HYD-7 ship, at the pilot house, which is generally close to, if not the worst case manned area for accelerations because of its location being high and forward. The data is derived by the Boeing "LINSEA" program, a simplified linear simulation program for craft motions response. The configuration of the struts and foils and control surfaces are described in Section 2.3.5.2. The control system used for this study was the PHM-1 control system with the gains to the control surface modified only to account for changes in the hydrodynamic effectiveness of the control surfaces. At 70 knots the after flap gains were turned to zero. Figures 2.2.7-l and 2.2.7-2 show the rms vertical and lateral accelerations for 1/3 octave frequency bands as a function of encounter frequency and significant wave height for fully developed sea conditions as defined by the ISSC - Bretschneider spectrum*.

(C) Figures 2.2.7-3 and 2.2.7-4 present total RMS accelerations as a function of significant wave height at 50 knots and 70 knots.

(U) A discussion of the power required to provide the predicted ride quality is presented on the page of text following Figure 2.2.7-4.

(U) Figures 2.2.7-5 and 2.2.7-6 show the variation in total RMS vertical and lateral accelerations as a function of ship heading relative to the sea.

(U) Figures 2.2.7-7 and 2.2.7-8 show the distribution of vertical and lateral acceleration peaks for worst case headings for the 4 sea states requested. These data were obtained by taking a Rayleigh distribution with the rms acceleration value being the la value from which the distribution is developed.

C) Overall these data indicate excellent riding qualities will be provided by the HYD-7 even up to 6 meter seas (which is lower sea state 7). Even at

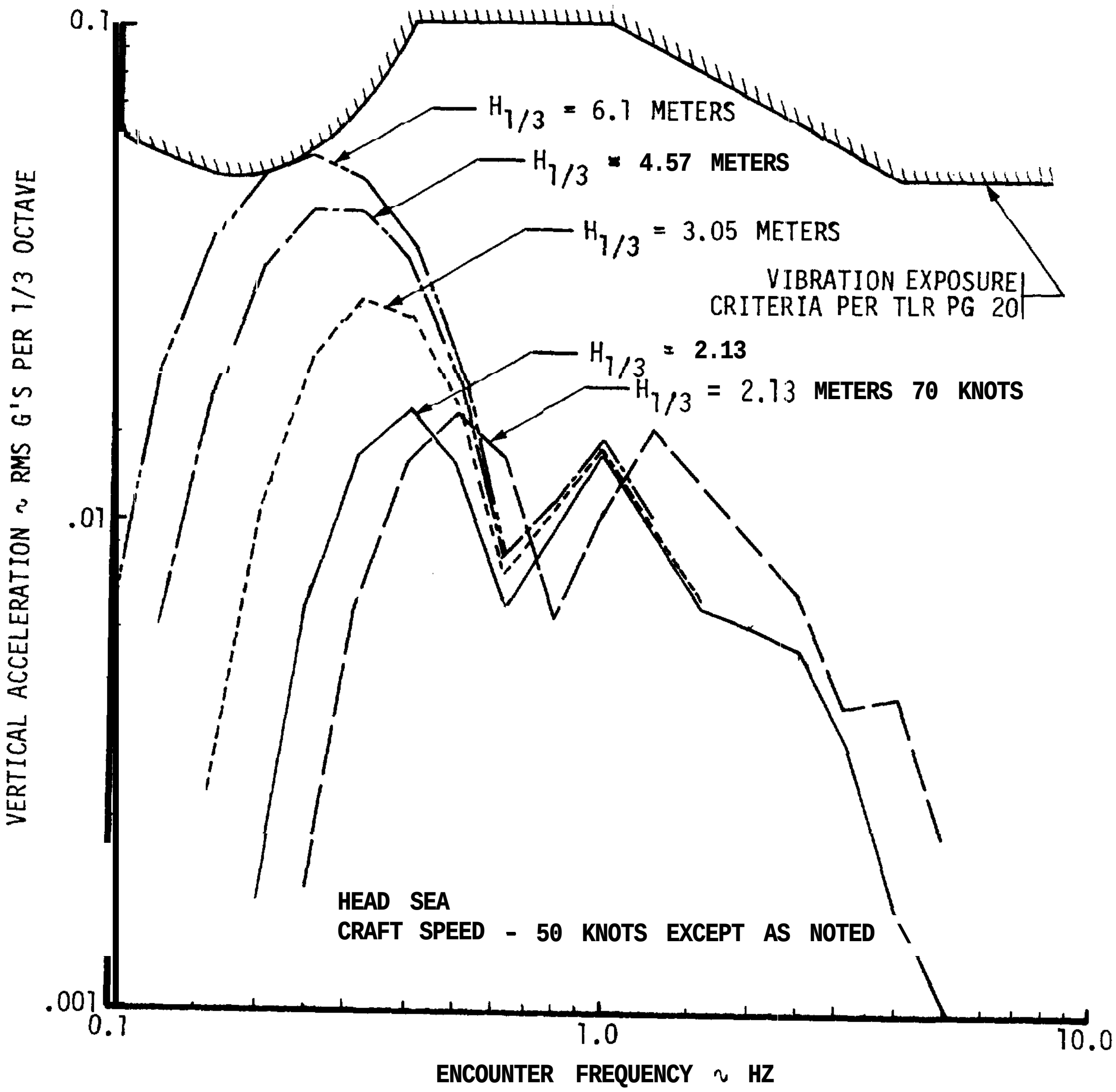
---

* The ISSC - Bretschneider spectrum is identical to the Pierson Moskowitz spectrum for the case of fully developed seas.

BOEING MODEL 1026-010

FIGURE 2.2.7-1

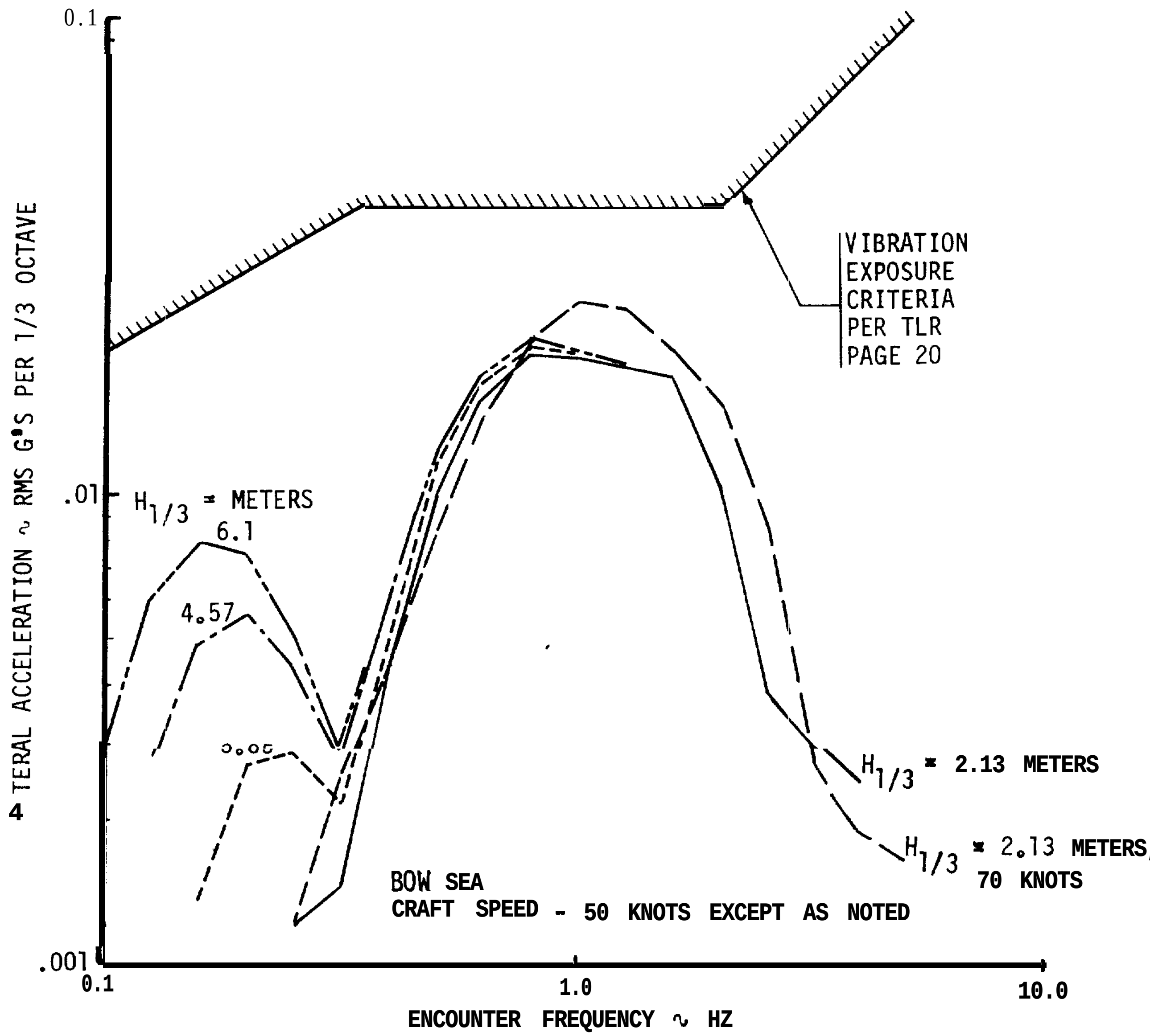
PILOT HOUSE VERTICAL ACCELERATION



BOEING **MODEL 1026-010**

FIGURE 2.2.7-2

PILOT HOUSE LATERAL ACCELERATION



BOEING MODEL 1026-010

FIGURE 2.2.7-3

EFFECT OF WAVE HEIGHT ON PILOT HOUSE VERTICAL ACCELERATIONS

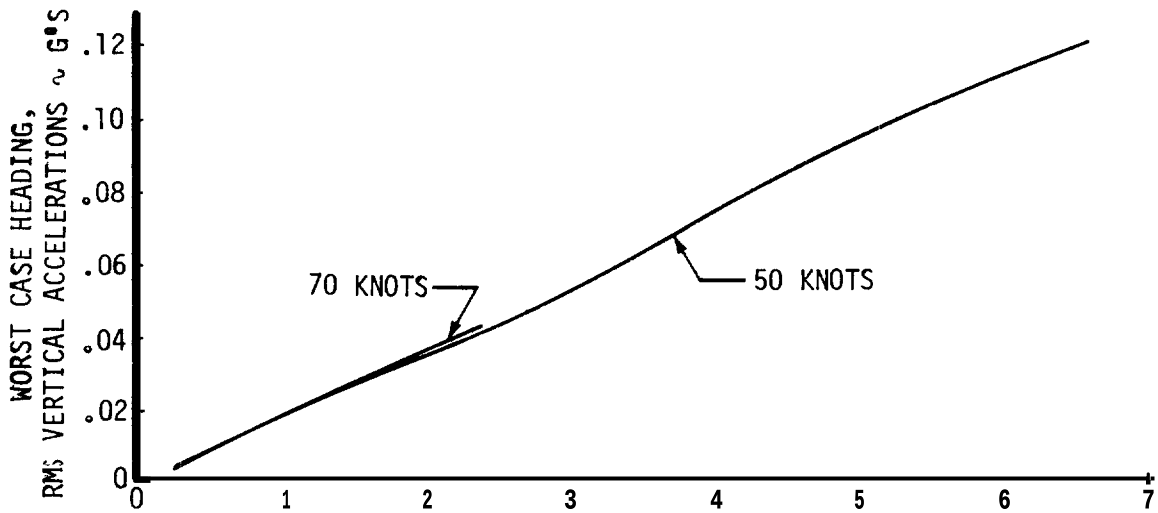
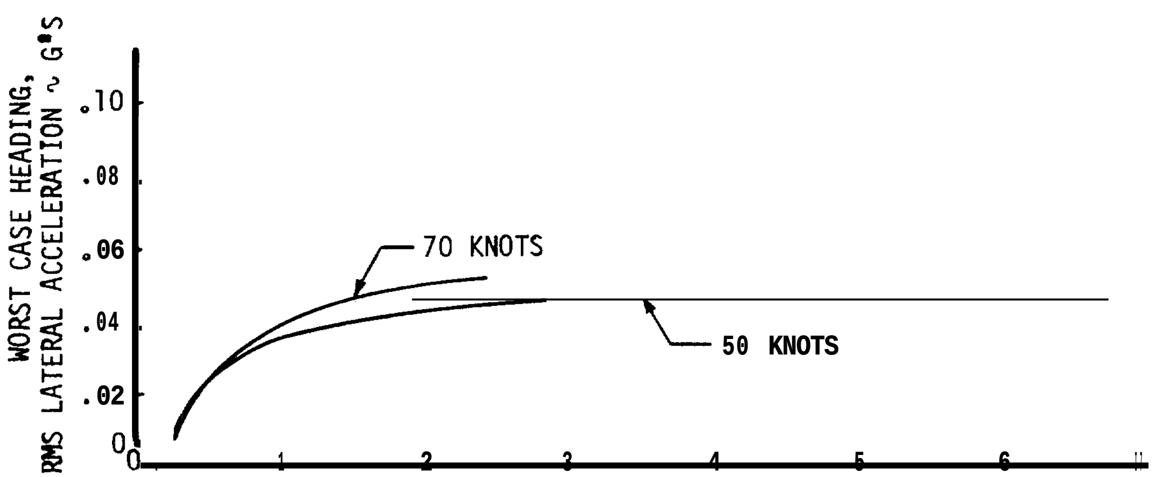


FIGURE 2.2.7-4

EFFECT OF WAVE HEIGHT ON PILOT HOUSE LATERAL ACCELERATIONS



(C) 70 knots the ride quality is excellent, which is as expected since in the supercavitating regime, the foil lift curve slope is much less than the slope in the subcavitating regime.

Power Required to Control Ride Quality (U)

(U) Estimates have been made of the maximum control power required to control the ride of HYD-7 to the levels presented above by extrapolating from subcavitating hydrofoil hardware and test data and considering the following:

1. Installed hydraulic power required increases as a function of ship displacement.
2. The variety of control surface types employed on HYD-7 (e.g. incidence control of forward foil, trailing edge flaps on aft foil in subcavitating mode and tipperons in supercavitating mode, etc.)
3. The significant increases in both dynamic pressure and frequency of encounter of disturbing seas at the higher maximum supercavitating design speed of HYD-7.

(C) The resulting estimates are as follows:

Total shaft horsepower installed in two completely redundant hydraulic systems......8120 SHP.

Ship Speed (Knots)	Operating Pressure (psi)	Maximum Flow Avail. (GPM)	Average Requirements Calm Sea (GPM)	(HP)	Design Sea (GPM)	(HP)
<50	4000	1060	15	190	172	620
>50	8000	1480	30	772	240	1730

BOEING MODEL 1026-010

FIGURE 2.2.7-5

PILOT HOUSE VERTICAL ACCELERATION VARIATIONS

WITH SHIP HEADING

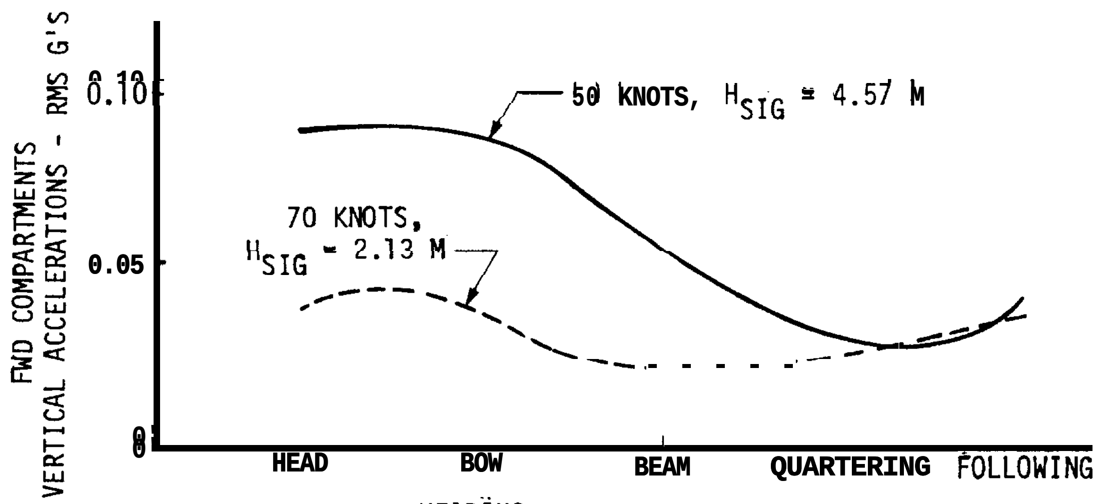
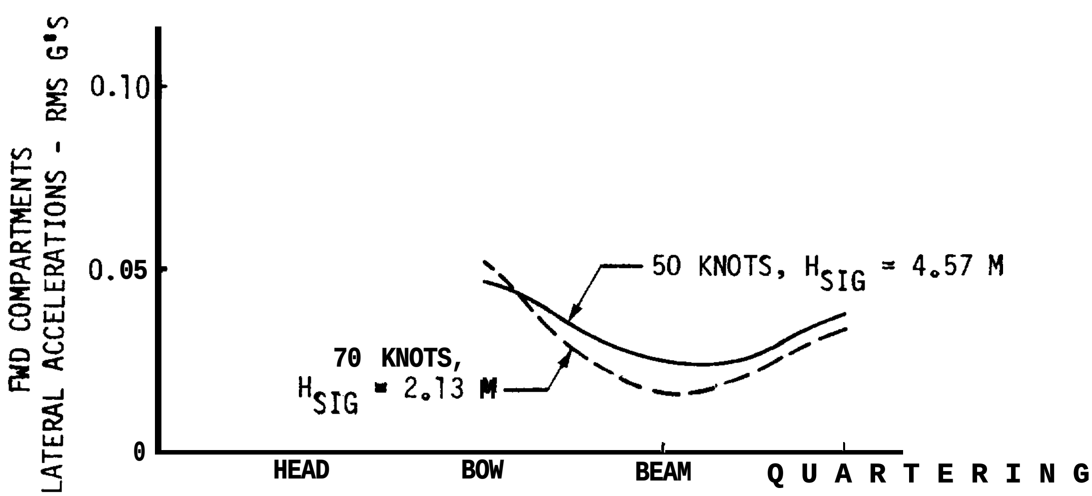


FIGURE 2.2.7-6

PILOT HOUSE LATERAL ACCELERATION VARIATIONS

WITH SHIP HEADING



BOEING MODEL 1026-010

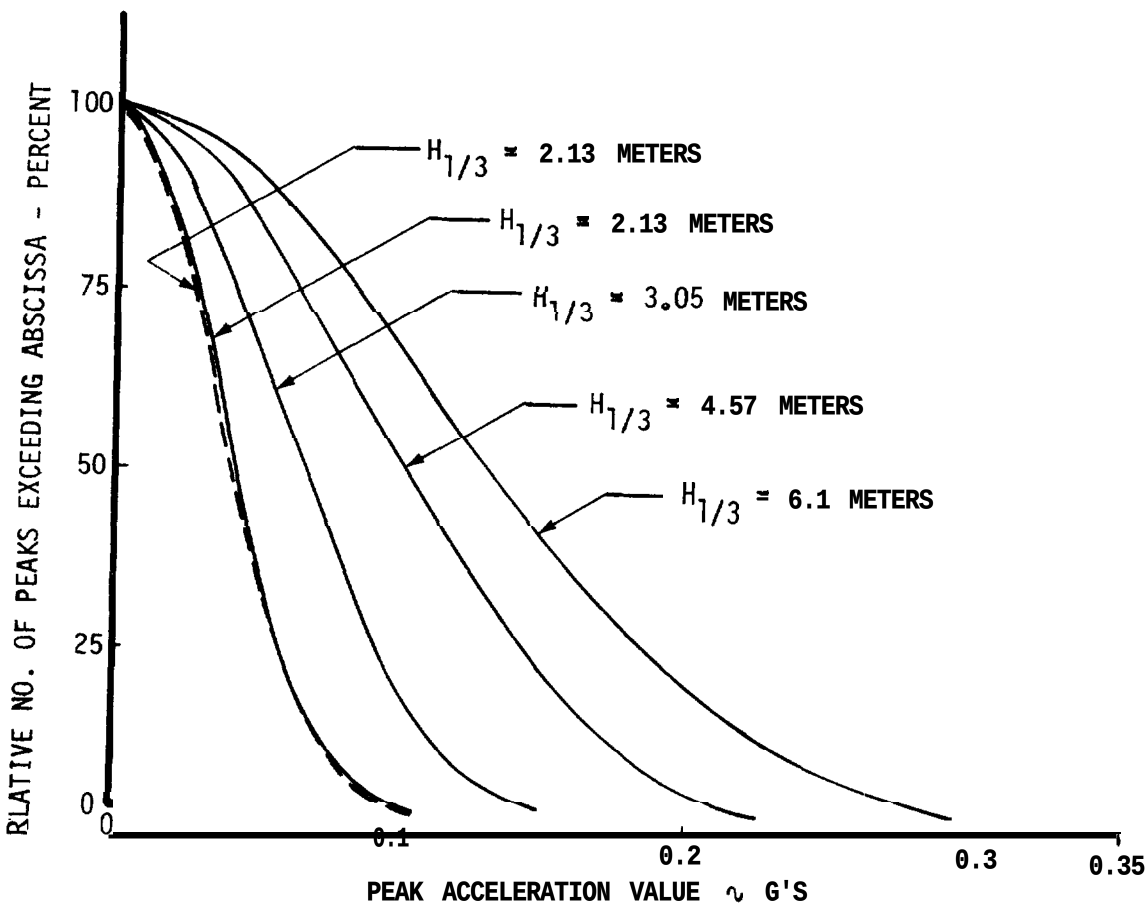
FIGURE 2.2.7-7

DISTRIBUTION OF VERTICAL ACCELERATION PEAKS

HEAD SEA OPERATION - PILOT HOIJSE

——— 50 KNOTS

---- 70 KNOTS



BOEING MODEL 1026-010

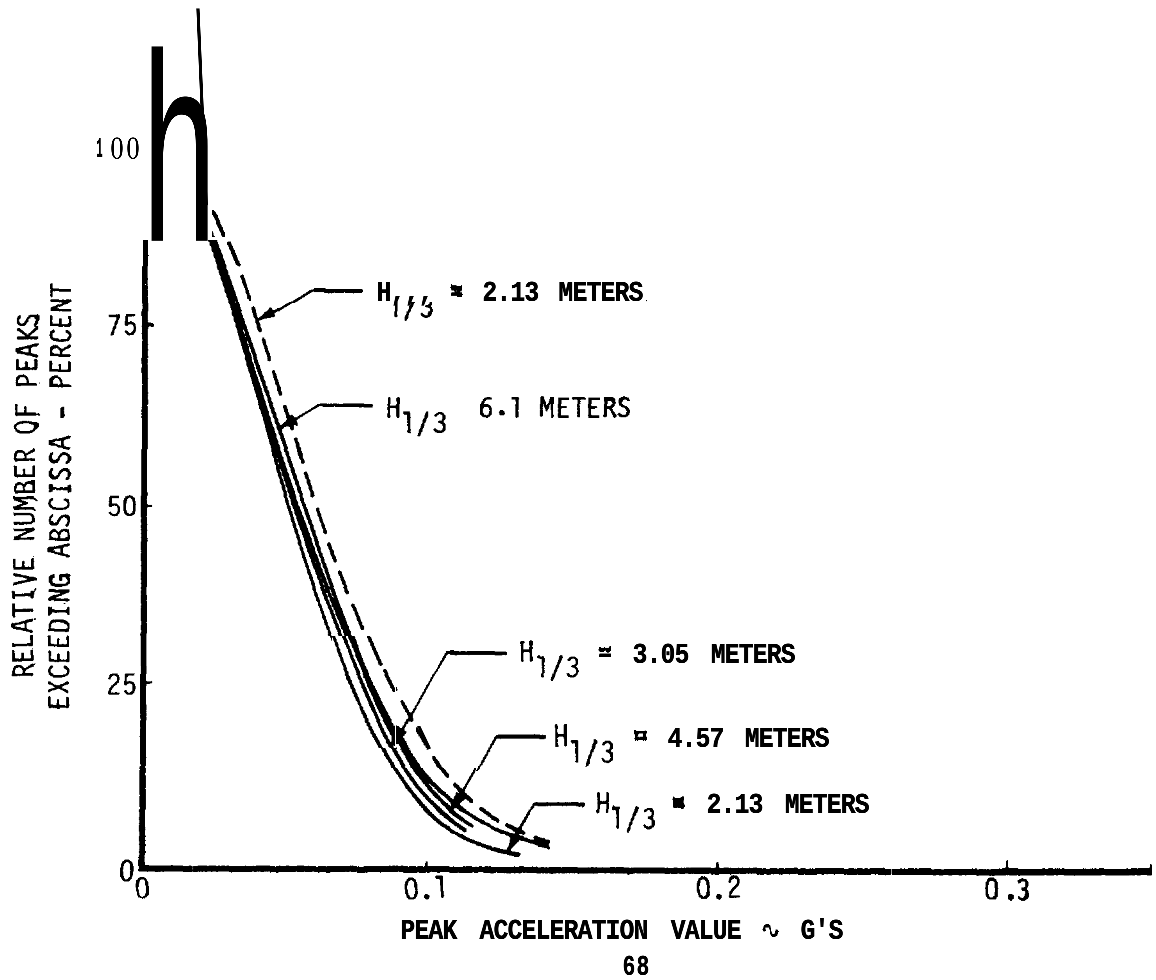
FIGURE 2.2.7-8

DISTRIBUTION OF LATERAL ACCELERATION PEAKS

BOW SEA OPERATION - PILOT HOUSE

——— 50 KNOTS

---- 70 KNOTS



2.2.8 **MANNING**

2.2.8(a) **GENERAL**

The manning concept for the HYD-7 is based on the requirements for manning Conditions I and III stations and on estimated maintenance and administrative requirements for the 1995 time frame. The following references were used in developing the manning concept:

(1) "The Essentially Manned Surface Combat System", NELC TD 428 of 1 May 1975
(2) "Manning Estimates for 700-ton and 2000-ton Hydrofoil Point Designs", NAVSEA 047C13 Serial 293 of 12 August 1976
(3) "Top Level Requirements for a 700-Ton Hydrofoil, ANVCE Point Design", 30 September 1976
(4) "Surface Vehicle Manning", ANVCE WP-014, 22 October 1976
(5) "ANVCE Surface Far-Term Point Design Manning", NAVSEA 032C Letter Serial 458 of 29 October 1976

Reference (5) gives a recommended manning of 79 total, with 5 officers, 4 CPO, and 70 other enlisted. Use of this total and category breakdown was directed by the advocate, although in-house studies indicated that 79 total with a category breakdown of 8-9 officers and 5-6 CPOs are required to man the HYD-7 more effectively.

Major considerations in the Boeing studies were ship missions, the required combat systems, the concept of the propulsion and auxiliary machinery plants, technology advances likely by the 1990-1995 period, and likely ship capabilities.

2.2.8(b) **HYD-7 MANNING**

Table 2.2.8-1 is a summary of projected manning requirements in the format prescribed by ANVCE WP-005, Revision A. Table 2.2.8-2 lists the Condition I operational station assignments. Table 2.2.8-3 lists the Condition III station assignments.

TABLE 2.2.8-1

PROJECTED MANNING HYD-7

OFFICERS

TITLE	RANK	CPO RATINGS	OTHER ENLISTED RATINGS		
Commanding Officer	LCDR	osc	1 QM1	1 EW1	2 MM2
Executive Officer	LT	FTMC	1 QM2	1 EW2	2 GS1
(Navigator)		STGC	1 QM3	1 EW3	2 GS2
Ship Control Officer	LTJG	GSC	1 QMSN	1 STG1	2 GS3
Combat Systems Officer	LT		1 BM1	3 STG2	1 EN1
Engineering Officer	LT		1 BM2	2 STG3	1 EN2
			2 BM3	1 STGSN	2 EM1
			3 BMSN	1 TM2	1 EM2
				1 TM3	
			1 RM1	1 FTM1	1 EM3
			2 RM2	1 FTM2	1 IC2
			2 RM3	1 FTM3	1 HT2
			2 RMSN	1 GMM2	1 YN2
			1 OS1	1 ET1	1 HM1
			4 OS2	1 ET2	1 SK1
			3 OS3	1 DS1	1 MS1
			2 OSSN	1 DS2	1 MS2
					1 MS3
Totals	5	4		70	

GRAND TOTAL: 79

TABLE 2.2.8-2

OPERATIONAL STATION ASSIGNMENT - HYD-7

Condition I

Station	Assignment
Commanding Officer	LCDR
Ship Control Station	
Officer of the Deck (OOD) (Ship Control Officer)	LTJG
Helmsman/Lee Helmsman (Ship Control Console)	BM1
Navigation Bridge	
Asst. Navigator/Junior OOD	QM1
P.O. of the Watch/Quartermaster/Signals	QM2
Quartermaster/Signals	QM3
Quartermaster/Signals	QMSN
Lookout	BMSN
Lookout	BMSN
Combat Information Center	
Tactical Action Officer (TAO Console) (Executive Officer)	LT
Combat System Configuration Coordinator	DS1
Surface Supervisor	OS1
Surface Search Radar Operator	OS3
Air Intercept Controller	osc
Asst. AIC	OS2
Air Search Radar Console (TAS MKXX)	OS3
Air Detector/Tracker	OSSN
Fire Control Engagement Controller (FCEC) (Combat Systems Officer)	LT
AAW/EC (Self-Defense Missiles)	FTMC
ASW/EC (MK48/ASW Standoff Missiles)	STGC
SUW/EC (Harpoon)	FTM1

TABLE 2.2.8-2 (Contd)

TWS Radar Operator	OS2
RPV Operations Control	OS2
RPV Pilot	OS3
Sonar Supervisor	STG1
Sonar Operator (Acoustic Console #1)	STG2
Sonar Operator (Acoustic Console #2)	STG2
EW/EC	EW1
ASMD/EW Console	EW2
EW Operator	EW3
<u>Communication Central</u>	
Supervisor	RM1
ACCS Operator	RM2
NAVMACS Console Operator	RM2
Radio Circuit Operator	RM3
Teletype Operator	RM3
Reproduction/Distribution	RMSN
<u>RPV Control</u>	
RPV Controller (Launch/Land)	OS2
RPV Handling, Assembly and Checkout	OSSN
<u>Sonar Launch Control</u>	
Sonar Winch Operator	STG3
Sonar Sensor Handling	STG3
<u>Electronic Casualty Control</u>	
Repair Supervisor	ET1
Radar System	FTM2
Comm. Systems	ET2
IC/Gyro	IC2
Sonar	STG2
Computing Systems	DS2

TABLE 2.2.8-2 (Contd)

Engineering and Damage Control	
Engineering Officer (EOS)	LT
Propulsion and Auxiliary Control (EOS Console)	GS1
Electrical Control (EOS Console)	EM1
Damage Control Assistant (EOS)	GS2
Main Propulsion Space	GS2
Hullborne Propulsion Space	GS3
Auxiliary Machinery Space	MM2
Forward Diesel Generator	EN1
After Diesel Generator	EN2
Forward Distribution Board	EM2
After Distribution Board	EM3
Repair Party No. 1	
Leader/Talker	GSC
Scene Leader	BM2
Investigator/OBA	BM3
Nozzleman/OBA	TM2
Hoseman #1	GMM2
Hoseman #2	YN2
Machine Repair/Stretcher	HT2
Electrical Repair/Stretcher	EM1
Repair Party #2	
Leader/Talker	GS1
Scene Leader	MM2
Investigator/OBA	BM3
Nozzleman/OBA	BMSN
Hoseman #1	FTM3
Hoseman #2	TM3
Machine Repair/Stretcher	GS3
Electrical Repair/Stretcher	RMSN, STGSN

TABLE 2.2.8-2 (Contd)

Medical Treatment	
Corpsman	HM1
Emergency Supply	
Issue	SK1
Battle Messing	
Food Preparation	MS1
	MS2
	MS3

Condition I Summary

5 Officers
74 Enlisted
79 TOTAL

TABLE 2.2.8-3

OPERATIONAL STATION ASSIGNMENT - HYD-7

Condition III

Station	Assignment
SCS	
Officer of the Deck (OOD)	LT/LT/LTJG
Helmsman/Lee Helmsman	BM1/BM2/2 BM3
Navigation Bridge	
Petty Officer of the Watch/QM/Signals	QM2/QM3/QMSN
Lookout	3 BMSN
Combat Information Center	
Tactical Action Officer (TAO)	OSC/FTMC/STGC
Surface Search Radar Console (APS116 Console)	OS3/OS3/OSSN
Air Search Radar Operator (TAS MKXX Console)	OS1/OS2/OS2
AAW/EC	FTM1/FTM2/GMM2
TWS Radar Operator	FTM3/ET1/ET2
ASMD/EW Console	EW1/EW2/EW3
RPV Control/Pilot (When RPVs airborne)	OS2/OS2/OS3
Sonar Console	STG2/STG2/STG2
Communications Central	
ACCS/NAVMACS Operator	RM2/RM2/RM3
Teletype Operator	RM3/RMSN/RMSN
Sonar Launch Control	
Winch Operator	STG3/STG3/STGSN
Engineering Operating Station	
Propulsion/Auxiliary Control	GS1/GS2/GS2
Electrical Control	EM1/EM1/EM2
Machinery Monitor/Security Patrol	EM3/MM2/EN2

TABLE 2.2.8-3 (Contd)

Condition III Station Summary

18 Stations

3 Officers

52 Enlisted*

*NOTE: 4 watchstanders required for 3-hour watch on helm

2.2.8(b)(l) PERSONNEL FUNCTIONS - CONDITION I

Ship Control

The HYD-7 is expected to be designed with a Ship Control Station (SCS) (Pilot House) above a Navigation Bridge (NBR). The SCS has almost 360 degree visibility and is designed to accommodate only a few people. It contains all the necessary instruments and equipment to maneuver the ship and control the engines, plus a display of tactical, navigation, and the necessary amount of collision avoidance information. The SCS is the Condition I watch station for the Officer-of-the-Deck (OOD) and the helmsman.

The Navigation Bridge directly below is much larger and its wings extend to the side of the ship. The NBR is not fitted with engine and attitude controls but should have heading, speed and height indicators. It can also have a more sophisticated tactical and navigation display than the SCS. The NBR will be fitted with periscopes for visual lookouts and for taking true and relative visual bearings. The bridge wings will be fitted with peloruses. A chart table or chart display will be installed, and position indicators from GPS or other sources. The NBR is the Condition I station for the Junior Officer-of-the-Deck (JOOD), two lookouts and quartermasters. The JOOD (QM1) performs tactical navigation, supervises visual communications and topside operations, and conducts the ship routine during Condition I.

The Navigation Bridge and the SCS are stations for the Commanding Officer during Condition I if he desires to leave the CIC, which is considered his primary station. Ship design is such that the NBR or SCS are readily available to him.

During Condition III, the OOD and helmsman are in the SCS and there is no JOOD. The quartermaster and one lookout are on the NBR in Condition III.

This arrangement and organization have the advantages of:

(1) 360" visibility in the SCS

(2) Requiring no additional personnel

(3) Reducing most Condition I and III noise in the SCS.

(4) Allowing the SCS to be small and compact with very few Condition I stations

(5) Allowing ample room for the added numbers of people for Condition I to be accommodated in the larger NBR.

(6) Ready access between CIC, NBR and SCS with CIC directly aft of NBR.

(7) The NBR provides room for a Unit Commander (if embarked) and separates him from the SCS.

This arrangement has the modest disadvantage of requiring the slightly additional weight and space of the SCS structure and instrumentation half a deck higher in the ship. Another disadvantage is slight added cost. Communications difficulties are not foreseen between the SCS and NBR.

Combat Direction System

Under the Tactical Action Officer (TAO) the combat organization may be organized into four groups. These are:

Air and Surface Section

This group is responsible for the operation of the TAS Mod XX air search radar, identification of air and surface vehicles, APS 116 surface and low altitude search radar, air and surface detection and tracking, air control, electronic warfare, RPV operations, and such navigation and tactical support as is required. The Chief Operations Specialist is in charge and is the Air Intercept Controller. He is assisted for surface operations, tactics and navigation by 2 Operations Specialists. He is assisted for air target detection, identification, tracking and air intercept by 3 Operations Specialists. He is assisted for RPV operations in the CIC by 2 Operations Specialists, and is assisted for electronic warfare by 3 Electronics Warfare Specialists who operate passive and active EW equipment. 2 Data Systems Technicians provide assistance with data processing operations in the tactical data system, one as Combat System Configuration Coordinator and one for casualties. The Air and Surface Section checks automatic detection and data link information in the tactical data system and correlates such information with electronic warfare data. The Air and Surface Section supports the TAO, Subsurface Section and Weapons Section.

Subsurface Section

This group, under the Sonar Supervisor, is responsible for the operation of all sonars, detection, classification and tracking of subsurface targets. The Sonar Supervisor is assisted by 4 Sonar Technicians; two operate sonar winches, and two are sonar operators for the four sonars. Since the sonars are such that it is unlikely that all four will be operating at the same time, each sonar operator can control up to two sonars (interchangeably) at each control and display console. This section operates underwater communications with friendly submarines (Sonar Supervisor). The section supplies underwater target data to the ASW Engagement Controller, who controls the ASW weapons. The Sonar Supervisor controls launch of ERAPS either over the side or with rockets. Launch and retrieval of APRAPS or the Active/Passive Towed Array with Depressor will be accomplished by 2 Sonar Technicians stationed at the sonar winch location under the orders of the Sonar Supervisor. All men in this section will be cross-trained as sonar operators so that reliefs for sonar operators can be provided in both Conditions I and III. An additional Sonar Technician is assigned for repair in the Electronic Casualty Control Group.

Weapons Section

This group, under the Combat Systems Officer (Fire Control Engagement Controller), is responsible for control of all weapons. The FCEC has one Engagement Controller (EC) each for AAW, ASW, and SUW. The AAW EC controls the vertically launched Advanced Self-Defense Missile. The ASW EC controls the MK 48 torpedo and the Advanced Stand-off ASW Weapon. The SUW EC controls HARPOON. The Weapon Section also controls the TWS radar. Battle reloading is not required for any weapon. The full load of weapons is carried in cell-type launchers, ready for firing. The Combat Systems Officer controls the launch and reload of Super RBOC and IR decoys. This section coordinates directly with the Electronic Warfare men for detection information.

Communications

The communications organization headed by the Ship Control/Communications Officer, supports the TAO, the remainder of the combat system and the Commanding Officer in all the functions of exterior communications. He will be assisted by 6 men qualified as operators, and one Electronics Technician available for repairs. During Condition I the tactical communications circuits may be expected to expand to the full limit of the ship's capability and a large portion of the effort will be devoted to satisfying the requirements of the remainder of the combat organization through satellite and other channels. Support will be rendered to the combat organization in achieving full effectiveness and readiness for data links installed. Condition I visual communications will be under the direct control of the Junior Officer of the Deck and carried out by quartermasters on the bridge with administrative support of the communications organization. With the amount of increased automation and complexity to be expected in naval communications by 1995, it is believed that a team of seven can adequately handle expected HYD-7 radio communication requirements.

Engineering and Damage Control

The Engineering Operating Station (EOS) (also Damage Control Center) is manned during Condition I for engineering with the Engineering Officer, Propulsion/ Auxiliary and Electrical Controllers. The Engineering Officer observes the action of these personnel and the status of the propulsion and auxiliary machinery. As Damage Control Officer, he controls the Repair Parties and supervises the actions of the Damage Control Assistant who is stationed at the damage control console in the EOS and is in communication with the two Repair Parties.

The Engineering Officer is a trained OOD, and is available as a backup for the Ship Control Officer as Condition I OOD. The Engineering Department has 17 enlisted men, capable of operation and routine maintenance and some emergency repair of propulsion, auxiliary, and electrical equipments.

Repair Parties

All the personnel (less Mess Specialists) remaining after other Condition I stations are manned will be stationed in two Repair Parties. While this group will contain the elements necessary for conventional repair parties for damage control purposes, it is also a group on a small ship from which personnel can be drawn for functions other than damage control. These functions are discussed below under Utility Task and Evaluation Manning.

2.2.8(b)(2) PERSONNEL FUNCTIONS - CONDITION III

A total of 18 stations are manned in Condition III with 55 men. One added man is allowed to reduce the helmsman watch to two hours on, six off or three on, nine off, as desired. Stations manned are (Table 2.2.8-2):

Station	Location
OOD	SCS
Helmsman	SCS
Petty Officer of the Watch	NAV. BRIDGE
Lookout	NAV. BRIDGE
TAO	CIC
Surface Search Radar (APS 116)	CIC
Air Search Radar (TAS MK XX)	CIC
RPV Control	CIC
Sonar Operator	CIC
Sonar Winch Operator (APRAPS)	Sonar Winches
AAW EC	CIC
TWS Radar Operator	CIC
EW Operator	CIC
ACCS/NAVMACS Operator	Radio
Teletype Operator	Radio
Propulsion/Auxiliary Control	EOS
Electrical Control	EOS
Machinery Monitor/Security Patrol	Machinery Plant

All officers except the Commanding Officer and Executive Officer stand OOD watch. Enlisted non-watch standers remaining are available for additional watches (such as relief or additional lookouts).

During Condition III, the TAO on watch, the AAW EC and the TWS radar operator will handle surprise air attack. Surface weapon firings will not normally be required before Condition I has been set, with Condition III personnel making preparations to launch missiles. In event of a surprise close submarine contact as at the end of a sprint tactic, the Condition III watches must be capable of firing a torpedo.

If the Towed Array Sonar is being used during Condition III instead of APRAPS, two men will be required at the sonar winch instead of one during launch and retrieval. One man is sufficient to monitor the Towed Array while it is deployed.

2.2.8(c) ADMINISTRATIVE ORGANIZATION

Figure 2.2.8-1 shows the Projected Ship Organization. The ship is organized with three departments and one division as shown. Each Department has an officer head and the Support Division is additional duty for the Ship Control Officer. The Executive Officer is the Navigator and is assigned the QM1 as Assistant Navigator.

The manning requirements indicate a relatively highly rated enlisted complement compared to conventional ships. This is necessary because of the complexity of the ship and the need for an increased level of experience and competence in a ship in which reduced manning level is vital to ship performance as a whole. With the manning level indicated, cross-training will be required. Depth of personnel in the various ratings is such that illness or incapacitation of one man will not reduce ship capability. As an example, even though the torpedo workload will not be high, 2 TMs are in the complement. Since only one IC is allowed, at least one EM should receive gyro/inertial navigation system training.

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PROJECTED SHIP ORGANIZATION

PERSONNEL TOTALS
5 OFFICERS
4 CPO
70 OTHER ENLISTED
79

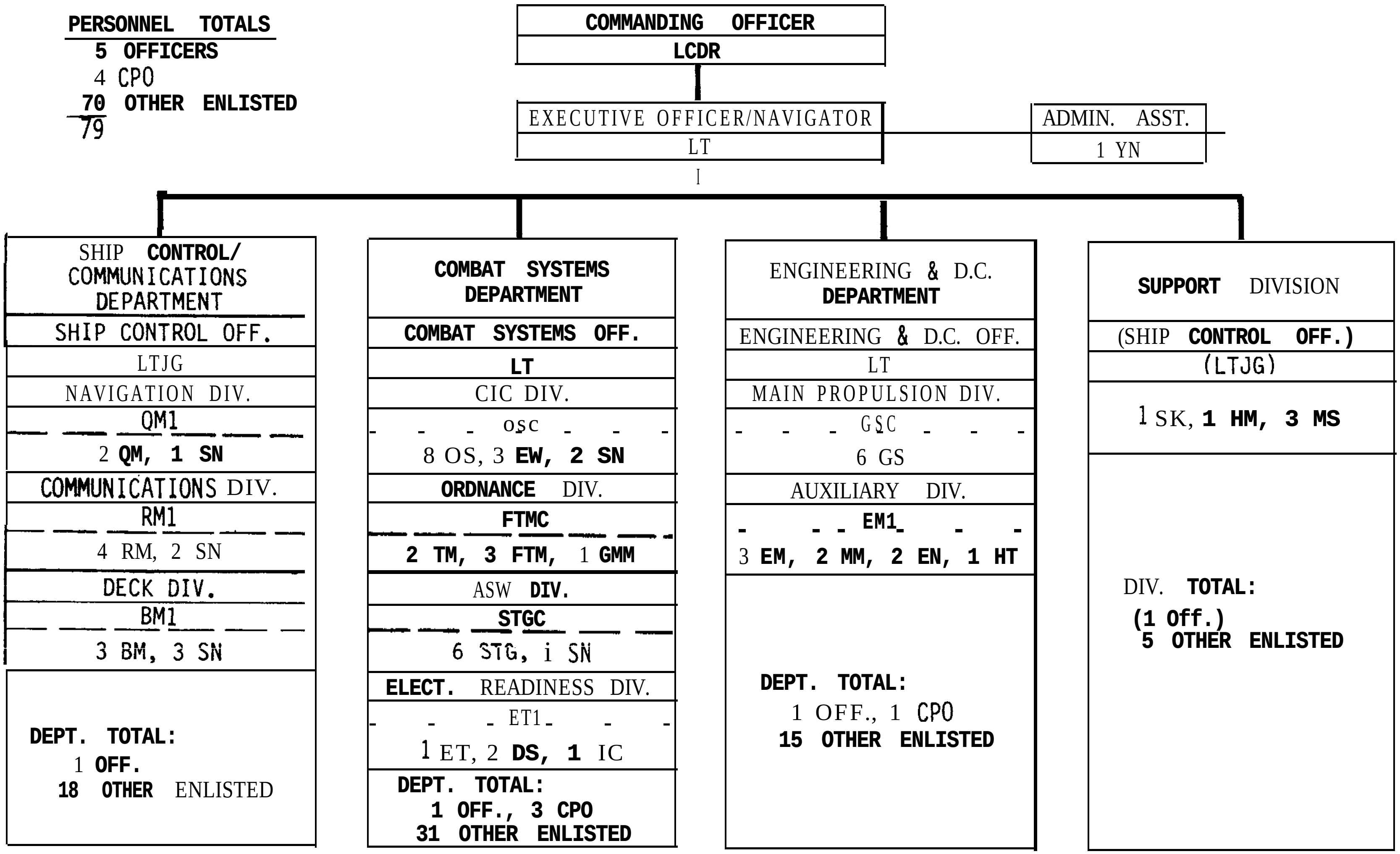

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FIGURE 2.2.8-1

2.2.8(d) UTILITY TASKS AND EVOLUTIONS (UT&E) MANNING

Some functions are irregular enough not to demand full time stationing of crewmen during Conditions I and III. Since some of these functions are top-side, it may be inadvisable and impractical to station men topside for these functions. Stationing them below deck in Condition I (as in the Repair Parties) in organized groups available for performance of these functions as required provides good control during Condition I and provides a ready source of cross-trained manpower in Condition III.

With Condition I set, a total of 16 men are available in the Repair Parties to handle UT&E. With Condition III set, a total of 52 enlisted non-watch-standers and men off watch are available for scheduled or non-scheduled evolutions which the men on watch cannot handle. Two off watch officers and the Executive Officer are available to supervise scheduled or non-scheduled evolutions in Condition III.

UT&E which can be performed are:

(1) Launching over-the-side ERAPS and expendable bathythermographs.

(2) Reloading rocket-thrown ERAPS.

(3) Reloading SRBOC and IR decoys.

(4) Launching deployed linear arrays.

(5) Recovering deployed linear arrays. (During this operation, the Repair Party may require the help of other personnel temporarily released from Condition I stations.)

(6) Assisting RPV launch and recovery.

(7) Refueling airborne helicopters from other ships (Not a TLR requirement at present)

(8) Emergency transfer of stores or personnel by VERT/REP during Condition I as required.

(9) Assistance to sonar handling personnel as required in event of casualty to dipped or towed sonar sensors.

(10). Assistance in repair of engineering machinery as required.

(11) Jettisoning of dud weapons as required.

(12) Assistance in feeding on station as required during long periods of Condition I.

(13) Underway replenishment.

(14) Special Sea and Anchor Detail.

(15) Search and Rescue Operations involving the ship's boat or swimmers.

Launch and reload of ERAPS buoys and expendable bathythermographs will be accomplished by cross-trained members of the Repair Parties in Condition I. For Condition III circumstances where ERAPS might be used, a special ERAPS Condition III watch could be set up from these cross-trained personnel. Launching and recovering deployed arrays will be a special evolution accomplished as ordered by personnel normally assigned to the Repair Party in Condition I, whenever launch or recovery is necessary. Temporary release from station of other Condition I personnel may be required for this operation. The same concept applies to Super RBOC and IR decoys.

The RPV system requires UT&E manning during launch and retrieval. Four or five men in addition to the OSs assigned for control should be sufficient to rig launch and retrieval equipment and to assist in RPV handling. Services of an MM or EN may be required if RPV engine difficulties arise. After launch, an RPV Condition III watch is required in CIC for control of the RPV. Since RPVs may be kept continuously airborne during Condition III, this watch may be considered a continuous Condition III requirement. While RPVs are airborne, although not listed as a Condition III requirement, an OS to man the deck RPV Control and a retrieval team must be in a standby condition ready for immediate service.

The operational employment of APRAPS will be intermittent but the nature and timing require a Condition III winch watch for APRAPS operations. Assistance to this watch may be necessary in some conditions. Use of the Towed Array Sonar watch will not usually be intermittent in Condition III, and may require added manpower in event of casualty. In Condition I, this sonar may require intermittent use and assistance in event of casualty or heavy sea states. Use of the Deployed Linear Arrays will be intermittent during either Conditions I or III and will require UT&E manning. APRAPS and the Towed Array will not be used simultaneously and normally neither will be in the water when the Deployed Linear Array is launched or retrieved.

2.2.8(e) MAINTENANCE/SUPPORT MANNING

The overall maintenance and support concepts for the HYD-7 include routine preventive and limited corrective maintenance as well as minimal administration/support to be provided by ships company. The ship system design will incorporate provisions which will maximize equipment utilization and minimize requirements for at-sea maintenance. Repair, maintenance, and administration/support back-up is required of tenders, repair ships, and advanced bases while deployed and from tenders and shore based intermediate maintenance facilities while in CONUS.

Organizational maintenance will be generally limited at sea to completion of required scheduled Preventive Maintenance (PM) and emergency Corrective Maintenance (CM) actions necessary to keep mission essential equipment in a ready condition. Systems/equipment will be of modular design which can be repaired by fault isolation and replacement of defective assemblies/modules. A limited supply of spare parts will be carried on board.

Normal Fleet tenders or designated land-based activities will serve as Intermediate Maintenance Activities (IMAs). Organizational level PM and CM outside of the at-sea maintenance concept will be completed by IMA maintenance personnel, with the assistance of the ship's crew. Also, normal IMA level facilities and support will be provided. Maintenance actions beyond the capability of the IMA will be accomplished at the depot level.

Administration/support back-up is also required of the support facility since

HYD-7 will not be self-sufficient in these areas. This includes such items as maintaining personnel service records and pay accounts, administrative support, supply, hygienic, food supplies, and ship's service support.

Maintenance manning projections have been determined within the guidance of the stated maintenance concept and the configuration of the ship's systems and equipments. The 3-M System will be applicable to the HYD-7 and those maintenance actions with a frequency of Daily (D), Weekly (W), and selected As Required (R) actions will be accomplished by the crew while at sea.

'Given these constraints, maintenance manning considerations necessitate that maintenance ratings be included in the ship's enlisted complement to accomplish required PM during the 15-day mission. The requirements for the capability to accomplish urgent repairs (corrective maintenance) also influences maintenance manning considerations.

Facility Maintenance (FM) manning has been considered only to the extent that routine daily housekeeping tasks can be accomplished during the 15-day mission. Thorough cleaning and major painting/preservation will be accomplished in port with the assistance of the assigned support activity.

Using empirical data furnished by the Naval Ship Research and Development Center, Table 2.2.8-4 - Maintenance Manning Analysis, indicates that the HYD-7 crew should be capable of performing 3-M maintenance while at sea. Table 2.2.8-4 assumes no maintenance is performed by the officer complement. An increase of the officer complement to 8 with a reduction of 3 enlisted men should be viable, since additional officers will allow some maintenance work to be performed by officers, usual for small ships.

In this study, automation to the degree described in the Combat Data System Sheets for the combat system was used in estimating combat system maintenance manning. The general impact on combat system manning is estimated as a reduction of manpower required over systems not produced with built-in

TABLE 2.2.8-4

MAINTENANCE MANNING ANALYSIS - HYD-7

Maintenance Manhours Required Per Week:

	M.M. HRS.
Facility Maintenance (Enclosed Volume 180,000 ft^3)	250
Preventive Maintenance	
Mechanical (from Gr. 2,3,5,7) (242 LT)	238
Electronics (from Gr. 4) (43 LT)	72
Corrective Maintenance	
Mechanical (½ PM)	119
Electronics (PM)	72
MR/PA = .3 (PM_{MECH} t PM_{ELEX})	93
UT&E Estimate (PHM Baseline - 41 M.M. Hrs.)	100
Administration and Support (from total manning) (79)	510
Total M. M. Hrs/Week	1454

Maintenance Manhours Available:*

Enlisted Watchstanders - 11.25 Hrs./man/Wk x 55 men	618.75
Enlisted Non-Watchstanders - 50 Hrs./man/Wk x 19 men	950.00
Total M. M. Hrs/Week	1568.75

* Manhours available include allowances for Service Diversions and Training of 4.5 hours for watchstanders and 6.0 hours (with a 20% Productivity Allowance) for non-watchstanders.

maintenance monitoring. For other systems where system description similar to the Combat System Data Sheets was not provided, it was estimated that a medium degree of automated maintenance monitoring systems would be available as built-ins by 1990 and would reduce maintenance manning requirements over that required for current and past systems which have not had such systems.

The effect on manning of centralization of administrative and maintenance facilities was not studied in this feasibility study.

Design Work Studies were not performed for the point design because of the nature of this feasibility study, the authorized effort, and time limitations.

2.3 SHIP SUBSYSTEM DESCRIPTIONS

The capabilities of the vehicle in terms of its performance and overall features are provided in Section 2.2. This section of the Point Design Description is restricted to internal subsystem descriptions. The descriptions include narrative, tables, concept feasibility schematics and drawings. The order and format of presentation are in accordance with ANVCE WP-005.

2.3.1 HULL STRUCTURE

General

The HYD-7 has a hull form basically similar to the PHM and the 1400 ton HOC. The hull structure typical scantlings were calculated from the Boeing developed HANDE computer program, Reference 2.3.1-1 based upon the criteria of Reference 2.3.1-2.

Hull Structure

The hull will be designed to resist hullborne and foilborne girder bending loads, hydrostatic loads while operating as a displacement craft and loads resulting from foilborne wave impact. Structural bulkheads are designed to withstand a static head of water to the main deck and in areas where the bulkheads provide boundaries for the fuel tanks, the structural members are designed for static and dynamic liquid loads. In addition, bulkheads are designed to support longitudinal framing loads resulting from foilborne wave impact. Figure 2.3.1-1 is a structural arrangement of the HYD-7 hull.

The HYD-7 hull is an all-welded structure of 5456 aluminum alloy sheets, plates and extrusions, with a minimum gage of 1/8 inch (3.175 mm). See Figure 2.3.1-1 for location of material thickness.

Hull bottom plating is designed for permanent deformation normal to the plate of 1.25 mm (.005 inch) per 25.4 mm (1.0 inch) of stiffened spacing.

Shell and Supporting Structure

The shell and framing were designed as shown on typical structural section of Figure 2.3.1-2.

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BOEING MODEL 1026-010

HULL STRUCTURAL ARRANGEMENT

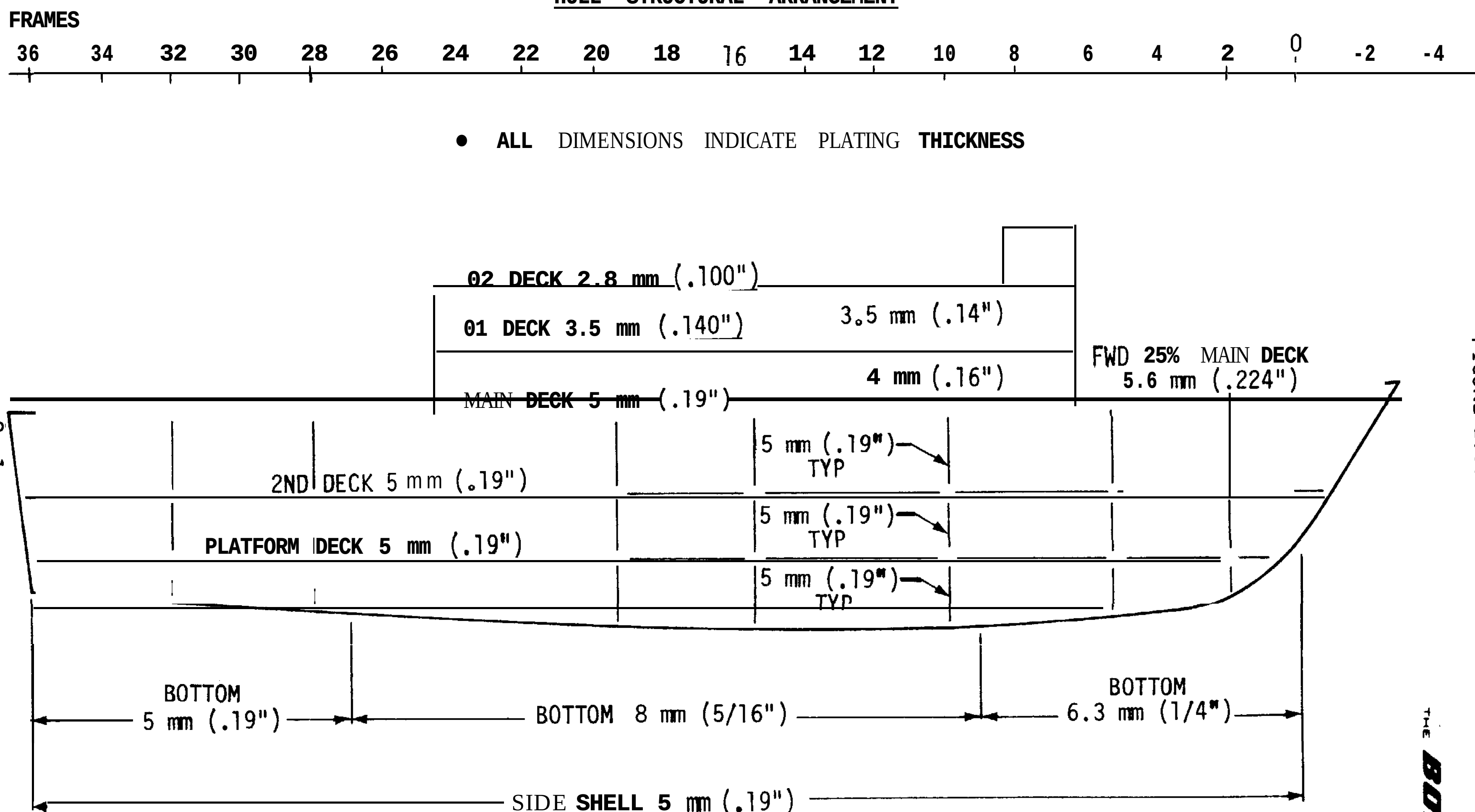

FIGURE 2.3.1-1

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Transverse frames are spaced on 1524 mm (5 feet) centers, in the interests of economical hull construction although lighter structure is possible with a decrease in frame spacing.

Plate and extruded "tee" stiffener combinations are used on the hull to permit tailoring of shell and framing to the design pressure maximum.

Side keelsons extend parallel to the keel at 2438.4 mm (8 feet) buttock lines. The keelsons utilize builtup "tee" sections welded to the plating and are continuous through transverse structure.

Shell longitudinal stiffeners like the keelsons are continuous through transverse structure.

Structural Bulkheads and Closures

Bulkheads utilize extruded "tees" welded to plates installed with the framing members, and placed vertically and in line with the main deck, second deck and platform deck stiffeners. Fuel tank ends utilize extruded tee section stiffeners welded to plate.

Decks and Platforms

All three decks utilize plates with longitudinal stringers. Transverse deck beams located on 1524 mm (5 feet) centers are supported by main deck girders and hull side frames. The girders are built-up "I" beams located on 2438 mm (8 feet) buttock lines. The upper flange of the girder is an insert plate welded into the deck.

Ballistic Protection

The HYD-7 TLR, Reference 2.3.7-1, Section 2.4.3, requires that ballistic Protection be provided for vital components.

Figure 2.3-i-3 depicts the selected location for ballistic protection material on HYD-7. Table 2.3.1-1 provides a listing of the dimensions of protected vital areas and ballistic protection material weights utilized for the

calculations resulting in a 21 L. ton total for HYD-7.

Technical Risk Areas

The general type of aluminum structural arrangement shown for the HYD-7 is achievable and is now being produced for hydrofoil craft such as PHM and the Boeing JETFOIL, but the increased foilborne speed of the HYD-7 causes some concern regarding the validity of the bottom impact design pressures and hull loads in general. There is no previous experience of conventional monohulled hydrofoil craft operating in that speed regime and confirmation of the impact loads would be needed before a final hull design is originated to preclude stress and weight growth problems. The HYD-7 weight summary, Table 2.3.1-2, includes increases in SWBS Group 110 structural weight over a similar (180 foot LBP PHM-like) subcavitating speed regime hull on the order of five percent. It is expected that this increase would cover the majority of uncertainties created by higher speed operation.

Foil system structural weights are in group 567. Structural foundation weights for the struts/foils are in the 180 group. Other structures are accounted for on the basis of the group breakdown shown in Table 2.3.1-2. Ballistic protection items are tabulated separately in 2.3.1-1. Frame spacing may be optimized -to weight or cost but not both. We have used a compromise assumption (5 feet) which is not the lightest but will substantially assist in cost reduction. These facts have been derived from previous Boeing studies. Material properties are in accordance with MAT-74-148. Corrosion allowances are not required for aluminum and titanium structures.

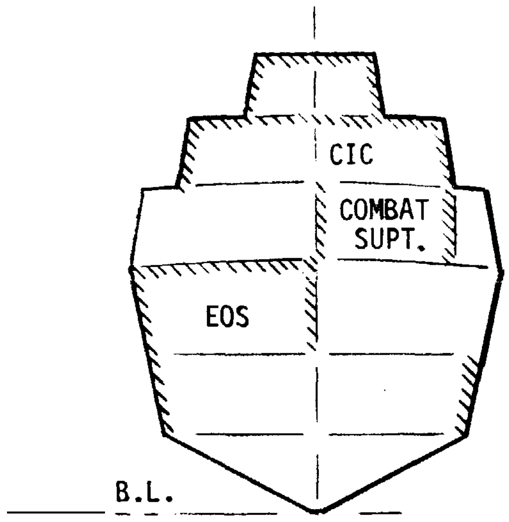
References.

2.3.1-1 Boeing Marine Systems Document D321-51312-2, Hydrofoil Analysis and Design Program (HANDE) Theory Manual - Volume II, July 1976.

2.3.1-2 Boeing Marine System Document D221-11000-1, Hydrofoil Craft Structural Criteria, April 1972.

BOEING MODEL 1026-010
BALLISTIC PROTECTION LOCATIONS

Ballistic protection boundary



BOW VIEW

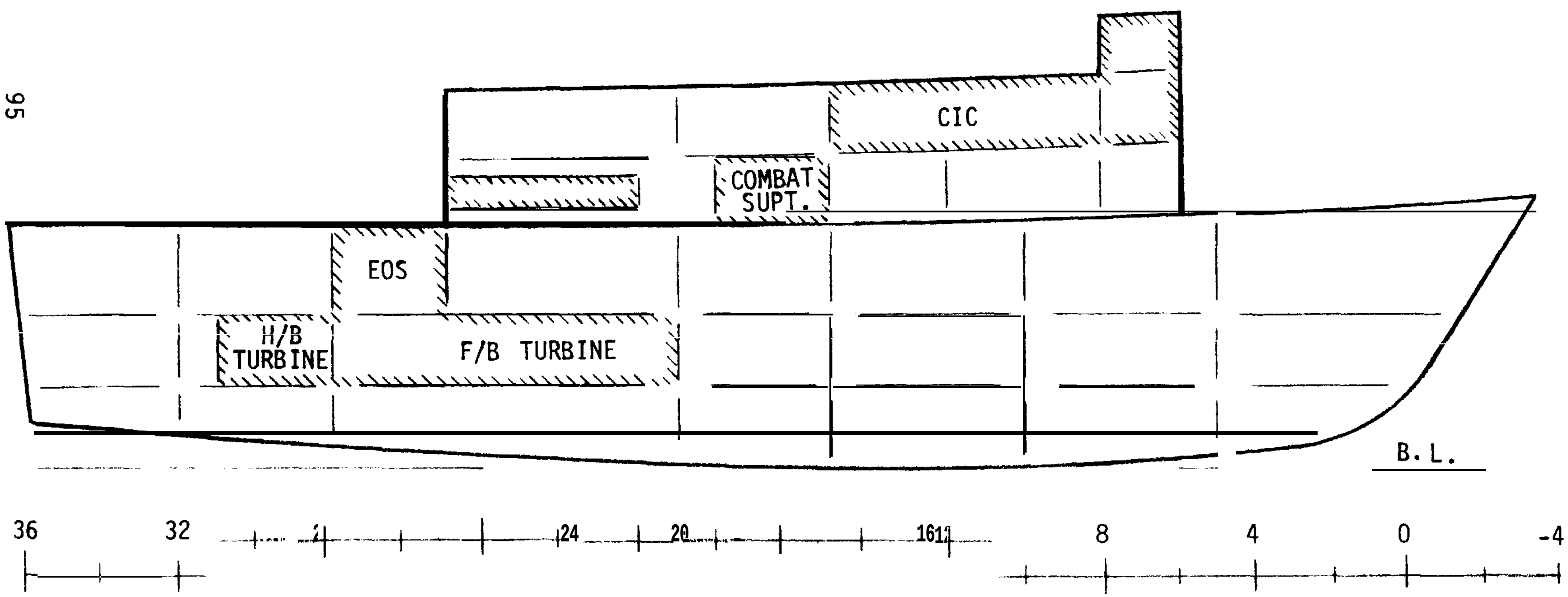


FIGURE 2.3.1-3

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TABLE 2.3.1-1

BALLISTIC PROTECTION CHARACTERISTICS

LOCATION	CHARACTERISTICS	DIMENSION	AREA (Ft^2)
Platform	Foilborne turbine enclosure (Outbd of engines only)	9 ft high x 45 ft lg (2)	810
Platform	Hullborne turbine enclosure (Outbd of engines only)	9 ft high x 15 ft lg (2)	270
2nd Deck	Engineer's Operating Station (EOS) (Sides and overhead)	10 ft high x 70 ft lg & 15 ft x 20 ft	1000
Main Deck	Missile battery shadow shield (Outbd belt for warhead shielding)	4 ft high x 40 ft lg (2)	320
Main Deck	Combat Support Space (Surrounding bhds only)	9 ft high x 32 ft lg (2)	576*
01 Level	Nav Bridge & CIC (Outbd bhd less windows - 50 ft^2) (Overhead less Control Sta. deck)	9 ft high x 31 ft wide x 44 ft lg	1300 1200
02 Level	Ship Control Station (Outbd bhd less windows - 168 ft^2 and overhead)	9 ft high x 16 ft wide x 10 ft lg	300 160

NOTE: All protection material weight is 8 lbs/ft^2 except * which is 6 lb/ft^2

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STRUCTURE WEIGHT

WBS	COMPONENT	WEIGHT LONG TONS	SHORT TONS	METRIC TONS	VOLUMETRIC DENSITY
110	**SHELL AND SUPPORTS**	63.4	71.0	64.40	1.14 LB/FT^3 18.31 KG/M^3
	111 PLATING AND STIFFS.	37.3	41.77	37.90	
	116 LONG, KEEL AND GIRDERS	9.0	10.8	9.10	
	117 TRANS. FRAMING	17.1	19.15	17.4	
120	**HULL STRUCTURAL BULKHEADS.**	16.1	18.03	16.36	.29 LB/FT^3 4.65 KG/M^3
130	**HULL DECKS**	23.6	26.43	23.98	.43 LB/FT^3 6.82 KG/M^3
150	**DECKHOUSE STRUCTURE**	18.0	20.16	18.29	.72 LB/FT^3 11.61 KG/M^3
160	SPECIAL STRUCTURES *	32.0	35.84	32.51	
170	MASTS, KINGPOSTS, ETC.	3.0	3.36	3.05	
180	FOUNDATIONS	28.7	32.14	29.17	
	182 PROPULSION PLANT	7.29	8.16	7.41	
	183 ELECTRIC PLANT	1.53	1.71	1.55	
	184 COMMAND AND SURVEILLANCE	2.96	3.32	3.01	
	185.1 FOIL/STRUTS	10.42	11.67	10.59	
	185.2 AUX. SYSTEM (LESS F/S)	2.54	2.85	2.58	
	186 OUTFIT AND FURNISHING	2.04	2.28	2.07	
	187 ARMAMENT	1.93	2.16	1.96	
190	**SPECIAL PURPOSE SYSTEMS**	6.20	6.94	6.30	
—	**CONTINGENCY**	5.00	5.60	5.08	
100	**HULL STRUCTURE**	196.00	219.5	199.14	2.44 LB/FT^3 39.10 KG/M^3

* **INCLUDES 21.0 L.T. OF** BALLISTIC PLATING **(SWBS 164)**

HYD-7 BOEING 1026-010

TABLE 2.3.1-2

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2.3.2 PROPULSION (U)

2.3.2.1 GENERAL (U)

(C) The HYD-7 propulsion plant provides the capability of five modes of ship propulsion. These are: (1) takeoff with one gas turbine engine, (2) foilborne operation with one gas turbine engine, (3) foilborne operation with two gas turbine engines, (4) hullborne operation with one foilborne gas turbine and (5) hullborne maneuvering. The ship utilizes two large gas turbine engines with a combined propulsion power level of 100,000 HP for foilborne and sustained hullborne operations, while two smaller gas turbine engines with a combined power level of 8000 HP are used for harbor maneuving and hullborne cruise to 16 knots. This combination provides requisite thrust continuously over the entire speed range from zero to 70 knots with reasonable economy.

(U) Configurations of the propulsion system are varied to meet each of the ships operational conditions. Gas turbine engines must be operated a greater percent of the time at near their continuous power rating to obtain a lower specific fuel consumption rate which results in greater range and endurance. With this rationale Table 2.3.2-1 tabulates which turbines are operational for each condition.

(U) The feature common to each mode of operation is through the use of matching pairs of marine gas turbine engines driving controllable, reversible-P.-itch (CRP) propellers through right angle spiral bevel and compound planetary gearboxes.

(U) The principal characteristics of each of the two different pairs of gas turbine engines are provided in tabular form in Table 2.3.2-Z.

(U) The CRP propeller provides the propulsive thrust for whip operation during foilborne, hullborne, and maneuvering modes of operation. In the foilborne mode thrust from the CRP propeller is for full speed ahead operation only. In the hullborne mode the CRP provides thrust for ahead and astern operation, for crash stopping, and for maneuvering the ship at low speed. Two CRP propellers were selected to provide the necessary thrust for all modes of

TABLE 2.3.2-1

PROPULSION GAS TURBINE OPERATIONAL CHART

SHIPS OPERATIONAL MODE		GAS TURBINE ENGINES (2) TF 40	(1) LM 5000 FT 9A-4	(2) LM 5000 FT 9A-4
Maneuvering	Docking	X		
	0-16 knots	X		
Hullborne	0-16 knots	X	X	
	20 knots		X	
Takeo-ff			X	
Foilborne	50 knots		X	
	Dash			X

TABLE 2.3.2-2

PROPULSION GAS TURBINE ENGINE CHARACTERISTICS

(See Note Below)

CHARACTERISTIC	PROPULSION TURBINE FOILBORNE	PROPULSION TURBINE MANEUVERING
Engine make and model number (typical)	P&W FT 9A-4 or GE LM5000	Advanced AVCO Super TF-40 or equivalent
Maximum air flow (lb/sec)*	300	30
Dry Weight, installed (lb.)	21,500	1500
Compression ratio at maximum rpm	31.3	9
Specific Fuel Consumption (lb/BHP-Hr)* (See Note below)	0.390	0.445
Maximum Coritinuous power*	50,000	4,000
Maximum intermittent power*	57,500	4,600
Power turbine speed (rpm)	3600	15,300
Length over inlet plenum to end of output shaft (in.)	328	70
Maximum diameter or overall width (in.)	114	62
Overall maximum height (in.)	106	54

Note: The characteristics listed here are typical or estimated values for existing engines or engines under development. These data were utilized for machinery arrangements and estimates of installed weights. All performance data utilized in this study have been taken from ANVCE working paper WP-011, Revision A for the 1980 time period.

* Under conditions of 26.7°C (80°F) at 14.7 psia with Navy standard installation losses.

operation and their characteristics are summarized in Table 2.3.2-3. It is envisioned that the CRP will employ a Prairie air system which introduces air into the propeller flow stream for noise reduction.

The propulsion plant for the foilborne and maneuvering modes are located in separate machinery spaces. Consistent with a philosophy of maximum protection, the ships service diesel generator sets are also separated by watertight bulkheads. The propulsion system arrangement is shown in Figure 2.3.2-l.

A propulsion system weight breakdown is presented in Table 2.3.2-4.

2.3.2.2 COGOG (FOILBORNE AND HULLBORNE) TRANSMISSION SYSTEM

The propulsion machinery chosen is an all gas turbine arrangement employing the "combining gas turbine or gas turbine" (COGOG) feature which has been developed and fully proven for propulsion systems in many modern ships. HYD-7 shall use the COGOG combination of either LM-5000 or FT9A-4 gas turbines for foilborne operation of the TF-40 gas turbine for maneuvering. They are depicted in the installation arrangement Figure 2.3.2-l with the transmission details shown on the schematic, Figure 2.3.2-2.

Leading particulars of the propulsion system are listed in Table 2.3.2-5.

Power from either of the two gas turbine engines (foilborne or maneuvering) is transmitted to the COGOG shoulder gearbox through synchronizing/positive engagement type clutches. The synchroclutch consists of a friction clutch in parallel with a positive drive dental clutch. The friction clutch synchronizes the driving and driven shafts, after which the dental clutch is engaged to provide a positive drive. The friction clutch is of the multi-disc type with positive oil circulation to absorb thermal loads imposed by the synchronizing cycle. The forced synchronized clutch brake includes a separate pack of friction plates in addition to the main plates and dental coupling to provide the braking and holding capability. Some of the capabilities of the clutch/brake combination include:

TABLE 2.3.2-3

CRP PROPELLER CHARACTERISTICS

Propeller Type*	Supercavitating
Propeller Model Number	KMW 398B
Diameter, Feet	8.0
Number of Blades	3
Slew Time (full ahead to full astern)	10 sec
Slew Rate	4°/sec

Performance (per propeller)

	FOILBORNE PLANT				MANEUVER PLANT	
Design Condition:	Takeoff	Foilborne	Foilborne	Hullborne	Maneuver	Idle
Ship Speed, knots	28	72	50	20	10	--
Power, SHP / RPM	13,300 / 480	50,000 / 930	25,550 / 650	250	1150 / 150	75
Thrust, lbs.	90,000	120,000	75,000	68,000	--	--
Disc Area Loading lb/ft²	1,790	2,387	1,492	1,352	--	--
Propeller Efficiency	0.58	0.57	0.64	0.53	--	--

* Employing a Prairie Air System

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BOEING MODEL 1026-010

COGOG PROPULSION SYSTEM SCHEMATIC

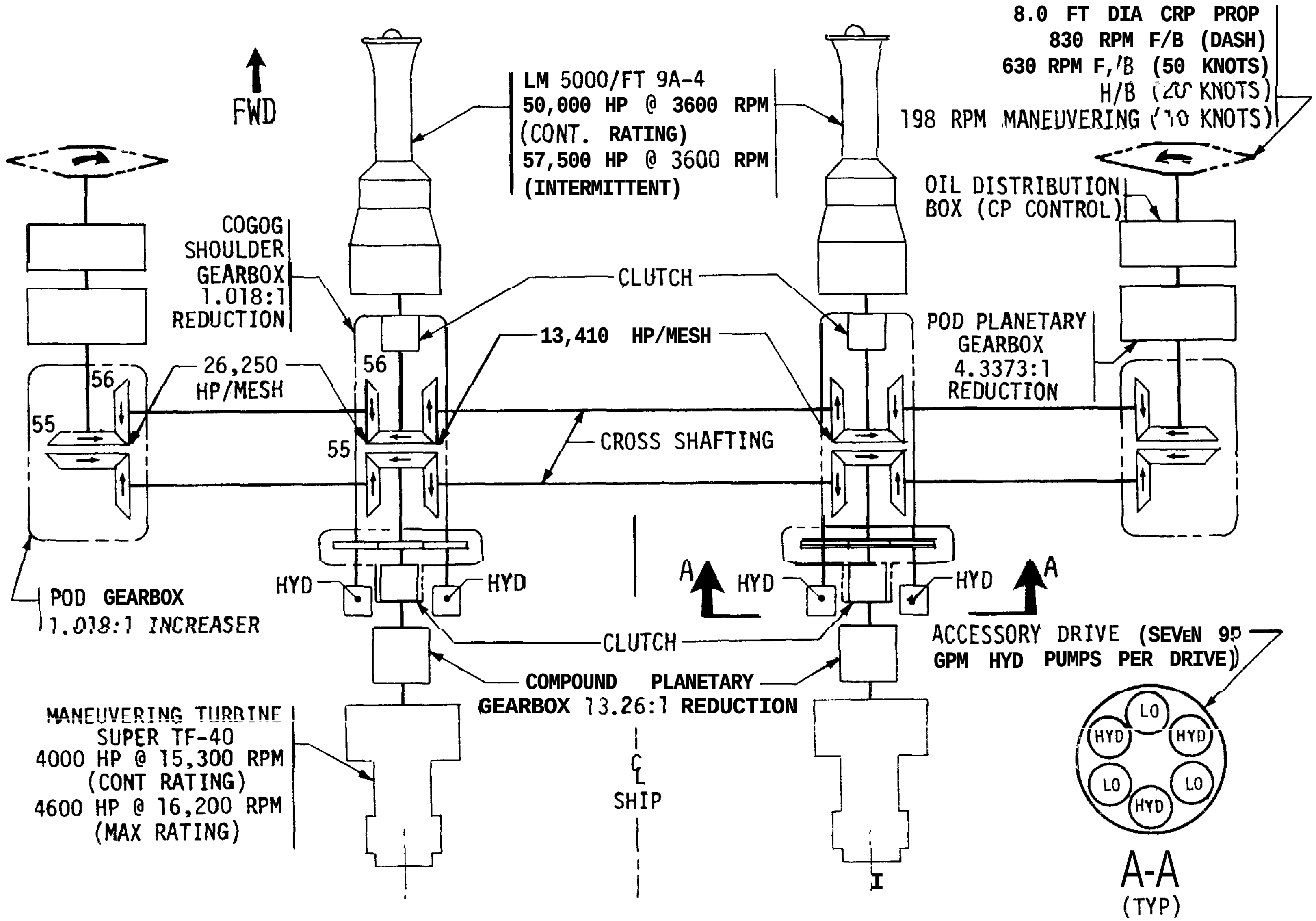

FIGURE 2.3.2-2

TABLE 2.3.2-4

PROPULSION SYSTEM WEIGHT BREAKDOWN

(All Weights in Long Tons Except as Noted)

SWBS GROUP NUMBER	DESCRIPTION	PROPULSION SYSTEM L. TONS	MANEUVERING SYSTEM L. TONS	TOTAL EACH SWBS GROUP LONG TONS	SHORT TONS	METRIC TONS	% OF TOTAL WEIGHT
234	Gas Turbine Engines	16.88	0.90	17.78	19.91	18.06	13.70
241	Propulsion Reduction Gears	22.78	0.80	23.58	26.41	23.96	18.10
242-244	Transmission Assemblies	18.42	0.31	18.73	20.98	19.03	14.40
245	Propellers	4.88	----	4.88	5.46	4.96	3.80
250	Propulsion Support System	33.23	0.76	33.99	38.07	34.54	26.20
260	Fuel and Lube Support System	15.55	0.25	15.80	17.70	16.05	12.20
290	Special Purpose System*	14.32	0.90	15.22	17.05	15.46	11.70
	TOTALS	126.06	3.92	129.98	145.58	132.07	100.00

* Includes 4 long tons for high impact shock protection.

TABLE 2.3.2-5

PROPULSION SYSTEM CHARACTERISTICS

		ENGINES UTILIZED		
		2 -- 50,000HP	1 - 50,000HP	2 4,000 HP
COMPOUND PLANETARY GEARBOX	Input HP	---	---	4000
	Input RPM	---	---	15,300
	Ratio (Reduction)	---	---	13.26:1
	Output RPM	---	---	1154
COGOG SHOULDER GEARBOX	Input HP	50,000	48,660	4000
	Input RPM	3600	2732.5	1154
	HP/Mesh	26,250 (52.5%)	13,410	2100 (52.5%)
	Ratio (Reduction)	1.018:1	1.018:1	1.018:1
CROSS SHAFT	HP	0	13,410	0
	RPM	3535	2684	1133
	Diameter in.	5.0	5.0	5.0
VERTICAL SHAFT	HP	26,250	13,410	2100
	RPM	3535	2684	1133
	Diameter in.	6.5	6.5	6.5
POD GEARBOX	Input HP	50,000	25,550	4000
	Input RPM	3535	2684	1133
	HP/Mesh	26,250	13,410	2100
	Ratio (Increaser)	1.018:1	1.018:1	1.018:1
POD PLANETARY GEARBOX	Input HP	50,000	25,550	4000
	Input RPM	3600	2632.5	1154
	Ratio	4.3373:1	4.3373:1	4.3373:1
	Output RPM	830	630	266
PROPELLER	Type	Controllable-Reversible-Pitch		Supercavitating
	Diameter	8.0 Feet		
	Thrust/Prop (# Max)	170,000	75,000	xx
	RPM (Dash)	830	--	
	RPM (5C K)	--	630	
	RPM (H/B 20 K)	--	330	--
	RPM (H/B 1 6 K)	--	xx	266

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1. It stops the power turbine shaft with the gas turbine at idle fuel flow.
2. It holds the power turbine shaft stopped on a secured gas turbine while the output side of the clutch is being driven by the other gas turbine.
3. It stops the propeller shaft from rotating with the gas turbine at idle and the propeller at zero pitch.
4. Synchronization regardless of shaft rotation.

The power transmitted to the COGOG shoulder gearbox is -into the conventional input pinion shaft which enables the drive, from either turbine, to be introduced at opposite ends of the same input pinion. With this arrangement there are no "idling" gears whichever engine is driving and, therefore, no risk of noise from unloaded gears. The power path is split through two spiral bevel gear meshes. The spiral bevel gearboxes employ the "hunting tooth" concept which retains a nearly 1:1 ratio but provides much less frequent contact between any two opposing gear teeth, thus distributing the wear evenly. This "twin double-bevel reduction gear drive" (GE-TDB gear drive) arrangement was developed by General Electric for use on the H. S. Denison and also on AGEH-1 PLAINVIEW. The power path is thrust balanced and split through two spiral bevel meshes instead of a single mesh, thus resulting in smaller and lighter weight gearboxes. Integral with the COGOG shoulder gearbox are synchronizing clutches from each gas turbine and accessory drive pads for mounting transmission lube oil and hydraulic power pumps. Table 2.3.2-6 outlines the principle characteristics of the accessory drive pads for the propulsion system. Anti-friction bearings are used throughout the unit to maintain the gears in satisfactory alignment which is usually more easily accomplished with ball and roller bearings. than with journal bearings.

One mode of ship operation is foilborne cruise at 50 knots which will require nearly full power from one 50,000 HP gas turbine engine and the thrust from both propellers. To meet this condition, a pair of cross-over shafts

TABLE 2.3.2-6

ACCESSORY DRIVE PADS

PROPULSION SYSTEM

MODEL 1026-010

	PUMP USE	PUMP QTY	RPM DRIVER	RPM PUMP INPUT	RATIO INCREASE
COGOG SHOULDER GEARBOX	HYD	7	3600	4750	1.32:1
	LO	5	3600	3600	1:1
COMPOUND PLANETARY GEARBOX	LO	2	3600	3600	1:1
POD GEARBOX	LO	1	3600	3600	1:1
POD PLANETARY GEARBOX	LO	2	3600	3600	1:1
PROP SHAFT ASSY	LO	1	630	3600	4.3373:1

NOTE: LO - Lube Oil
HYD - Hydraulic

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are installed to split the power of the engine to the port and starboard propulsion systems which is accomplished through the use of two additional output spiral bevel gears to the COGOG shoulder gearbox in a GE-TDB gear arrangement. Pedestal bearings and flexible couplings are employed for shaft support.

The power output of the COGOG shoulder gearbox is transmitted down to the pod gearbox by a pair of vertical strut downshafts. The shaftinq and associated bearings and couplings are enclosed in oiltight guards which make the connection between the COGOG gearbox casing and the pod gearbox casing.

The spiral bevel gears in the pod gearbox combine the power from the two downshafts into a single output gear shaft in a GE-TDB gear arrangement. The output shaft transmits the power to the planetary gearbox. Table 2.3.2-7 outlines the principal characteristics of the spiral bevel gears.

The COGOG and pod gearboxes and the pair of vertical drive shafts form what is known as a "locked-train" gear arrangement. This arrangement provides torsional flexibility in the vertical drive shafts and also the ability to "time" the assembly to equalize torque levels between the two parallel paths.

The pod planetary gearbox utilizes double helicall gears which provide an efficient configuration with regard to weight, size, noise and overall simplicity of gear and bearing arrangement. To insure proper load sharing of the gear meshes, the planet and sun gears are permitted to shift axially until they center themselves relative to their mates. Journal type bearings are used throughout the unit to provide greater durability, smaller size, lighter weight, and a simpler lubrication system. The reduction ratio is 4.3373:1 with the design approach being to keep upstream transmission components at a relatively high RPM, and lighter weight., without getting into shaft criticals and bearing problems. Maintaining high revolutions results in reducing torque and ultimately shaft size since torque is inversely proportional to RPM at a fixed power level.

The propeller shaft assembly transmits power from the pod planetary gearbox to the propeller, and also transmits the thrust developed by the propeller back to the pod structure. The propeller shaft assembly contains the bearings, double shaft seals, and gearing for a scavenge lube oil pump drive. This assembly is connected to the pod planetary gearbox output shaft with a diaphragm type coupling. Integral with the shaft assembly is the CRP oil distribution box which regulates the flow of oil to and from the propeller hub mechanism.

2.3.2.3 CONTROLLABLE REVERSIBLE-PITCH PROPELLER

The CRP system includes the hub and blades, oil distribution box, hydraulic oil power module, and associated tanks and lines. Figure 2.3.2-3 illustrates the hydraulic system for the propeller and Table 2.3.2-3 outlines the principal characteristics of the CRP propeller. The power supply unit is a self-contained, noise-isolated module that includes all associated components. There is an emergency pump for setting pitch if the main and attached hydraulic pumps are inoperative. There are four main parts to the CRP system:

1. The pitch changing hub mechanism which is actuated by a hydraulic servomotor.
2. The oil distribution box which regulates flow of oil to and from the hub mechanism.
3. The control apparatus which causes the propeller to change pitch in response to commands from the pilot house.
4. A Prairie Air System which takes air from the bleed air system and distributes it through the propeller shaft to the blade surface for emission into the water flow stream.

2.3.2.4 MANEUVERING PROPULSION SYSTEM

The operating requirement for the maneuvering system requires two engines of

4000 HP each. This system is used for docking, undocking, and harbor maneuvering or it may be used for low speed cruise (up to 16 knots). The engine is an advanced AVCO Lycoming Division Super TF 40 marine gas turbine or equivalent, which requires addition of a compound planetary gearbox to reduce the output shaft speed to a maximum of 858 RPM.

Connection of the compound planetary gearbox to the COGOG shoulder gearbox is accomplished with a Bendix diaphragm type coupling. The foilborne synchroclutches are disengaged while in the maneuvering mode of operation. The accessory drive pads and all foilborne components will be operating, but at a much lower power level. The compound planetary gearbox will have the same design philosophy as the pod planetary gearbox, however, the reduction ratio will be 13.26:1.

Table 2.3.2-4 lists weights of the maneuvering system drive components.

2.3.2.5 TURBINE ENGINE COMBUSTION AIR INTAKES

Each foilborne and maneuvering engine's intake duct system is designed to provide engine air-flow with minimum pressure drop, flow distortion and salt ingestion, and to provide anti-ice protection. The inlet system includes the inlet, demister panels, intake louvers, blow--in doors, cooling ducts, and cooling air fans.

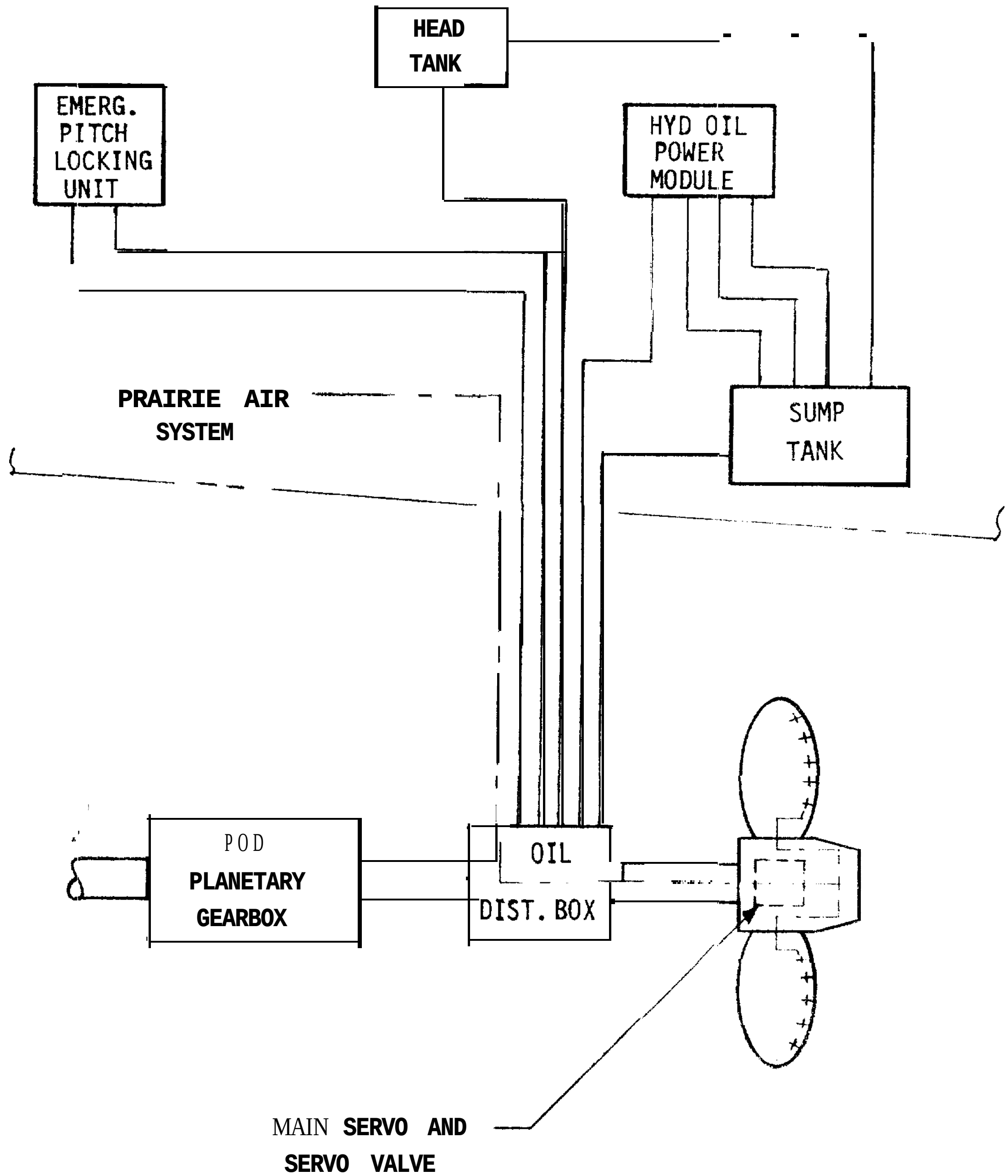
An anti-icing system is provided to protect the power plants from frost, freezing fogs, spray and rains, sleet storms and all but the heaviest snowfalls. The anti-icing system takes turbine compressor discharge bleed air (hot) and heats the turbine incoming air and melts impinging sleet, snow, and ice spray at the demister panels. This warmed air is then dumped into the turbine inlet airstream to protect downstream components.

FIGURE 2.3.2-3

BOEING MODEL 1026-010

CONTROLLABLE REVERSIBLE - PITCH PROPELLER

HYDRAULIC SYSTEM DIAGRAM



Turbine enclosure cooling is accomplished by the ejector principle which takes cooling air from the engine inlet, with turbine in operation, cools the machinery space and discharges this air to the commonly referred to "eductor nozzle" (secondary eductor). After turbine shutdown electric driven fans within the duct are used for machinery space cooling and this air is also discharged through the secondary eductor.

Figure 2.3.2-4 illustrates the combustion air intake and cooling air system.

2.3.2.6 TURBINE ENGINE EXHAUST SYSTEM

The exhaust duct system is designed to exhaust the engine airflow at a minimum exhaust pressure drop, and discharge the exhaust gases so that gases are not reingested into the inlet and do not cause overheating of the mast or topside installed equipment. Included in the exhaust system is an infrared (IR) radiation suppression seawater spray system. The exhaust system includes the stack, exhaust duct, exhaust nozzles, mixing tubes and spray rings. Turbine exhaust gases are discharged to the exhaust duct through the primary eductor, up to the exhaust nozzles and then combined with incoming air in the mixing tubes for temperature reduction.

Figure 2.3.2-5 illustrates the turbine engine exhaust system.

Reference 2.3.2-5 defines IR radiation and ship design methods to be considered for IR signature suppression.

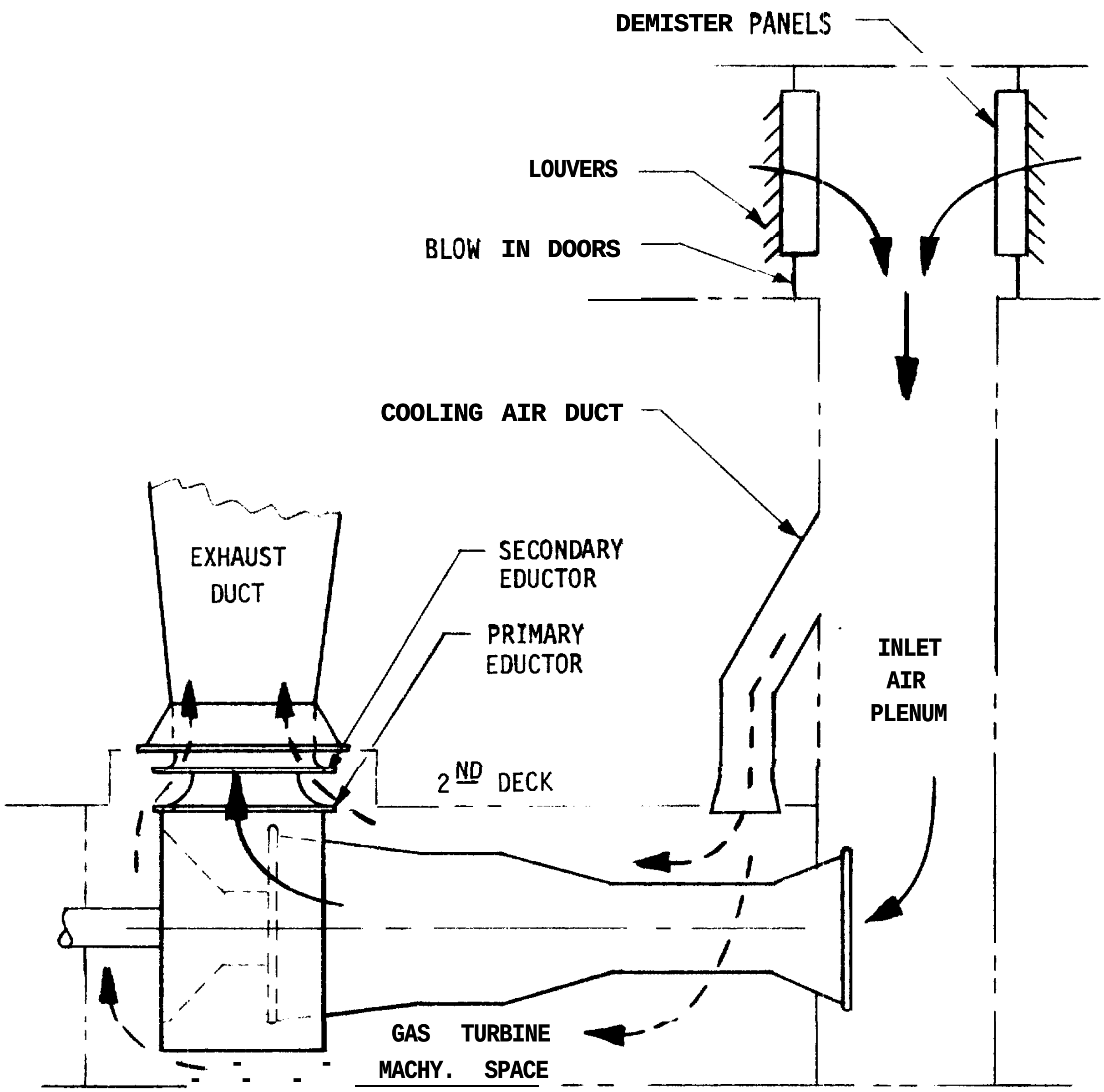
2.3.2.7 PROPULSION SYSTEM RISK AREAS

In evaluating the risks associated with the HYD-7 propulsion concept, the systems can be considered to be divided into the primary areas of engines, propellers, and transmissions. The secondary areas are mainly propulsion support systems which consist of air inlets, uptakes, washdown systems, fuel oil service, lube oil service, sea water cooling and control systems, and can be dismissed summarily by stating that known design practice exists which has been previously proven adequate on similar or more sensitive

FIGURE 2.3.2-4

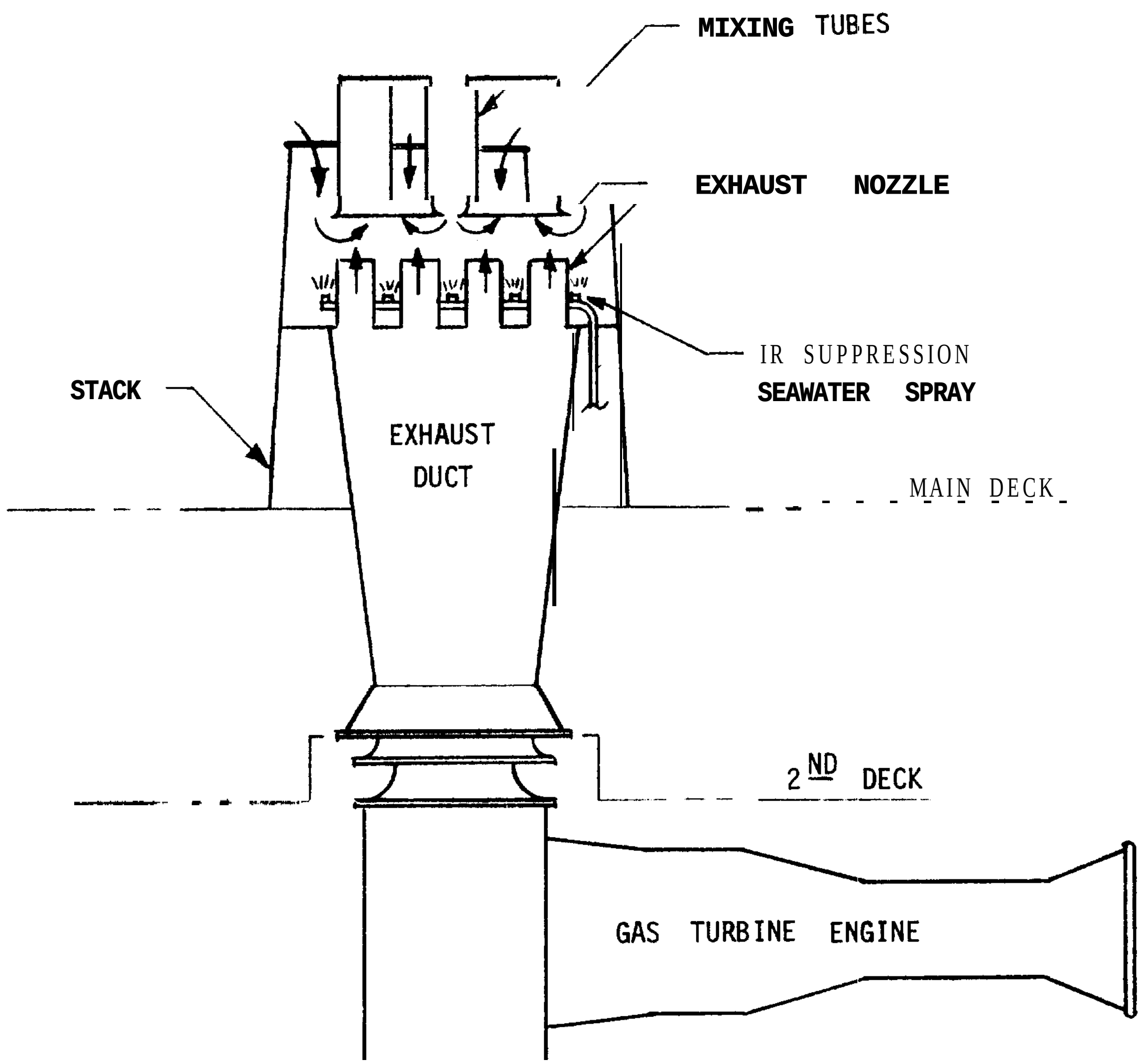
BOEING MODEL 1026-010

GAS TURBINE ENGINE COMBUSTION AIR INTAKE SYSTEM



BOEING MODEL 1026-010

GAS TURBINE ENGINE EXHAUST SYSTEM



(e.g. smaller) applications. Reference 2.3.2-l is a good source of proven guidelines and design practice. Thus, this area is considered to be of very low risk.

Each of the typical engines under consideration as listed in Table 2.3.2-2 are currently in either advanced development or fully developed and should be free of risk in the application time frame (1995) of concern. The development programs include such features as 3000 hour endurance tests and qualification to mature Navy turbine specifications. These engines were selected as a basis for preliminary design only and other engines could be substituted with similar features if they were acceptable at decision time.

The COGOG propellers chosen have been utilized and substantially demonstrated in numerous applications, including the Swedish SPICA class patrol craft, each of which has three KaMeWa supercavitating propellers operating very successfully over the range of loadings from low hullborne (subcavitating) speeds through the fully supercavitating mode (over 40 knots). Supercavitating propellers of titanium and Inconel type alloys have thoroughly demonstrated reliable operation and long life virtually free of cavitation-erosion damage over the entire range of HYD-7 operating conditions. The CRP propeller mechanism is currently operating on the DD963 destroyers at the same power level considered here and at considerably higher torque levels. The concept is adequately developed and risks are only those associated with scale.

In evaluating the risk involved with the proposed HYD-7 transmission systems, several facts must be addressed.

The first is that numerous problems have previously been encountered with hydrofoil mechanical transmissions. These problems along with identification of proven solutions are presented in References 2.3.2-2 and 2.3.2-3. The consensus reached by the References is that no single problem has emerged as unsolvable or beyond the current state of the art, and as long as all gear and bearing parameters are kept within the specific limits specified in those references,, (which are in line with current AGMA gear design and bearing manufacturers recommendations) proper care is exercised in the design process, and a proof testing program is adhered to, the risks associated with the HYD-7 transmission system are only moderate. The characteristics of the transmission system described in 2.3.2 are within the specified values in every respect. An example of the above is presented in Table 2.3.2-7 which indicates that currently recommended parameters for the HYD-7 bevel gearboxes do not exceed the recommended values.

A second major point deserving of emphasis here is that many of the previous shortcomings with hydrofoil transmissions can be attributed to an over emphasis on weight minimization. It is a normal tendency on high performance vehicles to try to achieve very low weight goals. But evaluation of prior hydrofoil design practice has shown that too many of the weight goals have been arbitrary and achieved only at the expense of adequate reliability. A pertinent example of proper use of material weight in the system is to provide a propulsion system design which has adequate stiffness as well as strength and thus assures that fretting and excessive wear problems are avoided.

The following areas requiring development to advance beyond our present standards are:

1. Gear materials i.e. VASCO-X2, Super Nitralloy
2. Bearing materials to withstand greater loads and temperatures.
3. Gear scoring and finishes (see Table 2.3.2-7)
4. Dynamic and vibration characteristics effecting transmission systems
5. Gear and bearing lubrication with the need to reduce oil quantity required.
6. Integral anti-friction bearing races on shafts and housings for installation of ball/roller cage assemblies resulting in smaller gearboxes.
7. Detection equipment for condition monitoring and incipient failure of gears., bearings, lubricant, etc.

TABLE 2.3.2-7

RIGHT ANGLE SPIRAL BEVEL GEAR PARAMETERS (FOR 26,250 HP PER GEAR MESH)

PARAMETER	VALUE PINION	VALUE GEAR	COMMENT
No. of Teeth	55	56	Within current design
Diametral Pitch	1.96	1.96	Gleason Experimenting with 1.4
Face Width - in.	5.102	5.102	Within current design
Pitch Diameter - in.	28.06	28.57	36 in. manufacturing limit
Pressure Angle	20°	20°	Current standard
Spiral Angle	30”	30°	Current standard
Torque	459,375 Lb-in		470,000 Lb-in (Gleason design limit)
RPM	3600		Within current design
Bending Stress	30,000 PSI		30,000 PSI is Gleason limit
Contact Stress	143,500 PSI		250,000 PSI for 10^9 cycles (Gleason limit)
Pitch Line Velocity	26,450 Ft/Min		30,000 Ft/Min (Gleason limit)
Scoring Index	338°F		Within the Gleason allowable of 360°F. However, the probability of scoring is high and a development program will be required.

The fourth fact that should be considered is that in spite of all of the above rationalization, a 50,000 HP transmission system of the type described has not yet been built nor demonstrated and that until that is accomplished, statements attesting to the adequacy of the design approach cannot be considered sufficient. That is, the HYD-7 transmission system must undergo considerable technology and component development, be built as a system and thoroughly tested to prove that the design is adequate prior to installation in a prototype ship. References 2.3.2-2 and 2.3.2-4 contain preliminary proposals cf other test programs for a similar 25,000 HP transmission to accomplish this. A thorough beginning-to-end development and test program, including consideration of all of the hydrofoil program? previous experience with transmission shortcomings, must be established early in the development program.

Assuming that the above is accomplished as a vital portion of the overall HYD-7 development program, only moderate risk would be expected from the propulsion system area.

REFERENCES

2.3.2-1 NAVSHIPS Technical Manual, 0941-038-7010, "Installation Design Criteria for Gas Turbine Applications in Naval Vessel?, Prepared by Gibbs and Cox, Inc., New York, N.Y. for Naval Ship Engineering Center, Philadelphia, Pa. under Contract NObs 83143.

2.3.2-2 Diehl and Lundgaard Report No. 7418-1, "Design Study for Large Hydrofoil Transmission System,Phase 1 - Definition Studies", Prepared for NSRDC Hydrofoil Special Trials Unit under Contract N00406-74-C-1582, August 22, 1974.

2.3.2-3 Boeing Marine Systems Document D315-51310-1, "Observations on the AGEH Foilborne Propulsion Transmission System Relating to HOC Development", March 1975.

2.3.2-4 Boeing Marine Systems Document, "Proposal for Development of Test Systems Definition and Costs in Support of a Barge Mounted Hydrofoil Propulsion Test Facility", October 1974.

2.3.2-5 Naval Research Laboratory, Washington, D.C., Tactical Electronic Warfare Division report titled, "Final Report of Electronic Warfare 'System Requirements Study for the PHM" dated June 1971 (Secret)

2.3.3 ELECTRICAL SYSTEM

The electrical system estimates presented for the Boeing HYD-7 are based on a primary 400 Hertz, 440 volts, 3 phase generating system, with conversion to 60 Hertz to meet requirements developed in the detailed design phase. Two diesel generators located in separated compartments would form the basic system with an emergency automatic start gas turbine generator back-up system located on the main deck. The two plants would work into a split bus, port and starboard feeder arrangement which is depicted in Figure 2.3.3-1. Location of the port and starboard Feeder Distribution panels has been separated longitudinally in the ship, with a view toward damage resistance. One feeder panel is located in the EOS while the other feeder panel is at Frame 18-19, also on the second deck. Power generation at 440 volts is transformer-reduced for 115 volt lighting and utility services. Conversion to 60 Hertz power will be by means of static converters. Generators will be controlled from the EOS as will disconnects, and normal and emergency transfer switching. As part of a later design development, the use of pneumatics for certain auxiliary system services, as well as consideration of an "integrated energy" approach to systems development may influence the loads and sizing of the system.

The electrical load estimate is tabulated in Table 2.3.3-1.

The electrical system weight breakdown is presented in Table 2.3.3-2.

Risk Assessment

Risks are minimal except that continued pressure for light weight component development is desirable.

REFERENCES

2.3.3-1 MIL-STD-1399 (Navy), "Interface Standard for Shipboard Systems" Section 103, "Electric Power, Alternating Current", 1 December 1970.

2.3.3-2 NAVSEC Design Data Sheet DDS9610-2,"Design Details of Generating Plants", 1 May 1970

FIGURE 2.3.3-1

BOEING MODEL 1026-010
ELECTRICAL SYSTEM SCHEMATIC

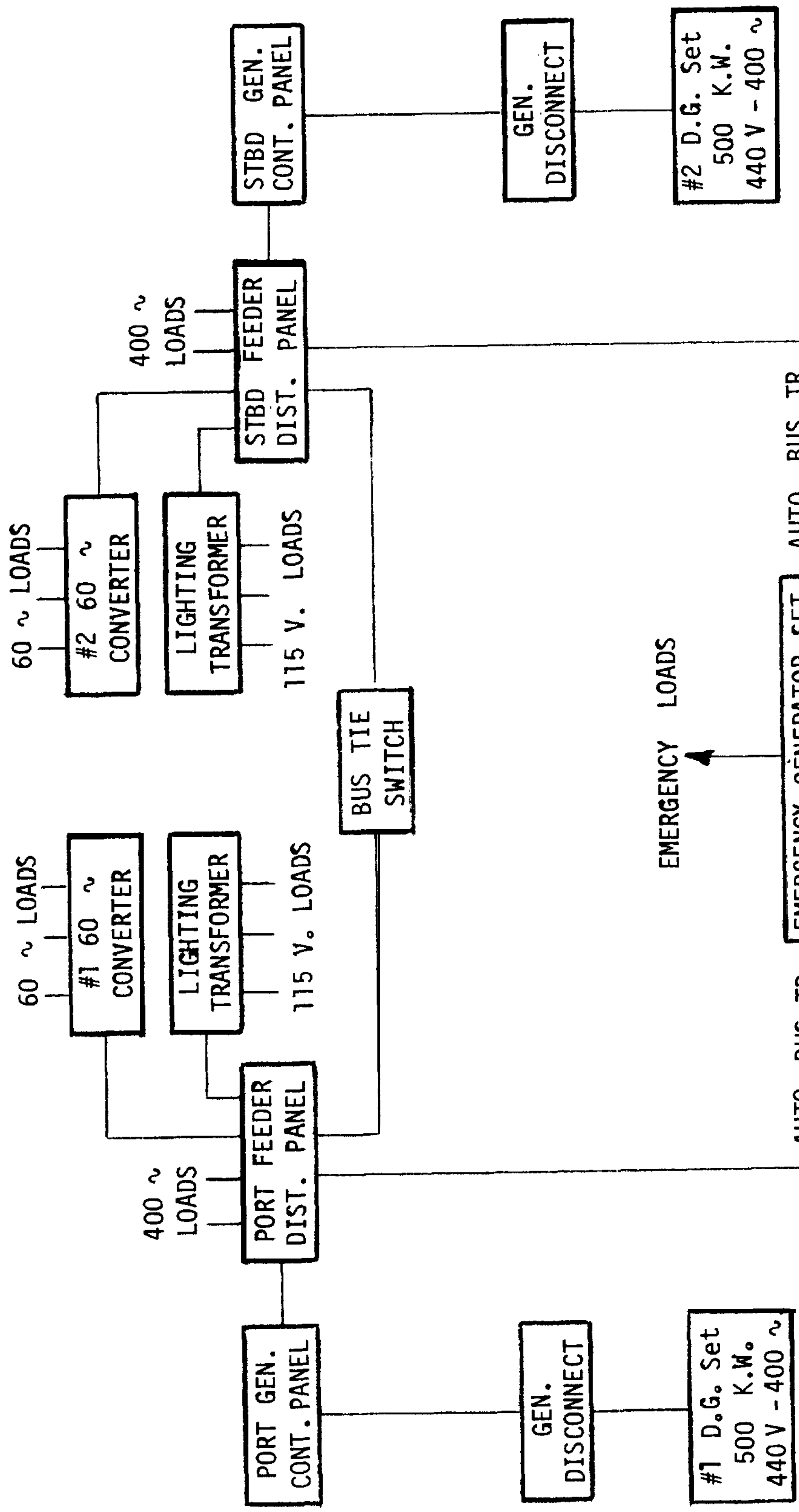


TABLE 2.3.3-1

ELECTRICAL LOAD ESTIMATE

Model 1026-010

ELECTRICAL LOAD CATEGORY	ESTIMATED CONNECTED LOAD (KW)
PROPULSION	150
AUXILIARY MACHINERY	300
DECK MACHINERY	20
SHOPS	20
IC, CM AND ELECTRONICS	80
ORDNANCE	330
HOTEL	150
AIR CONDITIONING, VENTILATION AND HEATING	300
POWER CONVERSION	30
TOTAL CONNECTED LOAD	1380 KW

● Maximum average load of 385 KW occurs during hullborne battle Condition I) operation.

TABLE 2.3.3-2

ELECTRIC PLANT WEIGHT BREAKDOWN

SWBS GROUP NUMBER	DESCRIPTION	TOTAL EACH SWBS GROUP LONG TONS	SHORT TONS	METRIC TONS	PERCENT OF TOTAL
311	Ship Service Power Generators	12.00	13.44	12.19	32.43
312	Emergency Generators	1.50	1.68	1.53	4.05
313	Batteries and Service Facilities	0.25	0.28	0.25	0.68
314	Power Conversion Systems	2.00	2.24	2.03	5.41
321	Power Cable	14.20	15.90	14.43	38.37
322	Switchgear and Panels	2.00	2.24	2.03	5.41
331	Lighting Distribution	2.00	2.24	2.03	5.41
332	Lighting Fixtures	1.80	2.02	1.83	4.86
398	Electric Plant Operating Fluids	0.25	0.28	0.25	0.68
399	Spare Parts	1.00	1.12	1.03	2.70
	TOTAL	37.00	41.44	37.60	100.00

2.3.4 COMMAND AND SURVEILLANCE

2.3.4(a) COMMAND, CONTROL, COMMUNICATIONS AND SURVEILLANCE EQUIPMENT LISTS

Table 2.3.4-1 lists characteristics of SWBS 410, 420, 430 440 and 490 subsystems. Equipment in the SWBS 440 category was given for HYD-7 in NAVSEA Code 6112, Serial 117 of 18 October 1976. Equipment in SWBS 410, 420, 430 and 490 are estimated requirements in those categories and are based on previous work by The Boeing Company for the 1400 ton HOC, except for major navigation components listed in the reference letter. For SWBS 440 certain other equipments over the list given in the reference and deemed to be required are added at the end of the SWBS 440 list and annotated as "Other SWBS 440 Requirements". Where available, physical characteristic data on equipments was taken primarily from the "Combat Data Sheets for AAW, ASW and SUW". Where physical data was unavailable, estimates were made. Total physical requirements can be considered conservative (considering the time period of 1995) and adequate for the purpose of a concept evaluation study.

2.3.4(b) WEIGHT, VOLUME, AND POWER REQUIREMENTS

Weight, volume, and power requirements are listed separately for C^3 and navigation and IC systems in Table 2.3.4-2.

2.3.4(c) GENERAL ARRANGEMENT

The general arrangement drawing shows the location of the C^3 system major components within the vehicle. (See ships general arrangement drawings.)

2.3.4(d) RISK AREAS

There are no significant technical risk areas evident in the C^3N equipments themselves, only a very few of the UYQ Data Display Group components and the Optical Communications System indicating medium technical risk. Medium administrative risks exist also for the above UYQ components and Optical Communications System. These estimates of risk are taken from the applicable Combat System Data supplied for the ANVCE Study.

TABLE 2.3.4-1

COMMAND, CONTROL AND COMMUNICATIONS EQUIPMENT LIST

SWBS 410 COMMAND AND CONTROL EQUIPMENT

POSITION/FUNCTION	CONSOLE	WEIGHT (LBS)	VOLUME (FT")	POWER KVA
C.O.	UYQ() Mod XX9 Large Screen Display	50	2.0	.375
	UYQ() Mod XX10 Alphanumeric Display(4)	200	19.6	.625
	UYQ() Mod XX6 Action Data Entry Module	25	.1	.025
	UYQ() Mod XX7 Comm. Module	25	.1	.063
TAO	UYQ MKXX Tactical Display/Auxiliary Console	600	37.5	2.000
Surface/Subsurf. Coordinator	UYQ () Mod XX8 Op. Summary Console	250	42.5	.375
Surface Radar Operator	Special Navigation Console	(50)	2.0	(Nav. Eqpt.)
	APS116 Radar Set Control & PPI	(50)	4.0	(APS-116)
Air Intercept Controller	UYQ MKXX Tactical Display/Auxiliary Console	600	37.5	2.000
Air Detector/Tracker TAS Operator	UYQ MKXX Tactical Display with TAS Mod XX Controls	800	40.0	2.000
Air Detector/Tracker Identification Oper.	UYQ MKXX Tactical Display/ Auxiliary Console, plus IFF	600 (36)	37.5 1.0	2.000 (TAS)
RPV Pilot	RPV Pilot Station	135	4.0	.250
RPV Control	RPV Control Console	135	4.0	.250
	FLIR/LLLTV Monitors	140	3.0	.250
	Digital Ships Head Ind.	2	.1	.010
	UYQ Mod XX7 Comm. Module	25	.1	.063

TABLE 2.3.4-1 (Cont.)

POSITION/FUNCTION	CONSOLE	WEIGHT (LBS)	VOLUME (FT^3)	POWER KVA
ASW Officer	UYQ MKXX Tactical Data/Acoustics Console	950	37.5	2.000
Sonar Operator	UYQ MKXX Tactical Data/Acoustics Console	950	37.5	2.000
Sonar Operator	UYQ MKXX Tactical Data/Acoustics Console	950	37.5	2.000
Fire Control Engagement Controller	UYQ MKXX Tactical Data/Auxiliary Console	600	37.5	2.000
ASW Engagement Controller	UYQ MKXX Tactical Data/Auxiliary Console	600	37.5	2.000
AAW Engagement Controller	UYQ MKXX Tactical Data/Auxiliary Console	600	37.5	2.000
SUW Engagement Controller	UYQ MKXX Tactical Data/Auxiliary Console	600	37.5	2.000
TWS Radar Operator	UYQ MKXX Tactical Data/Auxiliary Console with TWS Radar Controls	800	41.0	2.000 (Radar Control Power with TWS Radar)
EW Operator #1 and EW Operator #2	ASMD EW Mark XX Adaptation of UYQ Mod XX Tactical/Auxiliary Console	(600)	(37.5)	(Included in EWMKXX System)
F. C. Repairman	UYQ Maintenance Monitor Console	500	37.5	1.000

TABLE 2.3.4-1 (Cont.)

POSITION/FUNCTION	CONSOLE	WEIGHT (LBS)	VOLUME (FT^3)	POWER KVA
Unattended Equipment				
1 Central Equipment Cabinet		900	33.6	2.400
1 Acoustic Converter Cabinet		900	33.6	3.000
1 Beacon Video Processor		450	16.8	1.200
1 I/O Console		800	25.0	1.000
2 AN/UYK-7(XX) Computers		50	4.0	.220
1 Random Access Memory (two-circuit)		80	1.0	.250
TOTALS		13,317 -6,100* 7,217	690.0	35.400

*NOTE: This figure is a reduction of weight expected to be achieved in consoles and their equipment by 1995 where current weight values were used in the body of the above table.

TABLE 2.3.4-1 (Cont.)

SWBS 420 NAVIGATION EQUIPMENT

EQUIPMENT	WEIGHT (LBS)	INTERNAL VOLUME (FT^3)	POWER (KVA)
2 Magnetic Compasses	14	.500	.020
Alidades, Azimuth and Bearing Circles	54	.250	--
1 Barometer, Aneroid	2	.125	--
5 Clocks	25	.625	--
1 Chronometer	10	.280	--
1 Thermometer	1	.030	--
1 Psychrometer/Case	5	---	--
1 Sextant	8	1.000	--
1 Stadimeter	10	.500	--
2 Stop Watches	1	---	--
1 Navigation Timer	1	---	--
1 Set Navigation and Special Lights and Panels	214	4.000	1.100
1 Lead Line	40	1.500	--
1 Wind Direction and Speed Indicator	100	8.000	--
1 Omega Receiver	94	6.100	.162
1 Global Positioning System	200	4.000	1.000
1 Depth Sounder	150	9.000	.165
2 Lookout Periscopes	100	9.400	--
1 Inertial Navigator, (PL-41)	358	10.100	.400
8 Course Indicators	272	16.000	,150
2 Pelorous Stands	146	---	--
1 Synchro Amplifier (Heading Indicator)	57	2.000	2.000

TABLE 2.3.4-1 (Cont.)

EQUIPMENT	WEIGHT (LBS)	INTERNAL VOLUME (FT^3)	POWER (KVA)
1 A to D Converter	8	.300	--
2 Bearing Indicators (Periscope)	40	1.000	--
1 Speed Log System - UL-100 and Indicators	126	9.450	.220
1 Dead Reckoning Analyzer	44	2.500	.100
1 Chart Display or Equivalent	350	25.000	2.000
1 Special Navigation Console	50	2.000	.300
	2,480	113.700	7.620

SWBS 430 INTERIOR COMMUNICATIONS EQUIPMENT

EQUIPMENT	WEIGHT (LBS)	INTERNAL VOLUME (FT^3)	POWER (KVA)
Sound Powered Telephone System	300	8.000	--
Announcing Systems	336	6.000	.400
Intercom System	700	12.000	2.800
Recorder, Audio	56	2.000	.700
Video Recording System	100	3.000	.200
	1,492	31.000	4.100

SWBS 440 EXTERIOR COMMUNICATIONS EQUIPMENT

EQUIPMENT	WEIGHT (LBS)	INTERNAL VOLUME (FT^3)	POWER (KVA)
1 JTIDS Command Terminal System	453	In Cabinets	1.900
1 SATCOM Receiver System	194	In Cabinets	2.000
1 Bridge VHF TRCVR. System	32	400	.100
1 HF TRCVR (5) System	2,220	In Cabinets	11.800
1 VHF/AM TRCVR System	107.5	In Cabinets	.110

TABLE 2.3.4-1 (Cont.)

EQUIPMENT	WEIGHT (LBS)	INTERNAL VOLUME (FT³)	POWER (KVA)
1 UHF TRCVR (4) System	664.5	In Cabinets	2.500
1 HF RCVR (4) System	340	In Cabinets	1.200
1 VHF/FM TRCVR System	133	In Cabinets	.500
1 SATCOM TRCVR System	2,455	In Cabinets	1.380
1 ACCS/NAVMACS Control Console and Comm. Integration	450	54.000	2.000
1 Antenna Patch Panel System	161	5.900	.300
1 TTY System	611	In Cabinets	3.200
1 Crypt0 System, on-line	876	In Cabinets	2.800
1 VHF/UHF Remote Control System	120	2.900	.300
Sub Total	8,817	63.200	30.09
Other WBS 440 Requirements			
1 VHF/UHF Direction Finding System	200	In cabinet	1.000
1 Set Radio Cabinets (10½)	2,625	286.000	3.000
1 Sonobuoy RCVR(ERAPS)	50	In Cabinet	.200
1 LAMPS Data Link	800	In Cabinet	2.000
1 VHF RCVR (Deployed Arrays)	50	In Cabinet	.200
1 Visual Signalling System	207	---	.700
1 Underwater Communications System	205	8.00	--
1 IR/Laser Comm. System	200	---	3.000

TABLE 2.3.4-1 (Cont.)

EQUIPMENT	WEIGHT (LBS)	INTERNAL VOLUME (FT^3)	POWER (KVA)
1 Foghorn	33	---	--
1 Ships Bell	20	---	--
TOTAL	13,207	357.200	40.19
	-5,000*		
	8,207		

*NOTE: Weight reductions expected by 1995 from current equipment weight values used.

SWBS 490 SPECIAL PURPOSE EQUIPMENT

1 Ship Data Multiplex System	5,600	183.000	4.500

PHYSICAL CHARACTERISTICS SUMMARY - C^3N EQUIPMENT

SWBS 410	7,217	690.000	35.400
SWBS 420	2,480	113.700	7.620
SWBS 430	1,492	31.000	4.100
SWBS 440	8,207	357.200	40.200
SWBS 490	5,600	183.000	4.500
TOTALS	24,996	1374.900	91.82
	(12.19 ST)	$(38.93m^3)$	
	(11.06 MT)		
	(10.88 LT)		

TABLE 2.3.4-2

WEIGHT, VOLUME AND POWER FOR C^3, N AND IC SYSTEMS

A. C^3 Systems

	Wt (lbs)	Vol (ft^3)*	Power (KVA)
SWBS 410	7,217	690.0	35.4
:SWBS 440	8,207	357.2	40.2
SWBS 490	5,600	183.0	4.5
TOTALS	21,014 (10.23 ST) (9.28 MT) (9.13 LT)	1230.2 (34.83)	80.1

*NOTE: Equipment volume only. Does not include space required for maintenance and operations.

B. Navigation and IC Systems

	Wt (lbs)	Vol (ft^3)	Power (KVA)
SWBS 420	2,480	113.7	7.62
SWBS 430	1,492	31.0	4.10
TOTALS	3,972 (1.96 ST) (1.78 MT) (1.75 LT)	144.7 (4.10 M^3)	11.72

One of the goals of an overall HYD-7 design would be to produce an effective integrated C^3 system of the lightest weight possible in order to achieve maximum overall performance of the HYD-7. The currently stated weights for the UYQ Data Display Group and the probable number of components required indicate an area where weight reduction effort should be concentrated. Primary cause for weight is current shock specifications for shipboard electronic equipment. It can be expected that by 1995 some effort will be made to reduce the weiqht of these equipments, although there are no known programs in existence specifically devoted to weight reduction for such large and heavy equipments as tactical displays. Some element of risk exists in weight reduction if shock specifications are revised downwards to permit reduction to one-half to two-thirds of current weights. Weight reductions can also be foreseen in electronic technology advances and reorganization of common function electronics, modules in displays. Time exists before 1995 to develop and test light weight components so that technical risk is reduced to a minimum for this type of equipment. Risk can be minimized for 1995 equipments if early resolution can be achieved on ultimate shock specifications for equipment for advnaced ships while still achieving adequate reliability and maintainability, and programs are commenced early for this purpose to allow scheduled time for assessment of the adequacy of new designs.

While the Combat Data Sheets show minimum technical risk for the Ship Data Multiplex System and individual C^3 equipments may be technically achieved by 1995, the integrated design of the C^3 portion of the ship is also an element of risk to be considered. Recognizing the necessity for integrating equipments developed in different time periods, this risk can also be minimized and radically reduced if early and continuing attention is given this aspect of combat system design from the start of the ship program. Early resolution of the C^3 equipment and weapons and sensor suit and the inclusion of a Land Based Test Site in the program will minimize risk in this area.

An important advance required by 1995 is an integrated real time navigation system for piloting in hydrofoils. The achievement of the Global Positioning

System will aid in solution of this problem. Technical and administrative risks can be minimized in this area for a 1995 ship if early concentrated effort is made for navigation of high speed ships.

2.3.4(e) C^3 SYSTEMS RELATED TO PLATFORM FUNCTIONS OR MILITARY OPERATION FUNCTION

For the HYD-7 hydrofoil, a portion of the communications and navigation equipment is required to perform purely vehicle functions as differentiated from naval mission functions.

1. The following communications equipments are considered necessary to perform basic vehicle functions:

	Wt (lbs)	Internal Vol. (ft^3)
HF Transceiver with Antenna and Coupler	357	2.6
VHF Bridge to Bridge Radio System	32	.4
VHF Tranceiver (AM)	107	2.4
Ship Control Interior Communications	500	10.0
Set, Flags, Signal and Colors	36	5.0
2 Signal Search Lights	92	--
	1124	20.4
	(.51 MT)	(.58M^3)

	Wt.	Volume
Percentage of SWBS 430 and 440 Communications systems required for performance of basic vehicle functions	5.4%	1.7%

2. The following navigation equipment is considered basic to the vehicle functions:

	Wt (lbs)	Internal Vol. (ft^3)
1 Magnetic Compass	7	.25
1 Ea. alidade, azimuth and bearing circles	30	.33
1 Barometer, Aneroid	2	.125

	Wt. (lbs)	Internal Vol. (ft^3)
4 Clocks	20	.50
1 Chromometer/w case	10	.28
1 Thermometer	1	.03
1 Psychrometer/case	5	
1 Sextant	8	1.00
2 Stop watches	1	---
1 Set Navigation Lights	117	1.00
1 Lead/Line	40	1.50
1 Wind Direction Indicating System	100	8.00
1 Global Positioning System	200	4.00
1 Depth Sounder (DE-723)	150	9.00
1 Inertial Navigator (PL-41)	358	10.10
4 Course Indicators	160	2.00
1 EM Log System (UL 100)	126	6.60
	1335	44.72
	(.61 MT)	(1.3 M^3)

	Wt.	Volume
Percentage of SWBS 420 Navigation systems required for performance of basic vehicle functions.	53.8%	39.3%

2.3.5 AUXILIARY SYSTEMS

2.3.5.1 AUXILIARY SYSTEMS LESS LIFT SYSTEM

In general, all of the auxiliary system equipment required to perform HYD-7 SWBS group 500 functions are currently available in conventional form. Thus, none of the subsystems are considered to pose a significant threat to the feasibility of the concept.

(a) The location of major auxiliary system machinery components is presented in Figure 2.3.2-l. Other additional spaces are assigned for auxiliary machinery to be used in later stages of the design process.

(b) The identification by tabular format of the basic characteristics of major auxiliary subsystems is presented in Table 2.1.

(c) The auxiliary system weight estimate providing the percentage weight of each major subsystem is presented in Table 2.3.5.1-1. The subsystem weights have been obtained by modification and ratiocination from other designs including PHM, FFG-7, and the Boeinq HOC, and include consideration of: (1) the projected 1995 IOC date, that is, at least twelve years are available for technology improvements and weight reduction developments; (2) nearly all existing auxiliary systems equipment have been designed for conventional ships with minor consideration for the weight sensitivity of high performance ships. With the increasing emphasis on high performance ships in the technical community along with commercial interest in an expanding market, substantial decreases from today's conventional weights are expected.

(d) The risks attributable to the many auxiliary systems are negligible. As previously stated, all functions can be accomplished with existing conventional equipment. The only area of risk is in achieving the predicted weights. However, the potential for significant weight reduction does certainly exist, especially considering the time period available for development. Due to the multi-system make-up of the group, individual shortfalls in achieving weight reduction goals are not likely to have an overwhelming impact on ship performance and the overall feasibility of the concept.

TABLE 2.3.5.1-1

AUXILIARY SYSTEMS (LESS LIFT SYSTEM) WEIGHT ESTIMATE

SWBS GROUP NO.	AUXILIARY SYSTEMS	WEIGHTS			
		LONG TONS	SHORT TONS	METRIC TONS	% OF TOTAL
511	Compartment Heating System	1.26	1.41	1.28	2.00
512	Ventilation System	5.23	5.86	5.31	8.28
513	Machinery Space Ventilation System	1.64	1.84	1.67	2.60
514	Air Conditioning System	3.53	3.95	3.59	5.59
516	Refrigeration System	0.44	0.49	0.45	0.70
521	Firemain and Flushing System	3.91	4.38	3.97	6.19
522	Sprinkler System	1.07	1.20	1.09	1.69
523	Washdown System	0.25	0.28	0.25	0.40
524	Auxiliary Sea Water System	0.38	0.43	0.39	0.60
526	Scuppers and Deck Drains	0.13	0.15	0.13	0.21
528	Plumbing Drainage	1.89	2.12	1.92	2.99
529	Drainage and Ballast System	1.26	1.41	1.28	2.00
531	Distilling Plant	1.10	1.23	1.12	1.74
532	Service and Cooling Water	0.88	0.99	0.89	1.39
533	Potable Water System	1.76	1.97	1.79	2.79
541	Ship Fuel Handling and Stowage	6.36	7.12	6.46	10.07
542	Aviation and General Purpose Fuel System	0.82	0.92	0.83	1.30
551	Compressed Air Systems	2.49	2.79	2.53	3.94
555	Fire Extinguishing System	1.37	1.53	1.39	2.17
556	Hydraulic Fluid Systems	2.71	3.04	2.75	4.29
561	Steering Control Systems	2.14	2.40	2.17	3.39
567	Lift Systems (See 2.3.5.2)	--	--	--	--
571	Replenishment-at-Sea	0.76	0.85	0.77	1.20
572	Ships Stores Handling	1.45	1.62	1.47	2.30
574	Vertical Replenishment Systems	3.15	3.53	3.20	4.99
576	Auxiliary Handling Systems	1.20	1.34	1.22	1.90
581	Anchor Handling, Mooring, Deck Machinery	6.55	7.34	6.65	10.38
583	Boat Handling and Stowage	2.21	2.48	2.25	3.50
593	Environmental Pollution Control	2.21	2.48	2.25	3.50
598	Auxiliary Systems Operating Fluids	3.78	4.23	3.84	5.99
599	Auxiliary Systems Repair Parts and Tools	1.20	1.34	1.22	1.90
	TOTALS	63.13	70.71	64.14	100.00

2.3.5.1.1 HYDRAULIC FLUID SYSTEMS

The hydraulic systems are considered critical to the feasibility of the HYD-7 concept. These systems are included in SWBS 556 and include the centralized Ship Control Hydraulic System (SCHS) and Ships Service Hydraulic System (SSHS). The concept description of these systems is presented below.

The general hydraulic system arrangement is shown in Figure 2.3.5.1-1.

The ship control functions are completely isolated from the ships service functions. As a result, two independent hydraulic power systems were established. One of these is the SCHS, which is dedicated to providing only dynamic control surface (forward foil incidence, aft tipperon, aft trailing edge flaps, all spoilers and forward strut steering) actuation power. The other major system is designated the SSHS which includes all other shipboard hydraulic functions.

The SCHS is provided with a completely redundant dual pressure range (4000 and 8000 psi) fluid power supply consisting of two identical sets of hydraulic pumps which provide fail-safe operation in any underway mode. The switch from the primary subsystem to the alternate upon loss of primary system pressure is accomplished instantaneously and automatically by means of PHM type pressure- operated shuttle valves.

The SSHS is powered by a single or pair of 8000 psi pumps. One pump is mounted on each of the two ship's service diesels (SSD).

Ship Control Hydraulic System

The ship control servo-actuator peak flow requirements have been estimated to total 740 gpm at 8000 psi during high speed dash operation. The estimated peak flow during subcavitating operation is 530 gpm at 3000 psi. Each of the 8000 psi servo actuators is balanced and double-ended similar to the type utilized for forward flap and strut steering control of PHM.

BOEING MODEL 1026-010

HYDRAULIC SYSTEM SCHEMATIC

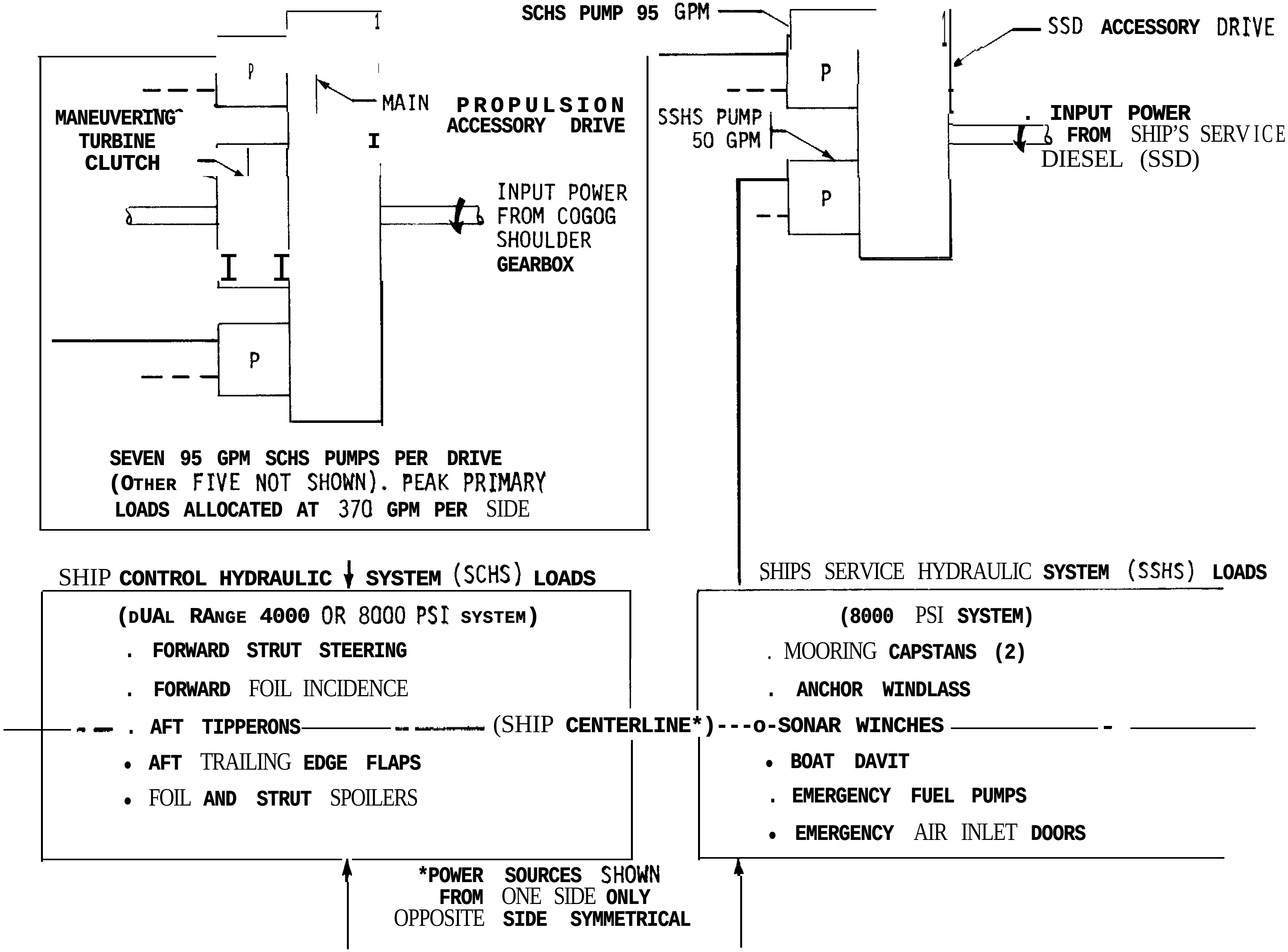


FIGURE 2.3.5.1-1

UNCLASSIFIED

The spoiler actuators are also sized for 8000 psi and are of the two-position solenoid valve controlled type.

iiydraulic power is provided to each actuator from either its primary or alternate SCHS subsystem through the shuttle valves which are mounted on each servo-actuator's manifold block.

Each SCHS subsystem has one dual range hydraulic pump driven by the SSD and seven driven by one of the two accessory drives which in turn are driven off of each of the COGOG shoulder gearboxes.

The SSD driven pumps permit checkout and limited operation of the SCHS when the propulsion turbines are not operating.

Ship's Service Hydraulic System

An evaluation has been made of all ship's service functions which would likely be hydraulic-powered from an 8000 psi SSHS source. These functions are listed on Figure 2.3.5.1-1. The maximum flow required is 50 gpm during hullborne operations.

Controllable-reversible pitch propeller hydraulic control power requirements indicate a preference for lower system pressures of 1200 to 1500 psi and favor use of an independent fluid system to minimize the probability of contaminating multi-purpose systems with sea water. Therefore, it has been assumed that the CRP hydraulic system power is provided by an independent electric-motor-pump.

Since the peak flow required for all of the ship's service functions could be handled by a single 50 gpm pump, it was decided to power the "single thread" SSHS from either or both single SSD mounted pumps. It is desirable to have SSHS power available at all times, including when only one SSD is in operation. (This will be the usual case except during critical operations such as General Quarters or docking.) At least one of the two SSD's will be operating at all times the ship is underway, as it is required to drive the ship's service electrical generator (mounted on the opposite end of the SSD). In the event of a pump or SSD failure, the other SSD would be started immediately and fluid power would again be available within seconds. It is not considered necessary to provide further redundancy in the form of additional fluid filters, reservoirs or plumbing in the relatively less critical SSHS,

Rationale for 4000/8000 psi Hydraulics

During the Light Weight Hydraulic System Conference sponsored by Naval Air Development Center (NADC) at Warminister, Pennsylvania on 2 through 4 June 1976, NADC made the commitment that it had undertaken the development of 8000 psi hydraulic systems for use on Naval aircraft. It has been claimed that 8000 psi technology can reduce hydraulic system weight by 30 percent and volume by 40 percent. NADC has stated that over 2000 pounds could be reduced from an F-14 aircraft by this approach and that the program has low to medium technology risk. NAVAIR has publicly stated that the program developments by industry would be funded. Both an actuator and pump supplier are known to be currently active in 8000 psi hardware development programs.

Similar or greater savings can be expected in the larger hydraulic systems required for hydrofoils. Even at 8000 psi, the HYD-7 installed capacity is predicted to be nearly 1600 gpm, which is a very large hydraulic system.

The higher dynamic pressures encountered during dash operation are nearly double the maximums experienced by contemporary subcavitating hydrofoils. This observation is the reason for recommending a dual range 4000/8000 psi hydraulic power source. In general terms, it follows that the maximum hinge moments expected in the subcavitating mode will be expected to be approximately 50 percent of those encountered in the dash mode. Subcavitating mode operation at the lower pressure will be more efficient, will reduce both the quantity of fluid required in the systems, and the size of reservoirs, filter packs and hydraulic fluid/sea water coolers required.

Dual range hydraulic pumps for 3000/1500 psi operation are within the state of the art and are currently listed in hardware catalogs.

Risk Areas

Two areas of moderate risk are of concern with respect to the proposed hydraulic system.

The first is that the 8000 psi components may not be adequately developed in time in sizes suitable for a HYD-7 system.

Hardware for low rates (<5 gpm) is currently operating in laboratories. NADC has a stated goal to fly an F-14 or Harrier aircraft with an 8000 psi system within one year. 3000 psi pumps with flow capacity of 95 gpm are currently NAVAIR qualified and in use on the standard F-14 airplane. Only minimal risk would be expected to be encountered in developing a high flow capacity pump in the time available.

The 95 gpm pump would require eight be utilized for each half of the HYD-7 SCHS. This quantity was proposed above. If a larger pump were qualified for 8000 psi or was forecast to be available by the design decision date, a lesser quantity would be required. It should be noted that the predicted flow rates required have been estimated by extrapolating from empirical data. The estimates are considered conservative and the flow rates actually required for HYD-7 may prove to be considerably reduced.

The other area of concern involves the ability to accurately predict the control power required during all modes of ship operation. The inadequacy of existing pertinent hydrodynamic data is of double concern here. First, the configuration of foils, struts and their control surfaces is considered to be fluid and would not be expected to be truly frozen until more and better hydrodynamic data is available. The second is that once the configuration is frozen, sufficient hydrodynamic data must be available to also predict all hinge moments for all modes of operation so that all of the hydraulic actuators can be adequately sized. The ability to predict the forward incidence controlled foil hinge moment is of special concern because of the expected size of that hydraulic load. All of these risks can be essentially eliminated by the development of a complete hydrodynamic test plan which will assure the availability of all required data in time to permit continuation of all phases of the detailed design of the ship.

Accurately determining the hydraulic flow capacity required has been shown to be difficult for conventional subcavitating ships. The lack of empirical data available for higher speed hydrofoils will make this problem even more difficult for HYD-7. The early inception of a comprehensive ship control simulation would be expected to be an invaluable asset to developing an adequate understanding of this area and will be required to keep the risk to a moderate level.

2.3.5.2 LIFT SYSTEM

2.3.5.2.1 GENERAL DESCRIPTION

The Boeing Model 1026-010 lift system configuration has a. canard arrangement with 20% of the lift on the forward foils and 80% on the after foils. (See Figure 2.3.5.2-l and Table 2.3.5.2-1). The forward foil is supported by a single steering strut, and the aft foil is supported by two splayed struts.

Retraction of the foil system was ruled out early in the study due to weight considerations, and the maximum hullborne draft was limited to 31 feet (9.4488m).

The strut and foil system weight breakdown is tabulated on Table 2.3.5.2-2, and lower level breakdowns are presented in Table 2.3.5.2-3 to 2.3.5.2-6. It should be noted that the primary structure weights have been increased by 10% for welds and 25% for fatigue design above the initial predictions.

The basic hydrodynamic form of the foil for supercavitating speed is shown on Figure 2.3.5.2-2. The foil is a NACA 16-207 section with ventilating spoilers on both top and lower surfaces. The struts, shown on Figure 2.3.5.2-3 are also ventilated to provide an air passage for foil ventilation.

The forward control surfaces consist of a $\pm 12^\circ$ steering of the forward strut about a vertical axis, and a $+10^\circ$ to -5° incidence control of the entire forward foils around a horizontal transverse axis.

The aft control surfaces consist of 25% of chord trailing edge flap for subcavitating speed controls with 20° down and 15° up actuation; and incidence control of foil tips (tipperons) provides roll control at supercavitating speeds. The tipperon span is limited to 5 feet due to structural considerations and is actuated within a range of $+10^\circ$ to -4".

2.3.5.2.2 FOIL SYSTEM AND CONTROL ARRANGEMENTS RATIONALE

Control considerations for the high speed supercavitating regime played a significant role in the choice of foil system configuration. The need for reliable

HYD-7 STRUT/F01 L PARAMETERS

BOEING MODEL 1026-010

- LOAD DISTRIBUTION - 20/80
- STRUT QUANTITY
  - FWD 1
  - AFT 2

- CRUISE DYNAMIC LIFT - 903 L.T.(917.50 MET TON)
- FOIL LOADING - 1448 LB/FT^2 (69.336 KN/m^2) (SUBCAVITATING MODE)*
- FOIL ASPECT RATIO
  - FWD 4.0
  - AFT 6.0
- FOIL T/C (FWD & AFT) - .07
- FOIL AREA
  - FWD 279.4 FT^2 (25.957m^2)
  - AFT 1117.4 FT^2 (103.810m^2)
- FOIL SPAN
  - FWD 33.43 FT (10.190m)
  - AFT 81.88 FT (24.957m)
- TAPER RATIO (FWD & AFT) - .50
- FOIL ROOT CHORD
  - FWD 11.14 FT (3.395m)
  - AFT 15.76 FT (4.804m)
- M.H.C.
  - FWD 8.67 FT (2.643m)
  - AFT 14.13 FT (4.307m)
- SWEEP ANGLE
  - FWD 14.04°
  - AFT 7.00°

- STRUT LENGTH
  - FOIL TO HULL 18 FEET (5.486m)
  - FOIL TO BASELINE
    - FWD 13 FEET (3.963m)
    - AFT 13 FEET (3.963m)
  - FOIL TO FBWL
    - FWD 9 FEET (2.743m)
    - AFT 9 FEET (2.743m)
- STRUT CHORD
  - FWD 9 FEET (2.743m)
  - AFT 13.2 FEET (4.024m)
- STRUT T/C

	FWD.	AFT.
AT FOIL	.10	.12
AT FBWL	.10	.12
AT HULL	.235	.235

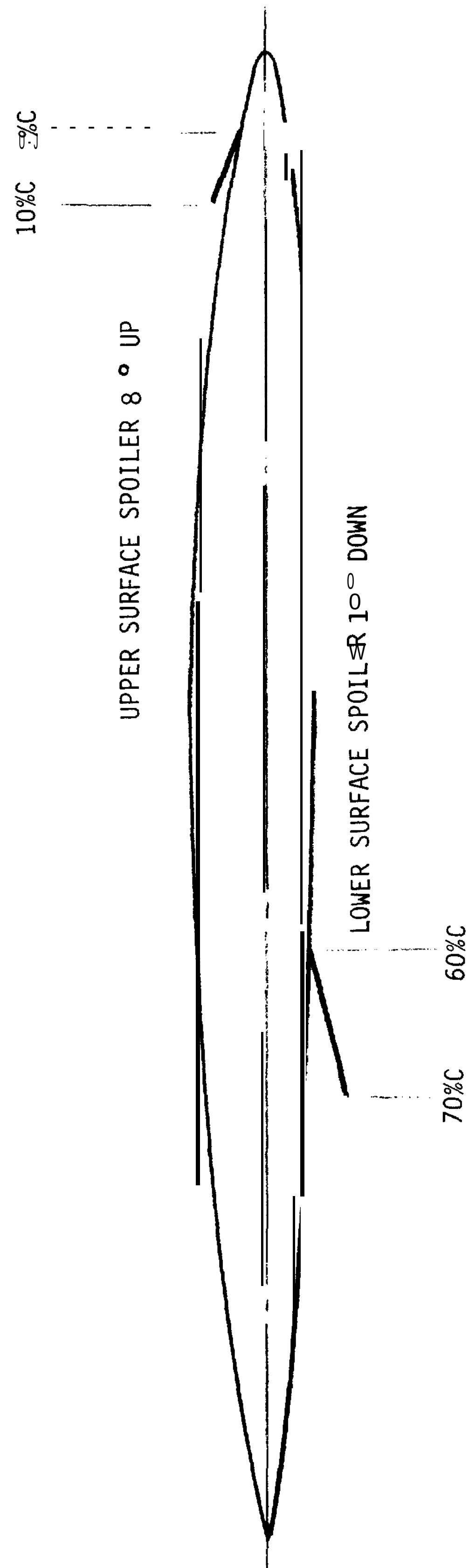
- STRUT SPACING (AFT)
  - AT FOIL 38 FEET (11.583m)
  - AT HULL 25 FEET (7.620m)
- AFT FOIL DIHEDRAL ANGLE
  - INBD 12°
  - OUTBD 12°
- FWD FOIL DIHEDRAL ANGLE - 0°

* 2068 lb/ft^2 (99.02 KN/M^2) in supercavitating mode with unwetting aft of spoilers.

TABLE 2.3.5.2-1

HYD-7

BASIC HYDRODYNAMIC FORM



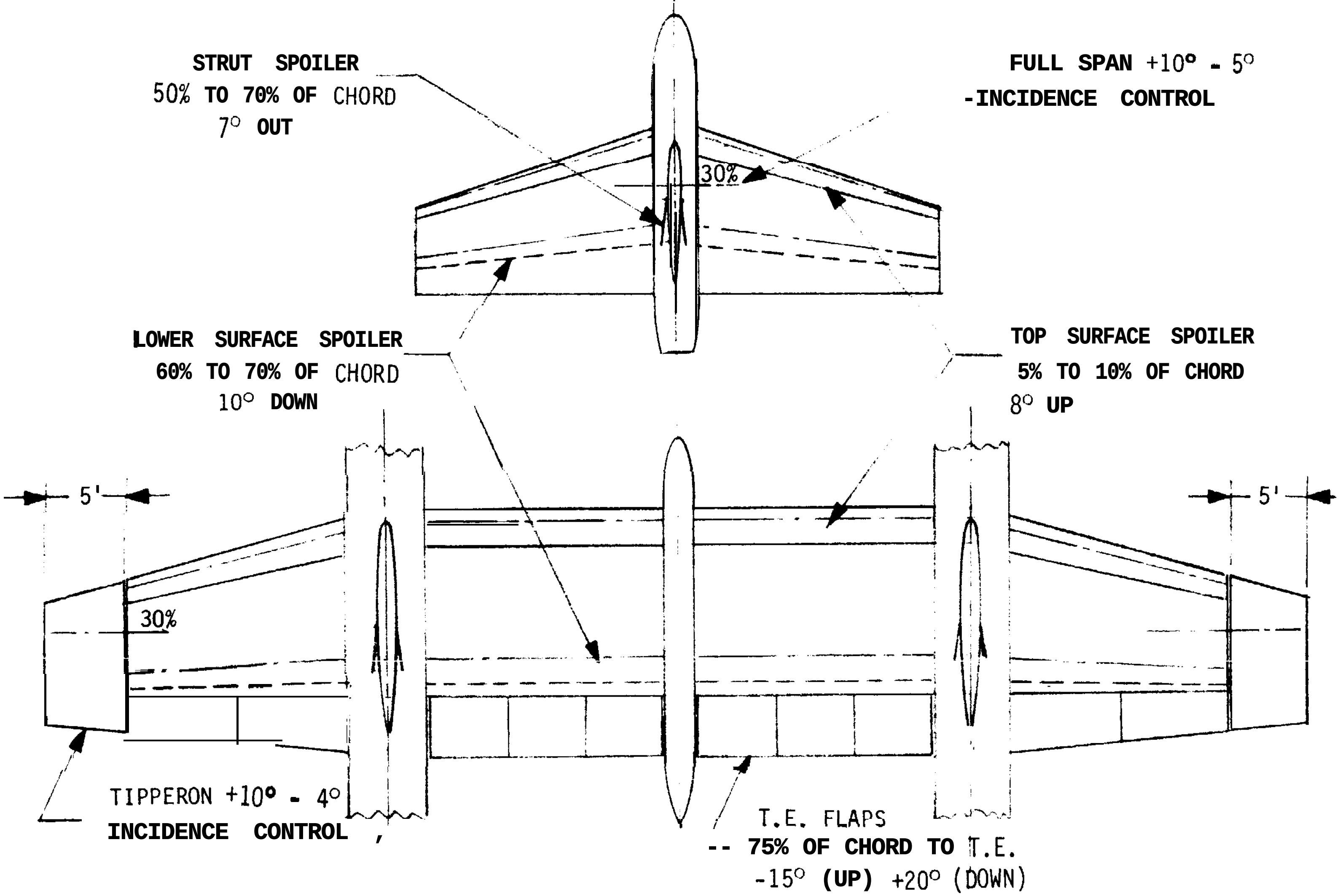
BASIC NACA 16-207 SECTION

BOEING MODEL 1026-010

FIGURE 2.3.5.2-2

THE BOEING COMPANY SEATTLE WASHINGTON

HYD-7 CONTROL CONFIGURATION



BOEING MODEL 1026-010

FIGURE 2.3.5.2-3

HYD-7

LIFT SYSTEM WEIGHTS

BOEING MODEL 1026-010

	LONG TONS			SHORT TONS			METRIC TONS			PERCENT		
	FWD	AFT	TOTAL	FWD	AFT	TOTAL	FWD	AFT	TOTAL	FWD	AFT	TOTAL
STRUTS	7.28	13.08	20.36	8.15	14.65	22.80	7.40	13.29	20.69	9.10	16.35	25.45
FOILS	6.88	31.90	38.78	7.70	35.73	43.43	6.99	32.41	39.40	8.60	39.88	48.48
PODS	1.13	9.30	10.43	1.27	10.42	11.69	1.15	9.45	10.60	1.41	11.63	13.04
RETRACTION	---	---	---	---	---	---	---	---	---	---	---	---
LOCKS	---	---	---	---	---	---	---	---	---	---	---	---
STEERING	4.58	---	4.58	5.13	---	5.13	4.65	---	4.65	5.73	---	5.73
CONTROL MECHANISMS	1.40	4.45	5.85	1.57	4.98	6.55	1.42	4.52	5.94	1.75	5.56	7.31
TOTAL	21.27	58.73	80.00	23.82	65.78	89.60	21.61	59.67	81.28	26.59	73.41	100.00
	LONG TONS			SHORT TONS			METRIC TONS			PERCENT		

TABLE 2.3.5.2-2

TABLE 2.3.5.2-3

FOIL WEIGHT
(All Weights in Long Tons)

FOILS	AFT	FWD
Skin	14.148	3.769
Spars	1.315	.269
Ribs	.619	.107
Fitting at ℄ Ship	.069	---
Strut Fitting	1.517	.537
Miscellaneous	.480	.217
Sub Total	18.148	4.899
Lower Spoilers Panels	.415	.132
Upper Spoilers Panels	.242	.066
Tipperon	1.512	---
Flaps	3.311	---
Sub Total	5.480	.198
Total Foil	23.628	5.097
+10% Weld	2.363	.510
+25% Fatigue	5.907	1.275
GRAND TOTAL	31.898	6.882

TABLE 2.3.5.2-4

STRUT WEIGHT
(All Weights in Long Tons)

STRUTS	AFT	FWD
Skin	5.110	2.715
Spars	1.533	.354
Ribs	1.150	.224
Hull and Foil Fitting	.768	.226
Miscellaneous	.533	182
Kingpost	----	1: 493
Sub Total	9.094	5.194
Spoiler Panels	.596	.203
Total Foil	9.690	5.397
+10% Weld	.969	.540
+25% Fatigue	2.422	1.349
GRAND TOTAL	13.081	7.286

TABLE 2.3.5.2-5

CONTROL SURFACE WEIGHTS - ACTUATORS AND MECHANISMS
(All Weights in Long Tons)---

	AFT	FWD
Tipperon		
Torque Tubes	1.230	
Actuator and Mechanism	.322	---
Incidence Control Actuator and Mechanisms	---	.522
Lower Spoilers (Foils) Actuator and Mechanisms	.350	.168
Upper Spoilers (Foils) Actuator and Mechanisms	.338	.162
Flaps Actuator and Mechanisms	.788	---
Strut Spoilers Actuator and Mechanisms	.533	.266
Sub Total	3.561	1.118
Miscellaneous +25%	.890	.280
GRAND TOTAL	4.451	1.398

TABLE 2.3.5.2-6

STEERING WEIGHT
(All Weights in Long Tons)

Bearings	1.065
Spacers	.266
Bearing Housing	1.885
Actuator	.138
Crank Arm	.143
Actuator Support	.166
Sub Total	3.663
Miscellaneous +25%	.916
GRAND TOTAL	4.579

POD WEIGHT

AFT	FWD
9.30	1.125

directional control, combined with the uncertainties and possible indeterminant side force characteristics of the struts led to the selection of a fully swivelled forward strut for steering and directional control. The swivelled steering strut has the advantage of maintaining the angle of attack on all the struts nearly zero, even when turning. Thus the tendency for unsymmetrical hydrodynamic phenomena on the struts is minimized. At the same'time the use of the total strut for steering tends to maximize directional control authority.

The supercavitating data for the foil system indicates that incidence control is the only sure way to control the foil lift. Thus, an incidence controlled forward foil system and incidence controlled tipperons (aft outboard foil tips) are provided for primary pitch heave control and roll control respectively. While it would be desirable from a controls point of view to utilize incidence control on the after foil system, it appears totally impractical to implement. Therefore, the concept for high speed control is to accomplish pitch heave control with only the forward foil. The after foil is a passive system at supercavitating speeds, with the lower tab deflected as necessary to achieve required steady state trims. The use of a passive aft foil causes the pitch motions to increase somewhat as is discussed in 2.2.5, but these motions are still well below one degree standard deviation.

The requirements for foil incidence control and swivelled strut control forward combined to create a strong case for a single strut, inverted T foil system. These decisions all lead in turn to a need to minimize the size of the forward foil system. By making the forward foil system small, the mechanical problems and added foundations necessary for the implementation of foil incidence control and strut swivelling are minimized. At the same time, the greater foil area aft results in a larger aft foil span which in turn tends to maximize the effectiveness of the tipperons to accomplish roll control. Thus a 20/80 (forward/aft) weight distribution between the forward and after foils results.

In the subcavitating regime, the swivelled forward strut and variable incidence foil forward continue to be used for control purposes; however, the after foil employs trailing edge flaps to supplement pitch/heave and roll control. Thus, in the subcavitating regime the control configuration does not depart significantly from contemporary systems such as the PHM-1.

The decision to use only small incidence controlled segments of the after outboard foil tips was reached after investigations into the roll control authority of such control surfaces, and mechanical implementation studies indicated that such a plan appears at this stage to be feasible.

The foil system is non-retractable, with a maximum navigational draft of 31 feet. With this constraint on navigational draft, a design study was conducted to determine the sea state capability of the ship. That study and the significant results are summarized as follows:

Basic Data (Table 2.1 and Figures 2.1-1 and 2.1-2)

Max. Draft = 31 ft.

Hull Draft = 11 ft.

Propeller Diameter = 8 ft.

(Propulsion Pod slung under after foil)

Physical strut length - Baseline to foil chord plane intersection = 13 ft.

For sea state evaluations it is necessary to find the effective strut length. The effective strut length, being the physical strut length plus an allowable hull immersion for cresting wave tops, minus a minimum foil submergence value. Mathematically this is expressed as:

$$l_{\varepsilon} = l_S + S_H - S_F$$

where: l_{ε} = effective strut length

l_S = physical strut length

S_H = allowable hull immersion for ½g upward acceleration

S_F = minimum foil submergence allowing no more than ½g downward

For subcavitating operation the allowable hull immersion is estimated to be 8 feet (a number arrived at by scaling TUCUMCARI and PHM measured data) and the minimum foil submergence is estimated to be 2 feet, resulting in an effective strut length of 19 feet.

In the development of the "Hydrofoil Ship Control and Dynamics Specifications"* it has been established that the effective strut length should exceed the significant wave height by 40%, for the ship to meet the full operational requirements in seas.

That is:

$$l_{\varepsilon} = H_{S} \quad (1.40)$$

Thus for the HYD-7 design with a 19 foot effective strut length, it is estimated that the ship should meet all its operational requirements in all seas with significant wave height equal to or less than 13.6 feet (4.1 meters).

Figure 2.3.5.2- shows long term distributions of wave heights for four (4) North Atlantic Ocean areas. These data were taken from Hogben and Lumb, "Ocean Wave Statistics" and represent essentially all the North Atlantic from the U.S. Atlantic sea shore to the European western shores. From these curves it is seen that the significant wave height is less than 4.1 meters 90% to 92% of the days of the year in these North Atlantic seas. Thus, it is concluded that the HYD-7 with its 19 foot effective strut length should be capable of meeting all its operational requirements at least 90% of the days of the year in the North Atlantic.

One last point with regard to strut length. The nominal rough water operating point should be chosen as the mid point of the effective strut which results in a mean rough water foil depth of 11 feet. (2 feet minimum submergence plus ½ effective strut length.)

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* Reference A.2-9

2.3.5.2.3 FORWARD FOIL & STRUT ARRANGEMENT

The forward strut/foil assembly is of the inverted steering "T" arrangement. See Figure 2.3.5.2-4. The assembly is capable of rotation of ±12° about a vertical pivot located 12.6 feet (3.84 m) aft of the forward perpendicular. Two radial spherical roller bearings located 6 feet (1.83 m) apart and a spherical roller thrust bearing spherically centered with lower radial bearing, provide support and rotating capability between strut and hull. Seals are provided below the lower bearing to prevent sea water from penetrating the lubricated bearing space.

The forward foil attachment to the strut also provides a pivot point for incidence control. Two 12-inch by 7-inch self-lubricating journal bearings mounted in the foil lugs located 23" apart provide the hinge for the incidence control of the foil. Forward of that hinge a vertical push rod attaches to a foil lug via an intermediary link. This push rod coincides with the steering pivot;is located inside that hollow steering pivot and issupported by a series of journal bearings. An incidence control hydraulic actuator is located above the steering mechanism on top of the steering pivot.

On each side of the pod, bow-tie shaped openings allow the incidence-controlled foil motions. A plate segment welded to the foil slides against the inner pod skin closing the opening in a non-watertight fashion.

Spoilers extending down the strut from the baseline to the upper surface of the pod are located on both sides between 50% and 70% of strut chord.

Upper foil spoilers are located between 5% and 10% of chord and lower foil spoilers are located between 60% and 70% of foil chord. The forward foil has no trailing edge flaps.

2.3.5.2.4 AFT FOIL & STRUTS ARRANGEMENT

The aft strut and foil assembly was located to position the struts in such a manner as *to* provide a direct path for the propulsion drive shaft between the engines and the pods while providing an acceptable engine arrangement inside the hull and providing quarter span foil support. The struts resulting from this arrangement are identical on port and starboard sides with right angle flange mounts at hull and foil.

The pods with the propulsion machinery mount to the foils on planes parallel to the strut flange mounting surfaces and normal to the drive shafts simplifying machinery alignment and sealing strut-foil and foil-pod-interfaces as shown on Figure 2.3.5.2-5.

The spoiler and control surfaces reach a maximum of complexity in the aft foil tip span where a combination of tipperon, trailing edge flaps and top and bottom spoilers combine with a tapered configuration. Thus, this area was selected for a design feasibility study. See Figures 2.3.5.2-6 through -9 for the preliminary design solutions reached from this study.

2.3.5.2.5 CONTROL SURFACE ACTUATION MECHANISMS

Spoilers

Spoilers along the foil span or down the struts are divided into segments with lengths matching the corresponding strut or foil rib spacing. Each spoiler segment is hinged by two self-lubricating spherical bearings to the main structural box. The spoilers are deployed by a series of identical over-center mechanisms that are actuated by a common rod pushed or pulled by a hydraulic actuator. The spoilers' hydraulic actuators are provided with end locks to mechanically lock the spoilers in either the deployed or retracted positions independent of hydraulic pressure.

The foil spoiler mechanisms (see Figure 2.3.5.2-6 and -7) consist of two wishbone links per spoiler segment with the forked end directly attached to the common rod and the other via a spherical bearing to spoiler segment lugs. During deployment, the pull rod will rotate slightly and this rotation will be absorbed by the actuator rod end spherical bearing. In the case of the strut spoiler, the back-to-back arrangement prevents any rotation of the rod. See Figure 2.3.5.2-8.)

The links in this case are of the dog bone type with spherical bearings at both ends, an extra fitting on the pull rod is necessary, and the pull rod is made square to stabilize the mechanism.

Tipperon

See Figure 2.3.5.2-9. Tipperon loads are taken by two spherical self-lubricated bearings located in the foil main structural box at the two outboard ribs located 36 inches (914.4mm) apart.

The tip rib supporting the first tipperon bearing protrudes top and bottom to provide the needed bearing support and also doubles as a fence to prevent discontinuity between the foil and deflected tipperon. All successive ribs provide bearing support for the tipperon torque tube.

2.3.5.2.6 LIFT SYSTEM STRUCTURE

The hydrodynamic and control surface requirements seriously reduce foil and strut cross sections, removing some of the prime structural material area to make room for spoilers and their mechanisms.

The loads and stress calculations were calculated by a Boeing computer program. The inputs to this program limited the foil structural bases to portion between 10% and 60% of chord and between leading edge and 50% of chord for the struts.

Ribs shaped to form an "I" beam section provide continuity across spoiler areas, and required the spoilers to be segmented into lengths equal to rib spacing. Foil leading edge and trailing edge loads are transmitted to the primary foil structure by the ribs acting as cantilever beams.

The main foil structural box fatigue analysis is beyond the scope of this study, but the preliminary design of the foils reflect basic fatigue design principles. The foil construction is intended to include a large ratio of machining while keeping welding to a minimum with the unavoidable blind welds limited to low stress areas.

(U) Figures 2.3.5.2-10 and -11 depict the proposed foil scantling structure. The material selected for the lift system primary structure components is a titanium alloy (TI-6AL-4V) with good mechanical properties and compatibility with the sea water environment. Titanium's other advantage is to reduce the lift system and overall vehicle weight.

(U) The manufacturing processes for titanium would,at the present be marginal for the manufacture of such large foils and struts, but the time frame for this ship is such that it can be predicted that the state of the art at the time of manufacturing will be more than sufficient to manufacture large struts and foils of titanium alloys.

Structure Resistance to High-Impact Shock (U)

(C) The HYD-7 TLR (Reference A.2-1) requires that near-miss underwater explosion attacks encountered in the foilborne mode and resulting in a keel shock factor of 0.3 or less will not inactivate mission-critical-function components.

(U) Dynamic analysis of the HYD-7 foil/strut assemblies have not been conducted to determine their adequacy. However, the studies reported in Reference 2.3.5.2-1 indicate that similar assemblies are transparent to UNDEX induced shock and adequate to assure their survivability under the the above design condition without flooding or "water-backing" their internal void spaces, Should such "water-backing" be considered desirable in the future to enhance shock survivability, only slight modification would be required to permit flooding of the titanium assemblies with fuel or sea water whenever UNDEX exposure could be expected.

FIGURE 2.3.5.2-10

THE BOEING COMPANY

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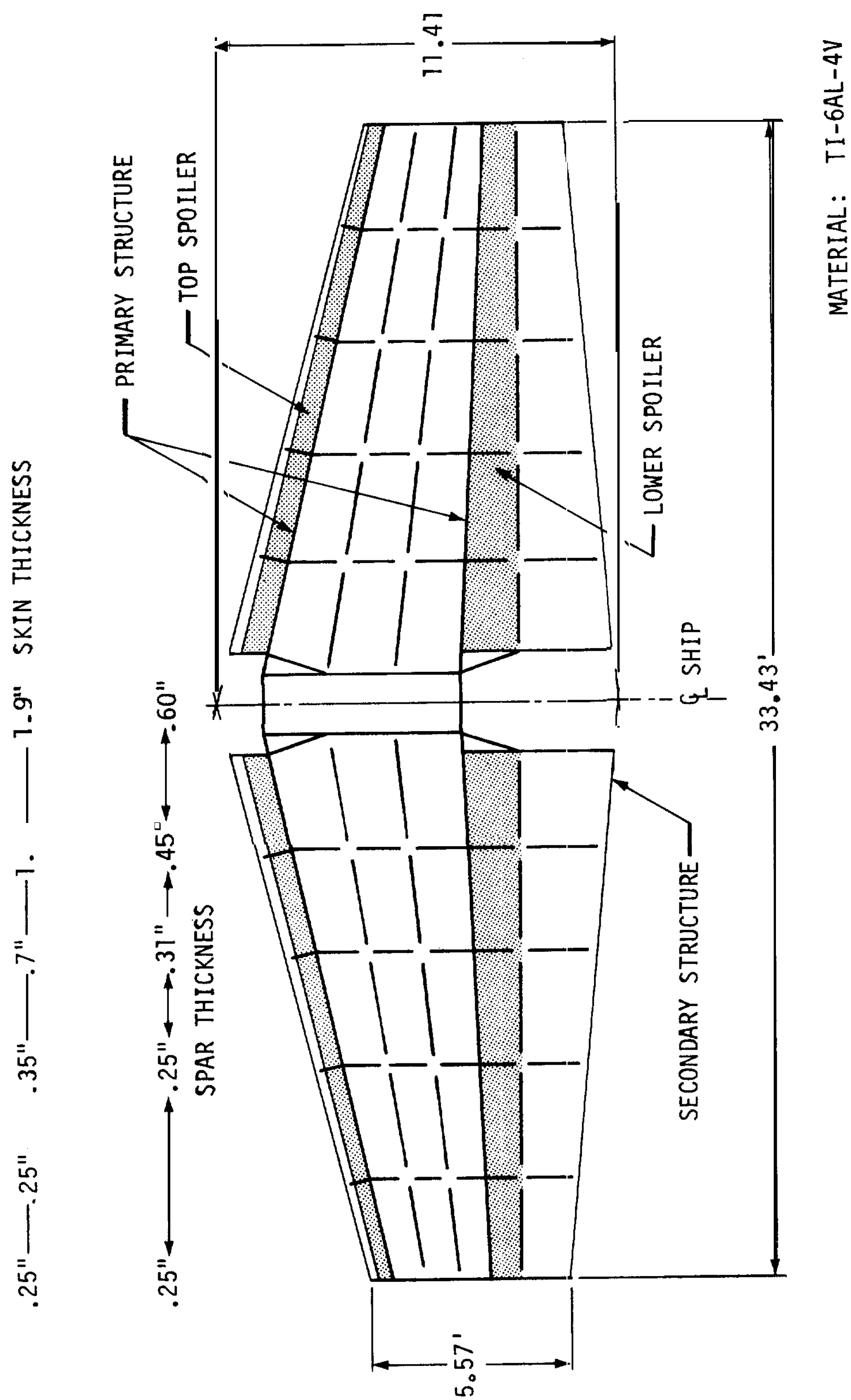
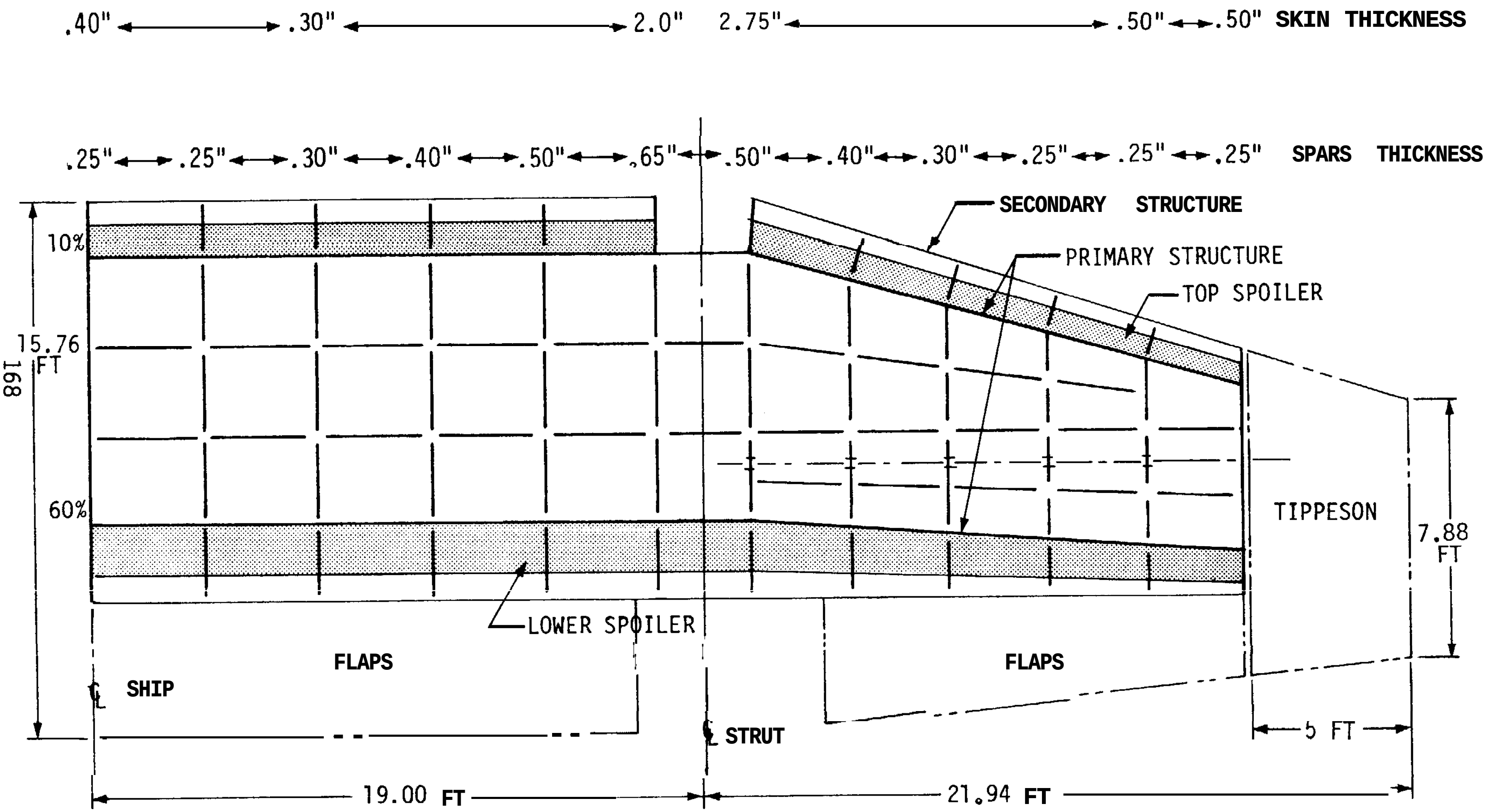
FORWARD FOIL SCANTLING



BOEING MODEL 1026-010

AFT FOIL SCANTLING



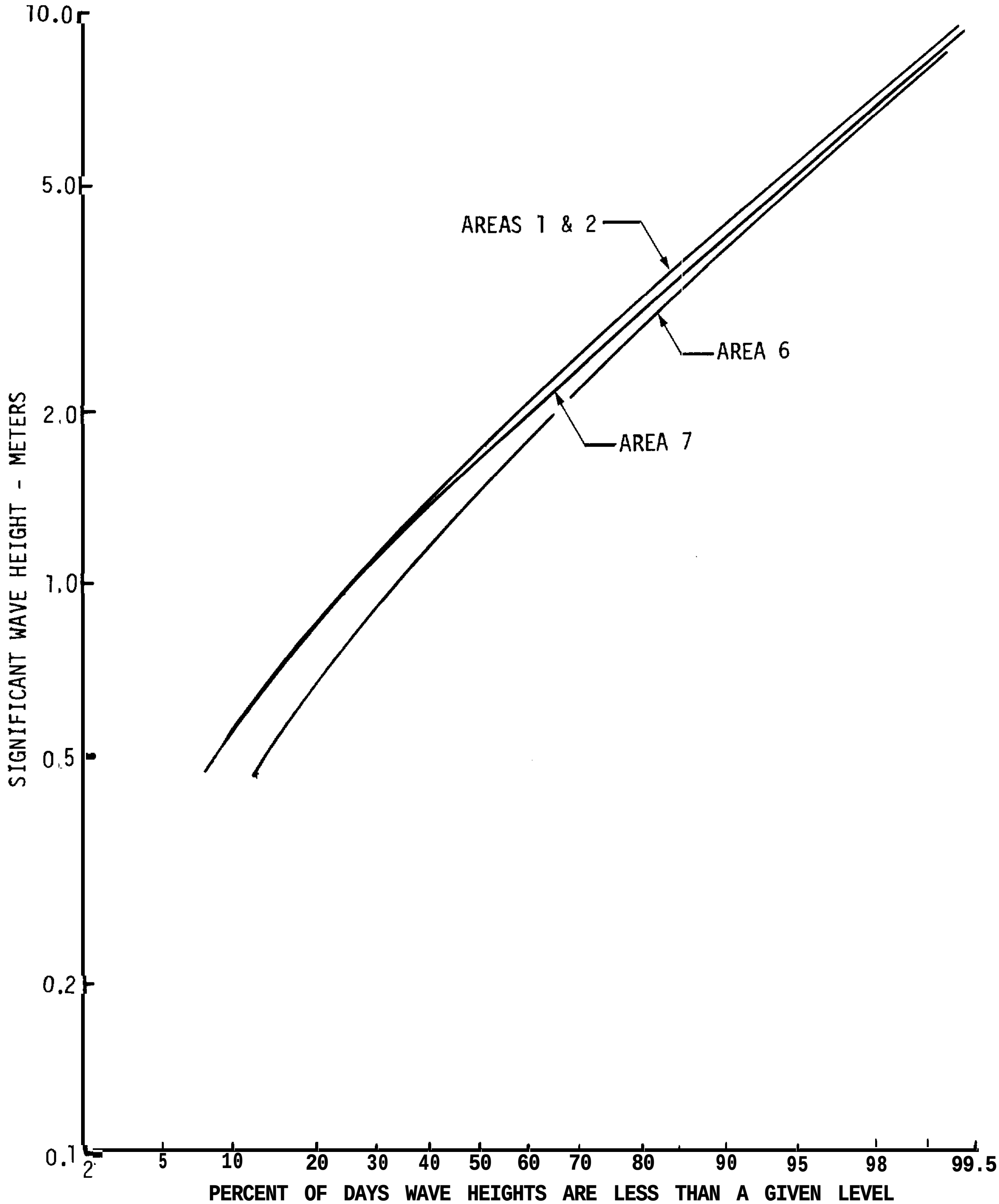
MATERIAL: TI-6AL-4V

FIGURE 2.3.5.2-11

FIGURE 2.3.5.2-12

BOEING MODEL 1026-010

DISTRIBUTION OF SIGNIFICANT WAVE HEIGHTS FOR NORTH ATLANTIC



REF: HOGBEN & LUMB

Risk Assessment (U)

(U) There are four elements of the notional strut/foil system employed in this study which are considered risk sensitive, roughly in order of importance:

(U) 1. The fundamental transcavitating data base used for the study is basic and discussed further in the section covering hydrodynamics.

(C) 2. The structural loads criteria used for this feasibility study are quasi-static in nature. Short of an elaborate analysis, it is not possible to predict to what extent fatigue/fracture criteria will govern. The risk involved is not a "show stopper" but impacts the predicted stress levels, and therefore, strut/foil system weights. The reduced section thicknesses and more complex structural arrangement of the proposed HYD-7 system made necessary by the 70 knot dash requirement would suggest that fatigue/fracture aspects of the design will be important.

(u) 3. The hydroelastic behavior of the system has not been analyzed. The structural response in this sense is somehwat subject to controls imposed at the detail design level and predictive techniques have been improving as a result of investigations carried out by DTNSRDC.

(U) 4. Titanium is indicated as a strut/foil material primarily to take advantage of its high strength to weight ratio and superior resistance to corrosion, although the ultimate wisdom of this choice should await a detailed comparison of the fatigue/fracture behavior for this and other candidate materials. It appears safe to say, however, that the titanium alloys will always exhibit an overall weight advantage as compared to any metallic competitors. The longer range prospectus of structural composites appears to be the key to still lighter foil systems, but it was not possible to deal with these materials in a contemporary sense for this feasibility study. As for the titaniums, there is no risk inherent in the material itself. The Navy has pursued a program of alloy development and characterization for some years and can write specifications for titanium wrought material with very suitable properties for marine structural application. The titaniums exhibit high weldability, have been increasingly employed in the chemical process industry and have been a very significant element of certain aerospace programs. In marine circles there has been a widespread, albeit somewhat erroneous impression, that titanium is very difficult to fabricate, particularly as regards welding processes. The impediment then is lack of visibility or a demonstration that detailed design and fabrication of strut/foil physical structures can be accomplished using titanium with acceptable production economy. This is not a question peculiar to HYD-7. The advantages of using this material in subcavitating hydrofoils as well as other advanced ship applications are manifest.

REFERENCES

2.3.5.2-l Grumman Aerospace Corporation Report No. RPT-M-150-23, "HY-130 Foil System Program for PHM Class Ship. Final Report," February 1975, Studies conducted under Contract N00024-74-C-0257.

2.3.6 OUTFIT AND FURNISHINGS

The "outfit and furnishings system" is a loosely allied collection of some 32 WBS elements, many of which are not systems in the classic sense. All of these are of a conventional nature. Many involve Navy standard components except where technological weight reductions are possible, as contrasted to normal surface ship practice when pursued at a detail design level. Group 635 (hull insulation) is of significance as far as fire protection policy is concerned in that the weights indicated in Table 2.3.6-1 assume that normal thermal and acoustic insulation requirements are provided by the passive fire protection insulation located as shown on Figure 2.3.6-1.

Risk Assessment

There are no significant technical risks in the outfit and furnishings group.

BOEING MODEL 1026-010

HYD-7 FIRE PROTECTION

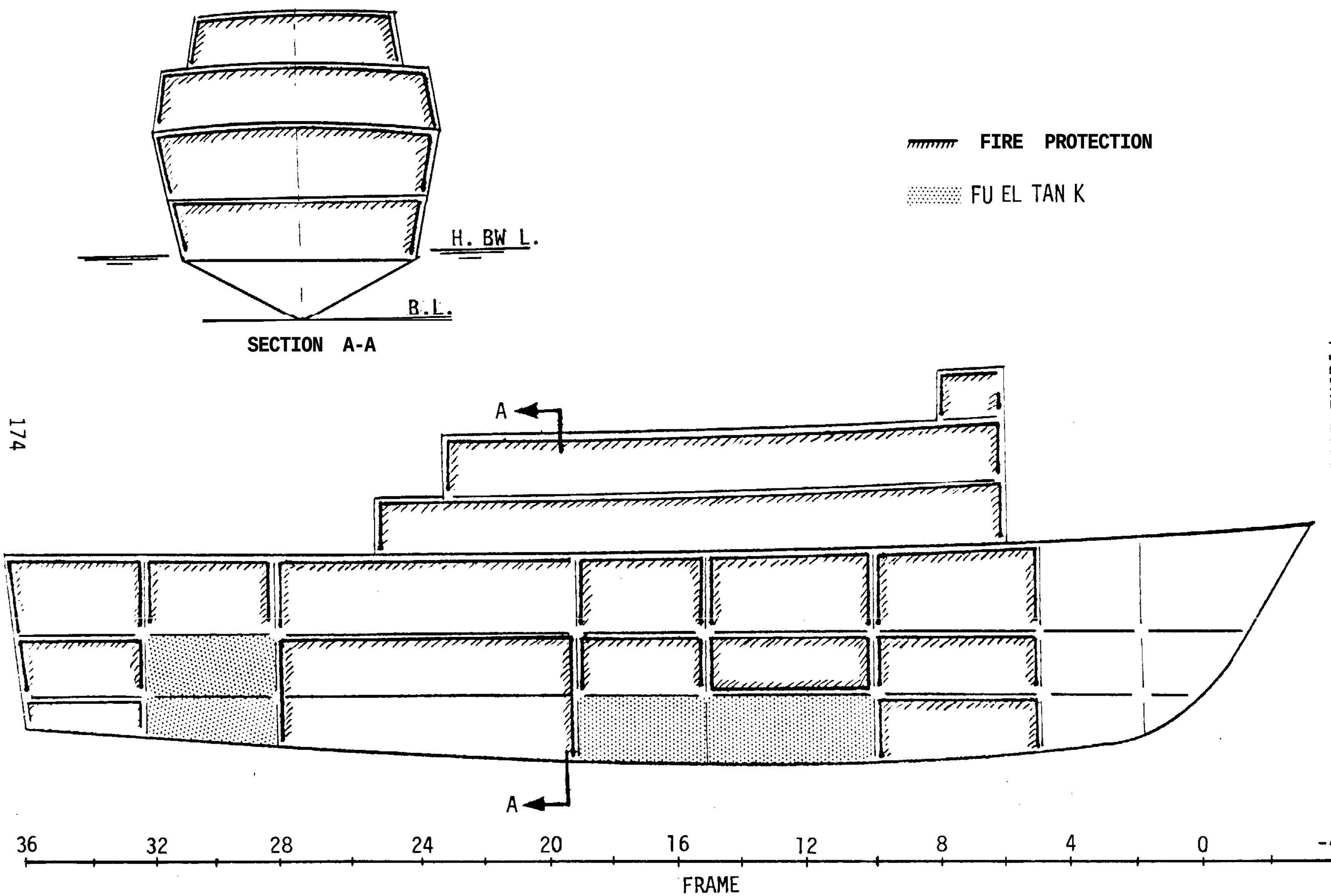


FIGURE 2.3.6-1

TABLE 2.3.6-l

OUTFIT AND FURNISHINGS WEIGHT ESTIMATE

SWBS GROUP NO.	OUTFIT AND FURNISHINGS SYSTEM	WEIGHTS LONG TONS	SHORT TONS	METRIC TONS	% OF TOTAL
611	Hull Fittings	1.11	1.24	1.13	1.95
612	Rails, Stanchions, and Lifelines	0.34	0.38	0.35	0.60
613	Mooring and Towing Fittings	0.50	0.56	0.51	0.88
614	Rigging and Canvas	0.10	0.11	0.10	0.18
621	Non-Structural Bulkheads	4.33	4.85	4.40	7.60
622	Floor Plates and Gratings	2.48	2.78	2.52	4.35
623	Ladders	0.92	1.03	0.93	1.61
624	Non-Structural Closures	0.34	0.38	0.35	0.60
625	Airports, Fixed Portlights, and Windows	0.12	0.13	0.12	0.21
631	Painting	3.71	4.16	3.77	6.51
	Deck Covering	2.46	2.76	2.50	4.32
634 635	Hull Insulation (Passive Fire Protection)	20.00	22.40	20.32	35.09
637	Sheathing	1.37	1.53	1.39	2.40
638	Refrigerated Spaces	2.05	2.30	2.08	3.60
641	Living Spaces - Officers	2.05	2.30	2.08	3.60
642	Living Spaces - Noncommissioned Officers	2.12	2.37	2.15	3.72
643	Living Spaces - Enlisted Personnel	2.46	2.76	2.50	4.32
644	Sanitary Facilities	0.96	1.08	0.98	1.68
651	Commissary Spaces	3.08	3.45	3.13	5.40
652	Medical Spaces	0.32	0.36	0.33	0.56
655	Laundry	0.24	0.27	0.24	0.42
661	Office Furnishings	0.55	0.62	0.56	0.96
662	Machinery Control Furnishings	0.12	0.13	0.12	0.21
664	Damage Control Stations	0.68	0.76	0.69	1.19
665	Workshops	1.23	1.38	1.25	2.16
671	Lockers and Special Stowage	0.90	1.01	0.91	1.58
672	Storerooms and Issue Rooms	2.46	2.76	2.50	4.32
	TOTALS	57.00	63.84	57.91	100.00

2.3.7 COMBAT SYSTEM (U)

2.3.7(a) DESCRIPTIVE SUMMARY (U)

(C) The mission of the HYD-7 is stated in Reference 2.3.7-1, the HYD-7 TLR. Briefly, the TLR describes a fleet ship capable of supporting broad categories of fleet operations in the ocean areas. Major capabilities are established in ASW, SSW, and AAW, with an alternate capability established in mine warfare and mine countermeasures achieved by off loading non-integral equipment used for AAW, SSW and ASW. The TLR includes a list of combat system equipments for AAW, SSW and ASW, but no list for mine warfare or mine countermeasures.

(U) Paragraph 2.3.7(c) lists weapons and sensors for warfare areas in accordance with the TLR and details weight, volume and power required. Similar data for command, control communications and navigation equipment necessary to support the ship were given in 2.3.4. A brief description of all these systems follows.

AAW (U)

(C) The Target Acquisition System MKXX is respresentative of a medium range early warning and acquisition radar which will be used to provide early warning on aircraft and missiles and will provide data for air control of ASW, AAW, and RPV aircraft. This radar is a high-powered version of the current TAS MK 23. The System will provide automatic processing of targets for the tactical data system for target designation and control purposes. It will also have an integrated IR search set for EMCON use.

(C) The APS-116 (surface version) will be installed as a surface search radar with periscope detection (and possibly debris avoidance) capability and in addition will aid in detection of low flying missiles. MTI can be developed by 1995 to give performance in the presence of land clutter.

(C) The Advanced Lightweight Track-While-Scan Fire Control System will provide radar control in automatic (with manual override) or manual modes for the Advanced Self-Defense Missile. Automatic detection, tracking and fire control,

(C) integrated threat evaluation and targeting and vertical launchers for the entire load of missiles (24) will provide a high capability for self-defense, limited most by the missile load and not by channelization or missile guidance requirements.

SSW (U)

(C) While the Advanced Self-Defense Missile may provide a very limited capability against small and close surface targets, the primary SSW weapon will be the HARPOON MKXX, a higher performance version of HARPOON. Over-the-horizon targeting will be accomplished by aircraft data or ship-launched RPVs. Within the horizon targetting will be accomplished by the TAS MKXX or by the APS-116 radar. The MK 48 torpedo will give added SSW capability.

RPV Launch and Retrieval Concept (U)

(U) Figure 2.1-5 depicts a concept of launching and retrieving RPVs. The configuration of launcher and retrieval gear is coordinated with the location and layout of the RPV room to provide a minimum of deck handling and a minimum of deck space required.

(U) For launching, an RPV is mounted on the launcher in the RPV room and checked out. The side doors are opened. The launcher is swung out and the RPV launched. The angle of launch compared to fore and aft need not be zero but can vary with the relative wind.

(U) For retrieval a boom supporting a retrieval net is swung out from the main deck and the RPV, approaching from aft, but not over the ship is landed in the net. The boom and net are then swung inboard on the deck. A crane removes the RPV from the net.

(U) This concept has the advantages of:

(1) Minimum deck space requirements.
(2) The RPV can be launched into the relative wind with reduced turbulence.
(3) The RPV is not flying directly into high turbulence and not directly into structure for retrieval.

(U) (4) Proximity of launch and retrieval gear to RPV room.

(5) Permits increased handling, launch and retrieval mechanization.

ASW (U)

(1) ASW Sensors (U)

(C) The HYD-7 will be fitted with two on-board and two off-board sonars. On-board sonars are the Active/Passive Reliable Acoustic Path Sonar (APRAPS) and the Active/Passive Towed Array with Depressor (SADTOS). The off-board sensors are the Expendable Reliable Acoustic Path Sonar (ERAPS) in over-the-side or rocket-projected configurations, and the Deployed Linear Array. These sonars support ASW functions as shown below

Sonar	Surveillance	Classification	Localization	Attack
APRAPS				
Passive	Yes	Yes	No	No
Active	Yes	Yes	Yes	Yes
SADTOS				
Passive	Convergence Zone	Yes	No	No
Active	No	No	Yes	OTS Weapons
ERAPS	Secondary Use	Yes	Yes	ASW Stand Off Weapon
Linear Array	Yes	Yes	No	No

(2) ASW Weapons (U)

(C) The ASW weapons are six MK 48 torpedoes (surface version) and twelve Advanced ASW Stand Off Weapons with ALWT. The MK 48s are mounted port and starboard on the main deck in single canisters firing aft and slightly outboard to avoid interference with the foils during launch. The ASW Stand Off Weapons are mounted on each quarter on the main deck in lightweight fixed launchers. Fire control for these weapons by 1995 will be integrated into AAW fire control or TDS computers with a launch control and monitor panel for each weapon.

(C) Guidance up-date for the ASW Stand Off Weapons will be accomplished by integration of a link into one or several of the installed radars.

C^3N (U)

(U) Command and control will consist of a tactical data system based on UYQ technology probably reduced one-half to two-thirds in weight by 1995. This data system will interface with fire control and AAW and ASW sensors through use of UYQ type consoles and dedicated launch, control and monitoring panels for the various weapons. RPV control and piloting (except for launch and recovery phases) will be conducted in the CIC in close coordination with AAW and ASW weapons and sensors. RPV relayed data and RPV sensor data will feed directly to the tactical data system for use by command and weapon users. The Joint Tactical Information Distribution System will serve as an exterior tactical data link replacing UHF Link 11. A replacement for the HF Link 11 is not indicated and the communication equipment list (Table 3-l) of letter NAVSEA Code 6112, Serial 117 of 18 October 1976 does not make provision for an HF Link 11 modem for HYD-7.

(U) The communications list includes (besides JTIDS) satellite communications, 5 HF transceivers, 4 HF receivers, 4 UHF transceivers and 3 VHF transceivers, with teletype and security systems. Added requirements not included in the NAVSEA 6112 list are a VHF/UHF direction finding system for homing on deployed linear arrays and triangulating ERAPS buoys, VHF receivers for ERAPS and deployed array data, visual and underwater communications equipment, and a LAMPS data link for use with RPVs and other ship's LAMPS.

(U) The navigation system will use the Global Positioning System (GPS) for real-time highly accurate navigation for piloting, open ocean navigation and mine warfare. GPS will increase the accuracy of over-the-horizon targeting employing other vehicles. OMEGA will be provided as backup for ocean navigation. By 1995, a real-time system for piloting, incorporating the navigation chart should have been developed.

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2.3.7(b)

(U) Location of weapons and sensors are shown in the General Arrangement drawings.

2.3.7(c) WEIGHT, VOLUME AND POWER CHARACTERISTICS - WEAPONS AND SENSORS (U)

(C)

	WEIGHT POUNDS	INTERNAL VOLUME CU. FEET	POWER KVA
AAW			
TAS MKXX (IFF included)	11,000	400	100.00
Adv LW TWS FCS	1,700	40	18.80
ASMD EW MKXX	4,000	100	75.00
ASMD with Launcher (24 Missiles)	18,000	415	(From FCS)
SSW			
AN/APS-116 Radar	300	33	5.90
Harpoon MKXX with Launchers	17,900	27	10.00
ASW			
Active/Passive Towed Array w/depressor	10,900	450	12.50
APRAPS	12,800	840	56.30
Depl Linear Array	9,100	126	27.50
ERAPS (20)	3,600	35	--
ERAPS, Rocket Projected (26)	13,000	175	--
ERAPS Launcher	3,700	54	2.50
MK 48 Torpedo (6)	20,500	300	--
Eject Lch Control for MK 48	6,000	320	1.25
ASW Standoff/ALWT with Launcher (12)	50,400	75	30.00
ASW Electronics	11,000	700	47.50
C^3N			
C&C (SWBS 410)	7,217	690	35.40
Comm (SWBS 430,440)	9,699	388	44.30
Nav (SWBS 420)	2,480	114	7.60
SDMS (SWBS 490)	5,600	183	4.50

(C)

	WEIGHT POUNDS	INTERNAL VOLUME CU. FEET	POWER KVA
Sub-Vehicles			
Standard Ship Launched RPV (12)	3,000	--	--
RPV Launch/Retrieval/Support	2,100	375	25.00
TOTAL MISSION SYSTEMS	223,996	5,840	504.10
	(101,816 kg)	(165.37m³)	

WEIGHT 112.0 Short Tons
100.0 Long Tons
101.6 Metric Tons

VOLUME 5,840 Cubic Feet
165.4 Cubic Meters

POWER 504 KVA (0.8 Power Factor)

2.3.7(d) COMBAT SYSTEM WEIGHT (U)

(U) (1) The installed combat system weight is assumed to be the weight of the entire combat system applicable to SWBS 400 and 700 items less the removable items classified as expendables (Para. 2.3.7(d)(2)).

	ST	MT	LT
Combat System Weight with expendables (2.3.7(c)	112.0	101.6	100.0
Less expendables (2.3.7(d)(2))	-57.2	-50.5	-49.7
Installed Combat System Weight	54.8	51.1	50.3

(C) (2) Combat System - Expendables Weight (SWBS F21-F27)

	WT. LBS
24 Adv. Self-Defense Missiles	10,800
8 HARPOON Missiles	11,600
8 HARPOON Canisters	5,320
46 ERAPS Sonobuoys	8,280
26 ERAPS Rocket Motors	8,320
6 MK 48 Torpedoes	20,500
6 Ejection Launchers	6,000
12 ASW Standoff Weapons/ALWT	36,000
Decoys (Active, IR, RF and hybrid)	1,500
12 Standard Ship-launched RPVs	3,000
	111,320
	(57.2 ST)
	(50.5 MT)
	(49.7 LT)

(3) Removable Weight for Mine Warfare Mission- (U)

(C) The HYD-7 TLR specifies two mine warfare missions as alternates; minelaying and minesweeping. Presumably these missions would not require both capabilities simultaneously. In order to perform either of these missions, expendables and other mission equipment would have to be off-loaded to provide compensation for mine warfare equipment.

(C) The TLR states that it will be necessary to reduce mission capabilities in other warfare areas in order to accomplish mine warfare missions, and that air defense will have to be performed by other vehicles. The following equipments can be off-loaded in a reasonably short time as compensation and reloaded without exorbitant delay and cost:

	WT., POUNDS
24 Advanced Self-Defense Missiles/Canisters	10,800
8 HARPOON/8 Canisters/2 Launchers	16,920
1 A/P Towed Array/Depressor/Winch (SADTOS)	10,900
1 APRAPS/Winch	12,800
6 Deployed Linear Arrays/Handling Equipment	9,100
46 ERAPS Sonobuoys	8,280
26 ERAPS Rockets	8,320
1 ERAPS Launcher	3,700
6 MK 48 Torpedoes	20,500
6 Ejection Launchers for MK 48	6,000
12 ASW Standoff Weapons/2 Launchers	50,400
12 RPVs and Launch/Retrieval Gear	5,100
18 Super RBOC and Launcher	1,466
1 Boat and Equipment	3,300
TOTAL (Maximum Off-Load Capability)	167,586
	(76.175 kg.)

(C) It may be considered too expensive in time and cost to remove this maximum; in particular the complex sonar equipment aft but below the main deck. If the APRAPS is retained aboard, but the Active/Passive Towed Array with Depressor is removed, the practical removable weight is then 156,686 lbs. It must be noted that some of this removable weight is well forward of the stern. If nearly all this weight of mines and launch gear are put aboard, some fore and aft compensation may be required from the fuel load. Vertical moment compensation may not be required since some of the weight removed is much higher in the ship than

(C) the minelaying system weight. Some mines could be launched from the forecastle. This location gives high risk of sea damage during transit. It is concluded that all mines should be launched from the main deck aft.

(4) <u>Weight Requirements and System Description for Mine Warfare Missions</u>. (U)

(a) Minelaying (U)

(U) The TLR for the HYD-7 does not specify in detail mine warfare systems. For the purposes of this study, a representative minelaying suit will be selected. The system will consist of mines, their launching system and the navigation system. Since the Global Positioning System is already part of the HYD7 navigation equipment, no added navigation features are required as an accurate fix can be recorded for each mine dropped.

(C) The selected suit will consist of EX-65 mines and the Pallet, Universal Mine Launcher (PUML). The launch system would require the HYD-7 to be built with deck fittings to allow rapid installation and securing of the PUML system.

(C) For a weight allowance of removable expendables of 156,686 lbs, the suit is 50 EX-65 mines, 17 pallets with three mines per pallet (less one mine), and 6 accelerator pallets (no mines). Added equipment is 50 mine cradles, and 6 power units supplied by ship hydraulic power. The launching system would be one line of 8 pallets on each side of the main deck aft with the pallets stacked 2 deep. The acceleration pallets would be at the stern in each line and the power units forward of each line, stacked 2 high. Two more lines single-stacked are inboard of the outboard lines.

(U) Sheet 3 of the General Arrangement Drawing shows the minelaying alternate for the main deck aft. (See Figure 2.1-3.)

(U) The manning total for the HYD-7 need not be increased for the minelaying mission. Since much combat system equipment will be

(U) removed, judicious replacement of some personnel by a maximum of 3 minemen and an officer trained in minelaying would allow rapid conversion and personnel readiness for the minelaying mission.

(C) Mine system weights are:

	WT. LBS.
50 EX-65 @ 2400 lbs.	120,000
50 Cradles @ 50 lbs.	2,500
17 Pallets @ 1200 lbs	20,400
6 Accelerator Pallets @ 1200 lbs	7,200
6 Power Units @ 1000 lbs	6,000
TOTAL	156,100
	(70,955 kg.)

(b) Mine Countermeasures (U)

(C) The TLR requires the HYD-7 to perform shallow water mine countermeasures. After removal of SADTOS, MK 48s and ejectors, the ASW Standoff Weapons (including launchers), and Deployed Linear Arrays, a clear deck area of about 44 feet by 50 feet is available for stowing, handling and launching MCM equipment. Removed weight would be 96,900 lbs, more than enough for the MCM equipment listed below. The margin remaining can be used for extra fuel if desired. The ship will retain its AAW and SUW weapons but will lose ASW capability.

(U) Shallow water MCM equipment will be derived from the Advanced Airborne MCM system and consists of those characteristics listed in Table 2.3.7-1.

(C)

TABLE 2.3.7-l

SHALLOW WATER MCM EQUIPMENT

EQUIPMENT DESIGNATION	WT. (LBS.)	SIZE (FT.) (EST.) Ht.	Width	Depth	REMARKS
Adv. Mechanical Sweep	1500	4.75	6.5	4.75	Drag, 10,000 lbs. - 15 knots
2 Spare Sweeps	3000	4.75	6.5	9.5	
Winch (aircraft type)	1440	8	4.5	5.1	
Magnetic Sweep	4240	6	2 dia		Tail only. Drag, 900 lbs - 6 kt. 1700 lbs - 9 kt.
Magnetic Winch Adv. 1 Spare Acoustic (MSB Sweep Power type) Sweep Pack	3000 5440 2500 2500	3 8 9 9	4.5 4 3 3 dia dia	4 5.1	Watertight Drag, 2500 3000 enclosure lbs lbs - - 8 10 kt. kt. on deck
Winch Cable	2000 2500	11	12	10	500 yd cable
Control Cabinets	2000	6	3	3	
Handling Eqpt.	4000	Various			
TOTAL	34120				

[redacted] UNCLASSIFIED

[redacted] UNCLASSIFIED

(U) Sheet 3 of the General Arrangement Drawing (Figure 2.1-3) shows a typical layout of MCM on the main deck aft.

(U) Added personnel required are estimated at 1 officer and 8 enlisted personnel. For efficiency, these should be experienced MCM personnel, so that conversion and readiness for MCM can be achieved in a short time. Personnel from ship's company can aid in handling and in navigation under the guidance of MCM personnel. "Hot bunking" may be required during an MCM mission.

(U) Winches will be powered by hydraulic motors supplied with power from the ships service hydraulic system.

2.3.7(c) COMBAT SYSTEM (WEAPONS AND SENSORS) RISK AREA 1995 DEVELOPMENT AND ADMINISTRATIVE RISKS (U)

(U) As for C^3N equipments, the Combat System Data Sheets (Reference 2.3.7-2) are used for risk determination. The risks for major systems are listed below. All risks stated are for 1995 except as noted in parenthesis after the risk. The voluminous definitions of risk assessment are given in Section 1.3 of the Data Sheets (Vol. I). Only the green, yellow and red assessments as given in the sheets for individual systems will be given below:

(C)

SYSTEM	1995 Risk (Unless indicated otherwise) DEVELOPMENT'	ADMINISTRATIVE
Tactical Display Components (UYQ System)	Green with a few Yellow	Green with a few Yellow
Ship Data Multiplex System	Green	Green
Lightweight TWS FCS	Green	Red
Target Acquisition System (T'AS MKXX)	Green	Red
AN/APS 116 Radar	Green (1985)	Red (1985)
Advanced EW Suite (RF & IR) (ASMD EW MKXX)	Green	Red
Active/Passive Towed Array with Depressor (SADTOS)	Green	Yellow
Active/Passive Reliable Acoustic Path Sonar (APRAPS)	Green	Yellow

(C)

SYSTEM	1995 Risk (Unless indicated otherwise) DEVELOPMENT	ADMINISTRATIVE
Expendable Reliable Acoustic Path Sonobuoy (ERAPS)	Green	Yellow
Deployed Linear Array	Green	Yellow
ASW Electronics	Yellow (1995?)	Yellow (1995?)
Harpoon MKXX	Green	Red
Advanced Self-Defense Missile	Green	Red
MK 48 MKXX Torepedo	Green	Green
Ejection Launch Control for MK 48	Green (estimated)	Green (estimated)
ASW Standoff Weapon/ALWT	Green (1990)	Yellow (1990)

Summary of Development and Administrative Risks (1995) (U)

(U) Development risks are satisfactory as most are green, with moderate risks for several major systems. The risk for Ejection Launch of the MK 48 was not given in the Combat System Data Sheets but can be assumed to be equivalent to the MK 48 Mod XX itself, if the weight of the launch tube can be reduced as stated to 1000 lbs. Presumably advanced composite materials could be used to achieve this reduction of 50% of the weight of a MK 25 torpedo tube.

(U) Adminis-trative risks vary from green through yellow to red for these major systems, presumably because of anticipated budgetary or cost problems. Given almost twenty years of lead time, these problems should be solvable if particular attention is paid during developmental phases to program management.

(U) In the UYQ program, adapability of UYQ components to hydrofoils as well as to other advanced ships where weight of combat system equipment is critical, a program for weight reduction is needed. Shock specifications for advanced ship equipment need verification in view of the character of advanced ships themselves. If shock specifications can be reduced realistically for advanced ship electronic equipment, a program for weight reduction of UYQ components could achieve results easily by 1995. As for C^3N systems, combat system integration risk can be minimized for weapons and sensors by early attention during ship design and by the use of a Land Based Test Site.

Operational/Ship Compatibility Risk Assessment (U)

(U) For all weapons and sensors assigned the HYD-7, these risks are green in the Combat Data Sheets. Because of the desire to save hull weight, hydrofoil length/beam ratios are usually in the region of 4 to 1, reducing availability of centerline length for a given displacement. This poses compatibility problems for the MK 48 torpedo because of its length and for RPVs. The Ejection Launch System for the MK 48 reduces this problem for the MK 48 but necessitates deck installations, exposing the torpedo canister to the elements and requiring deck space. Ideally the MK 48 should not be launched so that it will strike the foils in event of a non-start, indicating a launch from the main deck aft of the struts in a direction abaft the beam. Such a launch attitude is benign for wire guidance reliability.

(U) Compatibility with RPVs on HYD-7 depends on success of the concept described above in '2.3.7(a). Risk is evaluated as green for 1995.

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REFERENCES

2.3.7-1 "Top Level Requirements (TLR) for a 700 Ton Hydrofoil ANVCE Point Design (U)", Change No. 1, 30 September 1976, Enclosure (1) to ANVCE No. 124-76 of 30 September 1976, Prepared by DTNSRDC, Code 1152

2.3.7-2 "Advanced Naval Vehicles Concepts Evaluation Study, Combat System Data Sheets for AAW, ASW and SSW (U)", Volumes I and II (classified secret data), Prepared for OP96(V), Released by NAVSEA 6512, 30 June 1976

2.4 SURVIVABILITY AND VULNERABILITY (U)

(U) Primary responsibility for the material in this section lies with the Hydrofoil Technology Office, DTNSRDC. The information set forth below supplements their data input.

(C) (a) The! major ship design and arrangement features which impact the survivability/vulnerability situation are:

Propulsion foilborne can be accomplished with one main turbine inactivated.

Maneuvering turbines located in separate space.

Main generators in separate watertight compartments. Emergency generator on main deck.

Vertical missile installations located in cluster aft to minimize fragment exposure and ballistic armor protection.

All fuel tanks below the waterline.

Second deck is damage control deck.

(b) Ballistic protection of the ceramic type is deployed as per sketches and description in hull structure section of this report.

(c) A keel shock factor of .3 has been prescribed as appropriate for the foilborne operating mode. Weights have been added to the propulsion group as described in the propulsion section report to account for high shock additions. All vital propulsion equipment is considered to be designed to high shock specifications.

(d) The fire main will be a redundant pump loop system meeting conventional standards for riser locations and system isolation. The damage control outfit will include standard portable pumps, fog nozzles, and fire protection equipment. All main vertical hatches to compartments below the damage control deck will have scuttles for submersible pumps and fog/foam applicators. A single main drainage system will be provided for all machinery spaces. Fixed halon extinguishing systems will be installed in all machinery and fire sensitive compartments. Passive fire protection insulation is installed (see description of outfit and furnishings). The effectiveness of these measures would be similar after damage to any light surface ship. Schematic drawings are not necessary (see general arrangement drawings) to further elaborate on these systems.

3.0 LOGISTIC CONSIDERATIONS

The material in this section is the responsibility of the Hydrofoil Technology Office of DTNSRDC. The information set forth below is supplementary to their data input.

Although of short mission duration (14 days), the Boeing HYD-7 design has sought to indicate a reasonable level of self maintenance capability. A general purpose shop facility is located on the second deck port side aft, and a combined electronics repair shop and spare parts room are located on the 02 level just aft of the COC complex. It is believed that adequate allowance has been made for stowing other group spares and for GSK type maintenance commodities.

Few special tender or depot level maintenance facilities will be required. With fixed foils and a foil span of just over eighty feet, some selectivity in docking facilities is necessary, and high keel blocking would be needed. Weld repairs to titanium strut foil materials would be new but should be an easily acquired skill at the tender level and above.

The gas turbine plant itself will be highly automated and condition monitored in the centralized propulsion control space.

4.0 RISK ASSESSMENT

(U) Certain risks associated with HYD-7 have been discussed in previous sections of this report. Some of the more interdisciplinary aspects will be covered here.

(U) Risks m-ay be divided into two general groupings. In one there is a technologic gap or dearth of design data which must be resolved in order to establish that the concept is in fact feasible. The other merely involves errors or inaccuracies of scale as they affect the overall ship estimates due to use of simplified in lieu of rigorous analysis. The latter are lesser risks and may be resolved on paper or by test prior to engaging major program commitments.

<u>Hydrodynamics and Control</u> (U)

(C) Looking at the first category, the hydrodynamic basis vital to the development of the HYD-7 concept has some limited experimental background, but verification of the integrated or "mixed foil" concept is not presently evident. In the past 17 years, there has been a reasonable array of experimental work dealing with strut/foil systems for operation at speeds in excess of 50 knots. Aside from the design,construction and operation of Fresh-l, a test bed which operated at speeds in excess of 80 knots, no previous effort has been mounted to devise a full scale practical ship configuration which would provide the efficiency of a 16 series foil section in the subcavitating speed regime and at the same time assure stable flow conditions and reduced lift coefficients at 70 knots. There is also the question of a control configuration capable of providing the requisite dynamic control authority considering that conventional trailing edge flap control surfaces would be ineffective behind a fully developed cavity. Thus the need to deal with alternate concepts such as incidence control configurations and "tipperons" as well as trailing edge flaps to provide effective control elements in both operating regions. Flow conditions in the transition speed range need to be better understood in order to define the operating possibilities within this range in regard to not only hydrodynamic performance but also unsteady loads and forces. The nature and magnitude of the secondary drag hump must be determined and understood.

(U) The struts are involved in that devices to control strut ventilation and to superventilate the entire lift system must be employed. Last but not least the flow interrelationships between propeller and foil system, and between forward and aft foil systems must be thoroughly evaluated.

(U) The configuration set forth identifies the existence of these matters and provides a "best effort" approach within the framework of a limited study. However, the HYD-7 concept must be considered as tentative and a high risk prospect until a sound hydrodynamic basis can be established which can further be reduced to an acceptable structural and mechanical design.

(C) A program necessary to validate the hydrodynamic basis for a 70 knot hydrofoil can only be sketched out in broad terms at this point. Its principal elements would consist of:

(a) Reconfirmation of the basic design approach,

(b) Small scale pressurized tunnel tests looking into:

1. Derivation of foil polars for sub, transcavitating and supercavitating flow regimes.
2. Optimizing trigger flap locations.
3. Flow instabilities
4. Strut ventilation techniques (flaps, superventilation, etc.)
5. Appendage performance (pods, junctures)
6. Composite system tests.
7. Downwash and cavity persistence (foil interactions)

(c) Intermediate or full scale tests on available or specially designed test beds. This is a matter for separate determination in that the propulsor capability for 70 knot operation must be available. A reinstatement of the Fresh-l approach may be in order.

(C) The propulsion system is characterized by a high value of power to craft weight ratio necessary to meet the 70 knot route condition. The sensitive aspect of this is knowledge of the realistic limits, if any, that exist in

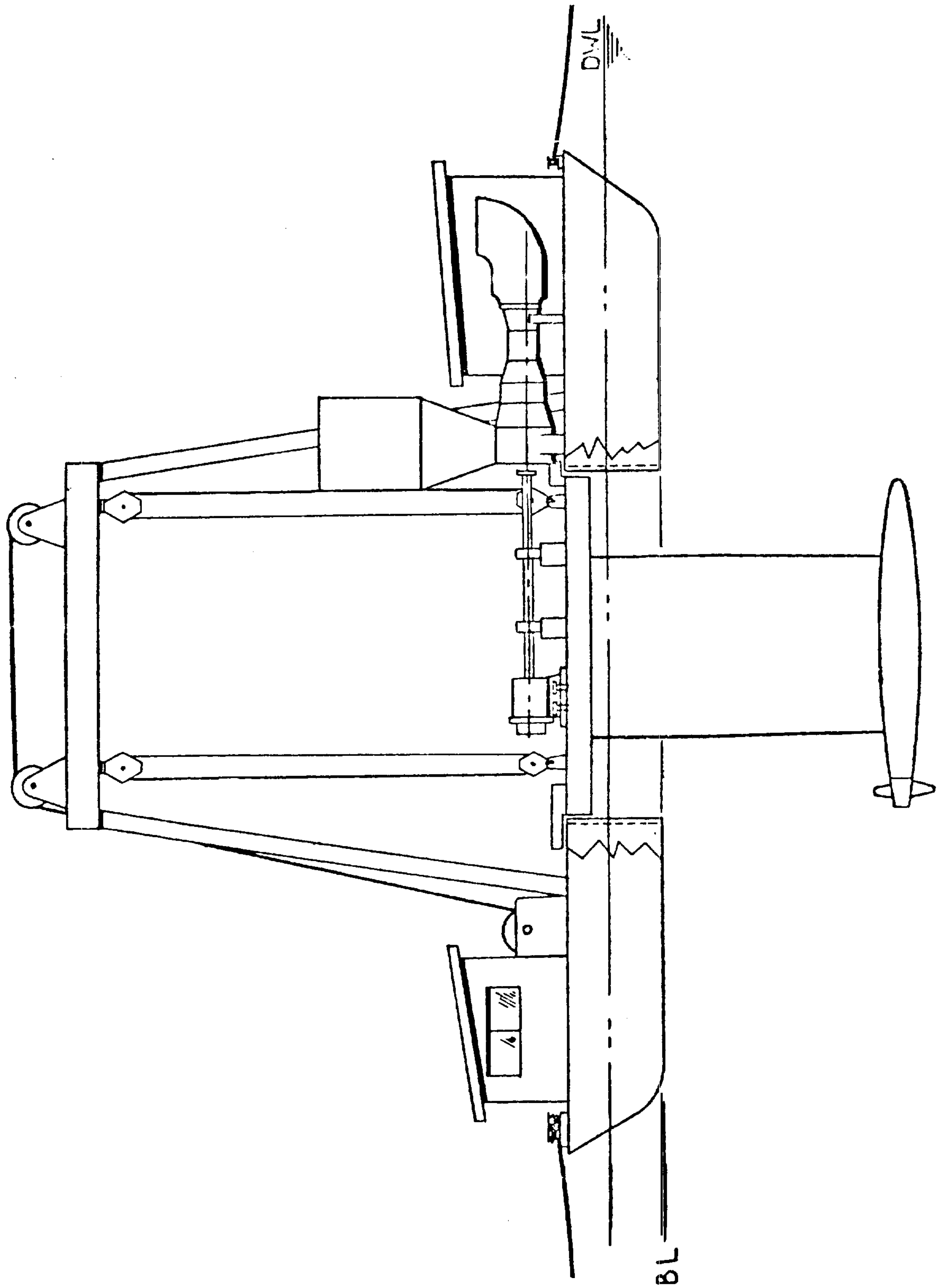
(C) the mechanical power train. Analysis indicates that the selected parameters of 50,000 SHP per power strut can be produced utilizing a dual downshaft angle drive system but the application will be pressing the state of the art, indicating the need for a program of careful design and test verification. However, the elements of this problem can be defined today to a much better extent than the hydrodynamics of the design and the transmission question can be classified as a moderate risk item.

(U) In addition to the need for a high quality detailed design operation, a procedure and schedule of environmentally oriented testing, sufficient to thoroughly verify the design conditions and establish system reliability is necessary. There are several possible approaches to this. One idea which offers an attractive compromise between test operations in the most realistic albeit inefficient environment (shipboard) but still retains the economies and control of integrated system laboratory testing was proposed by The Boeing Company in 1974 (Ref. 4-1) and is shown in concept in Figure 4-1 This speaks for a tethered barge mounting a prototype strut/transmission with a propeller type absorption unit which would operate at the same speeds and torques as the prototype system.

<u>Strut/Foil Materials</u> (U)

(C) Section 2.3.5.2 covering the lift system introduced the idea of titanium alloys for strut/foil structural use. No single metallic alloy ideally exhibits all the properties desirable for this stringent application, and for this reason there should be continued long range interest in the structural composites. In the meanwhile the titaniums, among metal candidates is attractive in that it offers the best strength to weight ratio, and excellent corrosion-erosion resistance, both properties that must be emphasized for a 70 knot ship. The development prospectus does not center around a long period of gestation in the laboratory. These materials have been under Navy development since the early 1960's and as materials are well understood. The principal impediment is that they have never been employed in any important sense for military ship construction and within the Navy department little feel or experience for the cost and fabrication aspects

FIGURE 4-1



BARGE TEST FACILITY CONCEPT

(C) exists, nor has a specific exercise oriented towards the deta-il design of a system to use this material, ever been executed. Substantial industrial experience has been gained over the years both in the chemical process and aerospace industries. On the SST program alone, a great deal of materials and processes research had been accomplished before the project was terminated. It appears then that the most direct route to establish a position would be to procure from qualified industrial sources the design and manufacture of a replacement titanium strut/foil system for one of the existing experimental craft (PCH, AGEH) or the PHM as a trial operation. As part of such a program, the design should include a complete fatigue/fracture analytical package as well as trade studies which display the influence of the specified durability criteria on the system weights and costs. The latter are the most arbitrary elements of the problem and can be expected to exhibit some strong trade sensitivities.

REFERENCE

4-1 Boeing Document, "A Proposal for Development of Test Systems Definition and Costs in Support of a Barge Mounted Hydrofoil Propulsion Test Facility", Transmitted by Boeing Letter 2-1178-0000-079, dated October 1 1974

APPENDIX A - DESIGN PROCESS

A.1 APPROACH

A.1.1 GENERAL

The general design approach employed by the HYD-7 study follows a generally established procedure.

1. Evaluation of TLR and Supplementary Material
2. Initial Ship Size Estimate
   a. Hull size estimate (volume and deck area requirements)
   b. Point preliminary drag estimates
   c. Preliminary propulsion requirements
   d. Preliminary propulsion concepts
   e. Preliminary foil system concepts
   f. Preliminary weight estimates
   g. Preliminary performance estimates
3. Initialization Review and Revisions
   a. Final concepts
   b. Weight and performance adjustments
   c. Drag data improvements
4. Data Generation and Validation
5. Ship Arrangements
   a. Firm weapons list
   b. Firm complement and habitability features
   c. Firm propulsion arrangements
   d. Firm foil system parameters
6. Final Weight and Performance Adjustments
7. Final Data and Report

A.1.2 HULL PARAMETERS

The hull parent form is the set of lines created for the PHM which have been scaled and adapted with a slight vertical scale warpage to retain suitable hull depth for two internal decks below the main deck. The key hull dimensions are given in Section 2.2.6.1. The PHM form has demonstrated its servicability in trials and has the advantage of providing high quality hull drag data from an extensive series of model tests at Stevens and Lockheed. This is particularly important for the hydrofoil in that resistance coefficients at all waterlines down to the baseline are needed to accurately address the takeoff drag cycle. The quality of this data would be that suitable for contract design purposes. Hull weights were generated from a "parent" hull structure previously developed for a 1400 ton 200 foot HOC design for which wave impact loads and for which discrete structural calculations have been accomplished. Overall group 100 weights were increased by 5% in consideration of the higher speeds of advance. It was not possible to run new wave impact load calculations within the framework of this program. The structural group includes a novel addition of 21 tons of ballistic armor (Group 164) areally distributed to meet new ship protection policies set forth in the TLR. Unit weights for the armor were provided by the advocate. The feasibility of practically providing ceramic armor protection, the cost and the secondary effect on structural weights has yet to be determined but this is not a condition peculiar to hydrofoils as a class.

A.1.3 PROPULSION SYSTEM

System properties and weights are largely derived by synthesis. ANVCE Working Paper 011 allowed the presence of "rubber" engines. However, the actual propulsion requirements coincided with the properties of either the FT9D-4A or LM-5000 gas turbines which provided excellent physical models for arrangement and weight purposes. A round of trade-off studies was conducted early in the design process to determine the best approach to meeting the enormous range of required power operating points within the physical confines of this rather small ship. The results of both the physical arrangements and performance comparisons led to the dual engine cross shaft arrangement as the best compromise. It was not physically possible to locate four smaller engines in the single main propulsion space and a fore and aft distribution of engines would have similarly made impressive demands for deck area and volume on the ship which was required to be within a 1000 metric ton limit.

Characteristics of drive train elements were calculated using identified design standards. The propeller was selected and performance calculated

(U) using the KaMeWa 3988 series charts, assuming a supercavitating controllable pitch unit. Propeller weights are ratioed from the AGEH (5.5 foot) diameter titanium propeller. The pod/propeller interface arrangement is a critical one and the tractor propeller configuration was chosen on the basis of least risk to maintain essential performance. The entire pod configuration is one that would eventually require further hydrodynamics study and test for general verification.

(U) A.1.4 ELECTRICAL (U)

Loads were selected on a scaling bas is employing PHM, the Boe ing 1400 ton HOC and other data points to complete the algorithm. The selection of diesel prime mover results from system trade studies in which the heavier weight of a diesel system is readily justified by fuel savings. Basic power generation is assumed to be 400 Hz. with 60 Hz. transformation as required, on the basis that 1995 technology should provide the lightest SWBS group 300 weights with that type of system.

(U) A.1.5 COMMUNICATIONS AND CONTROL (U)

Synthesized from a component basis. The group includes weight allowances for a multiplexing type of interior communications system with attendant reduction of wire weights.

(C) A.1.6 AUXILIARY SYSTEMS (U)

This multiplicity of systems, except for the major strut/foil (567) group has been approached by ratiocination primarily using a 1400 ton HOC prime development as a parent. The 567 (strut/foils) group has an analytical basis for the subcavitating sector of the drag curve (standard series 16 section shapes) and a derived rationalization for the high speed (70 knot) drag based on the "Tap-2" stable cavity foil system laboratory tests. This approach was formulated by NSRDC and is considered to be somewhat tenuous. It would be entirely necessary to provide a firmer hydrodynamic basis should a serious desire to prosecute this concept develop. Similar remarks may be directed to the hydrodynamics of foilborne control in the 70 knot speed range.

(U) Strut/foil structural data is based on a quasi-static calculated loads policy as per Reference A.2-2. Basic scantlings and weights are provided by a computer program which solves the statically indeterminate pi-foil moment equation and estimates scantlings and weights to a suitable degree of accuracy for feasibility study considerations. Special features such as the pods, control mechanisms and special foundations are produced by invention, layout and weight pickoff.

(U) The decision to deploy a fixed foil versus retracting foil arrangement stemmed from the total specification which limited the allocation of weights and forces compromises in several areas. For example, the high speed and substantial combat suite weight extracts a "price" which obviated the need to find weight economies elsewhere. For similar reasons, strut/foil structural weights were based on use of titanium as a reasonable approach for the 1990 time frame. A downstream possibility employing advanced composites exists but an engineering definition is not presently possible with these materials. An additional strong motive for non-retraction involved the power train continuity problem for this high performance transmission concept.

(C) An advanced analysis investigating the fatigue/fracture properites of the notional strut/foil system suitable for 70 knot speeds has not been accomplished, and would be an item of first importance in further prosecution of this concept. The same remark applies to the hydroelastic aspects of the design.

A.1.7 OUTFIT AND FURNISHINGS (U)

(U) Largely ratioed from other data points. Weights for passive fire protection (insulation) were generated by pick-off from the arrangements. Standard weight factors were specified by the TLR.

A.1.8 ARMAMENT (U)

(U) Component build up with data furnished by the Advocate.

A.2 DESIGN CRITERIA

The major design criteria, guidelines and assumptions used in the HYD-7 Point Design are presented in the Top Level Requirements, (TLR) for HYD-7, Reference A.2-1. This TLR specifies design requirements and design standards to a greater level of detail than is normally desirable at the beginning of a feasibility design as time and budget restrictions do not permit exploration of a more complete range of design alternatives. The stated purpose of the ANVCE TLR for HYD-7 is to, "provide the designers with sufficient direction and guidance to enable the design team to zero in very rapidly on a feasible point design. Furthermore, to enhance the military worth, risk and cost evaluation, consistency in specifying certain design standards and criteria is required."

Additional criteria for specific areas of the design are presented below.

(a) Hull Structure

The hull design loads are design limit loads and are based upon the criteria of Reference A.2-2. Structure designed to these criteria and limit loads will not exceed the yield strength of the material nor incur detrimental buckling. Reference A.2-3 is the hull design report for the similar 200 foot LBP Boeing Model 1026-009 hull structure from which the HYD-7 180 foot LBP hull has been scaled.

The hull construction material selected is an Aluminum Alloy 5456 with an H117 temper for plates and H111 for extrusions. A minimum hull plating thickness of 0.19 inch (5mm) has been utilized.

The material properties utilized are per References A.2-3 and A.2-4.

(b) Propulsion System

The design criteria for the propulsion system follows the guidelines set forth in NAVSHIPS Technical Manual 0941-138-7010, "Installation Design Criteria for Gas Turbine Applications in Naval Vessels", Reference 2.3.2-l.

The system design loading conditions at the engine and propeller are listed in Tables 2.3.2-2 and 2.3.2-3.

Transmission losses and parasitic power requirements are presented in Table A.2(b)-1.

Characteristics of the accessory drive pump pads are listed in Table 2.3.2-6.

The design features recommended for the foilborne transmission are tabulated in Table A.2(b)-2. These characteristics are a summary of those evaluated which have met the requirement of having been proven in similar applications.

The propeller selection criteria and assumptions are as follows:

Utilize a controllable, reversible-pitch propeller with proven, desirable mechanical simplicity, reliability, and maintainability characteristics.

Propeller performance must be verified by model test.

Assume no more than 20% back cavitation during hullborne operation at less than 20 knots.

Propeller material must have high resistance to cavitation erosion, fatigue failures in salt water environment, etc. Proven titanium and Inconel alloys to be given prime consideration.

Propeller design conditions:
--- Wake fraction, w = 0.05
--- Thrust deduction t = 0.017
--- Transmission efficiency = 0.95
--- Engine-transmission match at 3600 RPM
--- Available engine power at 80°F = 50,000 HP per engine, maximum continuous
--- Available engine power at 80°F = 57,500 HP per engine, maximum intermittent

TABLE A.2(b)-1

HYDRAULIC AND PARASITIC POWER LOSSES

FOILBORNE PROPULSION SYSTEM
HYD-7 Model 1026-010

	CONTINUOUS POWER	MAX INTERMITTENT POWER
Hydraulic	680	680
Lube Oil Pumps (Supply)	100	100
Lube Oil Pumps (Scavenge)	150	150
Transmission Losses		
5% x 50,000 HP	2500	----
5% x 57,500 HP	----	2875
TOTAL HP	3430	3805

TABLE A.2(b)-2

RECOMMENDED CHARACTERISTICS

HYD-7 FOILBORNE PROPULSION TRANSMISSION

Upper and Lower Bevel Gearboxes with Dual Strut Downshafts -

Dual Mesh Back-to-Back Bevel Gearing with Approximately 1:1 Ratio

Gear shaft/flange configuration	Solid steel forging-stiffness designed. Back-to-back gears attached with fitted bolts.
Tooth bending stress	30,000 psi maximum
Tooth compressive stress	200,000 psi maximum
Tooth scoring index	360°F maximum
Pitch line velocity	30,000 ft/min maximum
Diametral pitch	2.0 min.
Pressure angle	20 degrees
Spiral angle	25 degrees where possible (30 degrees elsewhere)
Gear material	Carburized AISI 9310/AMS6265 or better
Method of gear manufacture	Gleason method (Cut, case carburize to provide 58-63 RC and remaining depth of 0.110-.120 after grinding to ≤ 20 RMS) Tip ends chamfered.
Bevel bearing arrangement	Straddle mounted roller and ball thrust bearing with inner race retention provisions
Antifriction bearing B_{10} life	5000 hours minimum
Casing design criteria	Externally stiffened with internal clearances for foaming prevention and flushing space. Leak-proof o-ring pairs.
Mounting of bevel boxes	Three-point support as AGEH

Strut Shafting

- Dual downshafting
- Flexible couplings at top and bottom
- Balanced rotating assemblies
- Downshaft oil and water-tight guards

TABLE A.2(b)-2 (Cont'd)

Self aligning (spherical type mounting) babbitt sleeve bearings
Downshaft support balls in spherical seats

Propeller shaft assembly

Propeller cartridge assembly providing sealed inner enclosure between pod and shaft assembly
K-Monel propeller shafting
Roller bearing arrangement as utilized in AGEH-1
Dual carbon ring face seal assembly with separate seal oil system
CRP oil distribution box to be integral with the propeller shaft for reduction of pod length

Lubrication Oil System

Use of MIL-L-17331 (MS 2190 TEP) lube oil
Transmission system central lube distribution and scavenge plumbing network
Oil drain holes ≥ 0.50 inch, where possible

Propeller design conditions (continued):

--- Propeller submergence = 12.0 feet, foilborne

--- Propeller submergence = 27.0 feet, hullborne and takeoff

An inlet air system which includes a salt water separating subsystem will be provided for all combustion air. The subsystem will have a minimum separating efficiency of 98 percent for salt water droplets 5 micrometers diameter and above and at least 90 percent separating efficiency for droplets below 5 micrometers. Maximum pressure drop to the turbine at maximum air flow will not exceed 4 inches of water.

The ship will have provisions to minimize icing of the gas turbines inlet air system while operating under icing conditions. Bleed air from the propulsion engines will be provided to heat the combustion air inlet salt water separation system. A secondary by-pass system will be provided for engine start-up or emergency in case the primary anti-icing system is inoperative.

The exhaust duct system will be designed to discharge the foilborne engine combustion gases and cooling air at an engine exhaust pressure drop not to exceed 6 inches of water back-pressure at engine maximum air flow. The exhaust system will include an engine enclosure cooling air eductor and cooling air fans for post engine shutdown heat removal. Sea water cooling of the stack exhaust gases will be provided to permit infrared (IR) signature suppression when desired.

A propulsion control system will be provided to start, stop, control, and monitor all ship propulsion, electrical and auxiliary machinery functions by one man while underway, both hullborne and foilborne, from the Engineering Operating Station (EOS). The EOS will be separate and accessible to, but not necessarily adjacent to, the machinery space. Remote propulsion control and monitoring functions will also be provided to the conning team in the Ship Control Station (SCS).

(c) Electrical Plant

Three-phase, 450 volt, 400 Hz primary power will be provided from a pair of redundant ship service diesel generator sets located in separate compartments. Each set will have a power capacity of no less than the maximum design load as determined by the procedures presented in Reference 2.3.3-2 plus a growth margin of 30 percent. A separate light weight gas turbine emergency generator set will be provided to handle essential loads necessary for the minimal operation of the vessel. This set will be housed in a compartment on the main deck.

Conversion equipment will be provided to convert 400 Hz A-C power to 60 Hz A-C power for 60 Hz loads, and to D-C for ship service D-C loads and for automatic battery charging.

Power quality at electrical load terminals will be per MIL-STD-1399, Section 103, Reference 2.3.3-l. Types I, II and III power will be provided to the input terminals of load equipment as required.

Continuity of the electric power supply will be the primary aim of the electric power system design. To insure maximum continuity of service, the design of the ship service electric plant will be based on split plant operation. The capability for parallel operation of the primary ship service generators will also be provided.

The electric distribution system will be ungrounded except as required for special case exceptions.

(d) Command and Surveillance

SWBS Group 400 includes a multitude of systems with diverse functions. Much of this equipment will be GFE or GFP. For those items, the ship designer's primary task pertains to systems installation and integration, as opposed to equipment or subsystems design.

(e) Auxiliary Systems (Less Lift System)

As is the case for command and surveillance functions, the auxiliary systems of SWBS Group 500 include many systems with unrelated functions and a great deal of attention must be devoted to the development of requirements, to the particular equipment selected to meet those requirements, and to its needs in integrated subsystem design. Again, the best example of recent favorable experience in this area is with the Boeing designed and built PHM.

Thus, the design criteria for HYD-7 auxiliary system equipment has been in accordance with 1.500 of Reference A.2-5, except as modified by the qualification that all ratings, space weight, power and other characteristics and requirements will be modified to those values presented for the selected HYD-7 subsystems in Section 2.3.5 and Table 2.1 of this document.

(f) Lift System (Struts and Foils)

High speed supercavitating foil performance will be based on data supplied by Code 115 of DTNSRDC. The foil section based on this data will be a NACA 16 series foil with a thickness to chord ratio of seven percent or less. The foil will have an upper surface device to stabilize the cavity separation point near the leading edge. A lower surface control device will be used to reduce wetted area and increase the foil loading.

The ship will have a canard foil system arrangement with minimum area on the forward foil, subject to other considerations.

The forward and after foil areas will each be sized on the basis of 1448 pounds per square foot loading at the foilborne cruise condition.

The fore/aft foil area distribution will be selected with regard for producing a dynamically balanced foilborne cruise condition considering the selected strut locations.

Control surfaces will be selected which will provide the required incremental lift coefficient to permit design full load takeoff under 30 knots while providing the control authority required to satisfy ship control requirements at all speeds under all design sea conditions per Reference A.2-9. Strong consideration will be given to control surface configurations which minimize auxiliary control power requirements and limit local cavitation during operations in the subcavitating speed regime. (See rationale in 2.3.5.2.2.)

The lift system structural design criteria are based upon Reference A.2-2. The structure is designed to match the ultimate loads developed per Reference A.2-2. The tentative material selection is 4 Al 6V titanium with properties per Reference A.2-4.

(g) Outfit and Furnishings

SWBS Group 600 includes a variety of equipment and furnishings.

The best example of recent favorable experience in this area is with the Boeing designed and built PHM. Thus, the design criteria for HYD-7 SWBS Group 600 has been in accord with 1.600 of Reference A.2-5, except as modified by the qualification that all space, weight and other requirements will be modified to those values presented for the selected HYD-7 equipment described in Section 2.3.6 of this document.

The design goals for habitability will be in conformance with normal U.S. Navy standards, Reference A.2-10, and specifically to provide or exceed 14.0 cubic meters (494.4 cubic feet) of space and 508 Kg (0.5 long tons) of weight directly related to personnel.

This group will include weights for passive structural fire protection (insulation).

(h) Armament

The criteria, standards and assumptions utilized for the location and installation of armament are in accordance with References A.2-11, -7 and -8.

(i) Loads

The following load weight a lowances will be provided in the HYD-7 design:

Item	Weight		
	Long Tons-	Short Tons	Metric Tons
Crew and Effects	9	10	9
Provisions	4	4	4
Stores	1	1	1
Fresh Water	12	13	12
Ordnance - Main Vehicle	46	52	47
- Secondary Vehicle	0	0	0
Secondary Vehicle (RPVs)	2	2	2
Fuel (10 percent excess volume capacity provided)	181	203	184
Lube Oil	3	3	3
Hydraulic Fluid	1	1	1

(j) Weight Margins

The following weight margins will be carried at this phase of concept design:

Margin Category	Percent of Light Ship
Preliminary Contr. Design	2.0
Detailed Design	5.5
Building	1.4
Contract Modifications	1.4
GFM	0.7
Future Growth	2.0
Service Life	2.0
TOTAL	15.0

(k) Vehicle Design Criteria

The ship will meet the applicable stability and buoyancy criteria as defined in NAVSEC DDS 079-1, Reference A.2-12, with a 15% of light ship KG margin.

(l) Manning

The manning concept for the HYD-7 will be based upon the requirements for manning during Conditions I and III and considering the requirements for maintenance outlined in Reference A.2-13.

(m) Performance Criteria

1) All minimum performance requirements will be met at an ambient temperature of 80°F (26.7°C).
2) 'The ship will have a minimum of 25 percent thrust margin during takeoff for full load displacement in a calm sea.
3) The ship will have a takeoff speed of less than 30 knots.
4) Ship control and stabilization will be provided by the automatic control system at all hullborne and foilborne speeds of over twelve knots.
5) The effect of foil system lift will be considered when calculating hullborne performance.

REFERENCES

A.2-1 Top Level Requirements (TLR) For a 700 Ton Hydrofoil (HYD-7) ANVCE Point Design (U), Change 1, 30 September 1976, Prepared by DTNSRDC, Code 1152

A.2-2 Boeing Marine Systems Document No. D221-11000-1, Hydrofoil Craft Structural Criteria

A.2-3 Boeing Marine Systems Document No. D315-11001-1, "Structural Design Calculations for Hull Structure Design and Scantling Development for Boeing Model 1026 Hydrofoil Ship (DBH)", March 1973

A.2-4 NAVSEC Research and Development Report MAT-74-18, "Materials Information Profile," by A. G. S. Morton and J. J. Kelly, Materials Department, Annapolis, January 1975

A.2-5 Boeing Marine Systems Document No. SS312-10001-1, U.S. Variant Ship System Requirements (SSR) for PHM - 25 October 1'972.

A.2-6 Boeing Marine Systems Document No. D315-51000-2, DEH Mission Equipment Study - Integrated Navigation System - 29 March 1974

A.2-7 Boeing Marine Systems Document No. D315-51000-3, "HOC Mission Equipment Study, ASW-AAW and SUW Weapon Systems (U)", 7 April 1976

A.2-8 Boeing Marine Systems Document No. D315-51000-4, "DEH/AOC Missions Equipment Study ASW Sensor System (U)", 1 October 1975

A.2-9 Boeing Marine Systems Document No. D321- 51313-1, "Hydrofoil Ship Controls and Dynamics Specifications and Criteria", (Unpublished - in preparation. Expected release March 1977)

A.2-10 OPNAV Instruction 9330.5A, dated 30 August 1965, "Environmental Control Standards for Ships of the U.S. Navy", with Change 2 dated 23 January 1968

A.3 DESIGN PHILOSOPHY (U)

(C) At the local level, the design philosophy applied to HYD-7 can be summarized, with approximate priorities as follows:

a. Meet the overall TLR requirements

b. As well as possible, exercise the design philosophy set forth in Section IV of the TLR, which emphasized that "cost should be of equal importance with performance" and that "operability and maintainability should be considered of equal importance with basic vehicle performance".

c. Find inventive and developable concepts that could reasonably be supported for the 1995 time frame to solve the inherent problems of 70 knot ship design.

(U) The major trade studies and configuration decisions were taken with these philosophies in mind. The two turbine vice four turbine propulsion system was substantially influenced by vehicle cost (taken qualitatively) as well as the fact that the craft weight would have gone in excess of the TLR maximum of 1000 tons with a 4 engine propulsion configuration. In a similar vein, the fixed foil versus retracting foil decision addressed the same issues and substantially simplified the ships major mechanical installations. Also, both of these decisions favorably addressed the question of operability and maintainability.

(U) The invention of a simple concept to stow, handle, launch and retrieve the remote piloted vehicles at the least possible price in terms of ship installations speaks to the philosophy of a balanced design, in that the task to be accomplished is contingent to an operational requirement and would not warrant a handling installation that blankets the entire aft end of the ship in competition with the already extensive combat suite components located there. This approach to RPV handling is notional and obviously needs development and validation but it does represent a novel starting point.

(U) In this study, systems are not developed to a point where maintainability elements can be treated in a detailed sense The provision of modest qeneral

(U) repair facilities is considered to be of equal or greater importance to the ship sustaining itself at sea to carry out its mission, as are the passive self-defense features which now require over 40 tons of craft weight. The passive self-defense features required by the TLR need to be justified with a more deliberate appraisal of cost/benefits in view of the extensive ballistic armor system called out and the possibility of investing this weight in an improved combat system or performance capabilities.

A.4 TRADE-OFF STUDIES

A.4.1 GENERAL

The trade-off studies of primary importance in influencing configuration decisions and development of the Boeing Model 1026-010 design are the following:

Configuration
- Hull Form Selection
- Strut/Foil System
  - Canard versus airplane arrangement
  - Foil area distribution
  - Strut/foil system retraction
- Propeller Location

Subsystems
- Propeller Versus Waterjet
- Propeller Trades
- Superconducting Propulsion
- Quantity of Engines and Foilborne Transmission Concept Selection
- Auxiliary Power Prime Mover Selection

Performance
- General
- Speed for Best Range

A brief summary of each of these major studies is presented below.

A.4.2 TRADE STUDY DESCRIPTIONS

A.4.2.1 HULL FORM

The high speed operating requirement for HYD-7 requires that significant consideration be given to bottom impact loads when selecting hull form. The relatively high deadrise angle (>22° at the midships section transitioning to 14" at the transom) characteristic of the PHM hullform indicates that in this regard, the form would be expected to be equal to or better than other candidate hullforms.

In addition the PHM form has the following significant attributes.

1. It is suitable for a canard foil configuration with the LCB located at 57 percent of LBP aft of the forward perpendicular.
2. Sufficient testing has been conducted to provide adequate data for hydrofoil takeoff analysis (see section A.l)
3. The relatively low length-to-beam ratio makes the form desirable as it tends to minimize hull structural weight fraction while tending to maximize hull enclosed volume.
4. With only slight vertical scale modification, the form has been made suitable for housing two full internal decks below the main deck.
5. A detailed hull structural design report (Reference A.4-2) including a high confidence hull weight buildup has been prepared for the 200 foot LBP HOC hull. Scaling to the 180 foot HYD-7 hull has been relatively simple.
6. The hull has actually been built for PHM-1 and has proven very satisfactory in rough water operations. Trials data has also provided an opportunity to cross-correlate model test data which results in very high confidence ability to predict both hullborne and takeoff drag.

For these reasons, the form was selected for HYD-7. An LBP of 180 feet was determined to be the minimum size (and consequent minimum SWBS group 100 weight) to accommodate HYD-7 TLR imposed functions and components. The detailed hull characteristics are presented in 2.2.6. The HYD-7 hull structure is described and a Group 100 weight summary is provided in 2.3.1.

A.4.2.2 STRUT/FOIL SYSTEM

The rationale leading to the selection of the canard configuration leaned heavily upon previous experience with both airplane (small foil aft) and canard (small foil forward) type hydrofoils. Both operators and passengers who have ridden on both types in rough water have indicated a strong conscensus in favor of the canard arrangement. The Boeing position is best summarized in the open literature in Reference A.4-3. The primary consideration in the selection of the steerable forward strut, canard foil arrangement was the known demonstrated superior stability characteristics of that configuration under the inevitable condition of either fore or aft foil broaching in heavy seas. Retention of these stability characteristics is considered to be especially important for HYD-7 operation in the supercavitating speed regime. However, this must be tempered with the proviso that the span of the forward foil must be kept within manageable limits on this large ship.

The existing structural and mechanical design criteria for steerable forward tee strut/foil assemblies requires designing for the condition where one side of the foil (outside the center pod) has emerged from the sea and all the drag load is on the opposite, wetted semi-span. This leads to the finding that the size and weight of the structure and steering actuation assemblies are affected by the foil span-squared. At the same time, performance goals indicate that foil aspect ratio (span-squared/foil area) must be maintained as high as structural weight considerations will permit. Also, it is significant to note that the tee strut/foil configuration is less desirable structurally than a bent configuration. Studies have indicated that maximum ship performance will be achieved when the forward foil aspect ratio exceeds 4.0. Thus, the design path yielding best performance was found to be where the area of the forward foil was kept to a minimum. It was found that the practical minimum was near 20 percent of total area as when the foil area decreases to near that value the forward strut foundation cannot be moved appreciably further forward without imposing significant penalties on the design. The latter restriction is an indirect outcome of the desirable goal of producing a dynamically balanced foilborne configuration which is known to yield a maximum lift-to-drag ratio for a given vessel.

Previous Boeing studies which assessed the penalties of strut/foil retraction on the larger 1400 ton HOC were reported in Reference A.4-4. Those studies indicated overall ship weight penalties on the order of 7 percent of gross vehicle weight would be expected to be incurred (-68 long tons) in providing retraction capability if conventional steel (17-4PH or HY-130) strut/foil materials were employed.

In addition, initial performance estimates indicated a strong need to reduce initial HYD-7 lightship weights if the TLR "minimum acceptable" range requirements were to be achieved. Thus, two related investigations were conducted.

The first was to evaluate the feasibility and weight reduction potential involved in the utilization of titanium as the primary strut/foil material. The results proved to be positive, with only moderate risk forecast for the 1990-95 fabrication period and a predicted net weight saving of 24 percent of an initial design retracting strut/foil system weight.

The second involved a study of fixed or non-retracting strut/foil assemblies which were shortened to provide acceptable draft. It should be noted that the original TLR requirement of "6 meters maximum draft" was reduced to "no more than DD-963 maximum draft" (31 feet) in order to permit this comparison, yet preserve the desired operability of the craft.

The study produced the result that the acceptable draft, fixed strut/foil configuration would provide adequate seakeeping characteristics in 13.5 foot (4.11 meter) significant wave height seas. The seas are at or below this level in the North Atlantic Ocean during 90 percent of the year.

The non-retracting configuration further reduced predicted lightship weights by an additional 45 tons.

It also permits keeping the forward foil area small (~20 percent of the total foil area), which is desirable as discussed in A.4.2.2, above. Retraction would have required over 30 percent of the total area be provided by the forward foil.

In addition, the need for main propulsion transmission disconnect couplings, rated at 50,000 HP on each side with corresponding machinery arrangement complications, could be avoided.

The non-retracting configuration was thus selected on the basis of simplicity and minimum weight, while meeting all of the design requirements with minimal risk.

A.4.2.3 PROPELLER LOCATION

The problem of locating the propellers has been resolved by determining the condition of "least-hurt". Experience with earlier subcavitating hydrofoils such as PCH and AGEH have indicated a preference for locating the propellers on the back of the machinery pod or in the "pusher" posi-tion in order to minimize pod and foil erosion and joint sealing problems. However, propellers located in the conventional pusher position during the supercavitating mode would encounter the turbulent, ventilated wake of the strut and pod which would introduce potential propeller structural and performance prediction questions.

Moving the propellers to the front of the pod to the so-called tractor position results in operating them in the most desirable flow field available and thus is expected to provide more favorable performance than the pusher location. The problem of increased induced drag on the strut/pod/foil assembly from the high velocity wake of the propeller is somewhat minimized by locating the propeller below the foil in a drop-pod arrangement.

The tractor position for the propeller also permits use of a blunt base on the pods which reduce high speed drag at the expense of some increase in subcavitating drag.

However, the potential problem of the propeller wake flow on the strut/pod/foil will be a matter requiring further development in the form of tests and evaluation. It is believed that these problems can be overcome with minimal risk in the time available.

In considering all of the above, the tractor location was selected as the design solution most likely to yield the desired overall performance results with the least amount of technical risk.

A.4.2.4 PROPELLER VERSUS WATERJET PROPULSION

Previous studies as summarized in Reference A.4-6 have concluded that propellers are preferred over waterjets for large subcavitating hydrofoil (>500 tons) applications having long range (>1000 nautical miles) requirements. This is primarily because of their appreciably lower characteristic SWBS group 200 wet specific weight (pounds per shaft horsepower) and higher propulsive efficiency over the entire subcavitating speed regime.

Recognizing the above and the fact that all HYD-7 range requirements were specified for the subcavitating speed regime only (that is, there were no range goals nor requirements specified for operations with HYD-7 beyond 50 knots), a study of the feasibility and desirability of use of the same propeller in the supercavitating or dash speed regime was conducted. The results of that study are summarized in A.4.2.5, The results indicated that the CRP propeller would be acceptable, that all of the HYD-7 performance requirements could be met, and that reasonable performance could be expected in the dash speed regime. Thus, the propeller approach was selected.

A.4.2.5 PROPELLER TRADE STUDIES

A brief trade study was conducted to determine the propeller diameter which best satisfied the ship's powering and performance requirements. KaMeWa propeller data for the Model 398B was used for this evaluation. Propellers of 7, 8, 9, and 10 foot diameter were evaluated at a pitch diameter ratio of 1.4 to absorb 50,000 horsepower at a cavitation number of 0.25. The results indicated that the 9 foot diameter propeller had the highest efficiency but at the expense of high torque corresponding to the relatively low value of approximately 680 RPM. Low propeller RPM implies high transmission torque levels and correspondingly higher gear reduction ratios. These conditions result in increased weight in comparison with machinery designed for higher propeller RPM. With these considerations in mind, the 8 foot diameter propeller was chosen. The efficiency of the 8 foot diameter propeller was about 0.017 below the 9 foot diameter propeller, but the RPM was increased and torque correspondingly reduced by nearly 20 percent.

Additional studies showed that in order to obtain acceptable performance (high efficiency - see Figure 2.2.1-7) over the wide operating range, the pitch diameter ratio should be capable of being varied, implying the need to select a controllable-reversible pitch (CRP) type propeller.

A.4.2.6 SUPERCONDUCTING PROPULSION SYSTEM

Reference A.4-5 presents the results of a conceptual design study of a full-scale electrical propulsion system as applied to four ship configurations: (1) a small waterplane area twin hull (SWATH) ship, (2) a contrarotating propeller SWATH ship, (3) a hydrofoil craft, and (4) a surface effect ship (SES). The study presented data for single propulsion systems of 20,000 HP for hydrofoils and 40,000 HP for SWATH ships.

A review of the report was performed for possible adaptation to the HYD-7 hydrofoil Model 1026-010 from a weight and equipment geometry standpoint. Table A.4-1 tabulates weights of propulsion systems utilizing a DC generator - DC motor and a AC generator - DC motor. Weights of the generators, motor, transmission lines, cryogenic and refrigeration systems have been ratioed up as a function of horsepower ratios taken from the referenced report and the generator and motor lengths have been increased by these ratios. The geometry of the electrical equipment, which will have a direct affect upon hull arrangement, pod size, and strut thickness, is noted below.

DO 6000 2145 ORIG. 4/71

25,000 HP DC Generator - 3.0 ft OD x 8.5 ft long
25,000 HP AC Generator - 7.3 ft OD x 10.5 ft long
50,000 HP DC Motor - 4.8 ft OD x 14.6 ft long
Electrical Transmission Line - 13.5 inch OD

It was concluded that utilizing a superconducting propulsion system for Model 1026-010 would be undesirable for the primary reason that the baseline HYD-7 SWBS 200 weight is 130 long tons versus the 208 plus long ton total from Table A.4-1.

It was also noted that operating the cryogenic and refrigeration systems at 4.4°K will require special operating procedures which would impose restrictions on the operation of the ship. For example, the start-up time from a secured plant would be significantly increased over a conventional gas turbine plant. It is likely that continuous stand-b.y operation would be required in order to provide any reasonable level of ship response capability in getting underway from a dockside or anchored condition.

TABLE A.4-1

HYD-7 SUPERCONDUCTING PROPULSION SYSTEM WEIGHT BEAKDOWN

(All Weights in Long Tons)

SWBS GROUP NUMBER	DESCRIPTION	PROPULSION SYSTEM DC GENERATOR DC MOTOR	PROPULSION SYSTEM AC GENERATOR DC MOTOR
235	25,000 HP Generator (4 Units)	12.82	49.26
235	50,000 HP Motor (2 Units)	45.49	45.49
235	Transmission Lines and Buses	7.48	7.48
235	Cryogenic and Refrigeration System	71.40	54.62
234	Gas Turbine Engines	16.88	16.88
241	Generator and Motor Mounts	0.84.	0.84
242-244	Propeller Shaft Assembly	8.24	8.24
245	Propellers	2.98	2.98
250	Propulsion Support System	33.23	33.23
260	Fuel and Lube Support System	6.94	6.94
290	Special Purpose System	2.57	2.57
200*	Total Propulsion Plant	208.87	228.53

* Weights for the generator drive gearbox and its auxiliary systems have not been included in this tabulation.

A.4.2.7 ENGINE QUANTITY AND TRANSMISSION SELECTION

Once it had been established that a pair of CRP propellers was desired and that superconducting electrical power transmission was not acceptable for HYD-7, it was necessary to evaluate likely engine combination and mechanical transmission arrangement possibilities. Alternate propulsion system arrangements were considered and are shown in schematic form as Alternates 'A', 'B', 'C' and 'D'. These were evaluated considering feasibility and desirability through examination of their operational capabilities, ship endurance, machinery complexity and ship arrangement effects. Each alternate's advantages and disadvantages were identified, These are outlined below.

<u>Alternate "A" (Four 25,000 BHP Engines) - Figure A.4-1</u>

Advantages:

1. Use of two 25,000 BHP rated (LM 2500 size) turbines in the subcavitating foilborne speed regime results in increased range with the engines operating nearer their maximum continuous rating than would be the case with only two larger engines.
2. Two additional engines can be placed on the line readily for higher speed dash operation.

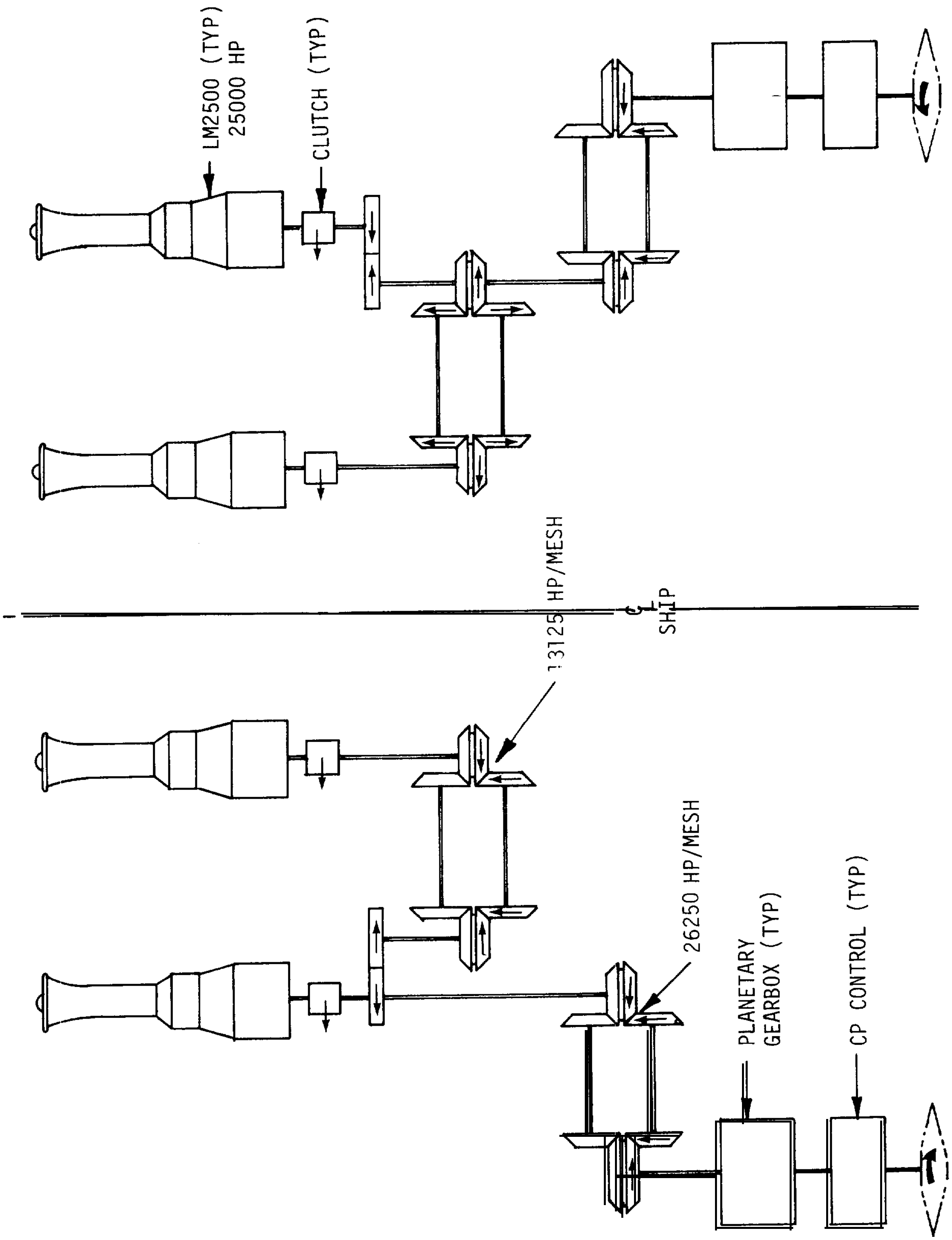
Disadvantages:

1. Utilization of two of the four 25,000 HP engines for hullborne operation at 16 and 20 knots will not meet requirements. See Table A.4-2.
2. The four abreast arrangement could not realistically be fit into the HYD-7 hull envelope. At best, the engine installation resulted in badly overcrowding the main machinery space, and provided inadequate athwartship space for passageway and maintenance operations.
3. The multiplicity of large intake and exhaust stack space requirements complicated topside and deckhouse arrangements.
4. Considerable weight is involved in the two dual engines combining boxes with the engines located alongside each other. (It should be noted that a four engine arrangement with two longitudinally spaced, opposing drive end pairs of engines mounted two abreast

FIGURE A.4-1

BOEING MODEL 1026-010

PROPULSION SYSTEM SCHEMATIC - ALTERNATE 'A'



was also examined briefly. That alternative was deleted on the basis that it consumed far too much longitudinal space on the second and platform decks in the already crowded hull.

Alternate "B" (Two 50,000 BHP Engines) - Figure A.4-2

Advantages:

1. The crosshaft permits single engine operation over the entire hullborne and subcavitating foilborne speed regime which results in lower SFC and greater foilborne range than with two or more engine operation.
2. Availability for engine maintenance is improved and increased turbine TBO's would result.
3. The second engine can be brought on line for high speed dash operations.
4. Lesser number of gearboxes and support equipment results in most efficient utilization of machinery space.

Disadvantages:

1. Separate propulsion systems would be required for low speed harbor maneuvering and docking, as disconnecting of cross-shafting has not been provided.
2. Greater SFC in hullborne mode with either dual or single engine operation far off rating.
3. Cross shafting cuts engine room off for longitudinal access and blocks crew accessability to aft bulkhead equipment.

Alternate "C" (Two 50,000 BHP and Two 7500 BHP Engines) - Figure A.4-3

Advantages:

1. Lower SFC and greater hullborne range with separate smaller hullborne engines. (Although this is true, performance studies showed that even though the two 7500 BHP engines would just provide 20 knot capability, the limited HYD-7 fuel load would not quite permit attaining 60 percent of the 20 knot range goal.)
2. Dash capability immediately available while foilborne without having to start up and put additional engines on line.

BOEING MODEL 1026-010

PROPULSION SYSTEM SCHEMATIC-ALTERNATE 'B'

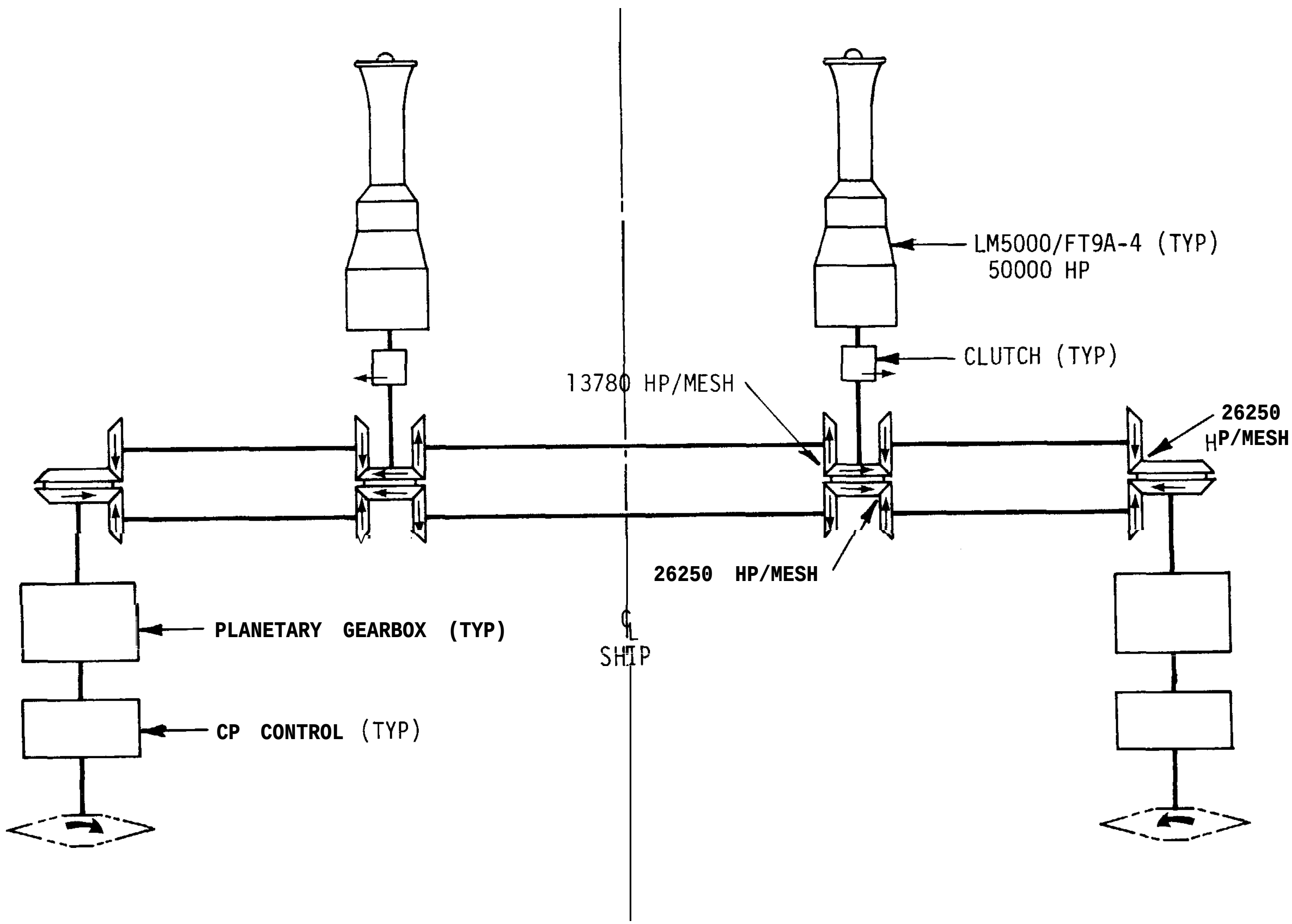


FIGURE A.4-2

3. The COGOG arrangement requires only a single pair of propellers. Separate hullborne transmission and shafting are not required. This saves weight and eliminates another form of appendage to deal with. This is especially considered important with the higher speed of takeoff, cresting and landing operations of HYD-7.

Disadvantages:

1. Greater SFC at subcavitating foilborne cruise with two 50,000 BHP engines operating at part load well below rating.
2. Offset-combining gearboxes are required for smaller hullborne engine installation.
3. Increased length of machinery spaces over alternate "B" would /be required.

Alternate "D" (Two 50,000 BHP Engines with Quadruple Crosshafts and Downshafts) - Figure A.4-4

Advantages:

1. Less power transmitted per gear mesh. (The 26,250 SHP/mesh transmitted on alternates A, B and C is near the current limit of gearing technology and limited life is a very possible outcome unless significant advances are made in the operating life expectancy of high scoring index gears.)
2. The crosshaft permits single engine operation over the entire hullborne and subcavitating foilborne speed regime which results in lower SFC and greater foilborne range than with two or more engine operation.
3. Availability for engine maintenance is improved and increased turbine TBO's would result.
4. The second engine can be brought on line for high speed dash operations.

Disadvantanges:

1. Greatly increased number of spiral bevel qearboxes (8). Complicates engine room arrangement, increases accessories and machinery weights.

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BOEING MODEL 1026-010

PROPULSION SYSTEM SCHEMATIC - ALTERNATE 'C'

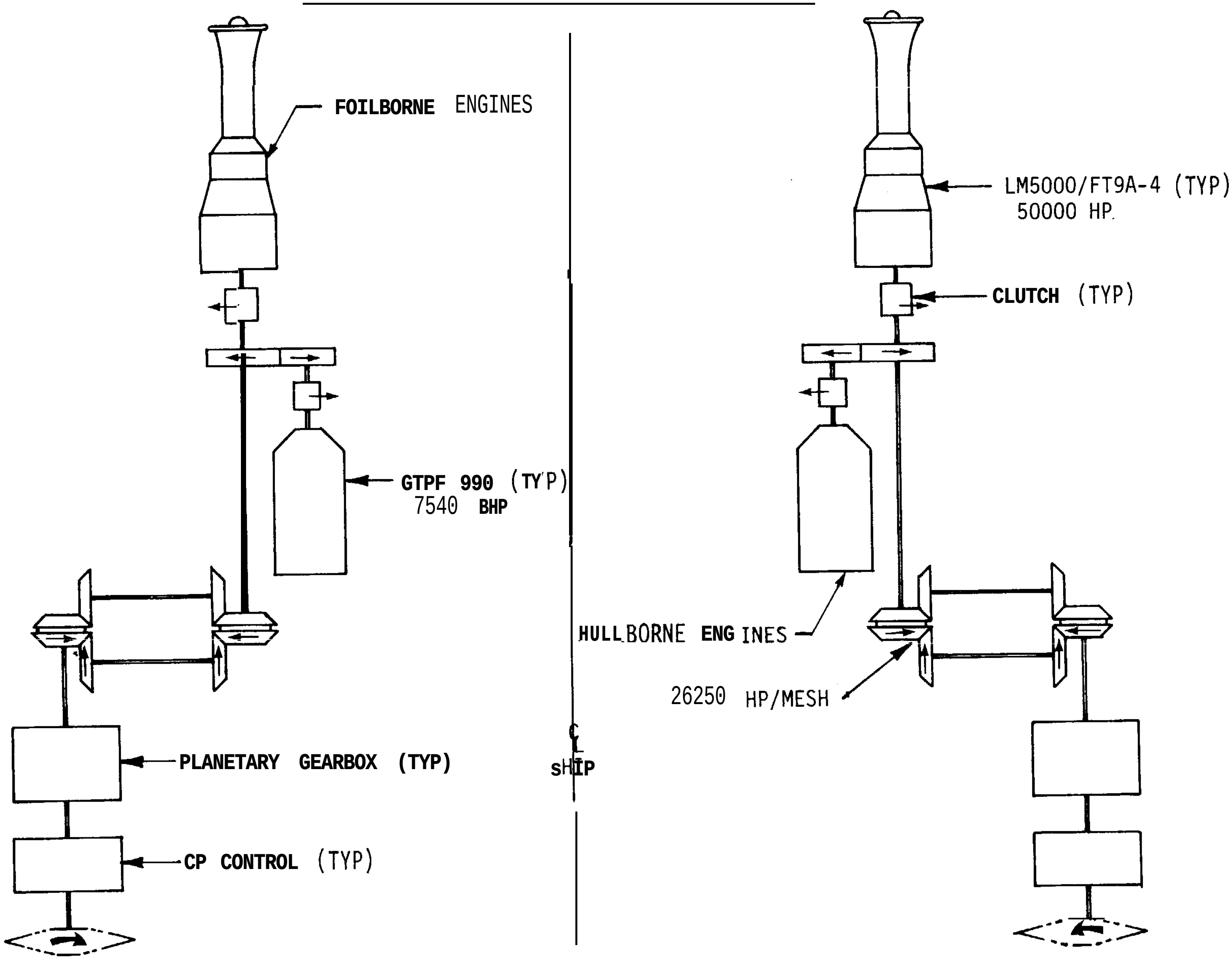
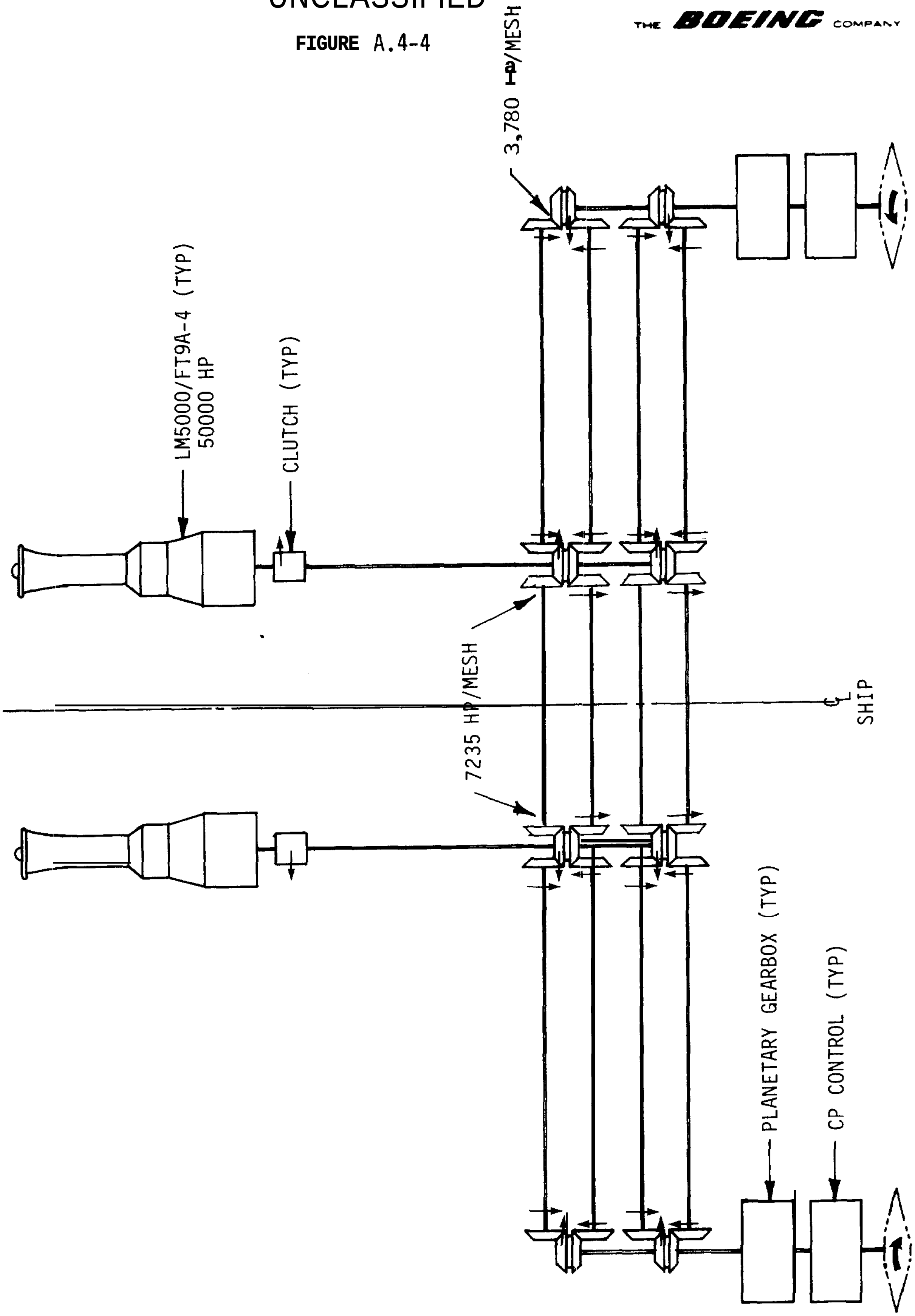


FIGURE A.4-3

FIGURE A.4-4

BOEING MODEL 1026-010
PROPULSION SYSTEM SCHEMATIC - ALTERNATE 'D'



2. Separate propulsion systems are required for low speed maneuvering and docking.
3. Crosshafting blocks crew accessibility to aft bulkhead equipment.
4. Four vertical drive shafts complicates the strut structural arrangement considerably.

In order to better quantify the performance aspects of this engine size and quantity trade, an analysis was conducted of the capabilities of the two basic engine combination alternatives: "A" with four 25,000 BHP rated engines, and "B", "C", or "D" with two 50,000 BHP rated engines. In this portion of the study unlimited flexibility of operation was assumed for simplicity with the realization that virtually any mechanical arrangement could be provided if shown to be advantageous from a net performance standpoint.

Table A.4-2 is a summary of the results of the study. The table shows that both alternates meet both the 16 and 45 knot "minimum acceptable" requirements of the TLR. In addition alternate "B" exceeds the 50 knot range goal. Neither of the alternates came close to meeting the 20 knot goal.

The 20 knot goal is deemed to be too ambitious for this concept. In a side study utilizing data from WP-011, it was found that a specific fuel consumption (SFC) of 0.256 lb/HP-hr would be required to achieve the 20 knot range goal with the model -010 181 long ton fuel load. This SFC value is 36 percent below the proper value plotted in WP-011 and is significantly below even the most optimistic SFC estimates for regenerative turbine technology forecast for the year 2000.

Another way of looking at the realism of the goal is to utilize the WP-011 specified SFC value (0.40 lb/SHP-hr) and calculate the quantity of fuel required to meet the goal. This yields a value of 284 L. Tons, which is nearly a 56 percent increase over the 181 ton baseline fuel value.

TABLE A.4-2

MODEL -010 RANGE - PROPULSION TRADE-OFF SUMMARY (U)

(All Ranges in Nautical Milesj

(C) TLR OPERATING CONDITION	TLR RANGE REQUIREMENT	RANGE PREDICTION ① ALTERNATE "A" ②		RANGE PREDICTION ① ALTERNATE "B" ③
Hullborne				
16 Knots - Min. Acceptable	1500	1700 (1)	1290 (2)	1500 (1) ④
20 Knots - Goal	2000	1200 (1)	880 (2)	1140 (1)
Foilborne				
45 Knots - Min Acceptable	1000	1273 (2)		1370 (1)
50 Knots - Goal	1300	1215 (2)		1325 (1)
70 Knots	None	790 (4)		830 (2)

① All ranges predicted for 1.4 meter design seas, using SFC data from WP-011 Revision A, corrected for Navy standard installation conditions and 26.7°C (80°F) operation.

② Alternate "A" has four 25,000 BHP (maximum continuous) rated engines installed.

③ Alternate "B" has two 50,000 BHP (maximum continuous) rated engined installed.

4 Numbers is parenthesis indicate number of engines actually utilized for that range prediction.

284 tons of gross fuel equates to a 29.3 percent fuel fraction which is approximately the same as the fuel fraction predicted by Boeing for the ANVCE 1400 ton HOC study, Reference A.4-1. That fraction is 29.7 percent. The significantly increased speed and power requirements of HYD-7 make it highly improbable that this high fuel fraction could be achieved or even approached in the specified time frame. Thus, the 20 knot range goal has been set aside for the remainder of this study effort.

Since the four 25,000 BHP engine alternatives were less desirable from both machinery arrangement and performance standpoints, it was decided to utilize a propulsion concept based upon two 50,000 BHP engines. Further, it was found from the propulsion studies leading to the selection of a COGOG machinery arrangement for the 1400 ton HOC and an evaluation of Alternate "C" that utilization of a smaller (4000 SHP) turbine in a COGOG arrangement provides significant benefits at a moderate weight cost. The weight increase is offset by decreased fuel consumption which saves fuel (and fuel cost) as well as providing increased hullborne range over the frequently utilized speed range from 8 to 16 knots. The 4000 BHP size was selected in order to provide 16 knot capability with the small engines.

The propulsion system concept developed from these studies is described in detail in Section 2.3.2 of this report.

A.4.2.8 AUXILIARY POWER PRIME MOVER SELECTION

A study trading off three different types of potential ships service auxiliary power prime movers was conducted. The evaluation was made primarily on the basis of performance. That is, on the minimum total of installed prime mover (including reduction or increasing gearboxes and necessary accessories) plus fuel weight for the TLR specified mission duration of 14 days.

In each case, a common pair of 500 KW, 400 Hz 440 volt generators was assumed. The remaining study assumptions and results are tabulated in Table A.4-3.

TABLE A.4-3

SHIPS SERVICE PRIME MOVER

TRADE STUDY ASSUMPTIONS AND RESULTS

24 Hour/Day Average Load	
--- 500 KW generator at 345 KW	617 SHP*
--- Hydraulic pump at no-load	15.6 SHP*
Mission Duration	14 days
Mission Energy Required by Prime Mover	212,550 HP-Hrs.
Prime Mover Rating	1000 BHP

INSTALLED ENGINE CHARACTERISTIC	OPEN CYCLE MARINE GAS TURBINE	REGENERATIVE MARINE GAS TURBINE	RECIPROCATING MARINE DIESEL
Specific Weight (lb/HP)	0.45	2.5	8.0
Weight of Two Engines (lb)	900	5,000	16,000
Installed SFC (lb/BHP-Hr.)**	0.707	0.439	0.361
Mission Fuel Weight	150,273	93,333	76,730
Total Weight	151,173	98,333	92,730

* Measured at prime mover output shaft.

** Basic SFC values were obtained from WP-011 and adjusted for installation and 26.7°C (80°F) operation.

(U) Even though a conservative value of 8.0 lb/BHP was assumed for the diesel alternative, it still emerged as the winner by a 6 percent margin due to its low characteristic fuel consumption.

(U) The description of the selected electrical system is presented in Section 2.3.3.

A.4.2.9 FOILBORNE SPEED FOR BEST RANGE (U)

(C) A study of the sensitivity of maximum range to foilborne speed was conducted for the baseline ship. The results are presented on Figure 2.2.3-2. The curve displays the two range minimums existing in the vicinities of 22 and 60 knots where total drag in both the high speed hullborne and the foilborne partially cavitating modes are near their maximums.

(U) The speed for maximum foilborne range occurs at 43 knots with at least 95 percent of that maximum range available over the speed interval from 37 to over 49 knots.

A.4.2.10 OVERALL PERFORMANCE (U)

(U) All of the configuration and subsystem studies summarized above have been conducted with their effect upon HYD-7 performance as a major consideration. For example, in both the above propulsion and ships service prime mover trades, performance was quantified prior to choosing between alternatives.

(U) Through this procedure, the synthesis of Model 1026-010 has produced a design which will meet the maximum dash speed requirement, both of the minimum acceptable HYD-7 range requirements, the 16 knot range goal, and falls short of only the 20 knot range goal, which is not considered realistically attainable, as discussed by Section A.4.2.7 above.

REFERENCES

A.4-1 Boeing Marine Systems Document D315-51301-1, "Feasibility Design Description of Hydrofoil Ocean Combatant (HOC) for ANVCE Study (U)", Prepared under Contract N00600-75-C-1107, 22 December 1976

A.4-2 Boeing Marine Systems Document No. D315-1101-1, "Structural Design Calculations for Hull Structure Design and Scantling Development for Boeing Model 1026 Hydrofoil Ship (DBH)", March 1973

A.4-3 AIAA Paper "Automatic Control of the Hydrofoil Gunboat, TUCUMCARI", by James E. Vogt, Boeing Marine Systems, presented at the AIAA 2nd Advanced Marine Vehicles and Propulsion Meeting, Seattle, Washington, May 21-23, 1969.

A.4-4 Boeing Marine Systems IR&D Document No. D315-51302-1, "Foil Strut Retraction Alternatives for the Hydrofoil Ocean Combatant," August 20, 1976

A.4-5 Garrett AiResearch Manufacturing Company of California, Superconducting Propulsion System and Ship Interface Study, 74-10565-1, -2, and -3, dated 1 September 1974; Prepared for U.S. Naval Ships Systems Command 03414 under Contract No. N00024-73-C-5487, Project Serial No. 546-58, Task No. 16756

A.4-6 AIAA Paper No. 74-306, "Hydrofoil Development - Issues and Answers", by William M. Ellsworth, Naval Ship Research and Development Center, presented at the AIAA/SNAME Advanced Marine Vehicles Conference, San Diego, California

A.2-11 NAVSEA 6512 Serial No. S760653, "Combat System Data Sheets for AAW, ASW and SSW (U)," Vol. I and II, 30 June 1976, Prepared for OP-96(V) for ANVCE

A.2-12 NAVSEC Design Data Sheet, DDS 079-1, "Stability and Buoyancy of U.S. Naval Surface Ships", 1 August 1975

A.2-13 NELC TD 428, "The Essentially Manned Advanced Surface Combat System"

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ACTIVE SHEET RECORD

SHEET NO.	REV LTR	ADDED SHEETS SHEET NO.	REV LTR	ADDED SHEETS SHEET NO.	REV LTR	SHEET NO.	REV LTR	ADDED SHEETS SHEET NO.	REV LTR	ADDED SHEETS SHEET NO.	REV LTR
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iii						38					
iv						39					
v						40					
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35						81					

THE BOEING COMPANY

ACTIVE SHEET RECORD

SHEET NO.	REV LTR	ADDED SHEETS SHEET NO.	REV LTR	ADDED SHEETS SHEET NO.	REV LTR	SHEET NO.	REV LTR	ADDED SHEETS SHEET NO.	REV LTR	ADDED SHEETS SHEET NO.	REV LTR
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ACTIVE SHEET RECORD

SHEET NO.	REV LTR	ADDED SHEETS				SHEET NO.	REV LTR	ADDED SHEETS			
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THE BOEING COMPANY

REVISIONS

LTR	DESCRIPTION	DATE	APPROVAL

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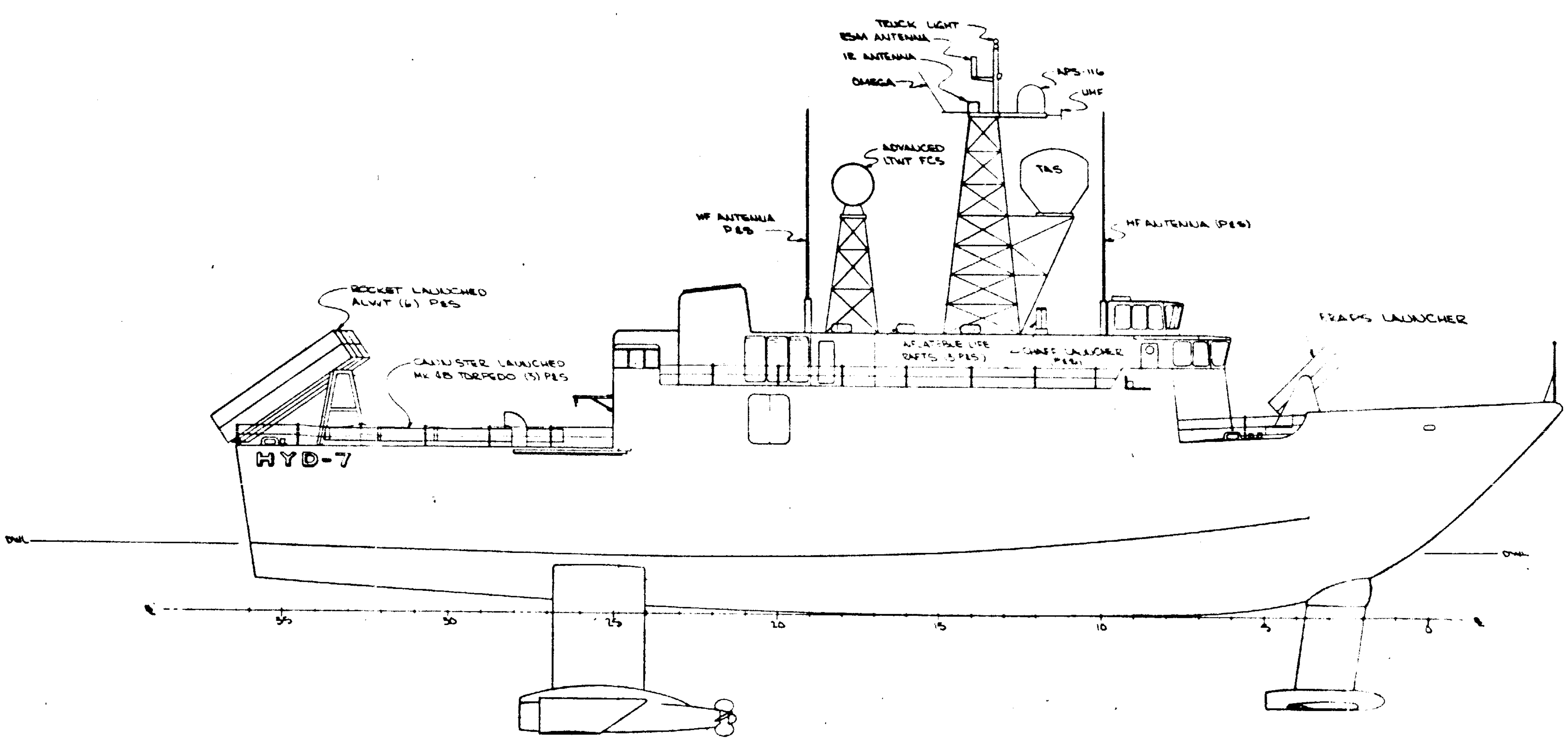

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FIGURE 2.1-1

CONTRACT NUMBER	THE BOEING COMPANY CORPORATE OFFICES SEATTLE WASHINGTON
DWN LAMOREE	STUDY ARRANGEMENT MODEL 1026-010 ANVCE HYD-7
CHK	
ENGR	
ORG	
PROJECT APPROVAL	315-11006
	SH 1 OF 2

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[redacted]

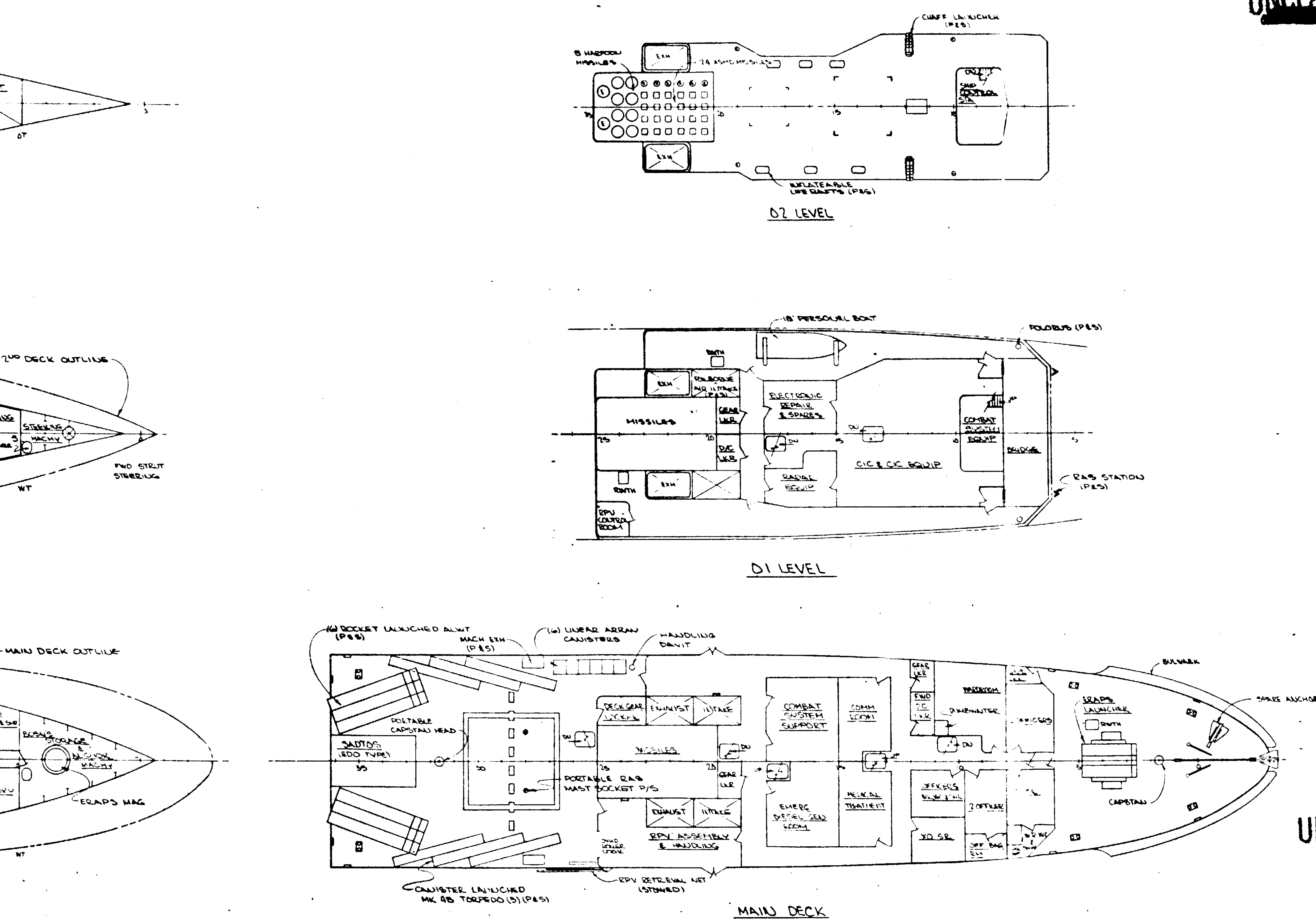

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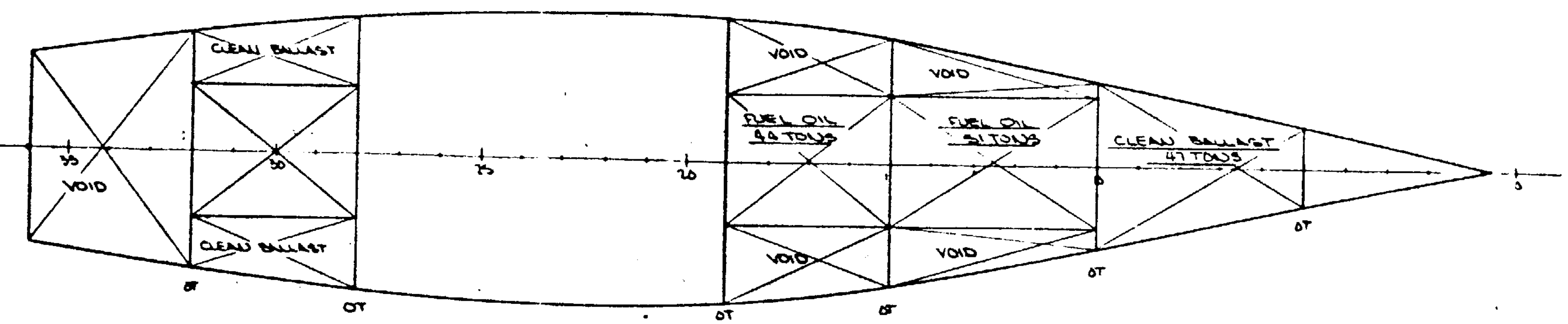
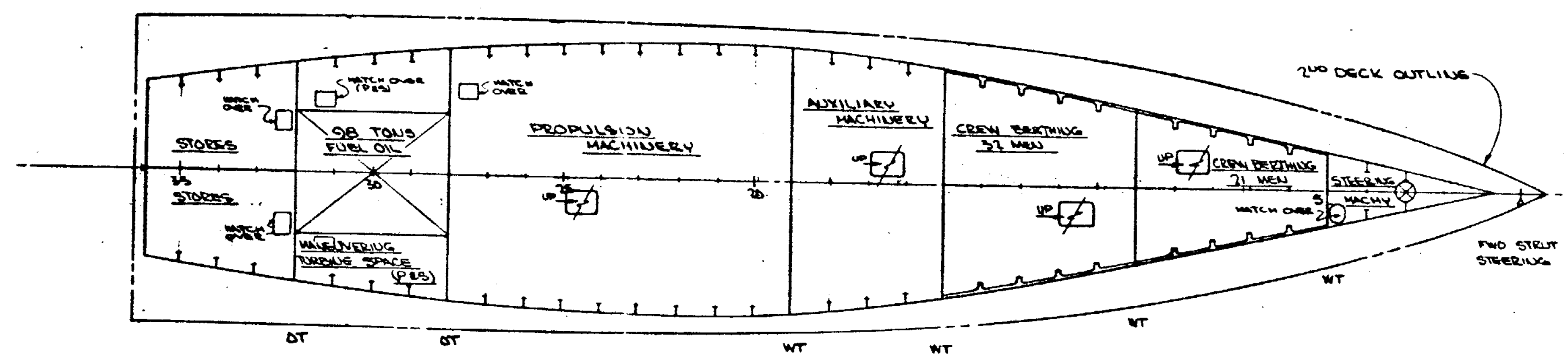
FIGURE 2.1-2

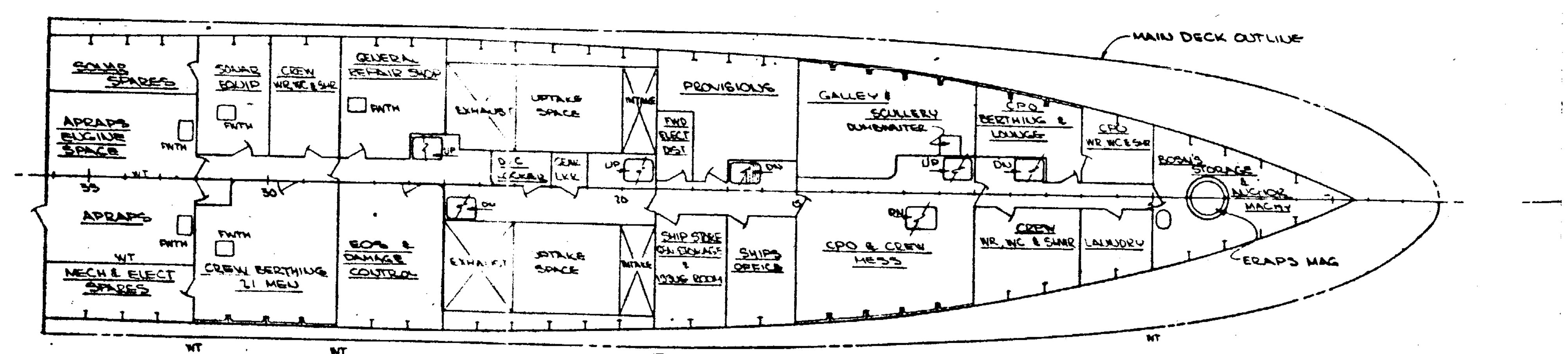
CONTRACT NUMBER	THE BOEING COMPANY CORPORATE OFFICES SEATTLE WASHINGTON 98124
DRN LAMORER 1/20/?	STUDY ARRANGEMENT MODEL 1026-010 ANVCE HYD-7
CHK	
ENGR	
APPD R. Acuse ?/?	SIZE CODE IDENT NO 315-11006
PROJECT APPROVAL	



HOLD



PLATFORM DECK



2ND DECK

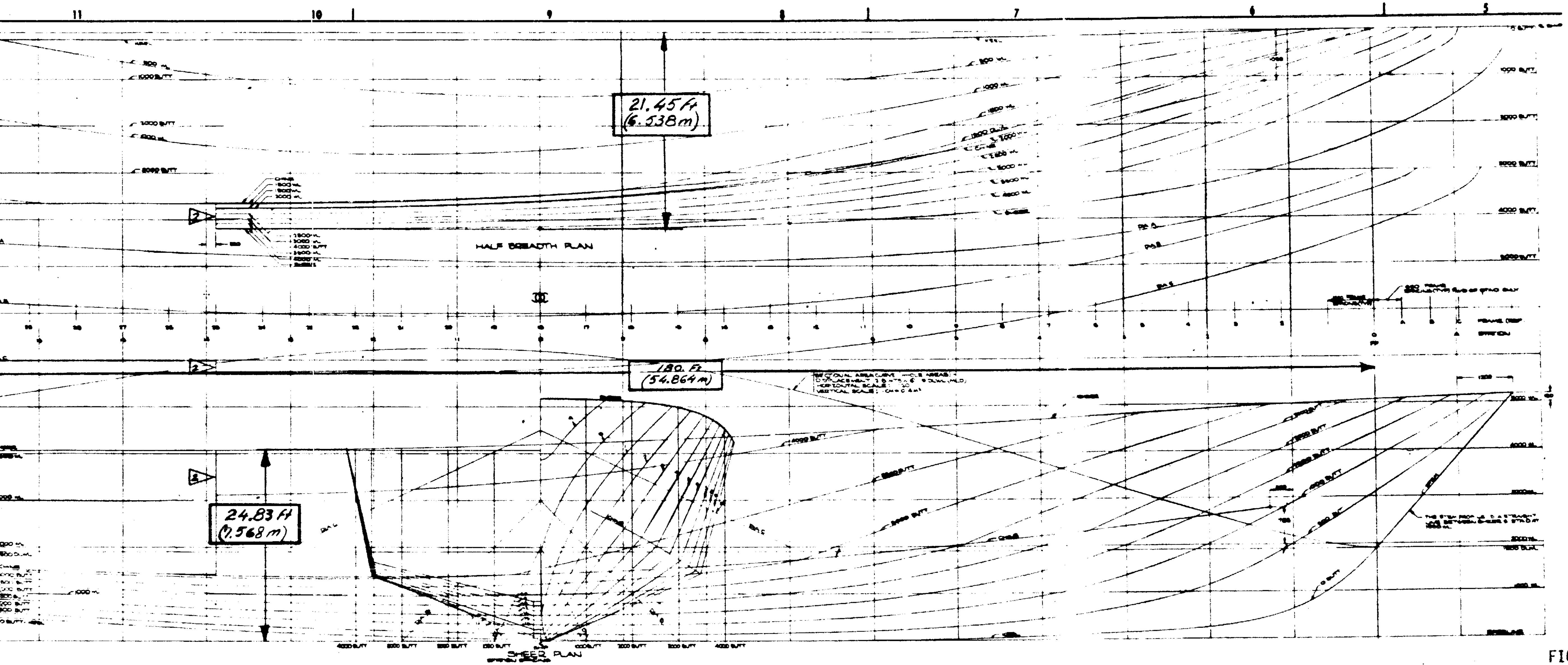


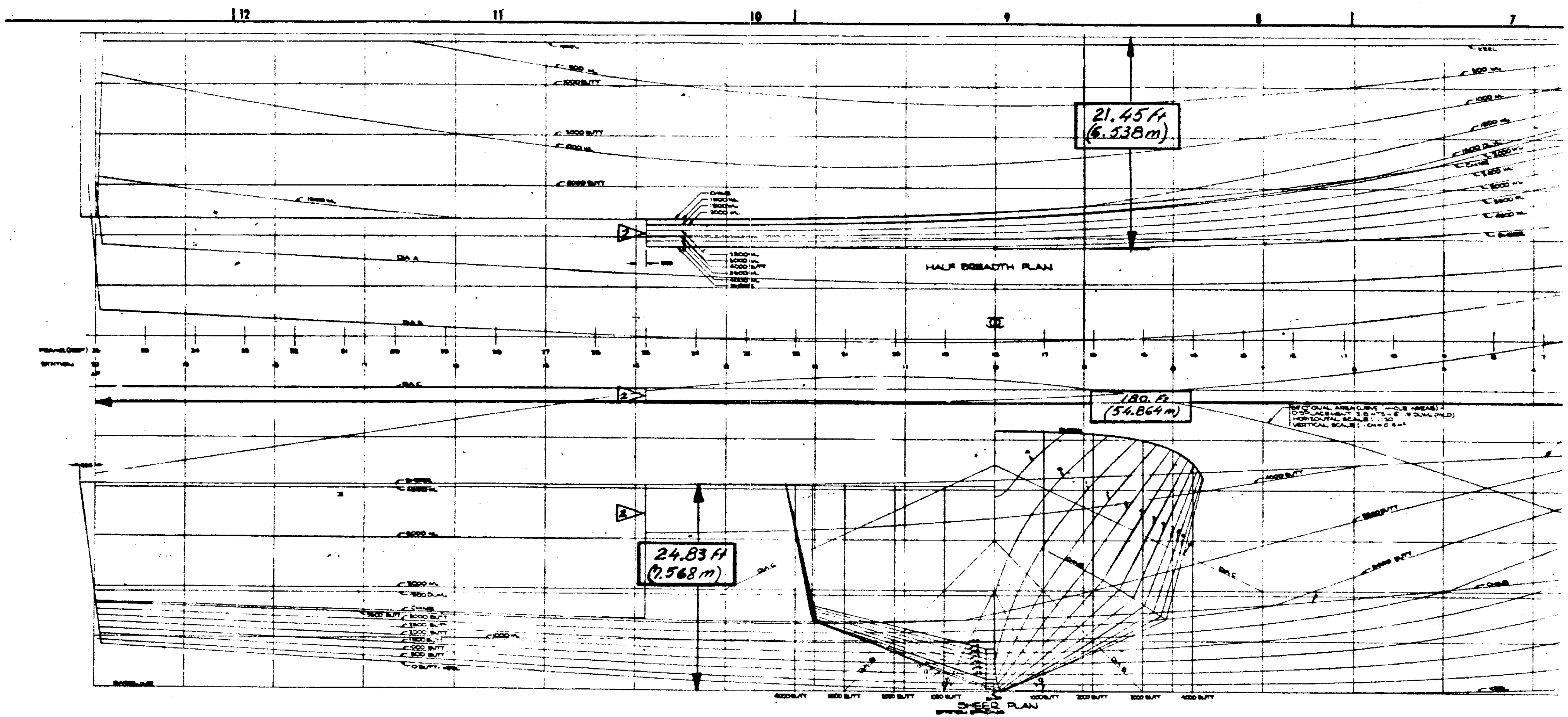
FIGURE 2.2.6-1

2 Strut Retraction Notches are removed for HYD-7.

1 This Dwg is a PHM Hull Dwg. Only the boxed in dimensions are valid for HYD-7. The scales are different in each axis.

CONTRACT NUMBER N00600-75-C-1107	THE BOEING COMPANY CORPORATE OFFICES SEATTLE, WASHINGTON 98124
DWN P. [signature] 1-21-77	HYD-7 (Model 1026-010) HULL LINES DEFINITION FROM PHM HULL LINES
CHK	
ENGR P. Miranda 1-21-77	
ORG	
PROJECT APPROVAL R. [signature] 1-21-77	SIZE — CODE IDENT NO 81205 — SK315-11007
	SCALE 1 — SH 1 OF 1

DRAWING RECORDS CLERK



▷ Strut Retraction Notches are removed for HYD-7.

▷ This Dwg is a PHM Hu
Only the boxed in dime
are valid for HYD-7.
scales are different
each axis.

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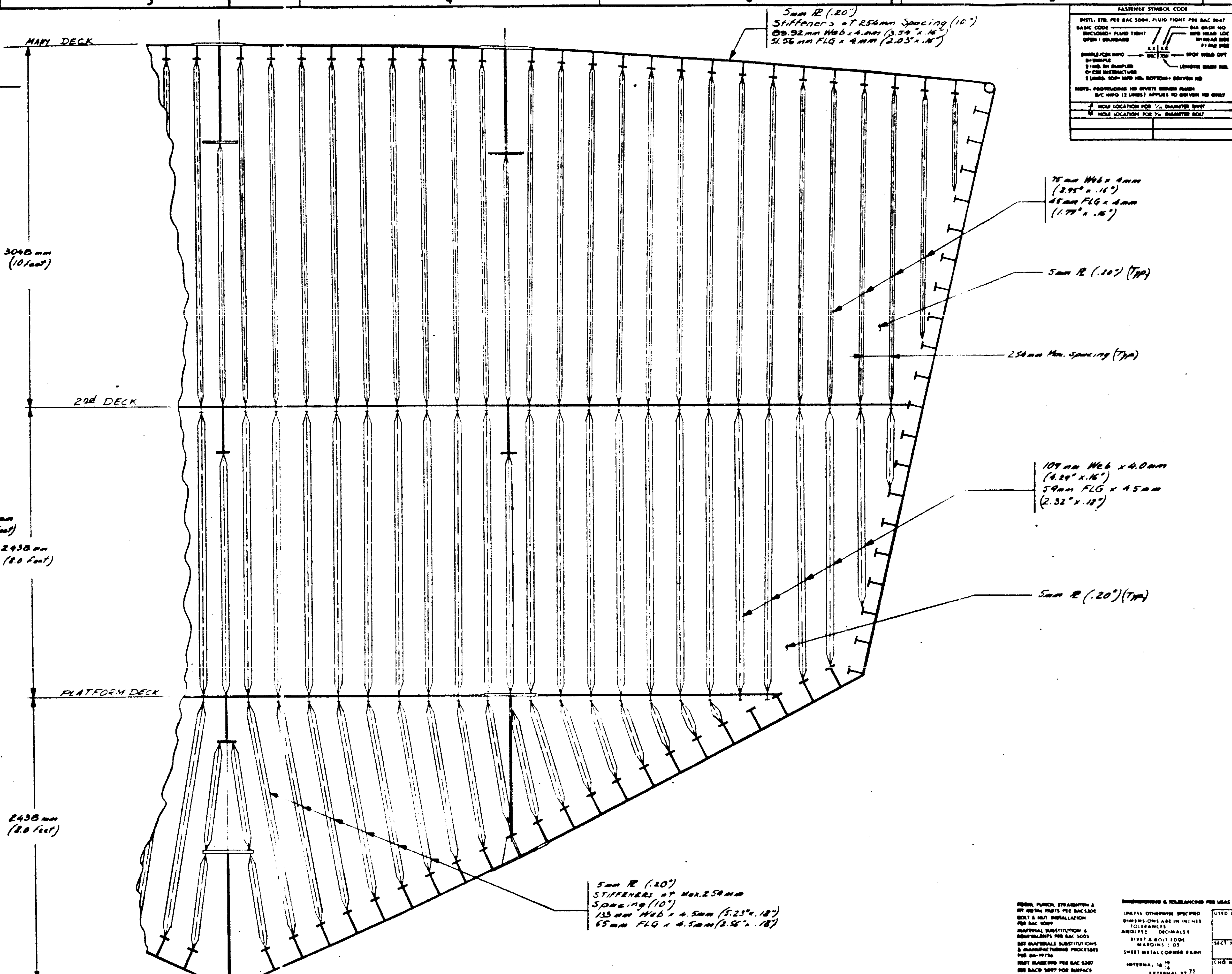

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FIGURE 2.3.1 - 2

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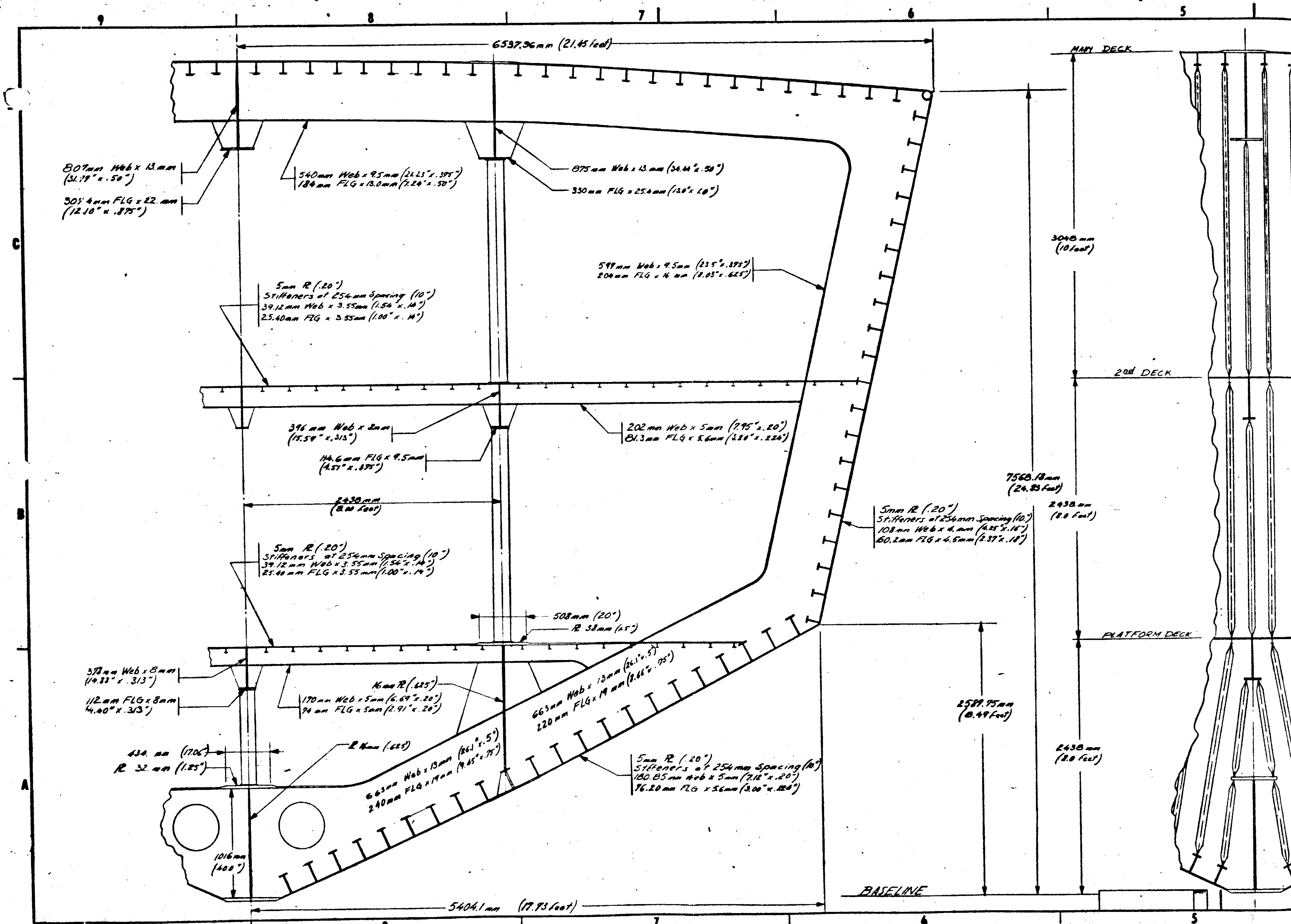
HYD7(1026-010) TYPICAL STRUCTURAL HULL MID-SECTION

SK315-11005

D315-51360-1



6537.96mm (21.45 feet)
MAIN DECK
2nd DECK
PLATFORM DECK
BASELINE
807mm Web x 13mm (31.79" x .50")
307.4mm FLG x 22mm (12.10" x .875")
540mm Web x 9.5mm (21.23" x .375")
184mm FLG x 13.0mm (7.24" x .50")
875mm Web x 13mm (34.44" x .50")
330mm FLG x 25.4mm (13.0" x 1.0")
3048mm (10 feet)
599mm Web x 9.5mm (23.5" x .375")
204mm FLG x 16mm (8.03" x .625")
5mm R (.20")
Stiffeners at 254mm Spacing (10")
39.12mm Web x 3.55mm (1.54" x .14")
25.40mm FLG x 3.55mm (1.00" x .14")
396mm Web x 8mm (15.59" x .313")
114.6mm FLG x 9.5mm (4.51" x .375")
202mm Web x 5mm (7.95" x .20")
81.3mm FLG x 5.6mm (3.20" x .224")
2438mm (8.00 feet)
7568.18mm (24.83 feet)
2438mm (8.0 feet)
5mm R (.20")
Stiffeners at 254mm Spacing (10")
108mm Web x 4mm (4.25" x .16")
60.2mm FLG x 4.5mm (2.37" x .18")
5mm R (.20")
Stiffeners at 254mm Spacing (10")
39.12mm Web x 3.55mm (1.54" x .14")
25.40mm FLG x 3.55mm (1.00" x .14")
508mm (20")
R 38mm (1.5")
378mm Web x 8mm (14.88" x .313")
112mm FLG x 8mm (4.40" x .313")
16mm R (.625")
170mm Web x 5mm (6.69" x .20")
74mm FLG x 5mm (2.91" x .20")
663mm Web x 13mm (26.1" x .5")
220mm FLG x 19mm (8.66" x .75")
2589.75mm (8.49 feet)
434mm (17.06")
R 32mm (1.25")
R 16mm (.625")
663mm Web x 13mm (26.1" x .5")
240mm FLG x 19mm (9.45" x .75")
5mm R (.20")
Stiffeners at 254mm Spacing (10")
180.85mm Web x 5mm (7.12" x .20")
76.20mm FLG x 5.6mm (3.00" x .224")
2438mm (8.0 feet)
1016mm (40.0")
5404.1mm (17.73 feet)

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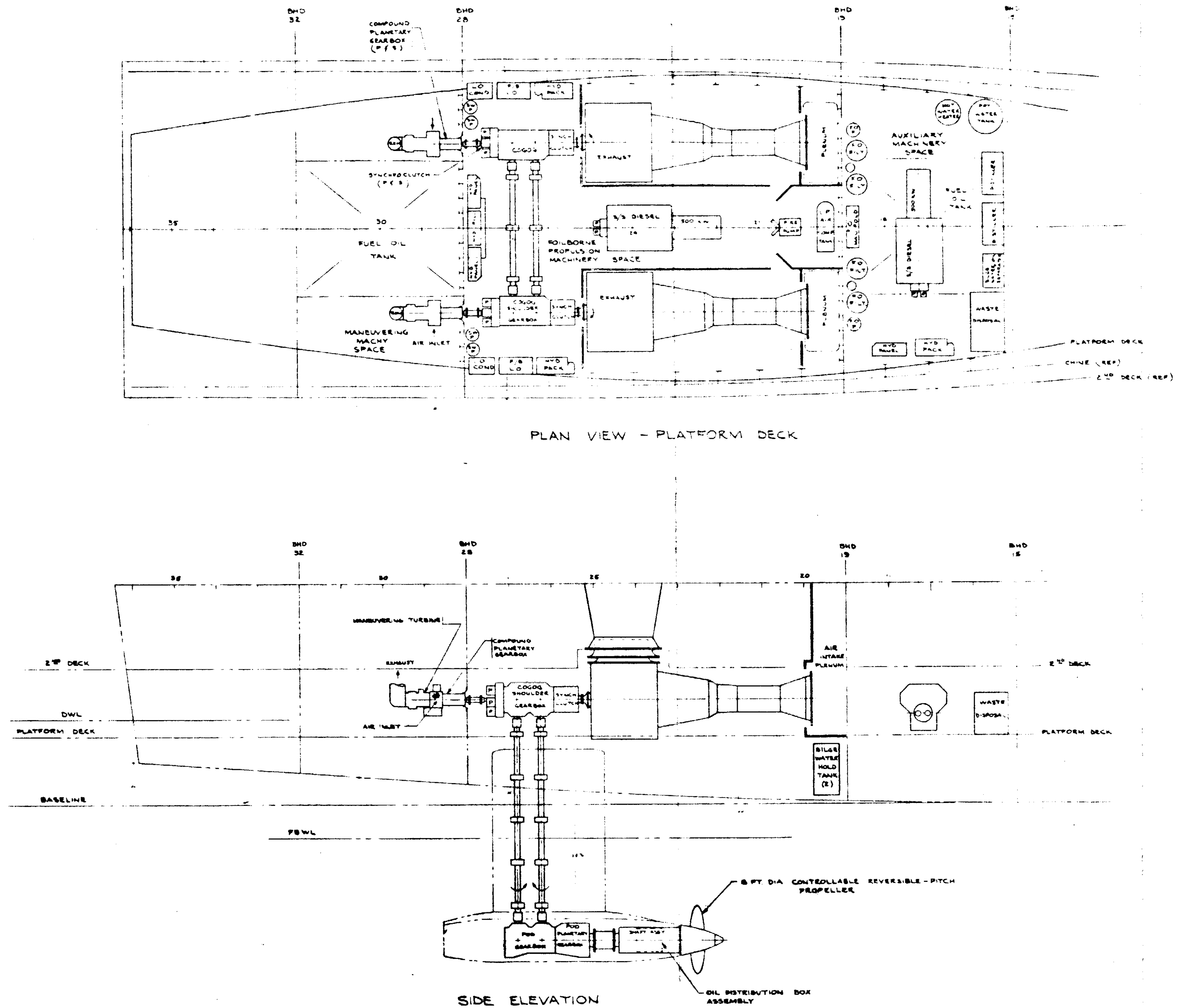

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FIGURE 2.3.2-1

ALTERNATE 'E' CONFIGURATION

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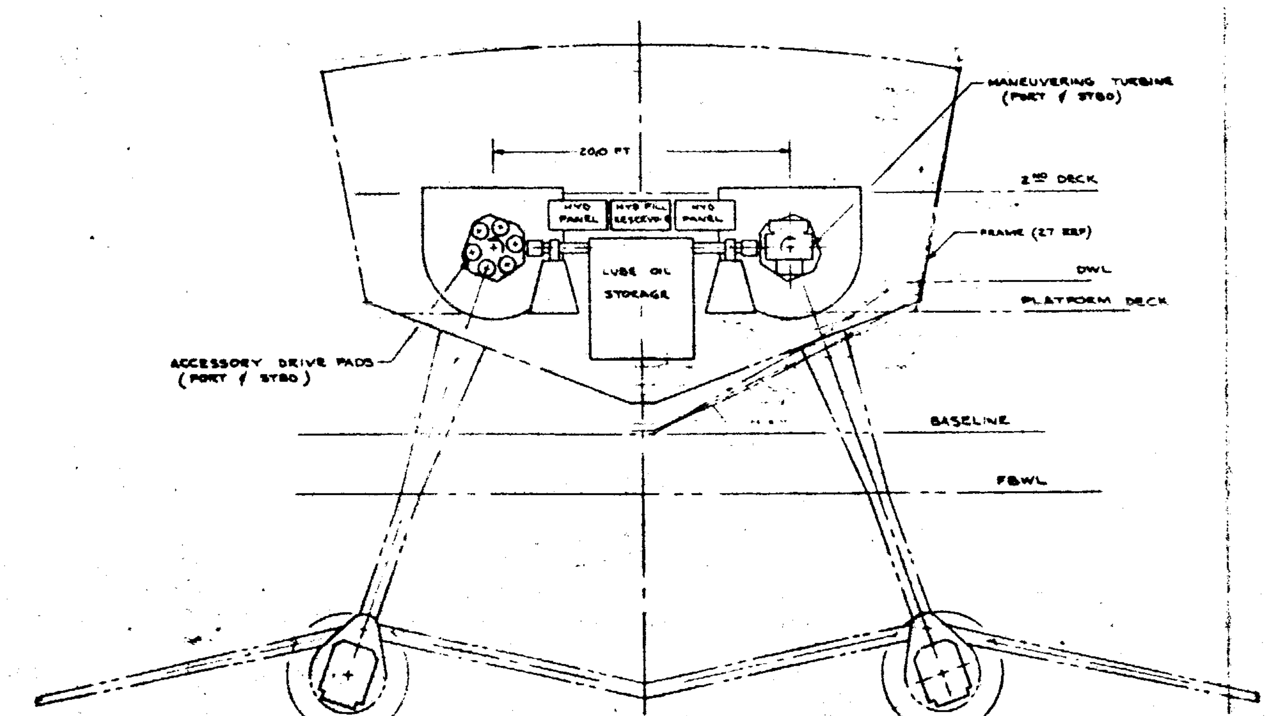
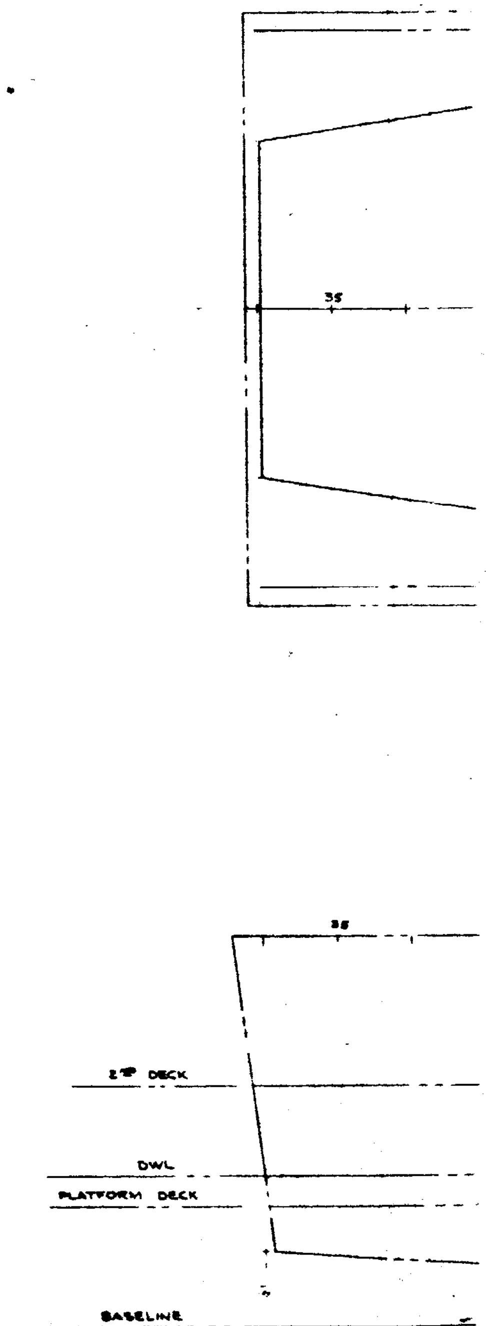
PROPULSION SYSTEM ARRANGEMENT MODEL 1026-010

81205 SK315-12004



REAR VIEW
(LKG FWD FROM BHD 28)



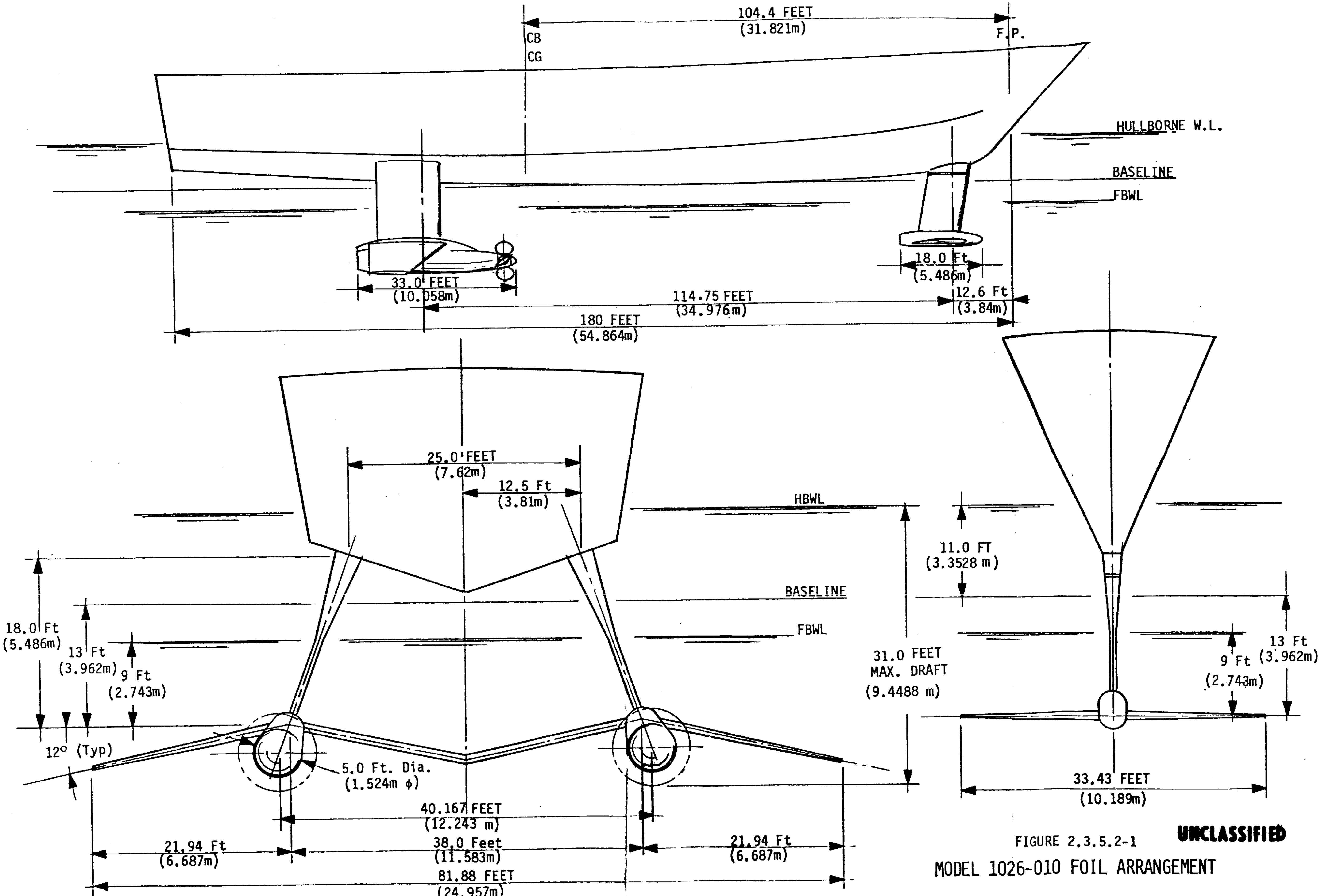


FIGURE 2.3.5.2-1

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MODEL 1026-010 FOIL ARRANGEMENT

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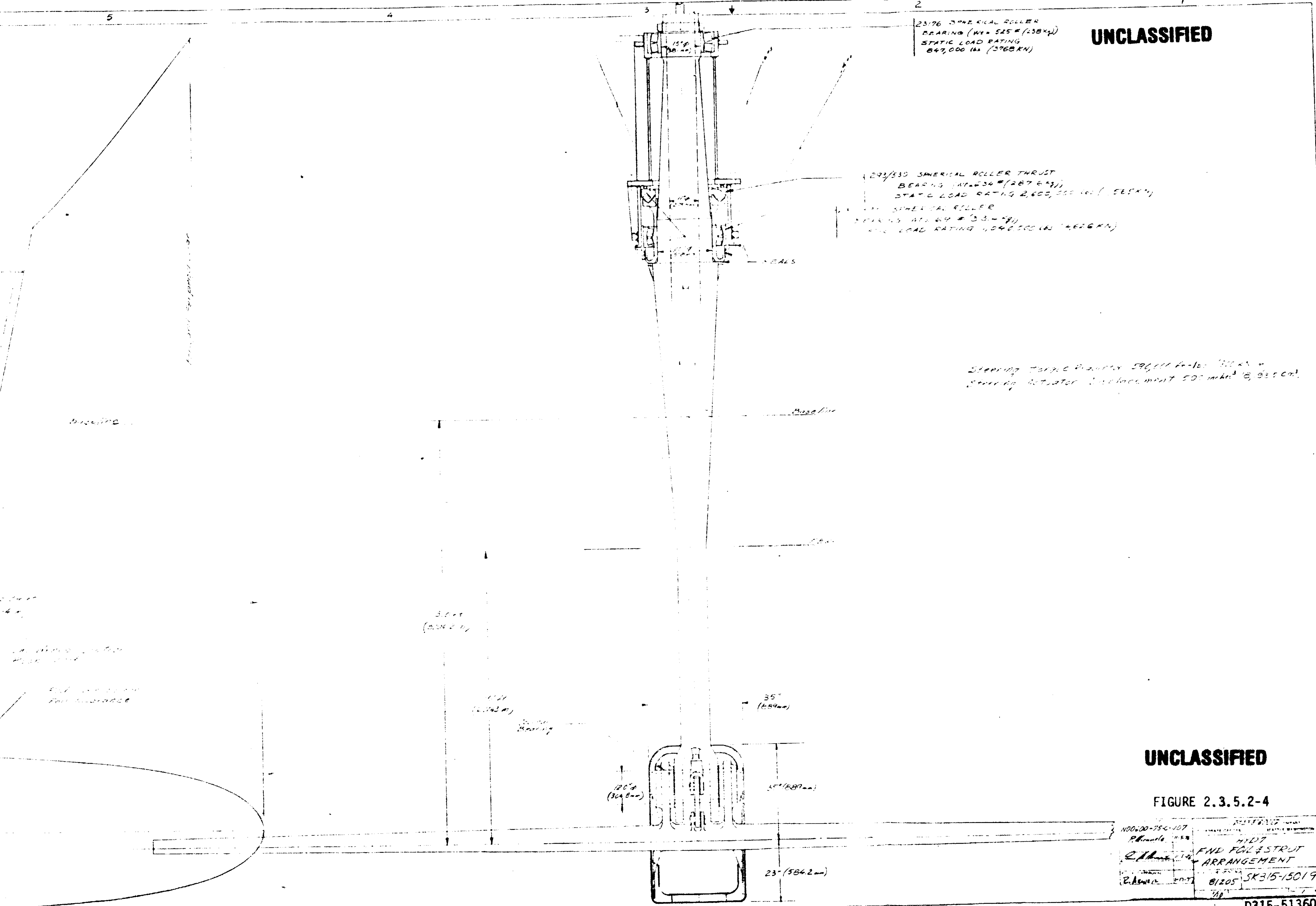

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FIGURE 2.3.5.2-4

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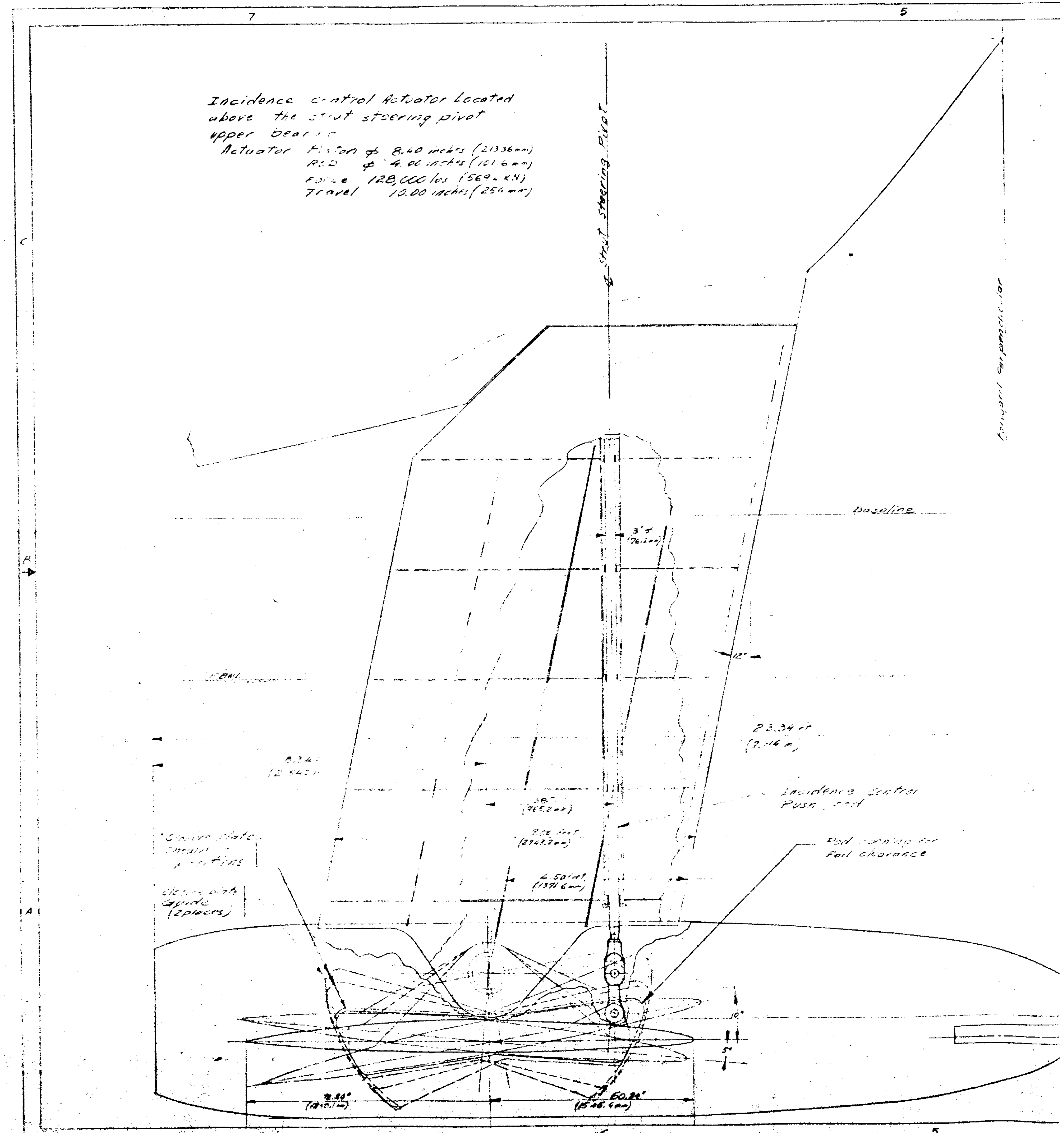

Incidence control Actuator Located
above the strut steering pivot
upper bearing
Actuator Piston ⌀ 8.40 inches (213.36mm)
Rod ⌀ 4.00 inches (101.6mm)
Force 128,000 lbs (569 kN)
Travel 10.00 inches (254mm)
℄ Strut Steering Pivot
baseline
23.34 ft
(7.114 m)
Incidence Control
Push rod
Rod bending for
Foil clearance
3" ⌀
(76.2mm)
38"
(965.2mm)
12"
10°
5°
60.84"
(1545.4mm)

UNCLASSIFIED

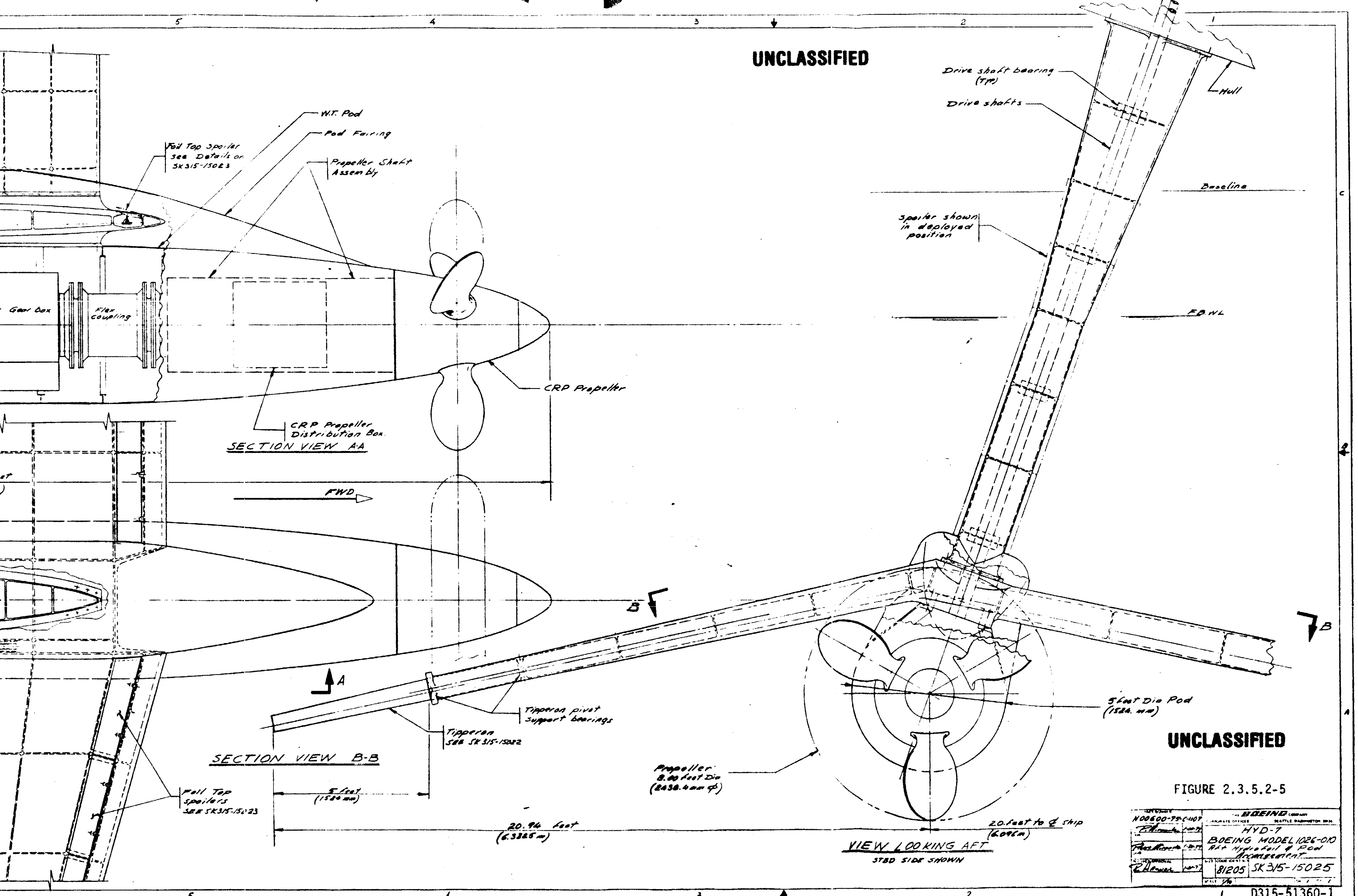

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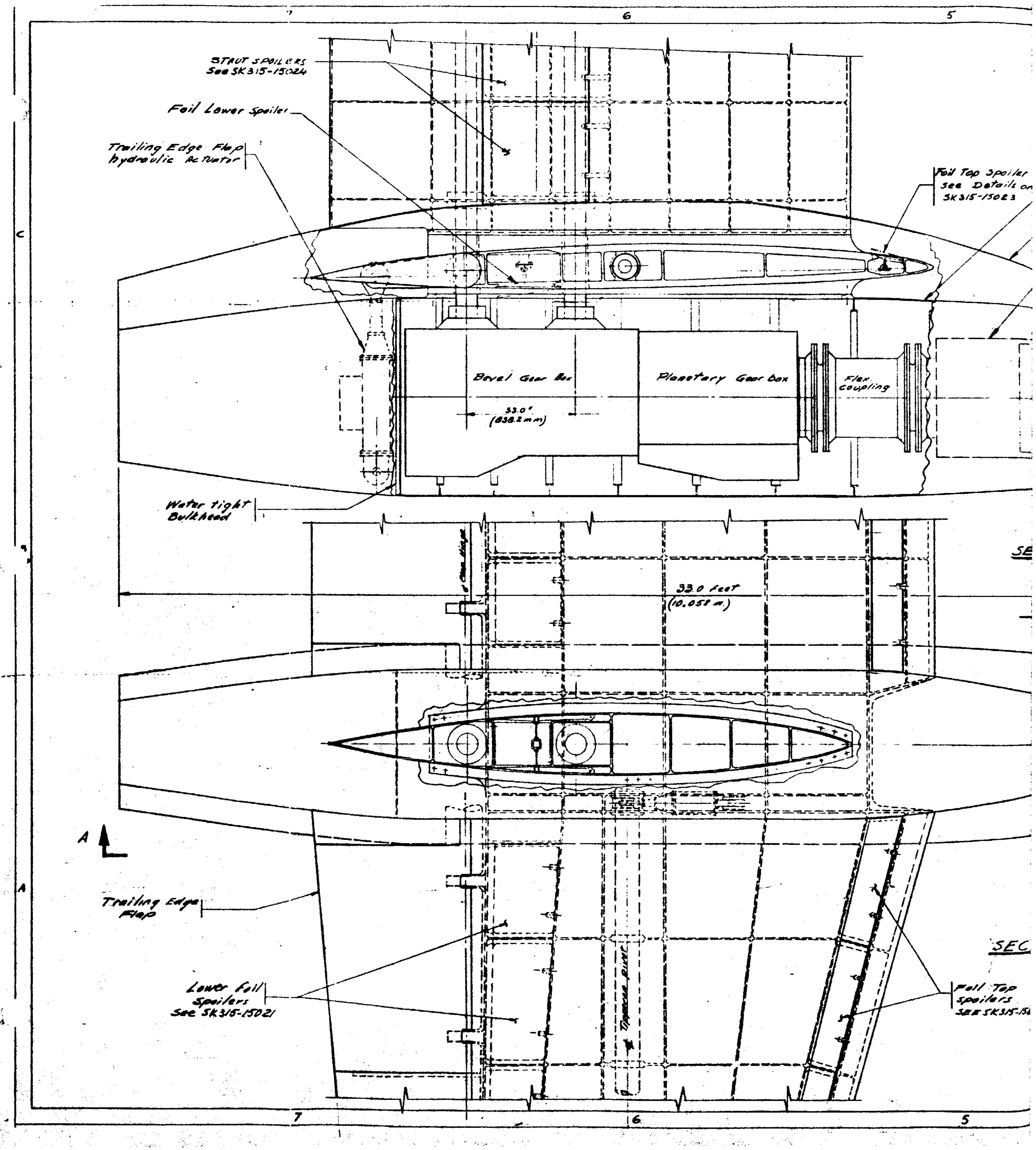
FIGURE 2.3.5.2-5

D315-51360-1


STRUT SPOILERS See SK315-15024
Foil Lower Spoiler
Trailing Edge Flap hydraulic Actuator
Foil Top Spoiler see Details on SK315-15023
Bevel Gear Box
Planetary Gear box
Flex coupling
33.0"
(838.2 mm)
Water tight Bulkhead
33.0 feet
(10.058 m)
A
Trailing Edge Flap
Lower Foil Spoilers See SK315-15021
Foil Top spoilers

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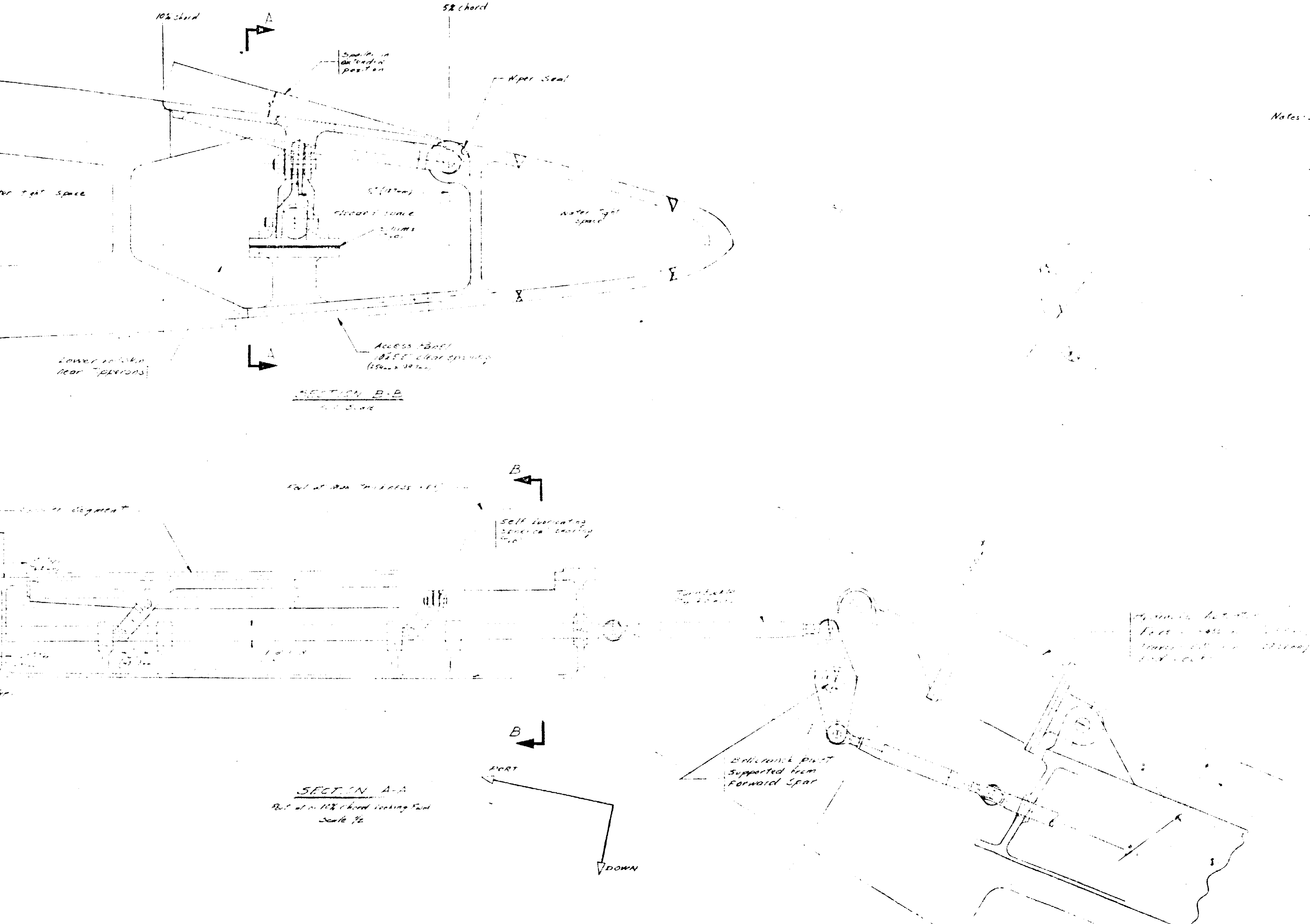


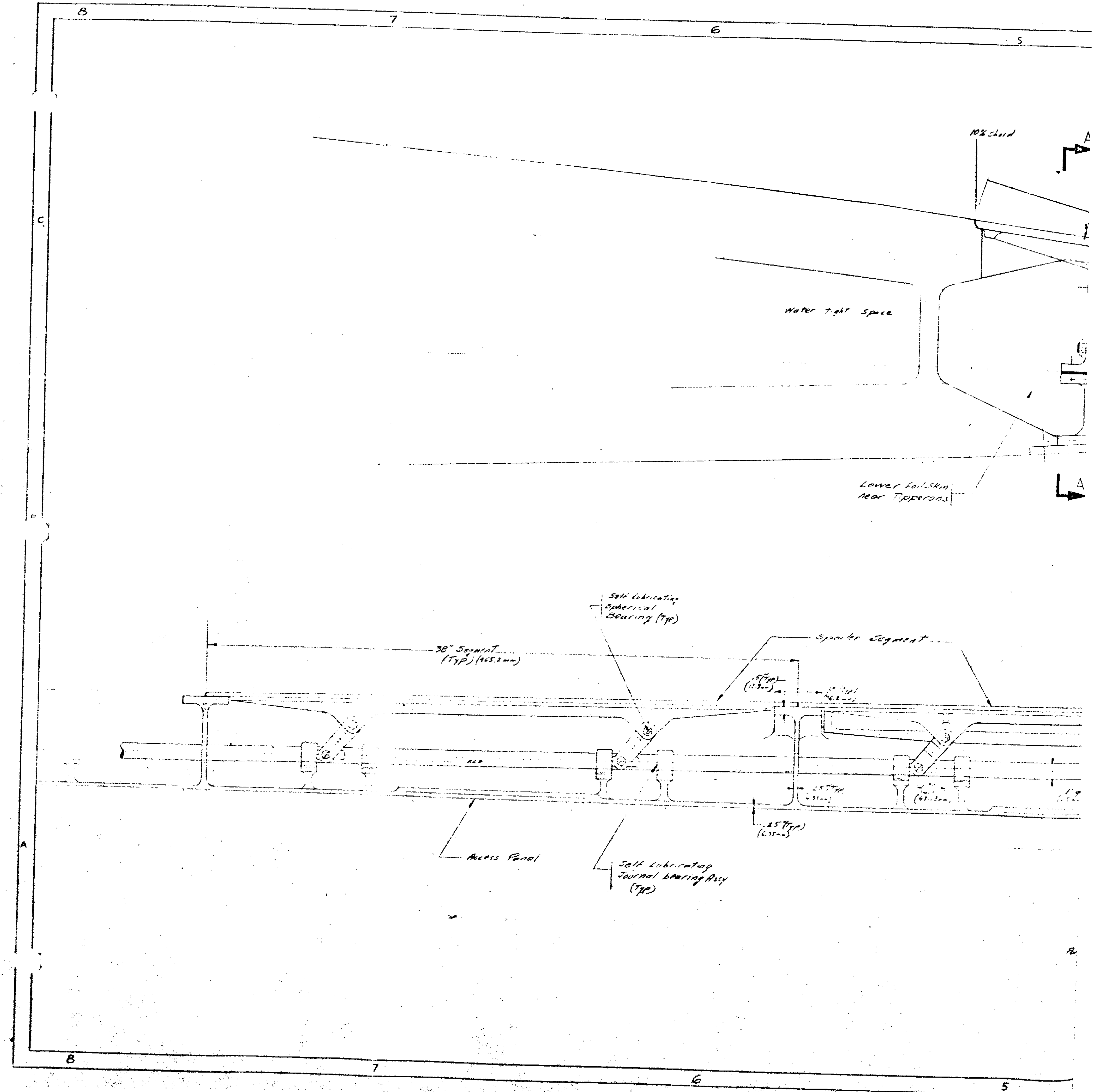
Notes: - Bellcrank shown in a vertical plane ... be in a plane ... sloping surface
- Spoiler actuating mechanism ... identical geometry along the ... span ...
- ...

UNCLASSIFIED

FIGURE 2.3.5.2-6

N00600-75-C-0407	HYD-7
	Boeing Model 1026-0-3 AFT FOIL TOP SPOILER & Actuating Mechanisms
	D205 SK315-15023

D315-51360-1


10% chord
A
A
Water tight space
Lower foil skin near Tipperons
Self Lubricating Spherical Bearing (Typ)
Spacer Segment
38" Segment (Typ) (965.2mm)
Access Panel
Self Lubricating Journal bearing Assy (Typ)

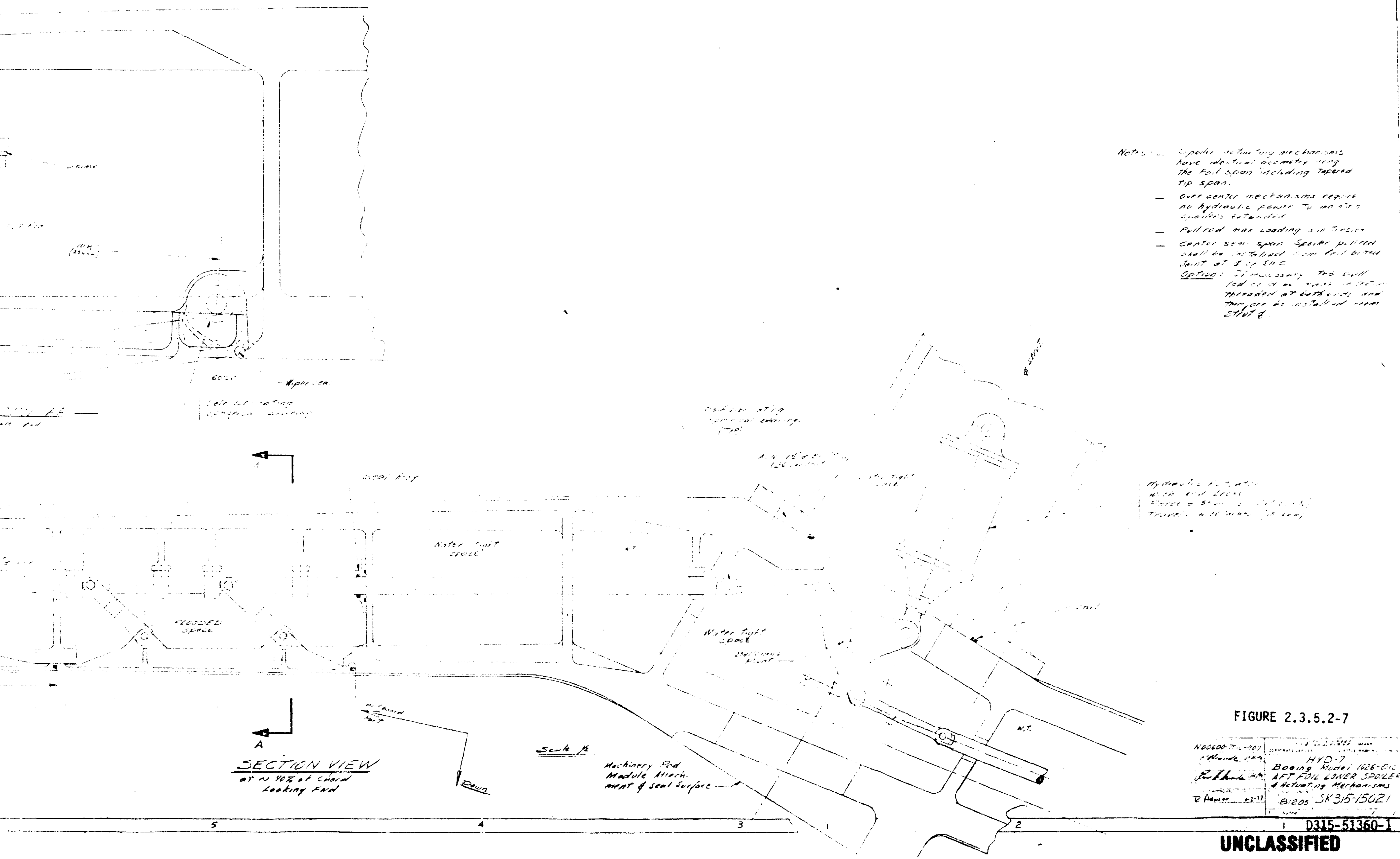
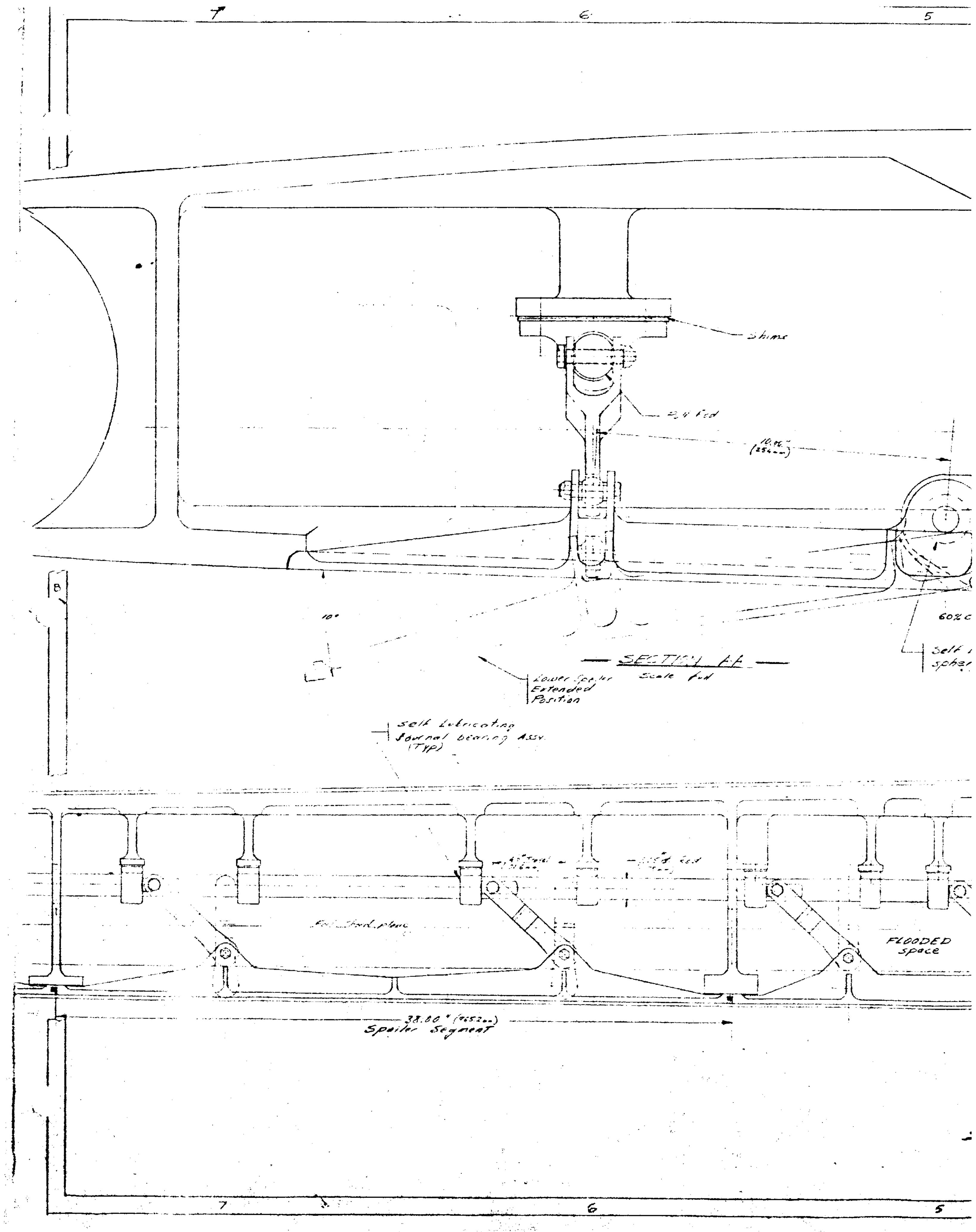


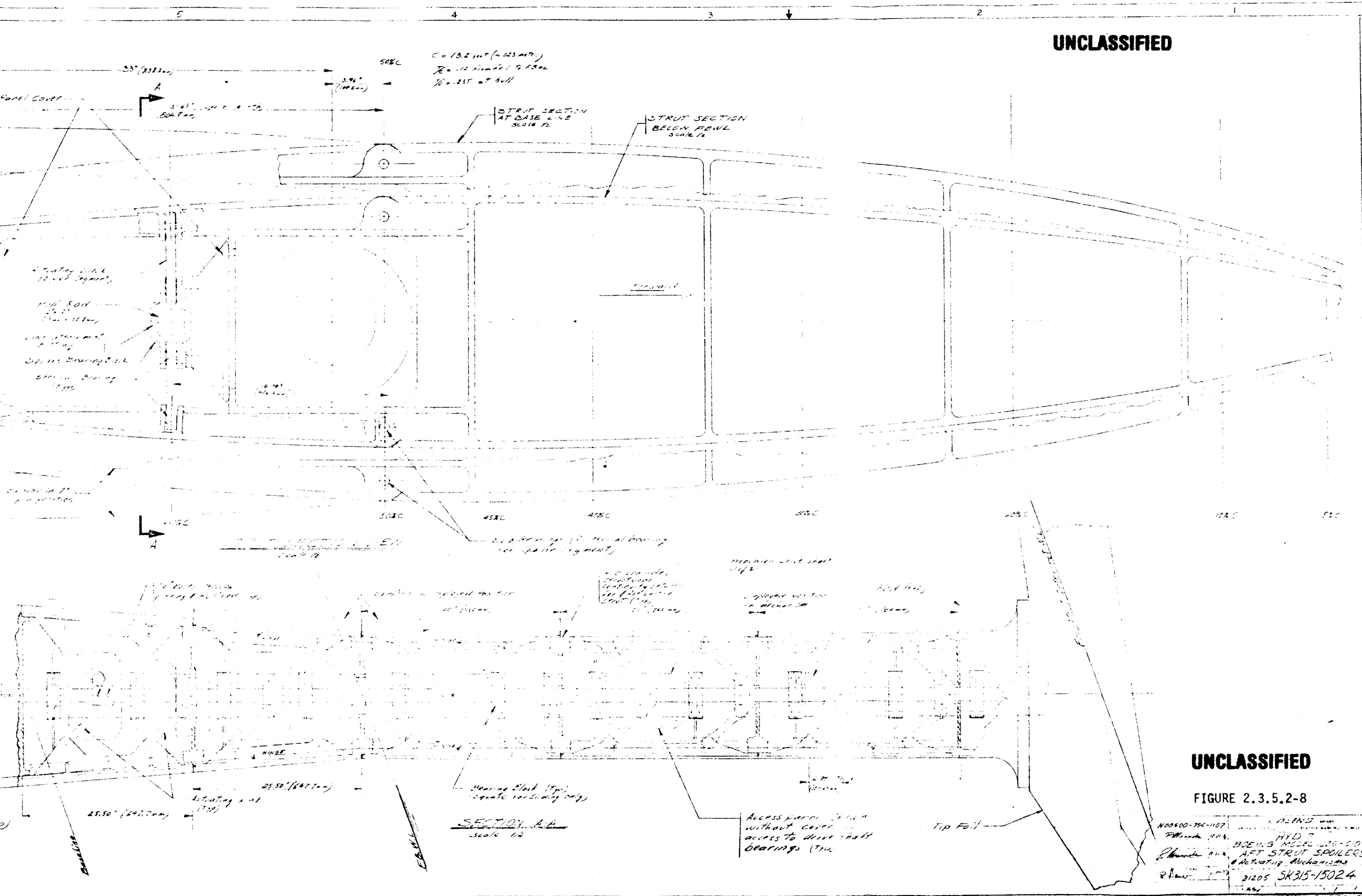
FIGURE 2.3.5.2-7

N00600-7?-C-0071	HYD-7
	Boeing Model 1026-01C
	AFT FOIL LOWER SPOILERS & Actuating Mechanisms
	81205 SK315-15021



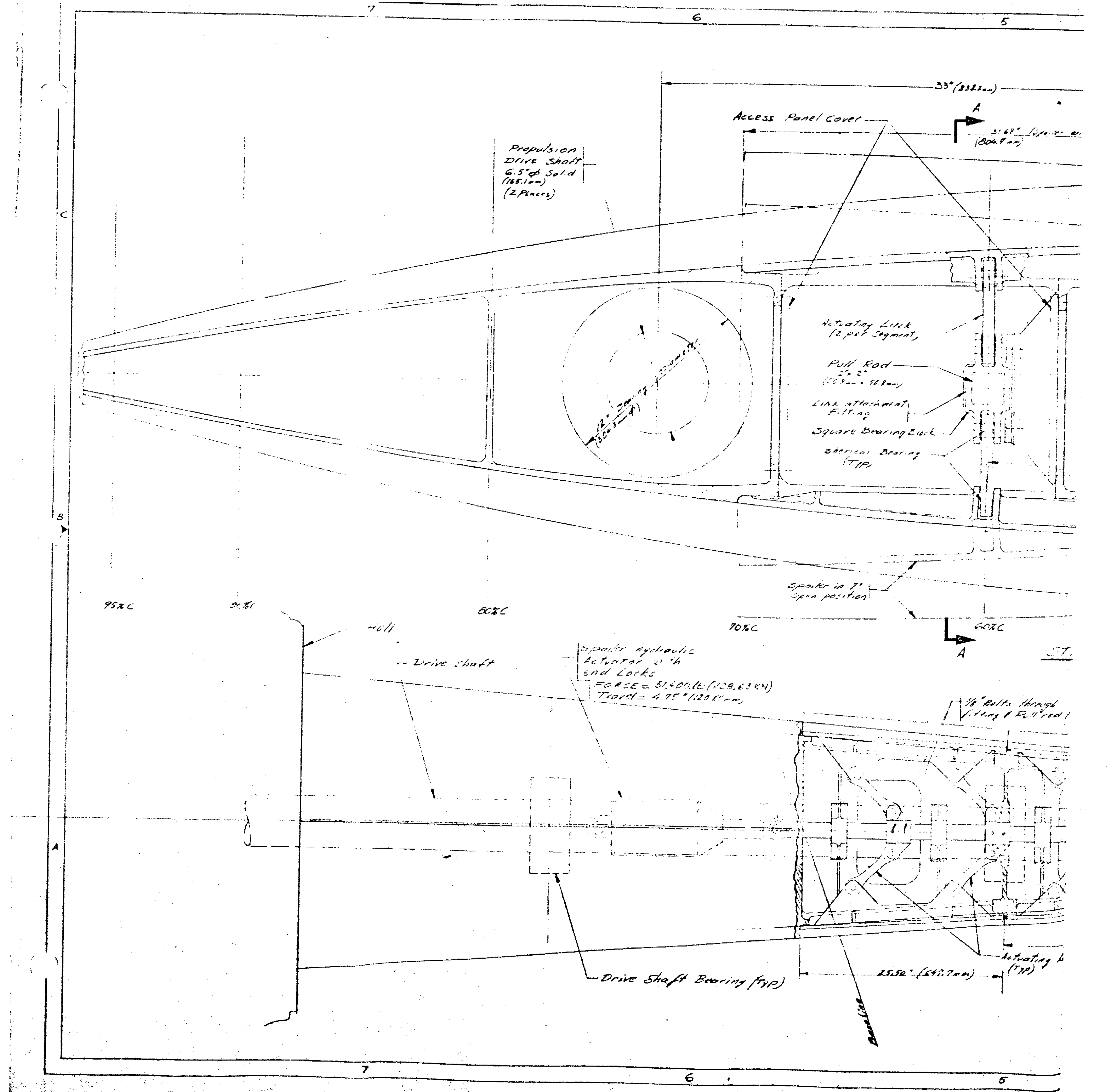
Shims
10.96"
(254mm)
60% c
Self
spher
10°
SECTION A-A
Scale Full
Lower Spoiler
Extended
Position
Self Lubricating
Journal bearing Assy
(Typ)
FLOODED
Space
38.00" (9652mm)
Spoiler Segment
7
6
5
B

UNCLASSIFIED



UNCLASSIFIED

FIGURE 2.3.5.2-8



Access Panel Cover
Prepulsion Drive Shaft 6.5"⌀ Solid (165.1mm) (2 Places)
Actuating Link (2 per Segment)
Pull Rod 2"x 2"
Link attachment Fitting
Square Bearing Block
Spherical Bearing (TYP)
Spoiler in 7° Open position
95%C
60%C
70%C
Drive Shaft
Spoiler Hydraulic Actuator with End Locks
FORCE = 51,400 LB (228.63 KN)
Travel = 4.95" (125.65mm)
Drive Shaft Bearing (TYP)
25.50" (647.7mm)
Actuating
Baseline

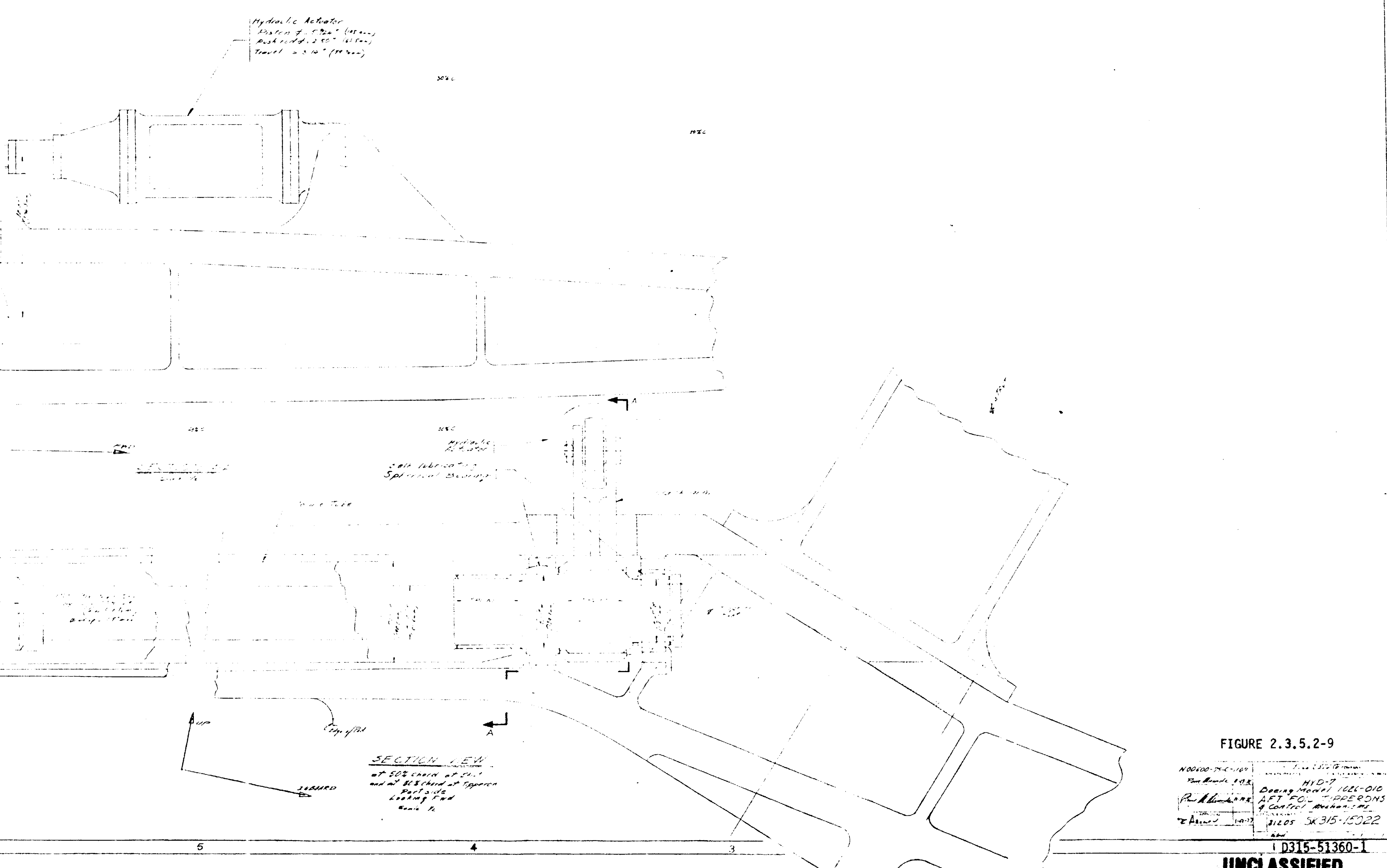
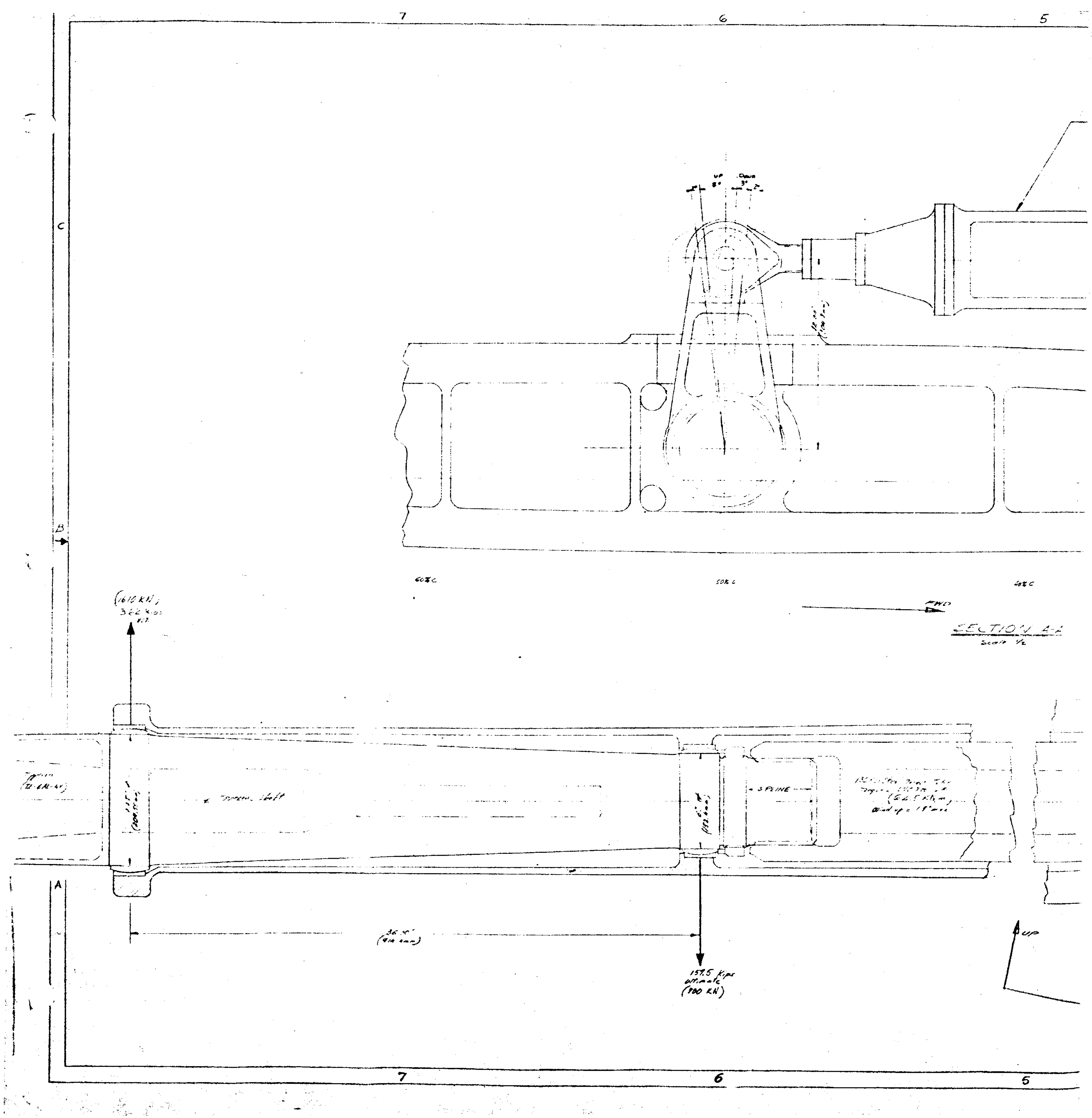


FIGURE 2.3.5.2-9



SECTION A-A
Scale 1/2
FWD
UP
SPLINE
(1610 kN)
362 Kips
157.5 Kips ultimate
(700 kN)
36.0"
(914 mm)