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Report 7588-950046

ANVCE LSES DESIGN SUMMARY REPORT
(FAR TERM) (U)

January 14, 1977

Prepared under Contract N00024-74-C-0922
CDRL D003
for the
Naval Sea Systems Command (PMS304)

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Bell Aerospace TEXTRON, New Orleans Operations
P.O. Box 29307, New Orleans, LA 70189

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REPORT DOCUMENTATION PAGE

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1. REPORT NUMBER: 7588-950046 ✓
2. GOVT ACCESSION NO.
3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle): ANVCE LSES Design Summary Report (Far Term) (U)
5. TYPE OF REPORT & PERIOD COVERED
6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s): Walter P. Haese
8. CONTRACT OR GRANT NUMBER(s): N00024-74-C-0922 ✓
9. PERFORMING ORGANIZATION NAME AND ADDRESS:

Bell Aerospace Textron
New Orleans Operations ✓
New Orleans, LA 70189

10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS:

CNO (OP-96)
Washington, D.C. 20350

12. REPORT DATE: 14 January 1977
13. NUMBER OF PAGES: 389
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office):

NAVSEASYSCOMD
Bethesda, MD 20084
ATTN: PMS 304

15. SECURITY CLASS. (of this report): [redacted]

15a. DECLASSIFICATION DOWNGRADING SCHEDULE: [redacted]

16. DISTRIBUTION STATEMENT (of this Report): [redacted]

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Advanced Naval Vehicle Concepts Evaluation
ANVCE
Parametrics and Point Designs
LSES (3000-ton)
Water Jets

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

In support of the ANVCE and in accordance with a Navy approved format, Bell submits the ANVCE Design Summary Report (Far Term). The report basically describes the Bell 1990 3000-ton LSES propelled by waterjets.

The report is presented in three major parts: (1) the ship principal characteristics, including general arrangement drawings; (2) ship performance, including thrust, drag, and power; maneuvering; range; stability; form; ride quality: and manning; and (3) ship subsystem

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-descriptions, including structures, propulsion, lift and ride control, electrical power, command and surveillance, auxiliary, outfit and furnishings, and combat systems. Special subjects include acoustic signature, h-engineering, and system safety. An LSES risk assessment is also provided. A propeller alternate is described in appendix C.

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6 Advanced Naval Vehicle Concepts Evaluation.

LSES (ANVCE) DESIGN SUMMARY REPORT (FAR TERM), (U) 8

January 14, 1977

Prepared under Contract 15 N00024-74-C-0922
CDRL D005
for the
Naval Sea Systems Command (PMS304)

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ABSTRACT

In support of the Advanced Naval Vehicles Concept Evaluation (ANVCE) and in accordance with a Navy-approved format, Bell submits the ANVCE Design Summary Report (Far Term). The report basically describes the Bell 1990 3000-ton LSES propelled by waterjets.

The report is presented in three major parts: (1) the ship principal characteristics, including general arrangement drawings; (2) ship performance, including thrust, drag, and power; maneuvering; range; stability; form; ride quality; and manning; and (3) ship subsystem descriptions, including structures, propulsion, lift and ride control, electrical power, command and surveillance, auxiliary, outfit and furnishings, and combat systems. Special subjects include acoustic signature, human engineering, and system safety. An LSES risk assessment is also provided. A propeller alternate is described in appendix C.

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(Submitted under separate cover)

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LIST OF ILLUSTRATIONS (Cont)

LIST OF ILLUSTRATIONS (Cont)

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1. INTRODUCTION

This report has been prepared by Bell Aerospace Textron, New Orleans Operations, in support of the Advanced Naval Vehicles Concept Evaulation (ANVCE) program in which the Navy is conducting an in-depth analysis of several advanced ship concepts. The program includes the development of two 3000-ton SES point designs, near term (1980) and far term (1990). The point designs will be utilized to establish cost effectiveness, comparisons, risk assessments, and military worth. This report presents the results of the far-term (1990) design. The near-term (1980) design is documented in Bell New Orleans report 7588-950047.

The 1990 ship was developed from the data and test base of the 1980 ship, with projections of technology and hardware improvements to 1987 that are realistic and intended to be on the conservative side, Complete documentation of the 1980 ship data and test base is available at PMS304.

The description is presented in three parts: First, the principal characteristics of the ship, which includes a list of the general arrangement drawings. Second, the ship performance, including thrust, drag, and power; maneuvering; range; weight; stability; form; ride quality; and manning, Third, a description of the ship subsystems, which covers structures; propulsion; lift and ride control; electrical; command, control, and communications; auxiliary systems; outfit and furnishings; combat systems; and the acoustic signature. Finally, an assessment of the overall risk of the LSES is included.

2. GENERAL DESCRIPTION OF SHIP

This section provides an overall description of the ship and its systems and a performance summary.

The ship described is a development of the near-term ship described in Bell New Orleans Report 7588-950047, and uses some of the basic subsystems of that ship. Also, the model test programs for the Bell LSES included testing at higher displacements, which provides credibility to the performance estimates.

The far-term ship shown in figure 2-l is a frigate-size Navy ship designed to use the surface effect principle to reduce hydrodynamic drag to achieve high speed in open-ocean operation. Full-load displacement is 3450 metric tons (3396 long tons).

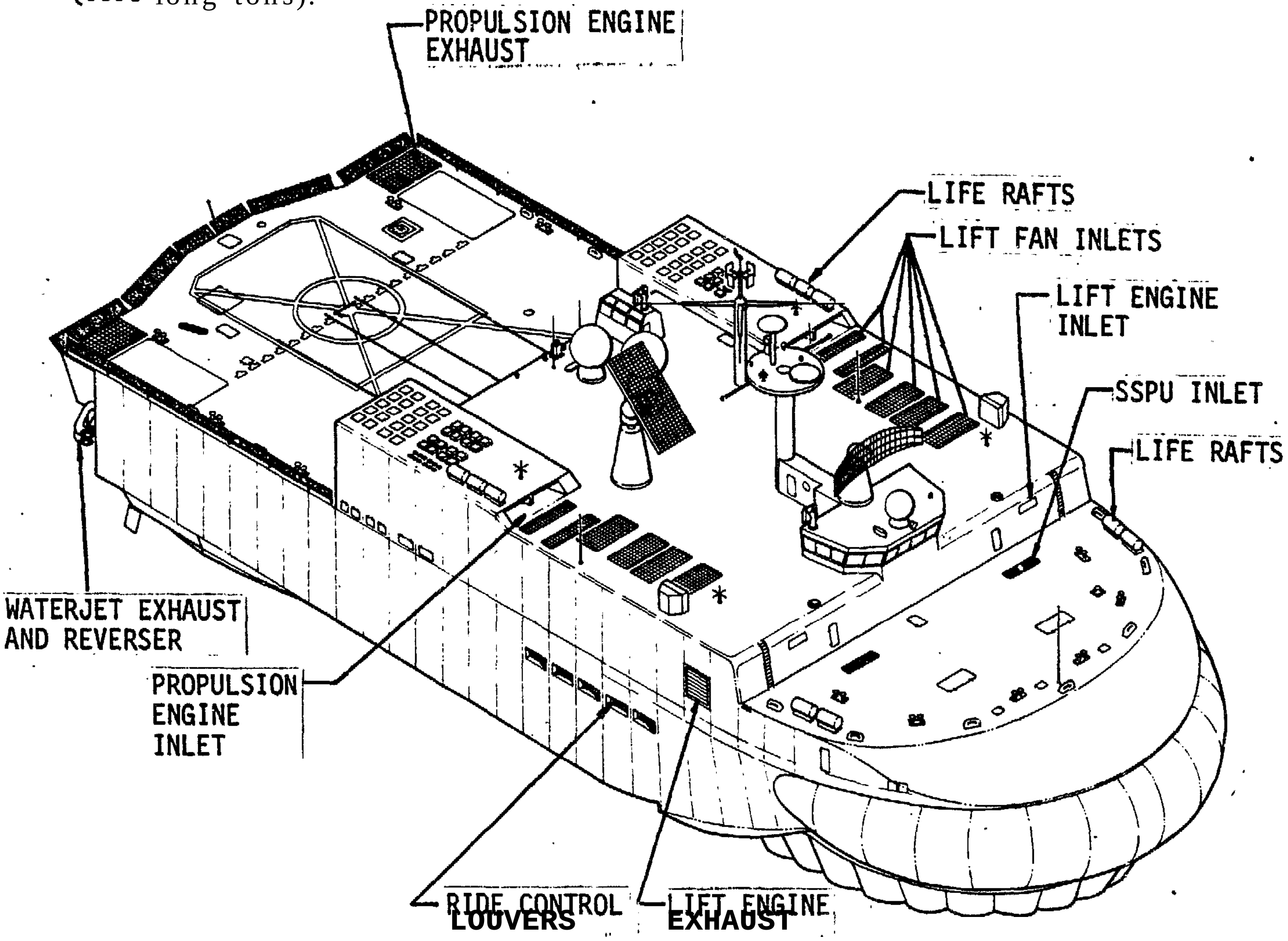

Figure 2-1 LSES CONFIGURATION

2.1 Principal Characteristics

2.1.1 Table of Characteristics

Table 2.1-I is a listing of the principal characteristics of the LSES ANVCE (Far Term).

2.1.2 General Arrangement Drawings

The following general arrangement drawings of the ship are included in the appendix of drawings.

DRAWING NO.	TITLE
AD-76-58 AD-76-59	Midship and Type Sections
AD-76-40	Outboard Profile Plan - Bow and Stern
AD-76-46	Inboard Profile
AD-76-47	Inboard Profile Section through Sidehull
AD-76-43	General Arrangement Main Deck
AD-76-42	General Arrangement Second Deck
AD-76-41	General Arrangement Third Deck
AD-76-44	General Arrangement - 01 Level
AD-76-45	General Arrangement - 02 Level & Rooftop
AD-76-48	Outboard Profile Plan - Bow & Stern (Propeller)

TABLE 2.1-I

LSES PRINCIPAL CHARACTERISTICS

OPERATION: Protect and defend against air, surface, or subsurface threat.

DIMENSIONS		
Length		273 ft
Beam	[on cushion)	107 ft
	(hard structure)	106 ft
Cushion Depth at CL		18 ft
Cushion Area		20,412 ft^2
Cushion Pressure		342 psf
POWER PLANTS		
Propulsion Engines		4 40,000 hp MCP marine gas turbines
Propulsors		4 advanced **waterjet** propulsors
Lift Engines		2 25,000 hp MCP marine gas turbines
Lift Fans		Cushion: 4 variable-geometry double-entry centrifugal Seals: **2 fixed-geometry single-entry** centrifugal
SYSTEMS		
Crew and Complement		16 **officers/11 CPOs/113** EM
Fuel Weight (lift, propulsion, auxiliary, helicopter)		1271.98 mt
Fuel Volume (lift, propulsion, auxiliary, helicopter)		1560.04 m^3
Electrical		3 **SSPUs** (2 **450-kw 400-Hz** and 1 **100-kw** 60-Hz generators each)

TABLE 2.1-I (Cont)

SYSTEMS (Cont)

- Hydraulic Requirements for Ship Systems
  - 3 SSPU systems (20 gpm/4000 psig each)
  - 4 propulsion systems (60 gpm/4000 psig each}
  - 4 ride control systems (120 gpm [2 60-gpm pumps]/4000 psig each)
- Steering and Reversing
  - 2 30-ft^2 rudders (±30° deflection]
  - 4 waterjet sleeves (±30° vertical & lateral deflection)
  - 4 thrust reversers (135° deflector per waterjet pair)
- Other Auxiliary Systems

Climate Control:	Requirements of OPNAVINST 9330.7A are met by electric air preheaters in ventilation intakes, heating elements in HCUs, and standard convection and duct insert heaters, cooling of occupied areas by 19 1.5- to 10-ton self-contained HCUs and forced ventilation of machinery and inhabited areas. Heat exchangers are located in main inlet/exhaust ducts for waste heat recovery.
Engine Start Pneumatics:	185 lb/min at 67 psia
Compressed Air:	2 55-cfm 100-psig air compressors. A 3000-psig air system charges torpedo launchers.
Seawater:	4 400-gpm 400-psig (reduced to 150 psig) from waterjet propulsors 3 600-pgm 150-psig firemain pumps
Freshwater:	System meets requirements of OPNAVINST 9330.7A for 140 accommodations. 2 100-gal/hr distillers 2 2500-gal tanks [brominated water) 2 400-gal tanks (distilled water)

TABLE 2.1-I (Cont)

SYSTEMS (Cont)

Other Auxiliary Systems (Cont)

Lubrication:

Propulsion and lift engines (6): 18-gpm supply; 54 gpm scavenge
SSPU engines (3): (sized by vendor]
SSPU gearbox (3) : 11-gpm supply; 32-gpm scavenge
Propulsor gearbox (4) : 165-gpm supply; 233-gpm scavenge
Cushion fan bearings (port or stbd): 8-gpm supply
Seal fan bearings (port or stbd]: 4-gpm supply
Accessory gearbox (port or stbd): 2.5-gpm supply; 6.25-gpm scavenge
Main gearbox (port) : 290-gpm supply; 725-gpm scavenge
Main gearbox (stbd) : 217-gpm supply; 543-gpm scavenge

Fire Extinguishing:

Firemain:	Saltwater is provided by 3 electric-driven centrifugal pumps (550 gpm at 150 psig each) and by tap-off from the 4 waterjet pumps (400 gpm at 400 psig, reduced to 150 psig, each).
Sprinkler system:	0.8 g-pm of saltwater spray per ft^2 of magazine area
Halon 1301:	42 45-pound Halon 1301 containers with suitable detectors, pipes, and valves provide two-shot capability in all high fire risk areas.
High expansion foam:	3 5000-cfm and 4 2000-cfm foam generators are supplied from 2 40-gal foam proportioner tanks to provide backup to Halon 1301 in most high fire risk areas.
Aqueous film-forming foam sprinklers :	AFFF sprinklers are located in hangar area.
AFFF fire stations:	7 AFFF stations with seawater as backup are located on the main deck and 01 level.
Portable extinguishers:	Portable Halon 1211, CO_2, or potassium bicarbonate (Purple K) extinguishers with backup from 7 seawater fire stations on the second deck protect all other areas.

TABLE 2.1-I (Cont)

SYSTEMS (Cont)

Other Auxiliary Systems (Cont)

Underway Replenishment:	Capability is provided for refueling at 3000 gpm and 40 psig through a standard 7-inch connection and for vertical replenishment and ship to ship.
Anchoring, Mooring , and Towing :	Adequate bitts and chocks for 8 breast lines, 3 spring lines forward and 3 aft; towing with lo-inch nylon line; and a 3000-pound fluted anchor with 1126 feet of 11-inch nylon line and an 11-foot 1-3/8-inch chain,
Pollution Control System:	Requirements of OPNAVINST 6249.31) are met. Waste oil pollution is controlled by the oil and water separator plus 14 submersible bilge pumps and a waste oil holding tank. An evaporative sewage waste system is used. Noise and air pollution abatement systems are also included.
Fuel Distribution:	A maximum of 1392 mt of usable fuel could be contained in 4 integral transfer tanks, 2 main engine tanks, and 2 helicopter tanks (1271.98 tons are loaded in the baseline case). Ship attitude trim is accomplished by fuel transfer.

Special Systems

O_2/N_2:	Where required, 0, and N_2 are supplied from storage systems.

WEIGHTS

Full Load Weight (Displacement]	**3450** mt
Empty Weight	1989.91 mt
Fuel (lift, propulsion, auxiliary, helicopter).	1271.98 mt
Other Load	188.1 mt

TABLE 2.1-I (Cont)

(C)MOBILITY PERFORMANCE SUMMARY*

Maximum Speed (calm water, MCP)	97.3 kt (180.2 km/hr)
Maximum Speed (1.4-m significant wave height, MCP)	83.8 kt (155.2 km/hr)
Maximum Speed (4.57-m significant wave height, MCP)	33.9 kt (62.8 km/hr)
Hump Margin (in 1.0-m significant waves with MIP)	25%
Average Best Range Speed (calm water)**	89.1 kt (165.0 km/hr)
Average Best Range Speed [at 1.4-m significant wave height)**	79.6 kt (147.4 km/hr)
Time to Accelerate to V_{max} (nominal lift flow, SS calm, MIP)	299 secs
Time to Decelerate from V_{max}*** (nominal lift flow, SS calm, reverse thrust at MIP)	60 secs
Stopping Distance from V_{max}*** (nominal lift flow, SS calm, reverse thrust at MIP)	3037 ft (926 m)
Turn Radius at 70-kt Entry Speed (SS calm)	3200 ft (1.05 km)
Range (SS calm)	4120 nmi (7630 km)
Range (1.4-m significant waves)	3570 nmi (6612 km)
Endurance (SS calm)	46.2 hr
Endurance (1.0-m significant waves]	44.8 hr

*4 40,000 hp propulsion turbines, full load displacement

**Average over entire mission; cruise speed at initial weight ≤ maximum speed.

***Assumes optimum trim and nominal lift power (lift power cut at low speeds). Performance can be improved by reducing lift power at high speeds.

TABLE 2.1-I **(Cont)**

(C)COMBAT SYSTEM

	Asw	AAW	SUW
Surveillance/ Detection	Deployed Linear Array, Towed Array	Advanced Dual Band 2D Radar, Rotating Phased Array Passive ECM	APS 114, ASMD EW MKXY
Localization	APRAPS, ERAPS, Sonobuoys, Mini RPV	Adv ALTWSFCS, Mk 74, MOD XX FCS	Adv ALTWSFCS, Mk 74 MOD XX
Identification/ Classification	Helo Data Processor, ASW Electronics	AN/UPX 25, AN/UPX 28	AN/UPX-25, AN/UPX-28
Fire Control	ASW Fire Control Mini RPV	Adv ALTWSFCS, Mk 74, MOD XX FCS	Adv ALTWSFCS, Mk 74 MOD XX, LAMPS, Mini RPV
Armament	MK 48 Torpedo, ALWT	AMRM, ASDM	Harpoon, ASMD
Aircraft	LAMPS (2)		LAMPS (2)

2.2 Vehicle Performance

The various *curves* that describe the performance of the ship are presented in this section. Unless otherwise stated, all performance data presented assumes an ambient temperature of 80 F and head sea operation, with headwinds corresponding to the sea state,

2.2.1 Thrust, Drag, and Power

The ship thrust and drag characteristics, together with corresponding power requirements, are summarized herein.

The point design considered here was defined on the basis of parametric studies described in detail in appendix A of this report.

The drag of this ship at various weights and speeds, and in various sea states, was estimated using the Boll New Orleans performance math model, These drag values formed the basis of the performance predictions.

Figure 2.2.1-l shows ship drag as a function of speed for a range of operating sea states*, *at* 80°F ambient temperature, for the ship at its full-load displacement (FLD) of 3450 metric tons (3396 long tons). Thrust lines have been superimposed corresponding to waterjet thrust derived from four propulsion engines operating at both maximum continuous power (MCP] and maximum intermittent power (MIP) (40,000 hp and 46,000 hp, respectively). Intersections of the thrust and drag curves establish maximum operating speeds for the chosen conditions,

Nominal lift flow has been used for all performance calculations. 2KSES and LSES *test* data indicates that increased lift flow can give some reduction in high-speed drag, and therefore higher maximum continuous speed, but this has not been considered here.

---

*Sea state definitions are consistent with ANVCE Working Paper WP-010, as follows;

Sea State	Significant Wave Height ft	m	Corresponding Headwind Knots
0	0	0	0
3	4.6	1.4	10
4	6.9	2.1	16
5	10	3.05	26
6	15	4.57	38

These values have been used for all calculations presented here, unless otherwise stated.

Thrust margin over drag in sea state 3 at FLD is seen from figure 2.2.1-1 to be about 25 percent.

For low-speed operation (in the vicinity of secondary hump and below), it has been assumed that the ship operates in the partial-cushion mode as described earlier for the 2KSES and LSES. For these it was determined that reduced air flow to bow and stern seals led to increased sidehull immersion, reduced cushion pressure) and as a result reduced drag through secondary hump.

Figure 2.2.1-2 presents a breakdown of the total ship drag to its separate components, as a function of speed, for the ship at FLD in sea state 3. Figure 2.2.1-3 shows the total power required for the same conditions, broken down into lift and propulsion components.

The drag and thrust of figure 2.2.1-1 have been nondimensionalized by dividing them by ship weight, and the results presented in figure 2.2.1-4. The resultant curves cannot be used to estimate the drag at weights other than FLD as total ship drag does not vary directly with weight. Figure 2.2.1-5 shows similar data corresponding to an ambient temperature of 59°F. The thrust curves in figure 2.2.1-5 assume a 2-percent increase in power associated with the reduction in ambient temperature from 80° to 59°F. This corresponds to maintaining a constant gas generator speed, in which case power is inversely proportional to the square root of the absolute temperature,

Figure 2.2.1-6 presents overall propulsive coefficient as a function of speed for various propulsion engine power levels up to the NIP rating (46,000 hp) , Overall propulsive coefficient (OPC) is defined as

$$\mathrm{OPC} = \frac{T_N \times V_\infty}{BHP_p \times 550}$$

where

T_N = Net thrust (lb) = ship drag as shown in figure 2.2.1-1

V_∞ = Ship speed (ft/sec)

BHP_p = Total propulsion engine power at output shaft (hp), Propulsive thrust values shown in this report, and as used to compute OPC, include a deduction for any contributions to ship drag caused by the presence of the propulsion system, including the modification to hull lines required to accommodate the propulsion system. Thus, ship drag figures quoted herein are representative of a prismatic **sidehull** with no propulsor fairing. This approach is identical to the approach labeled *prismatic propulsive coefficient* in the Navy-supplied format for the LSES Proposal Performance Data Summary, appendix A to RFP N00024-76-R-5342 (s) , The Navy format recommended the *use* of an alternate accounting system, denoted *overall propulsive coefficient,* in which the drag due to modifications to hull lines was included in ship drag and only the drag of the open inlet and any appendages below the keel was deducted from thrust. The former accounting system has been used here, however, to facilitate comparison between waterjet and propeller propulsion systems. The distinction is somewhat academic in the case of waterjets, however, since the waterjet inlet fairing has been found to not have a significant effect on ship drag at most speeds,

Transport efficiency is presented in figure 2.2.1-7 as a function of ship speed and sea state, for the ship at FLD. Transport efficiency is defined as

$$\frac{\text{Ship Weight (lb)} \times \text{Speed (ft/sec)}}{\text{Total power (lift} + \text{propulsion} \pm \text{auxiliary) (ft-lb/sec)}}$$

Sea state/speed envelopes for continuous operation of the ship at full-load displacement are presented in figure 2.2.1-8. Curves are shown for both hullborne and cushionborne operation. Cushionborne performance is shown for operation in head seas with no rind and RCS system inoperative, and for head sea operation with corresponding head winds with RCS both on and off. (With RCS off, nominal lift flow is assumed.)

It will be noted that the effect of head winds is to reduce the maximum speed. This reduction is generally small, except in the highest sea states where the additional drag results in a sudden drop in speed to subhump.

The effect of RCS operation is also to reduce performance in the high sea states. 2KSES and LSES work, however, has indicated that significant increases in performance can be obtained for operation in other than head sea conditions.

The figure also includes estimates for two ride quality limit curves for the 4-hour exposure criteria. The upper curve is for RCS on, the lower for RCS off. These indicate that the 1990 design may be ride-limited for sea states greater than 6 and speeds less than about 57 knots.

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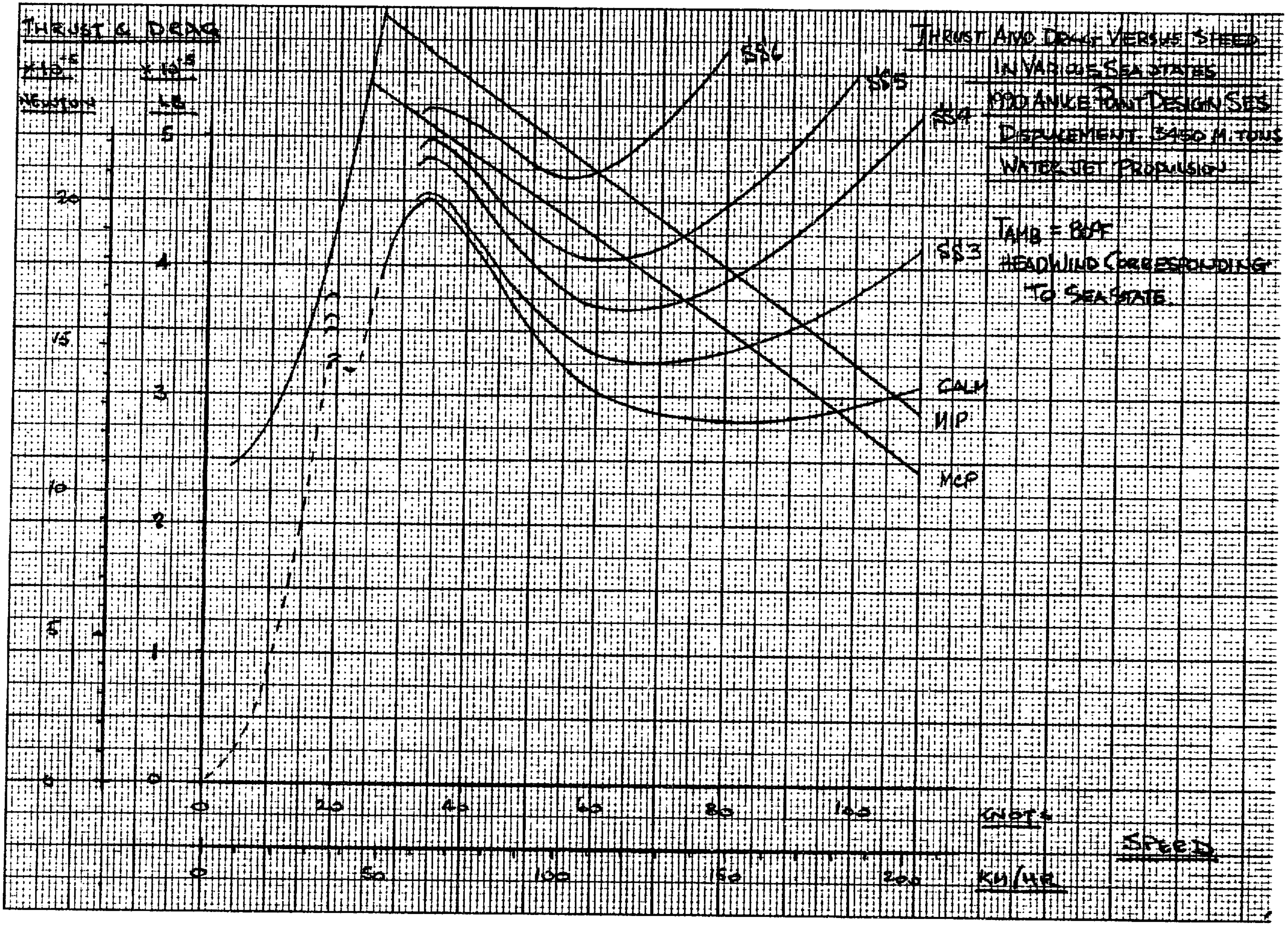

Figure 2.2.1-1 THRUST AND DRAG VERSUS SPEED IN VARIOUS SEA STATES

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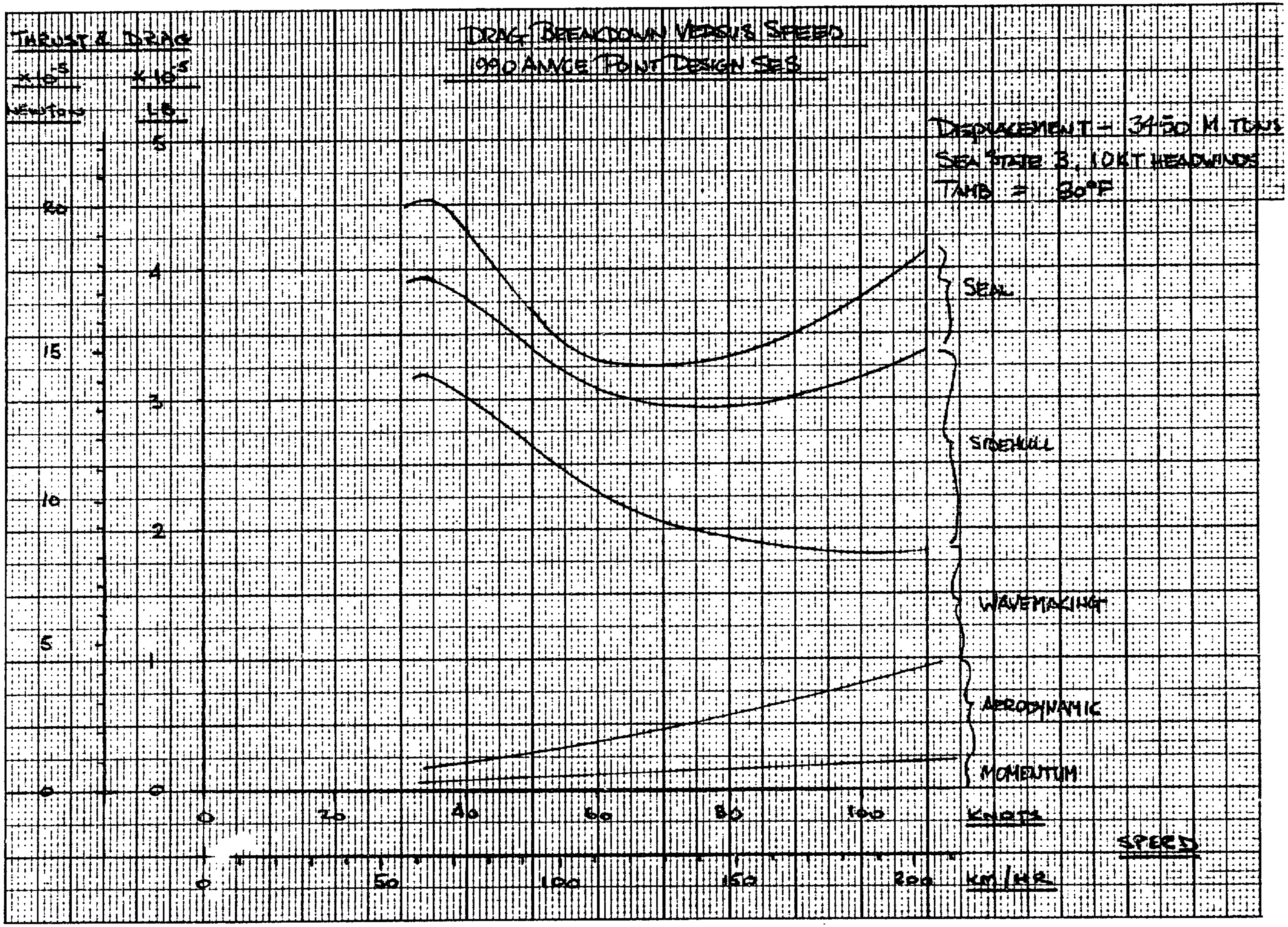

Figure 2,2.1-2 DRAG BREAKDOWN VERSUS SPEED

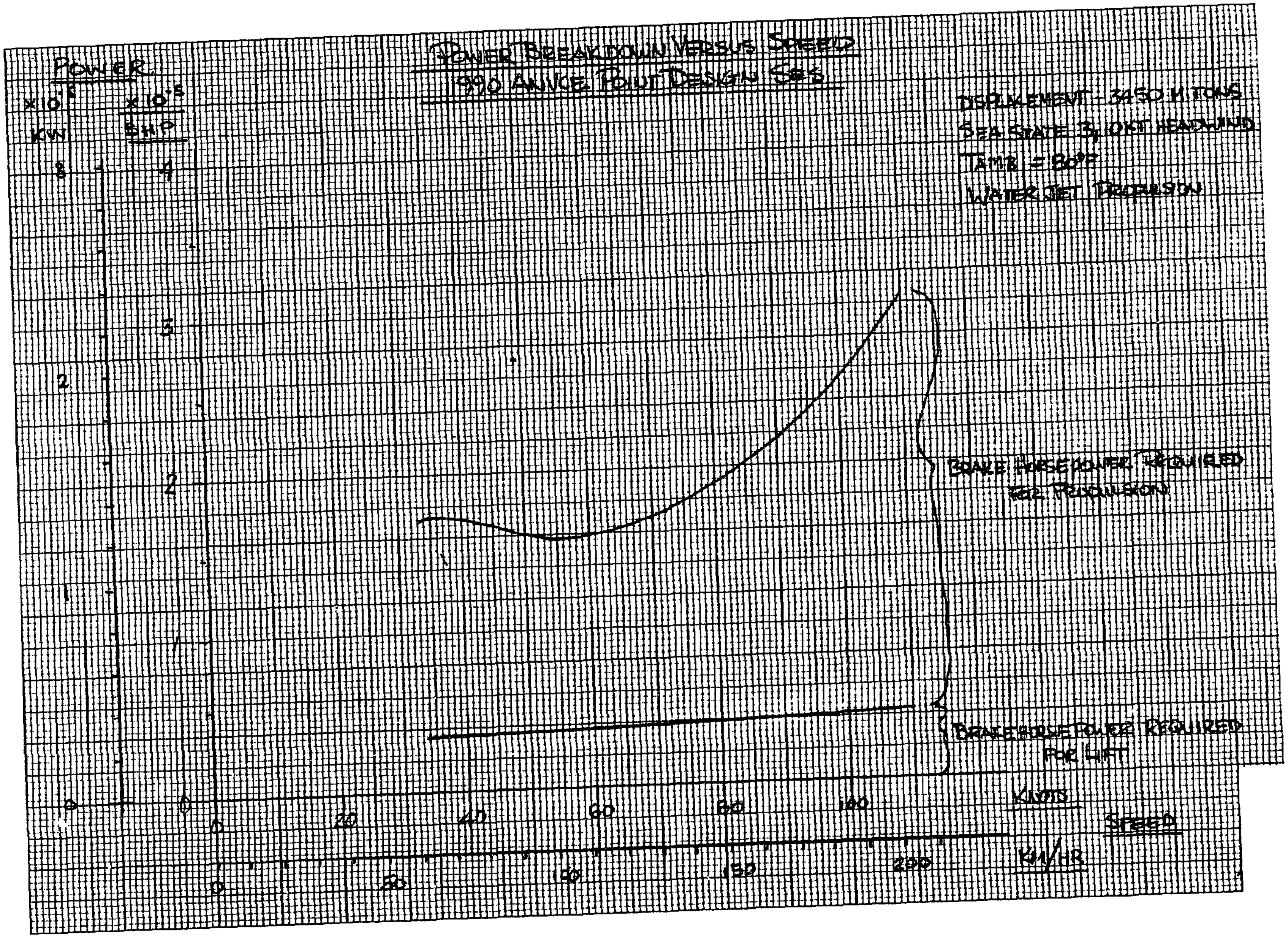

Figure 2.2.1-3 POWER BREAKDOWN VERSUS SPEED

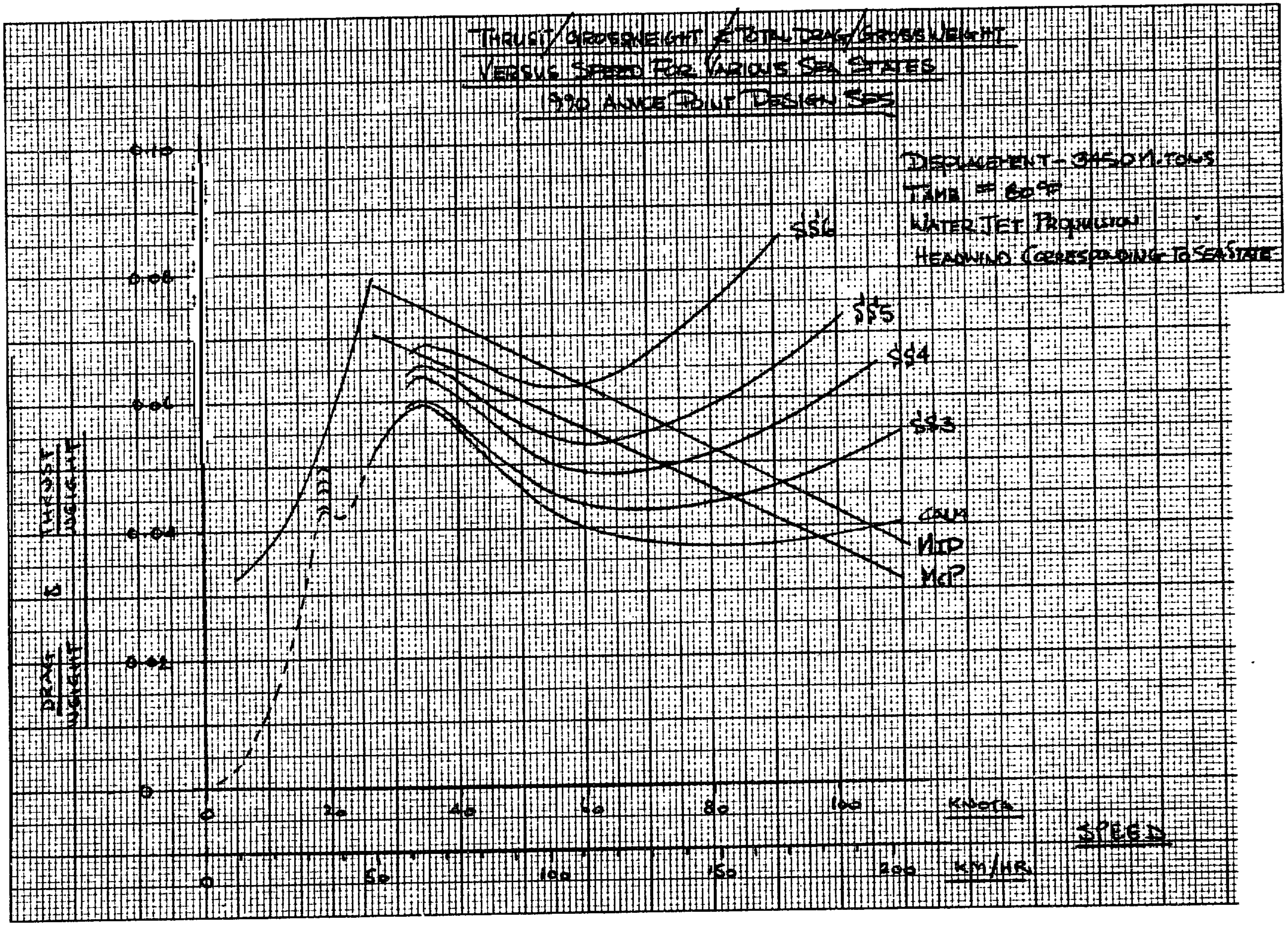

Figure 2.2.1-4 THRUST/GROSS WEIGHT AND TOTAL DRAG/GROSS WEIGHT VERSUS SPEED FOR VARIOUS SEA STATES

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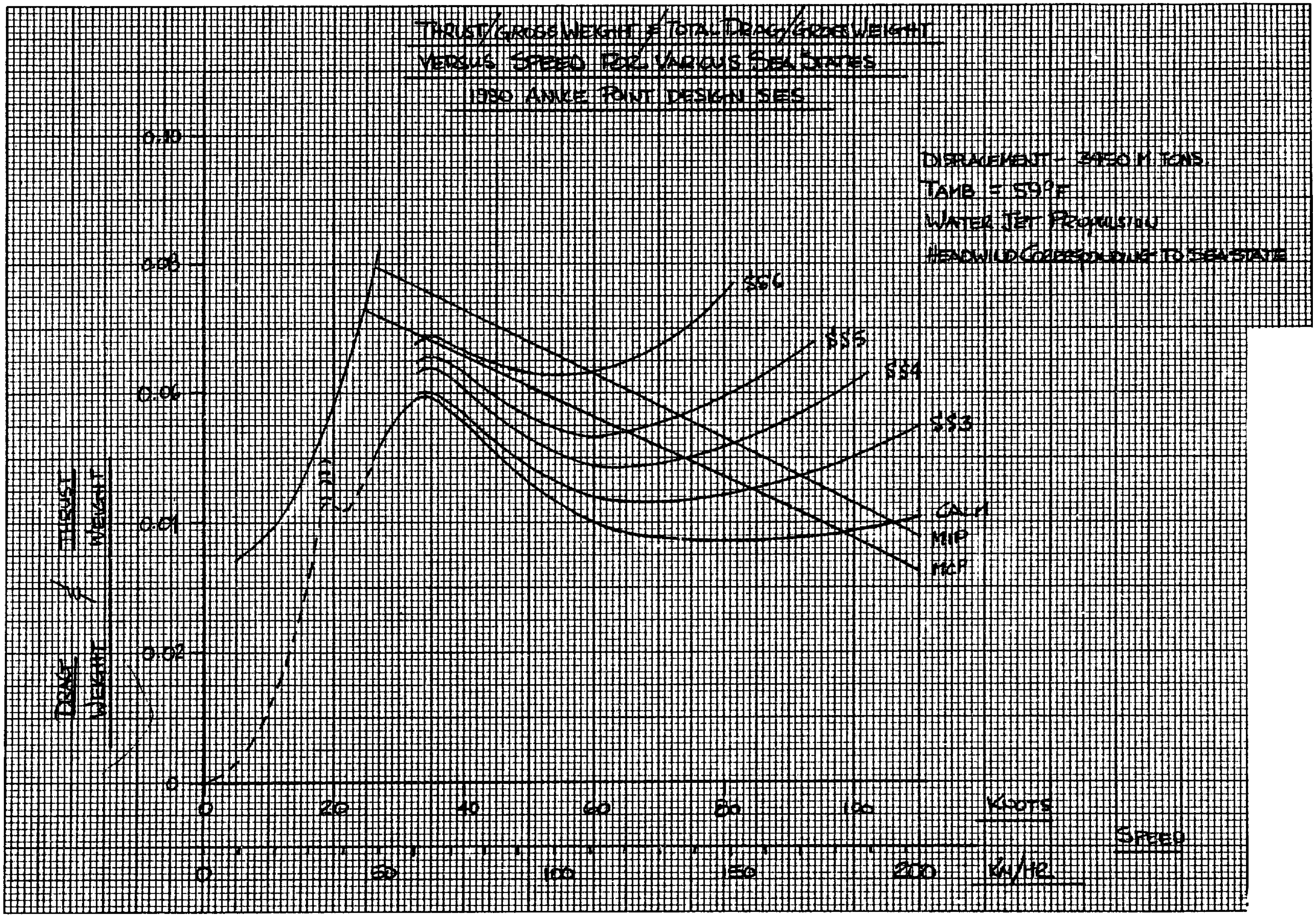

Figure 2.2.1-5 THRUST/GROSS WEIGHT AND TOTAL DRAG/GROSS WEIGHT VERSUS SPEED FOR VARIOUS SEA STATES

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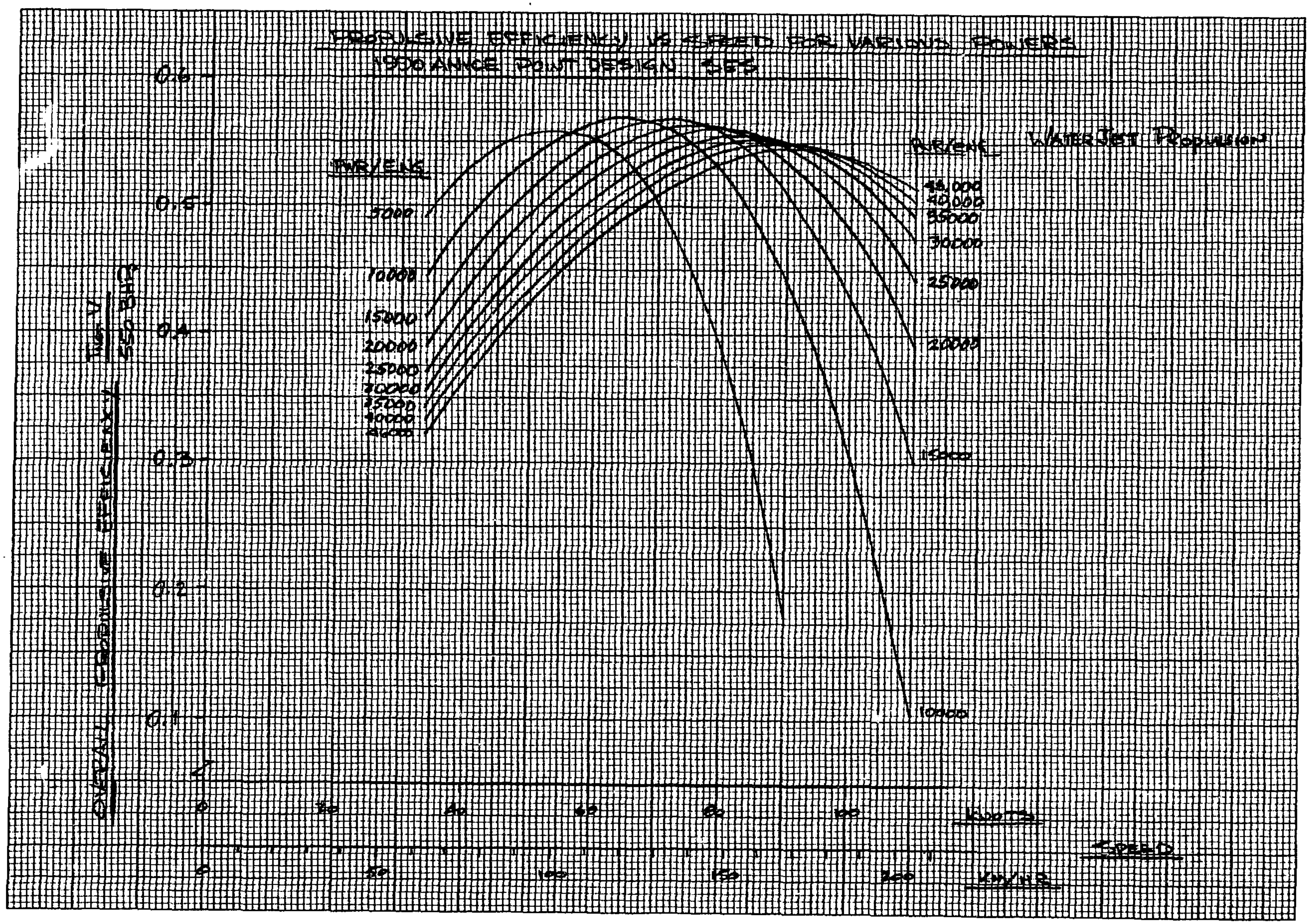

Figure 2.2.1-6 PROPULSIVE EFFICIENCY VERSUS SPEED FOR VARIOUS PROPULSION ENGINE POWER LEVELS

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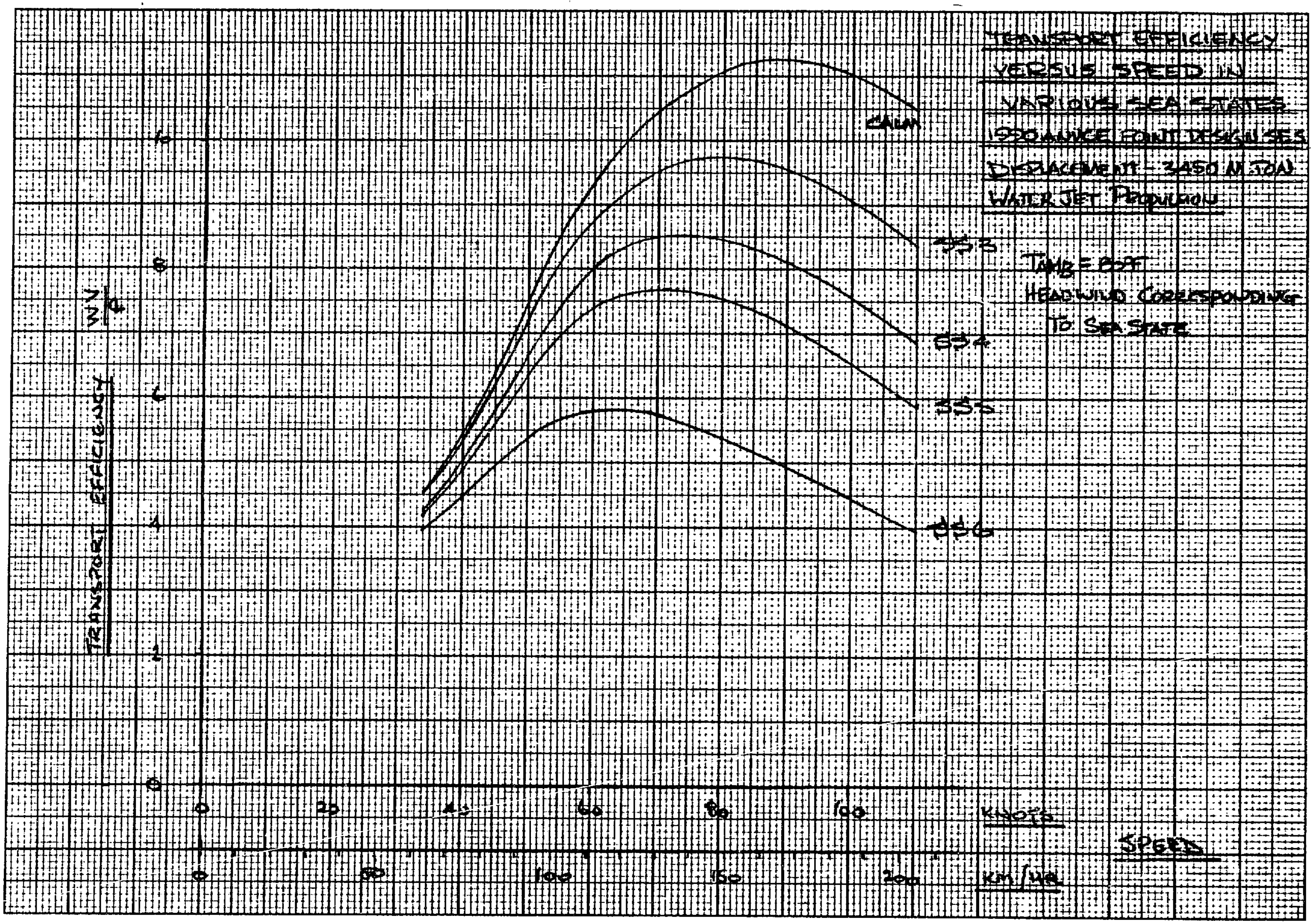


Figure 2.2.1-7 TRANSPORT EFFICIENCY VERSUS SPEED IN VARIOUS SEA STATES

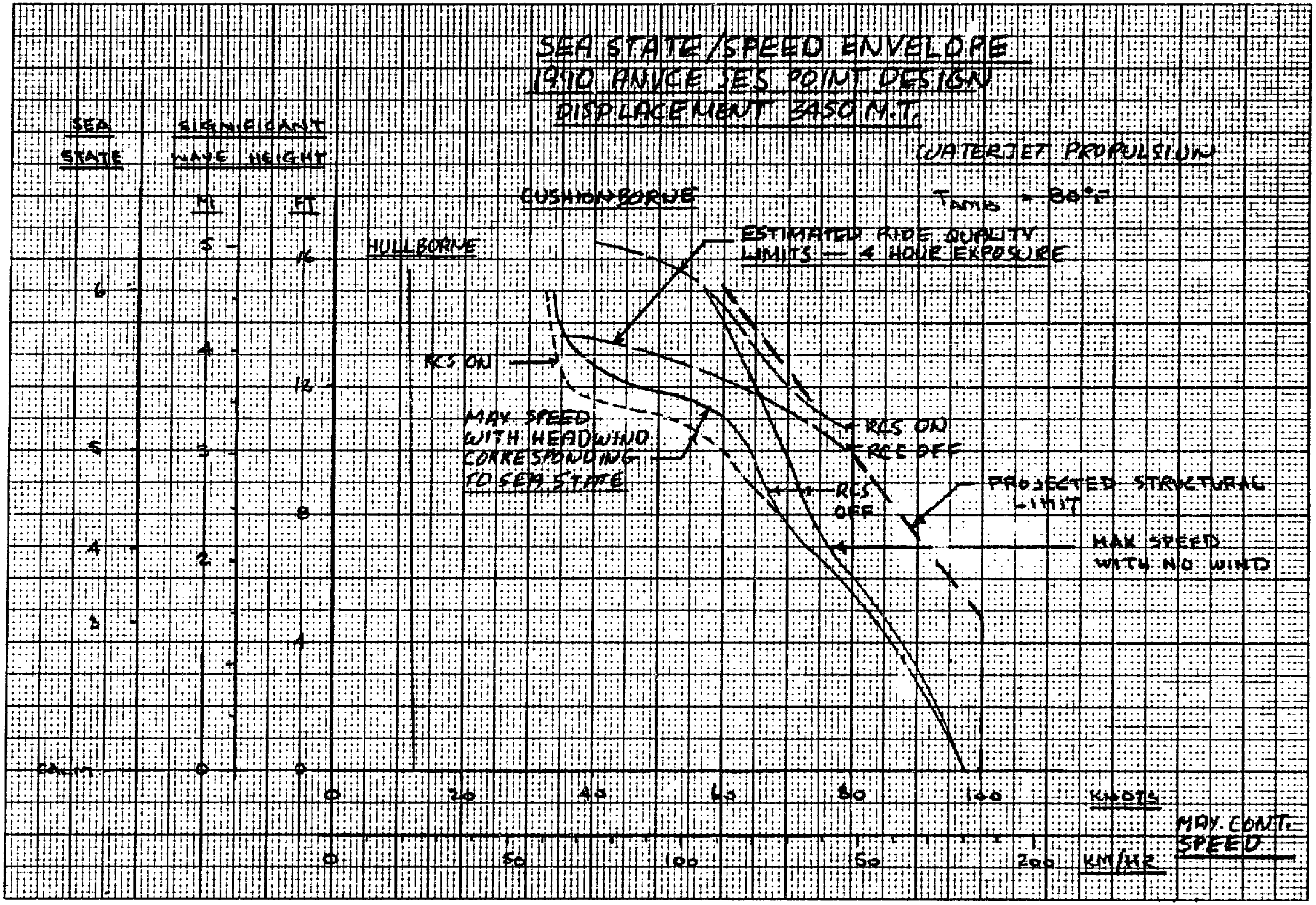


Figure 2.2.1-8 SEA STATE/SPEED ENVELOPE

2.2.2 Maneuvering

2.2.2.1 Introduction

This section presents the maneuvering characteristics of the 1990 LSES during low-speed operation, both cushionborne and hullborne, and during high-speed operation. The predictions have been made through the use of digital computer simulations of the ship, updated from the 2KSES to represent the baseline 1990 LSES full-load displacement (FLD) of 3445 long tons (3500 metric tons). Two different programs were employed for the low-speed and high-speed maneuvering predictions:

a. A 3-degree-of-freedom program, representing surge, sway, and yaw motion during low speed (less than 20 knots) (37 km/hr) operation on- and off-cushion. The simulation was similar to the 1980 LSES except that the rudder area was set to zero to simulate a swing rudder in the up position. The effect of added mass has been included in the equations of motion. The added mass terms are proportional to the square of the draft. Thus, hullborne values are much more significant than cushionborne values. Even hullborne, however, the lateral added mass of 165,000 slugs is the only term of any great significance. Hullborne, the longitudinal, lateral, and yaw added mass terms are 0.7, 69, and 14 percent of those of the ship alone.

b. A 6-degree-of-freedom program, representing all rotational and translational degrees of freedom during on-cushion, above-hump operation.

2.2.2.2 Low-Speed Maneuvering Capability

The low-speed turning capability of the 1990 LSES is summarized in figures 2.2.2-l through 2.2.2-4. Figure 2.2.2-l shows the final steady-state values of speed loss, yaw rate, and sideslip angle, together with tactical diameter and advance distance as functions of control deflection for initial speeds of 5 and 19.4 knots (9.3 and 35.9 km/hr) respectively, with the ship on full cushion. In all cases, the turns were started with the ship on a straight track, all controls centered, and propulsive power corresponded to the initial speed. At the initiation of the maneuver, the waterjet steering sleeves were deflected at their design rate of 6 deg/sec to the commanded position, and propulsion power was left unaltered.

At both speeds, the 1500-yard (1372 m) tactical diameter required by the TLR can be achieved with less than full control deflection. Corresponding information for the ship on partial cushion is shown in figure 2.2.2-2, and again the TLR specification can be readily achieved. Hullborne turning from initial speeds of 5 and 10 knots (9.2 and 18.5 km/hr) is depicted in figure 2.2.2-3. In this case the TLR can be easily exceeded using waterjet deflection.

Calculations of the capability of the ship to turn on its own axis from a condition of dead-in-the-water indicate a capability to change heading 180 degrees at zero forward speed in less than half a minute. In a situation where sideforce alone is desired as, for instance, moving away from a dock against an adverse wind, the ride control system (RCS) doors on one side (see figure 2.2.2-4) can be opened to generate a thrust of up to 40,000 pounds (178,000 N). This is sufficient to overcome a current of 2.5 knots (4.6 km/hr) or a wind of 27 knots (50 km/hr) from the worst angle.

Low-speed maneuvering analysis showed that the LSES has adequate ship heading control during low-speed forward and astern operation.

2.2.2.3 High-Speed Maneuvering

The LSES derives its primary directional control forces from swinging of one rudder and/or deflection of the four waterjet thrust vectoring sleeves. Since the rudders are more effective than the waterjet sleeves and produce lower drag than the equivalent thrust loss from the waterjets, the rudders are intended as the primary means of high-speed directional control. It may be noted that the recent test operation of the SES-100B with the fixed, canted fins removed has demonstrated excellent maneuverability and handling qualities of the basic SES configuration in this respect. The rudders are still effective at sub-hump speeds although the waterjet thrust vectoring is more powerful. Accordingly, at speeds up to main hump, it is intended that the waterjet system be used as the primary directional control. The transition between the low-speed mode and high-speed mode will normally be made between 30 and 40 knots (55.6 and 74.1 km/hr) though either system will be available at any time in the event of a failure of the other.

The maneuvering capabilities of the ship using one swing rudder control were determined. From an initial speed of 80 knots at approximately the optimum trim angle of 0.9 degrees for the ship at FLD, the TLR specification of a 5000-yard (4572 m) tactical diameter can be realized with a rudder swing angle 7.4 degrees. Due to the sideslip and turn rate of the ship, the rudder angle of attack is less than 3 degrees under those conditions, and is well under the ventilation angle. In reality, the onset of rudder ventilation has not presented any handling problems during tight turns on the SES-100B. Figure 2.2.2-5 presents this information.

Corresponding information was generated for initial speeds of 40, 50, 60, and 80 knots (74, 92.6, 111.1, and 148.1 km/hr). In all cases, the 5000-yard (4572 m) tactical diameter can be achieved without rudder ventilation, and even smaller turn radii are possible with larger rudder swing angles.

The maneuvering capabilities of the ship using waterjet steering sleeve deflection only were also determined. The swing rudders are in the up position, and power is held constant during the entire turning maneuver. With both swing rudders in the up position, the ship directional stability is reduced and the waterjets control yaw moment is able to trim the ship at sideslip and roll angles required to turn the ship rapidly. In the event of a system failure during the turning maneuver, both swing rudders can be deployed to stabilize the ship.

Figure 2.2.2-6 shows the 1990 LSES turning characteristics versus waterjet steering sleeve deflection from an initial speed of 80 knots. The TLR specification of a 5,000-yard (4,572 m) tactical diameter can be obtained with a deflection of 18.5 degrees. The ship decelerates to 56 knots with a yaw rate of 0.76 deg/sec and pitch, roll, and sideslip angles of 0.8°, 3.6°, and 6.0°, respectively.

Corresponding information was generated for initial speeds of 40, 50, 60, and 80 knots (74, 92.6, 111.1, and 148.1 km/hr). Figure 2.2.2-7 shows the steady-state turning characteristics required to meet the TLR. Note that larger waterjet deflections, with corresponding larger roll attitudes and yaw rates, are required as the initial speed increases.

Typical tracks during high-speed turns presented in figure 2.2.2-8 show the advance and transfer distances following various waterjet sleeve deflections from an initial speed of 80 knots (148.1 km/hr).

2.2.2.4 Acceleration and Deceleration

Figure 2.2.2-9 shows predicted acceleration characteristics of the ship at full-load displacement (3450 metric tons, 3396 long tons) in calm water. Maximum intermittent power (MIP) is assumed for these calculations except at low speeds where the power applied to the propulsors is limited to avoid cavitation damage. Lift power is assumed to be nominal except at low speeds where partial cushion operation is assumed.

Speed and distance covered, as functions of elapsed time, are presented in figure 2.2.2-10 for deceleration maneuvers. The ship is assumed to be traveling in calm water at maximum continuous speed, on nominal lift power; the propulsors are put in full reverse thrust and power is increased to MIP when the maneuver starts. No allowance is made for control activation time. While such time might result in increased stopping time, a reduction in the time, not examined here,, can readily be achieved by a reduction in lift power during the maneuver, which would give a large drag increase.

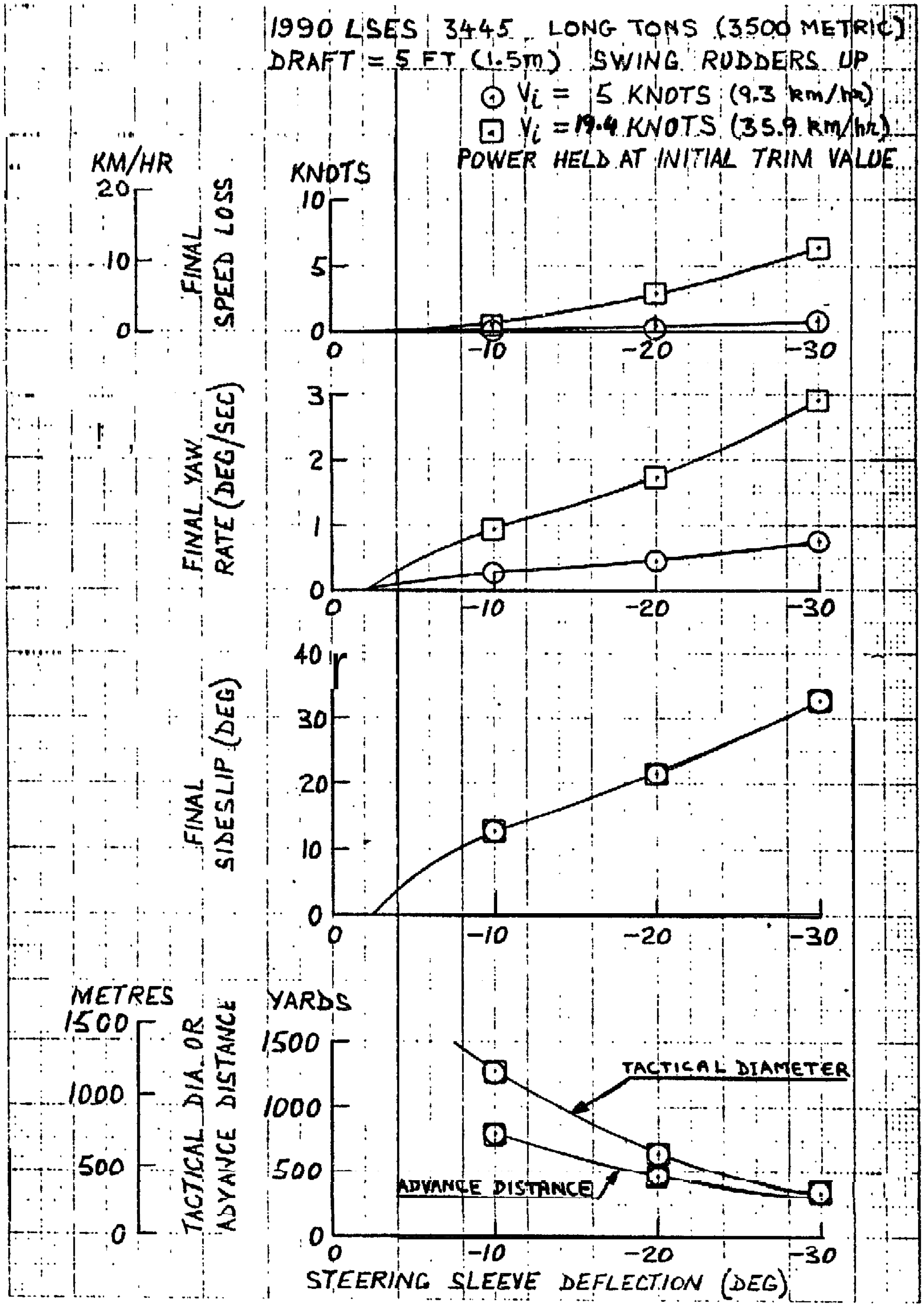


Figure 2.2.2-1 FULL-CUSHION LOW-SPEED TURNING PERFORMANCE – DRAFT= 5 FT (1.5 m)

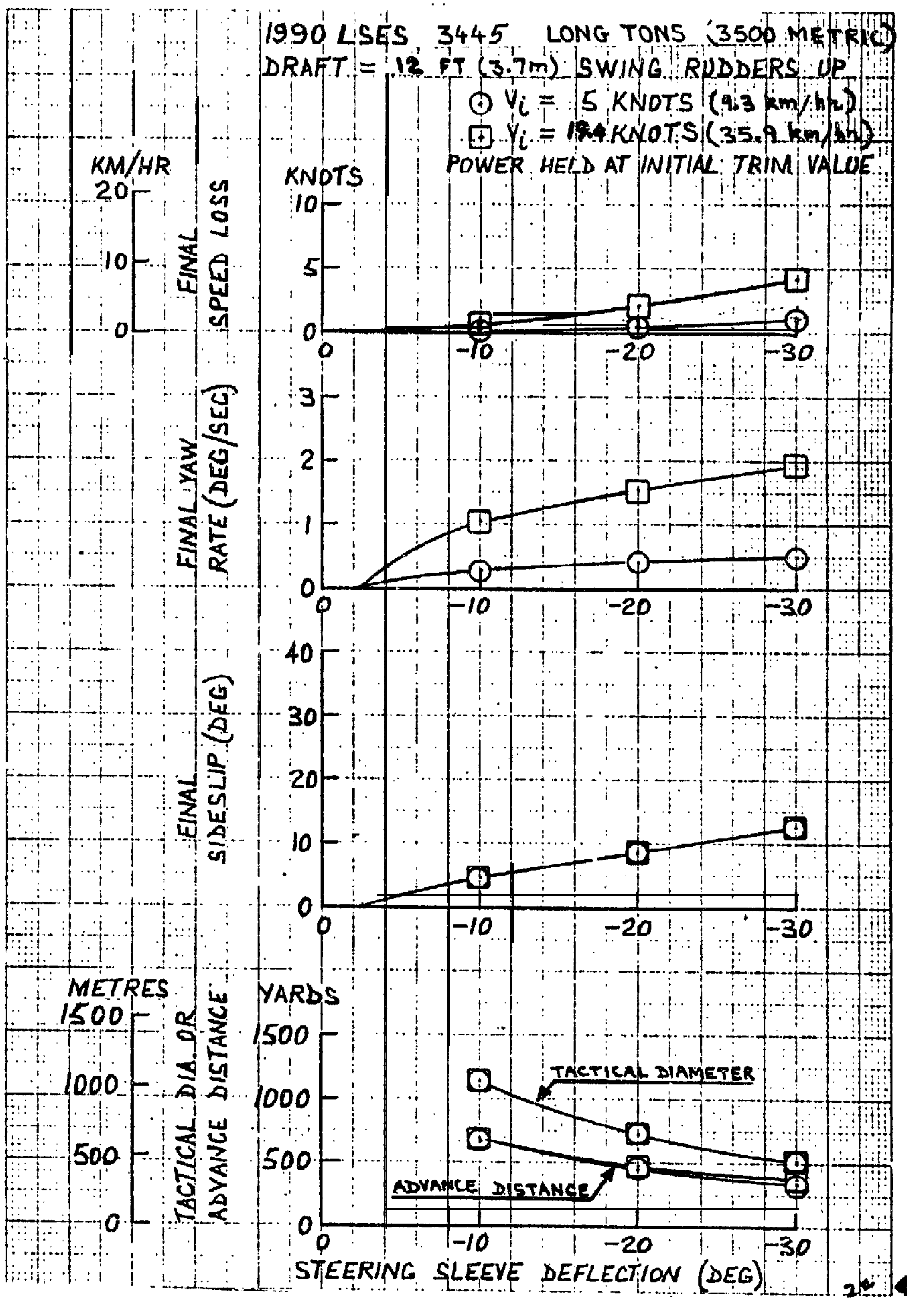


Figure 2.2.2-2 PARTIAL-CUSHION LOW-SPEED TURNING PERFORMANCE – DRAFT= 12 FEET (3.7 m)

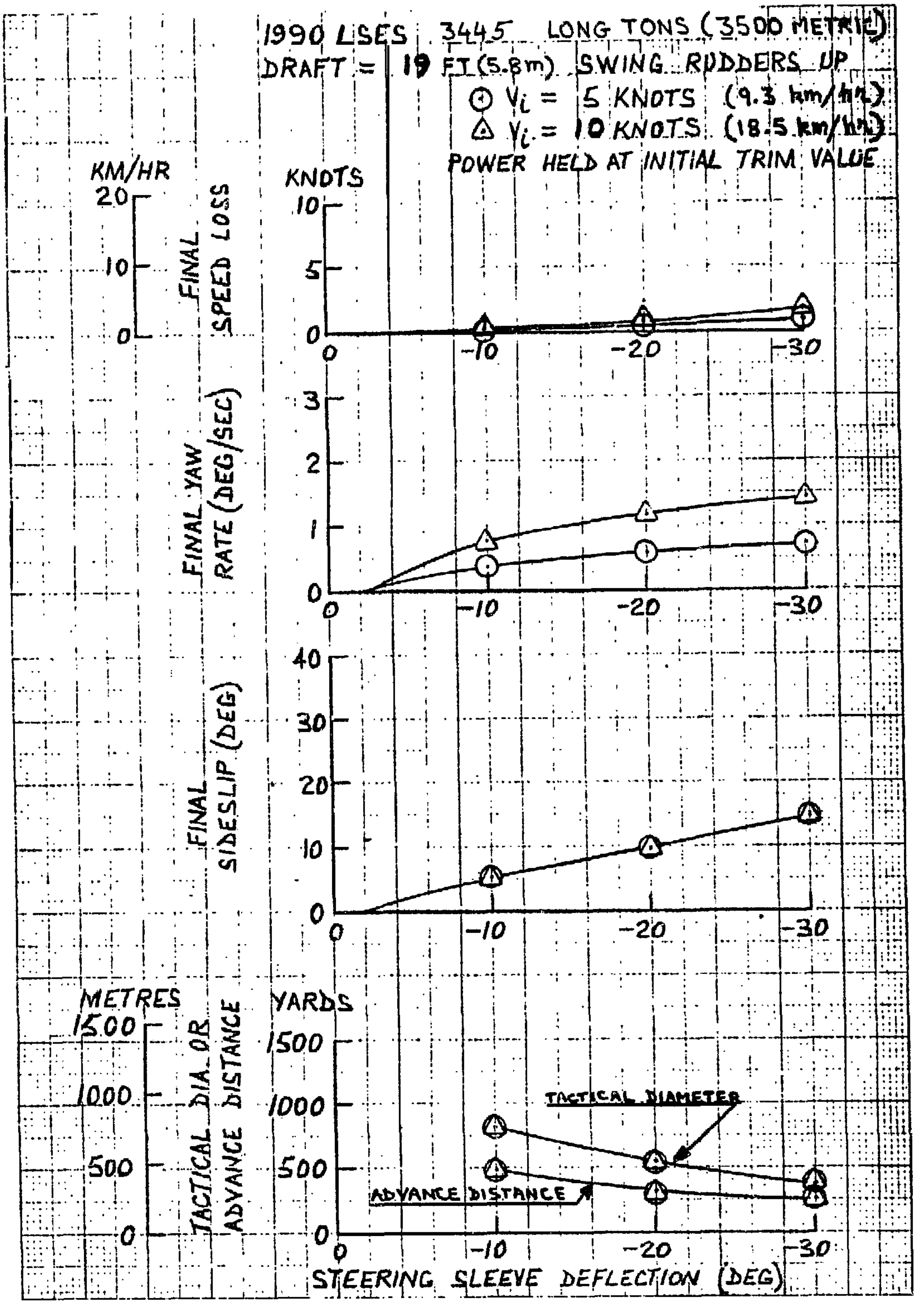
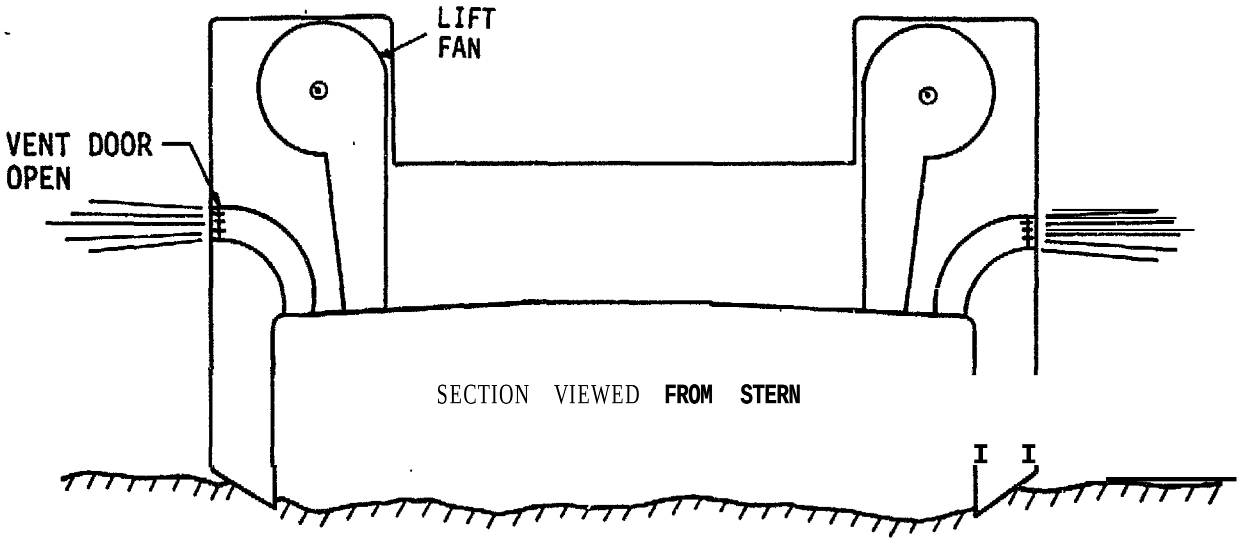
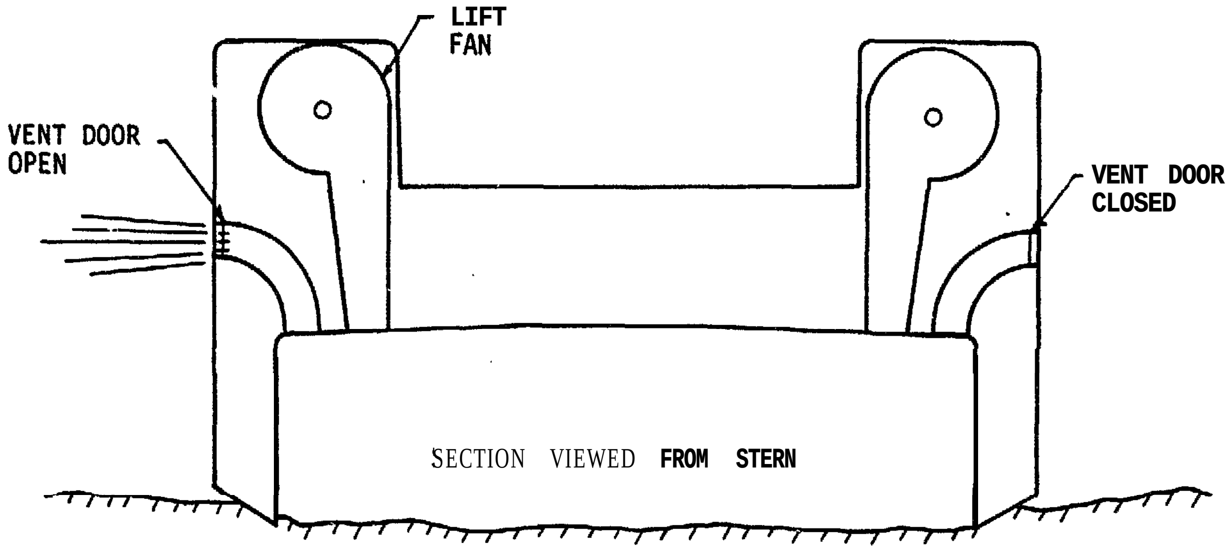


Figure 2.2.2-3 OFF-CUSHION LOW-SPEED TURNING PERFORMANCE — DRAFT = 19 FT (5.8 m)



(a) RCS VENT DOORS IN NORMAL OPERATION



(b) RCS VENT DOORS USED TO PRODUCE SIDEFORCE

Figure 2.2.2-4 USE OF RCS VENT DOORS AS PUFF PORTS TO PRODUCE SIDEFORCE

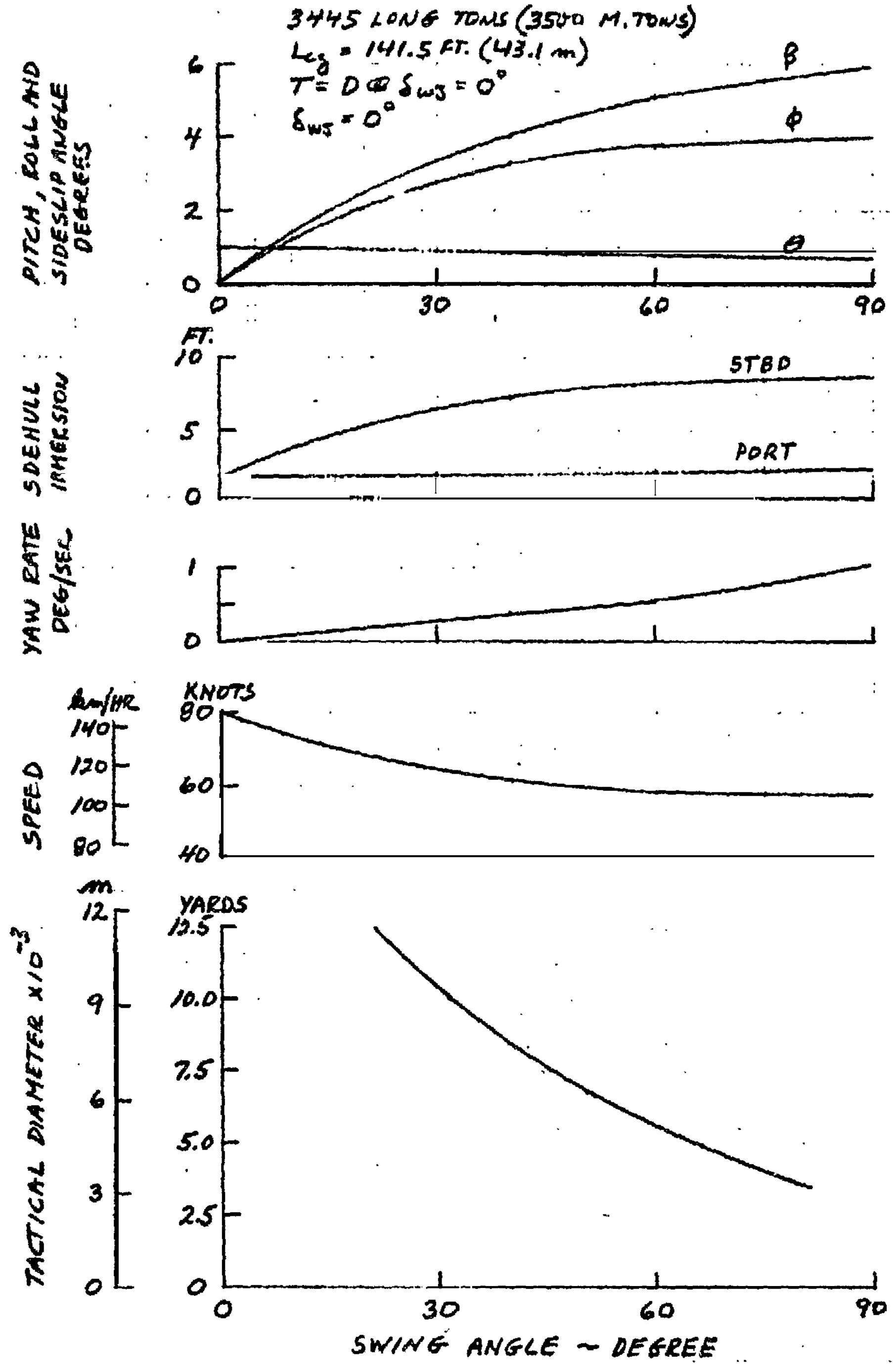


Figure 2.2.2-5 TURNING CHARACTERISTICS VERSUS RUDDER SWING ANGLE V_i = 80 KT (148.1 KM/HR), POWER HELD CONSTANT

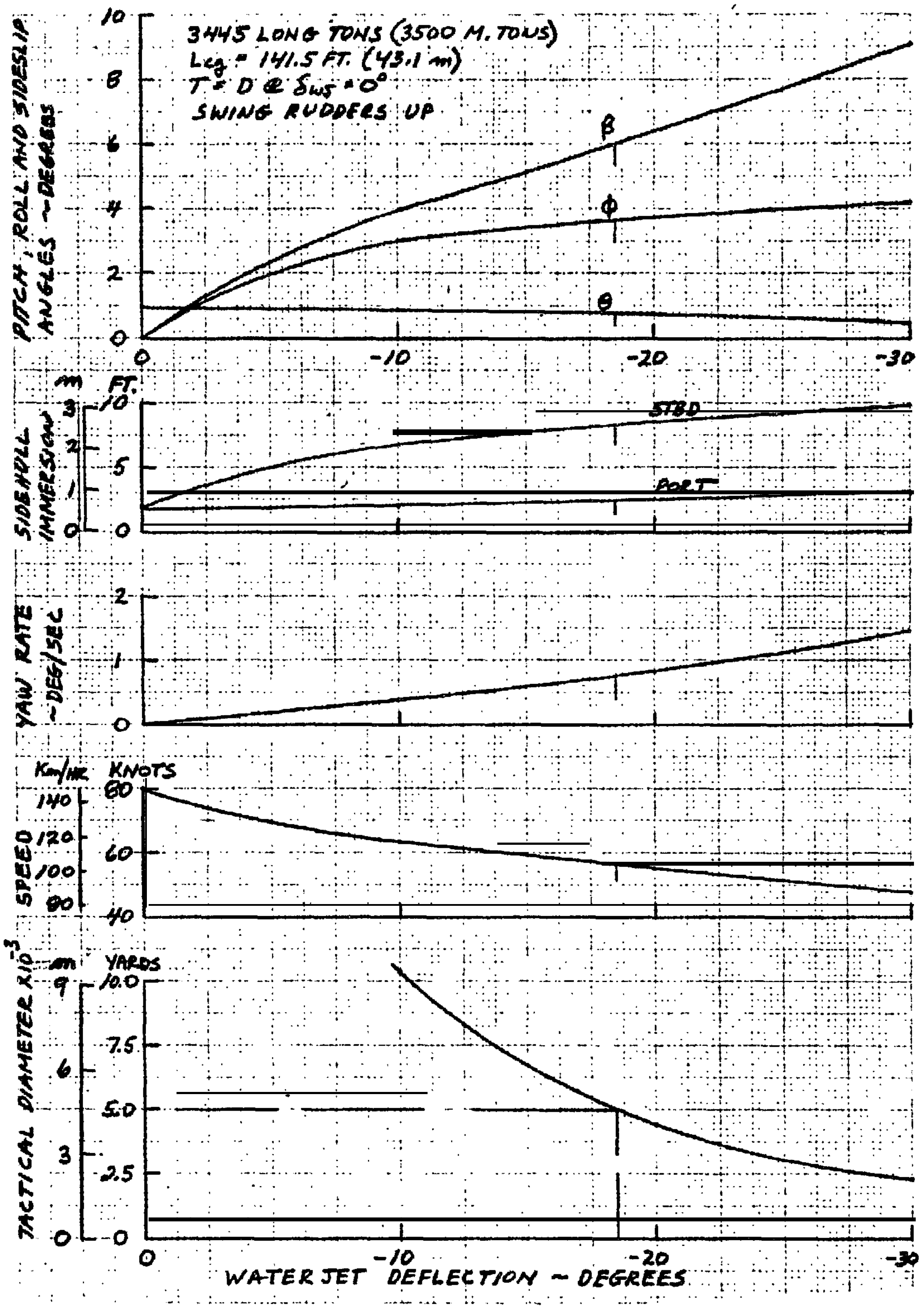


Figure 2.2.2-6 TURNING CHARACTERISTICS VERSUS WATERJET DEPLETION
V_i = 80 KT (148.1 KM/HR), POWER HELD CONSTANT

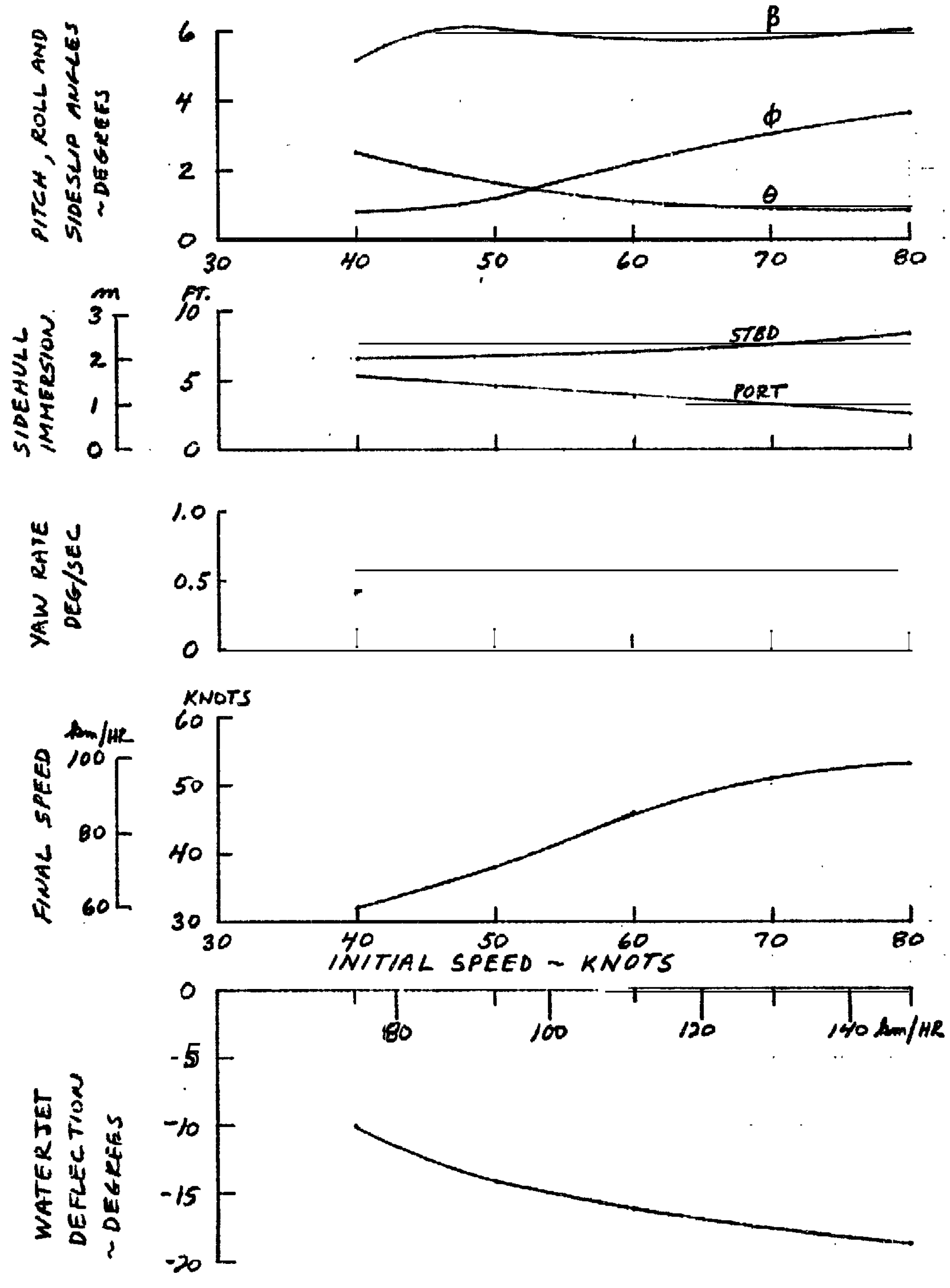


Figure 2.2.2-7 TURNING CHARACTERISTICS VERSUS INITIAL SPEED WHILE MEETING TLR 5000-YARD (4572 m) TACTICAL DIAMETER

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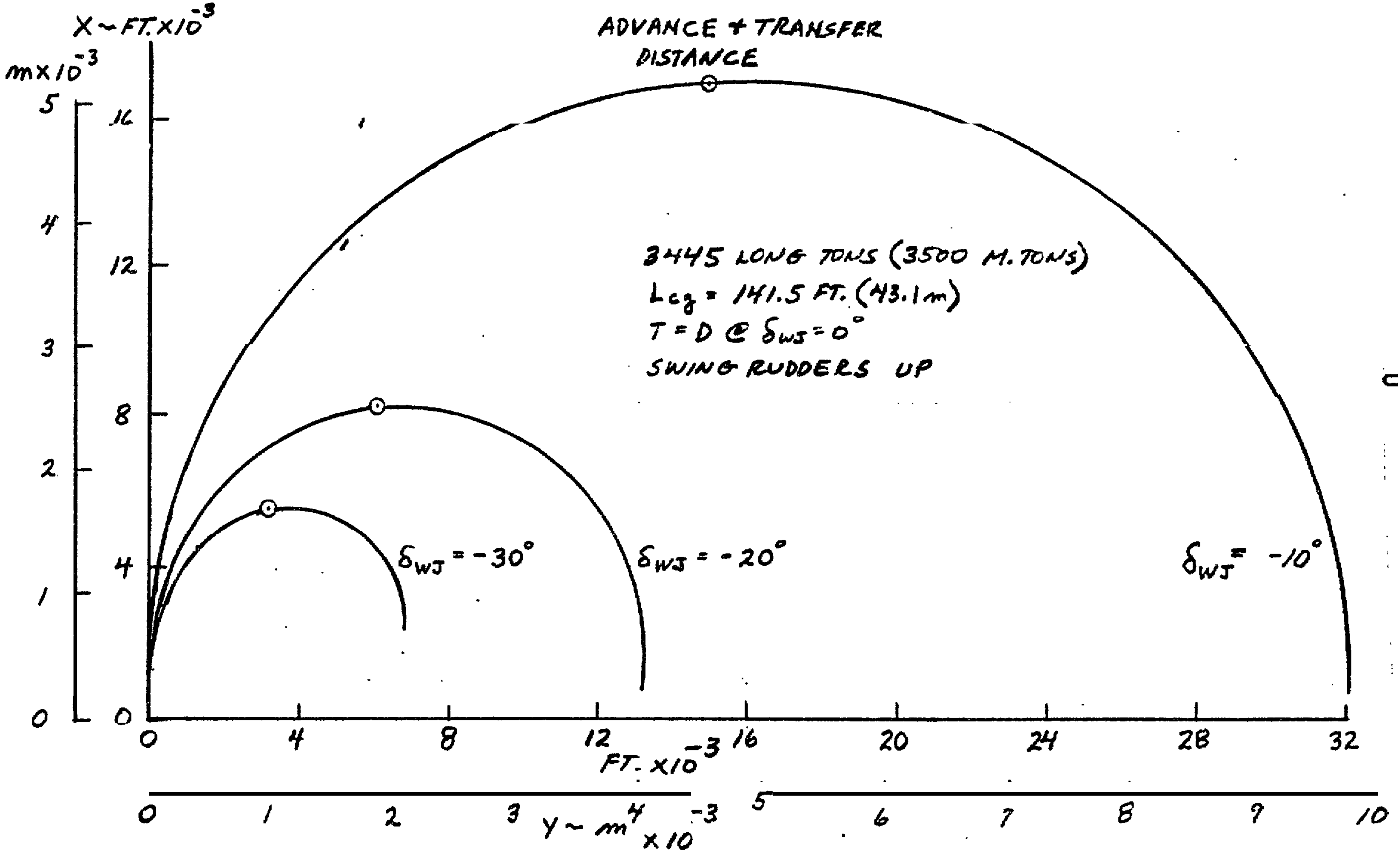

Figure 2.2.2-8 TYPICAL TRACKS OF HIGH-SPEED TURNS V_i = 80 KT (148.1 KM/HR), POWER HELD CONSTANT

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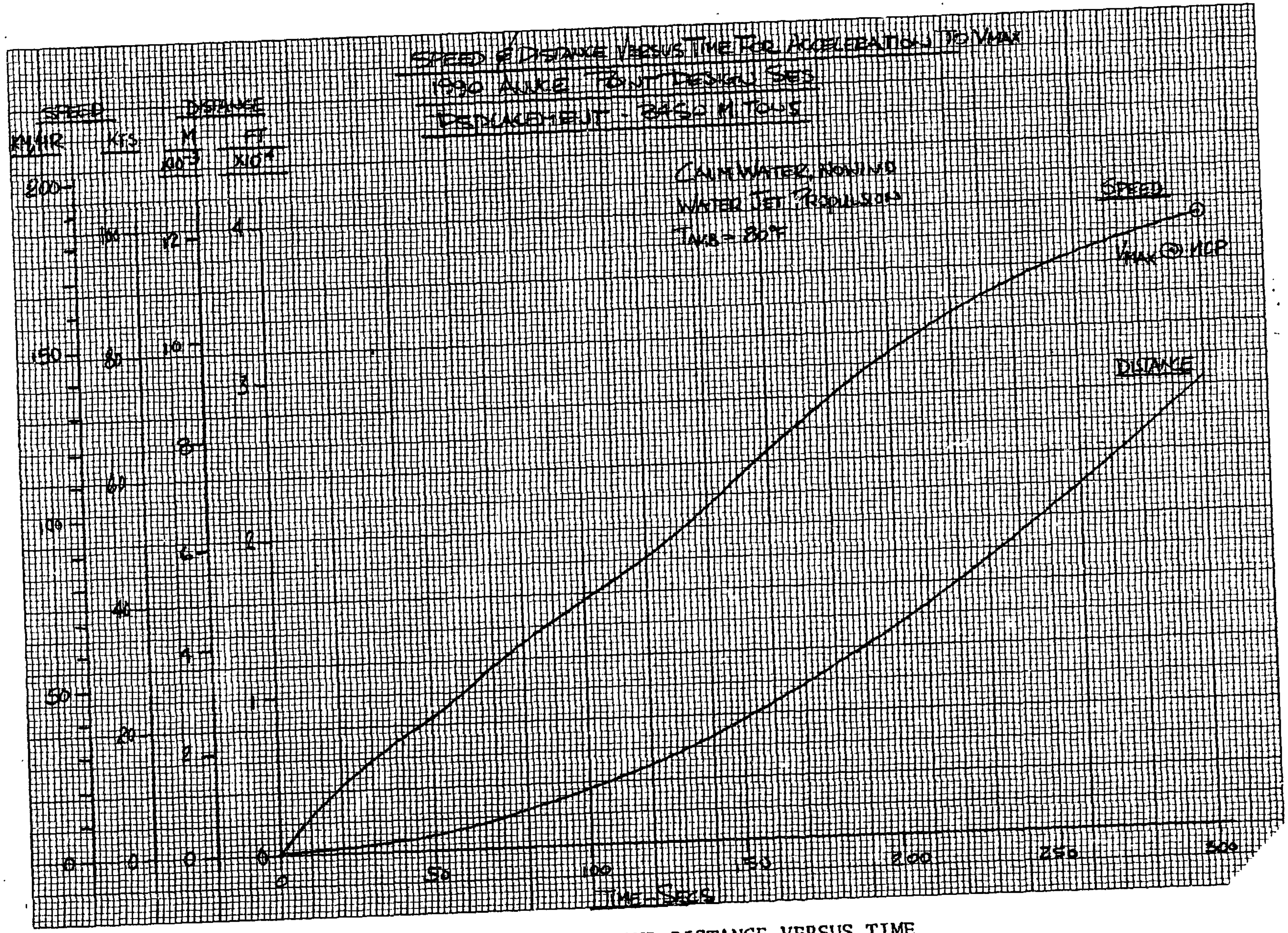

Figure 2.2.2-9 SPEED AND DISTANCE VERSUS TIME FOR ACCELERATION TO V_{MAX} (MIP)

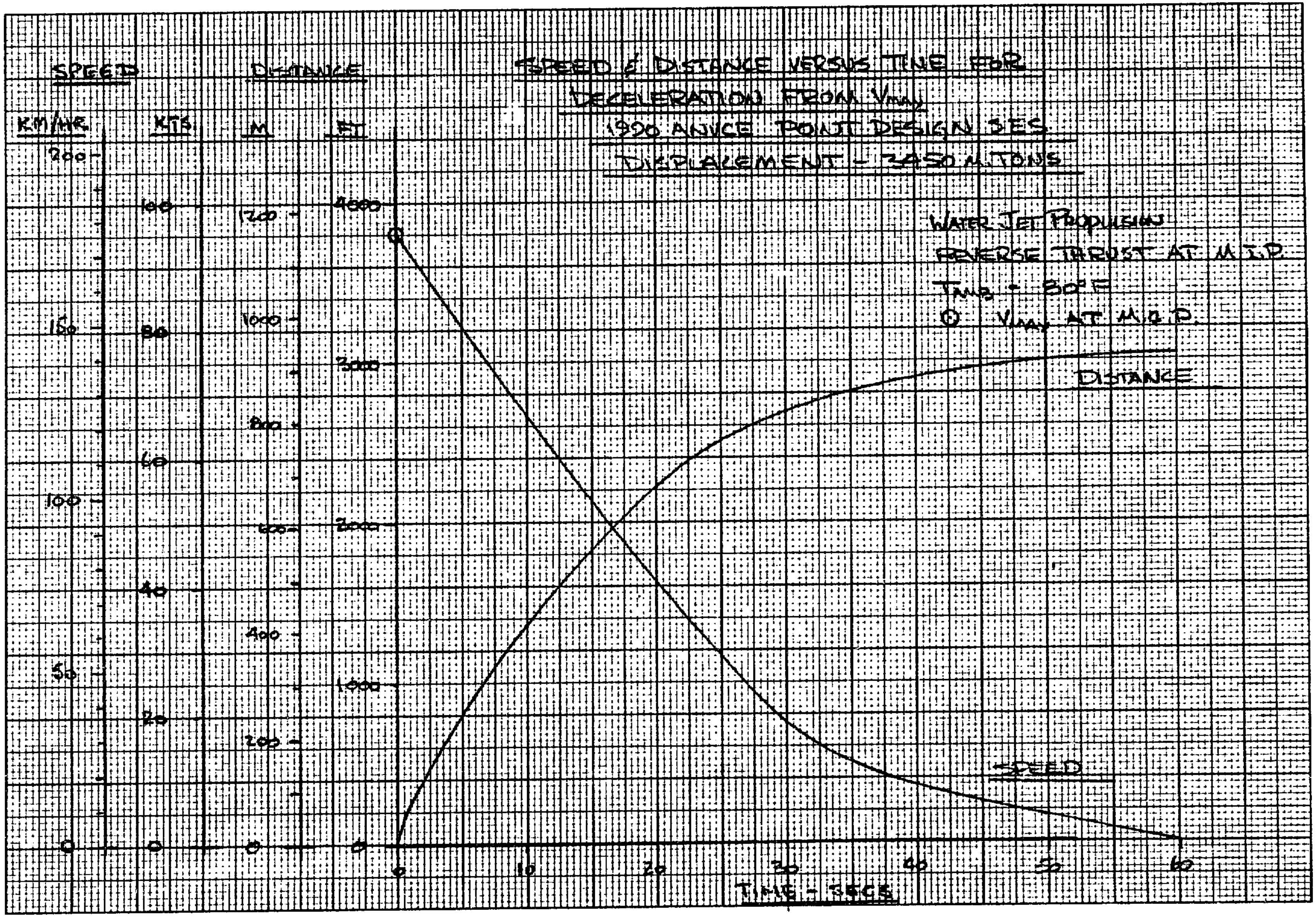

Figure 2.2.2-10 SPEED AND DISTANCE VERSUS TIME FOR DECELERATION FROM V_{MAX} (MCP)

2.2.3 Range and Payload

Specific range in the form of distance traveled per mass unit of fuel is shown in figure 2.2.3-1, as a function of speed and sea state for the ship at full-load displacement. Limiting speeds at MCP are also shown on the figure.

Figures 2.2.3-2 and 2.2.3-3 present range data for various sea states, for the ship initially at FLD. For figure 2.2.3-2, constant-speed operation was assumed. As noted in the figure, the higher speeds cannot be achieved with the ship at the initial displacement, the maximum speeds for these conditions being as shown in figure 2.2.1-8. For these cases, range (and endurance) are calculated on the basis of the ship traveling at its maximum speed until fuel burn-off reduces displacement to a level at which the desired speed can be achieved; thereafter, this speed is maintained constant.

Constant speed does not give maximum range since the optimum cruising speed varies with displacement, in general decreasing with fuel burn-off. Figure 2.2.3-3 shows maximum obtainable range using optimum speed throughout. Three curves are presented, one assuming no head wind and RCS inoperative, the other two assuming head winds appropriate to the given sea states, with RCS both on and off. In all cases, seas (and wind where considered) are taken as head, and lift flow with RCS off is assumed nominal. There is evidence that significant improvement in performance can be obtained in sea states other than head.

Figure 2.2.3-4 corresponds to figure 2.2.3-2, and shows cruise endurance in hours as a function of sea state and operational speed. Figure 2.2.3-4 also shows the endurance obtainable at subhump ship speeds using a reduced lift power condition. At the very lowest speeds, lift power corresponds'to the minimum flow required to inflate the cushion, as determined during 2KSES model tests at Hydronautics, Inc., in 1973. As speed is increased in this region, it is assumed that lift power is increased to maintain optimum performance, ie, minimum total fuel consumption. It is assumed that one lift engine and two propulsion engines are operating in this condition, allowing an improved sfc to be realized relative to that obtainable with all engines running at lower power levels. The remaining engines can be brought on-line quickly if rapid ship response is required in a combat situation. The endurance obtained at subhump speeds exceeds that estimated for post-hump operation, and must be shown using a separate scale. The corresponding subhump ranges can be readily calculated from endurance and cruise speed. It will be noted that at 10 knots, the range obtained approximately equals that achievable at optimum high-speed cruise in sea state 3 (this is only true for the waterjet-propelled ship). This operating mode will allow efficient operation of the SES at speeds consistent with conventional ship performance.

Figure 2.2.3-S shows range as a function of military payload in sea state 3, for an initial weight in all cases of 3450 metric tons (FLD). The calculations assumed that fuel could be directly traded for payload, with no allowance being made for change in residual fuel with change in total fuel, or for weight of increased tankage required. The nominal military payload is 301.5 metric tons; this includes an allowance of 8 tons for helicopter fuel,

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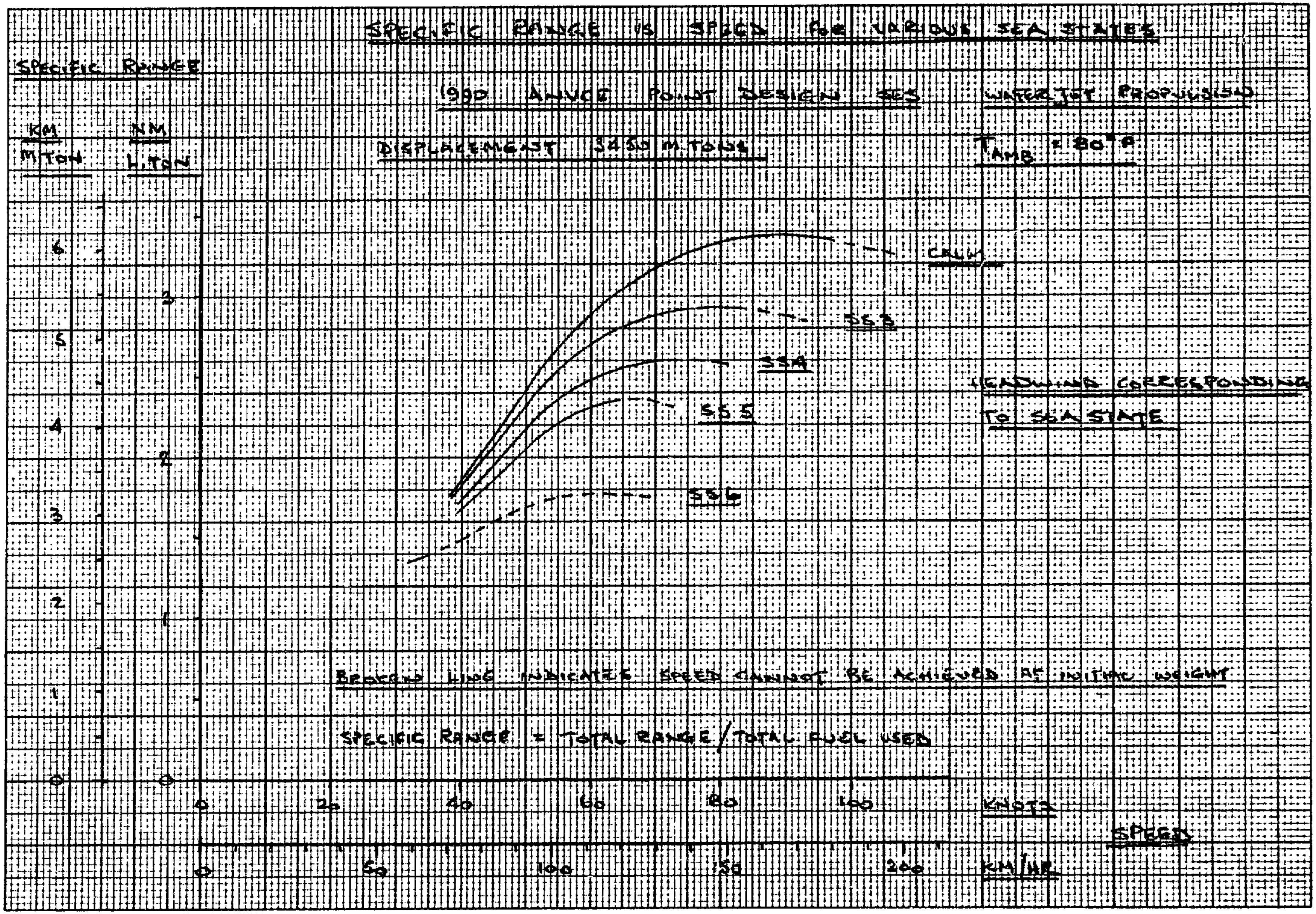

Figure 2.2.3-1 SPECIFIC RANGE VERSUS SPEED FOR VARIOUS SEA STATES

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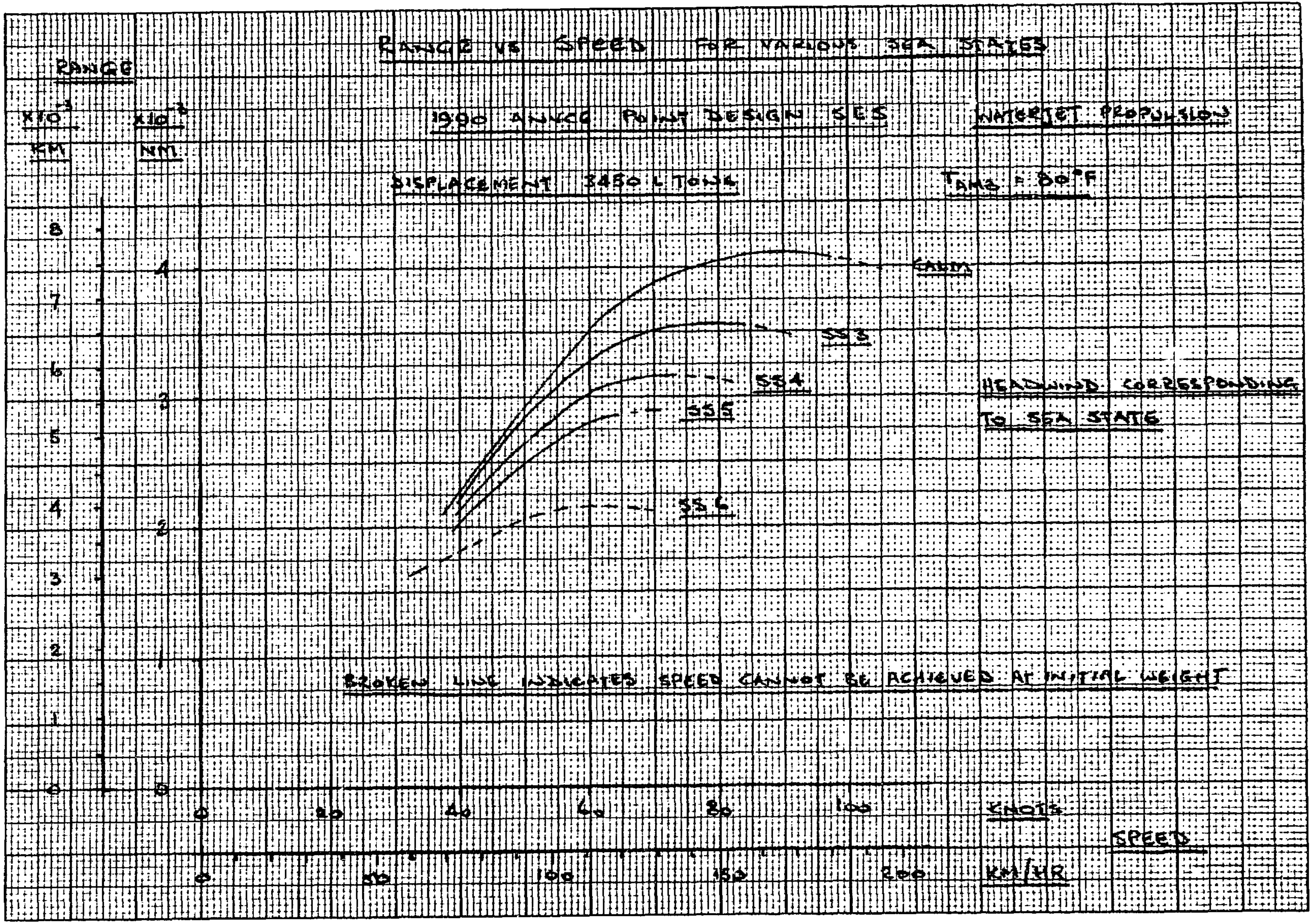

Figure 2.2.3-2 RANGE VERSUS SPEED FOR VARIOUS SEA STATES

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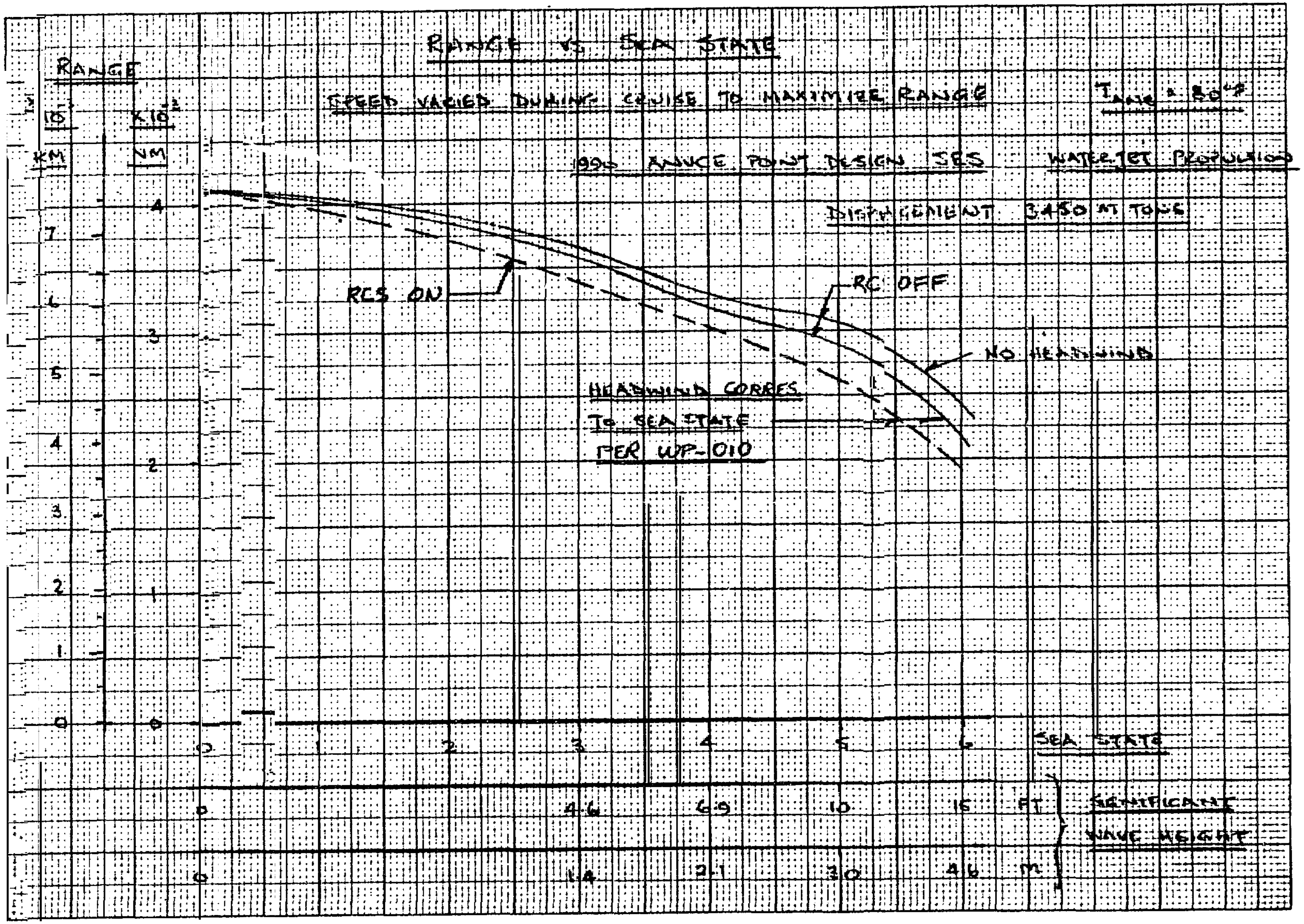

Figure 2.2.3-3 RANGE VERSUS SEA STATE

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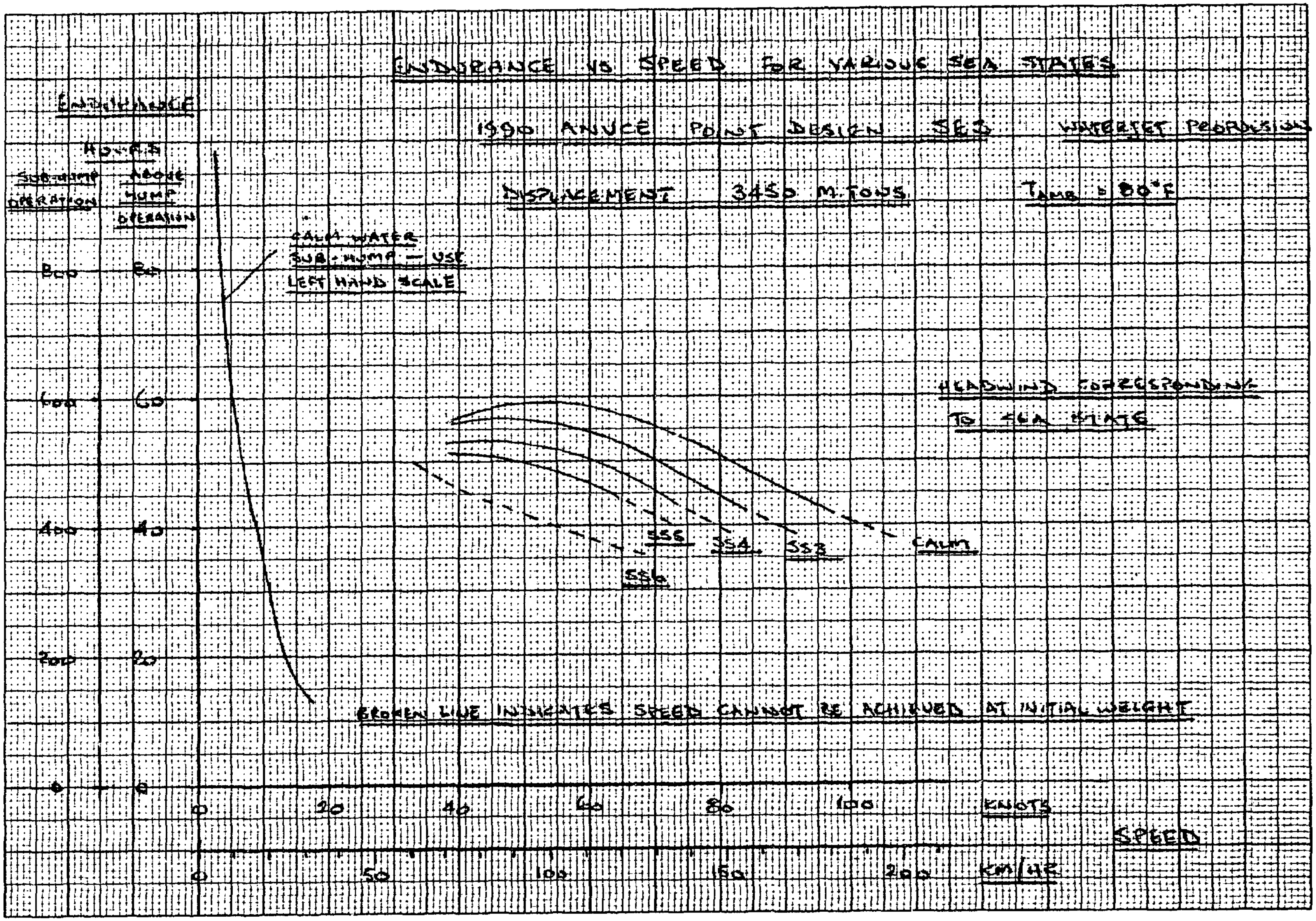

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Figure 2.2.3-4 ENDURANCE VERSUS SPEED FOR VARIOUS SEA STATES

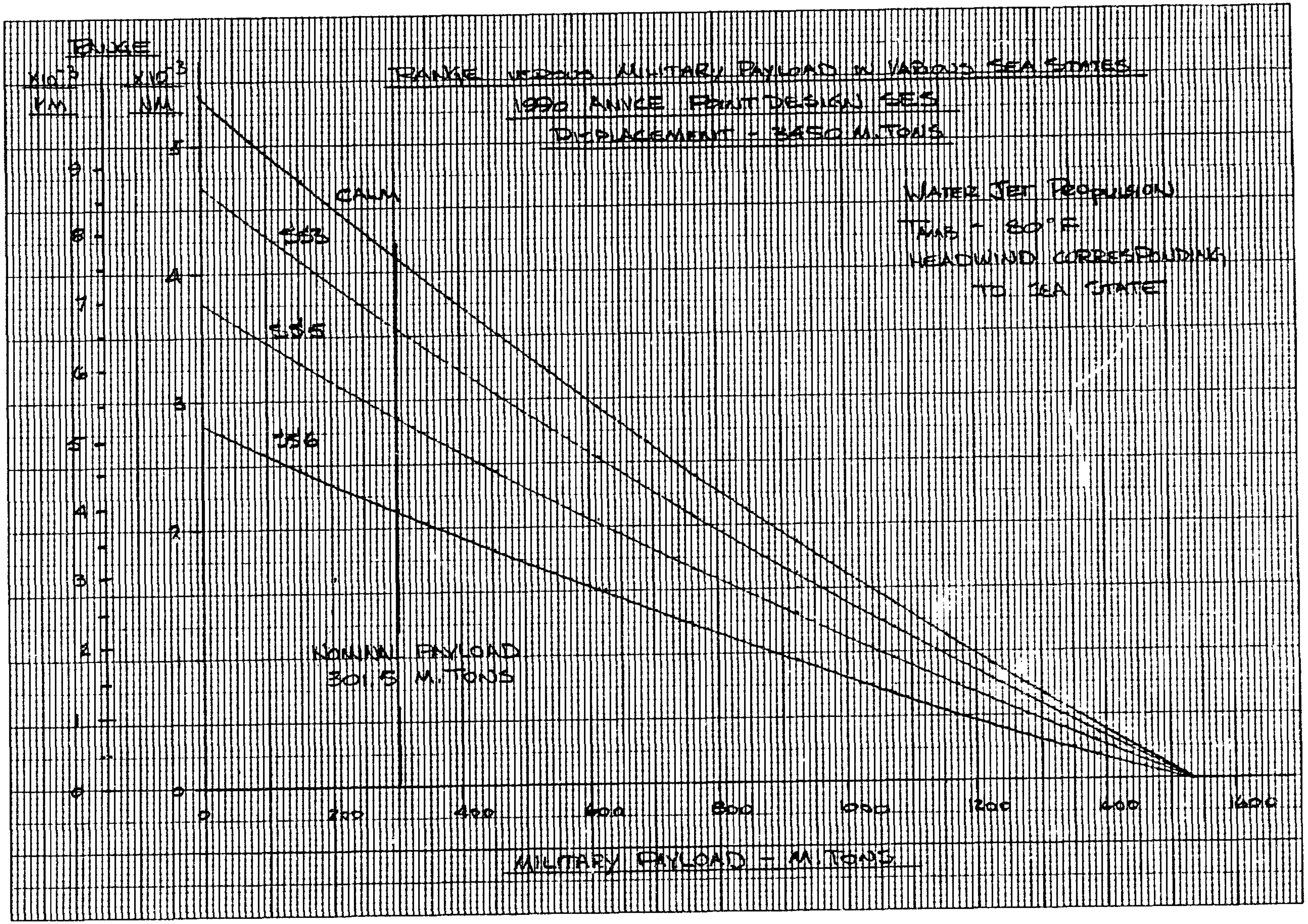

Figure 2.2.3-5 RANGE VERSUS MILITARY PAYLOAD IN VARIOUS SEA STATES

2.2.4 Weight and Volume Summary

2.2.4.1 Weight Summary

Table 2.2.4-I presents the summary weight estimates for the 1990 SES design configuration equipped with 40,000 hp propulsion engines. The weights reflect the study results of this phase of the ANVCE point design study and incorporate the following criteria:

a. Top Level Requirements (TLR), dated 30 September 1976.

b. Ship Work Breakdown Structure, NAVSEA 0900-039-9010.

c. Margin allocation in accordance with WP-015, dated 15 November 1976, applied to the Weight Empty as defined in WP-002, revision B, dated 15 November 1976

d. Manning and habitability

(1) Onboard personnel, number 140
(2) Berthing accommodations, number 140
(3) Messing accommodations, number 65

e. Stores, Onboard provisions and storage for 140 personnel for a 15-day mission in accordance with the stockage criteria of WP-015, dated 15 November 1976

f. Potable Water

(1) Onboard allowance - 25 gallons each for 140 personnel
(2) Storage space for 40 gallons each for 140 personnel

g. Underway replenishment. Alongside fueling and replenishment is included.

The 1990 SES weight estimates are based on LSES weight estimates and analyses, with weight reductions factored in for expected improvements in technology for the 1990 time frame. Anticipated improvements include the economical use of titanium tubing in fuel and hydraulic systems, use of higher pressure hydraulic systems, use of reverse osmosis distillation for potable water, improved manufacturing techniques to allow use of thinner gage sheet without weld distortion, and improvements in aircraft handling systems,

Major increases in weight, however, have resulted from incorporation of ballistic armor for personnel and equipment protection, passive fire protection of 1 pound per square- foot on specified equipment and machinery room surfaces, changes In the number and type of missiles carried,.addition of 15 personnel to crew complement, increase in provisions allowance, and most importantly the requirement for a 15-percent margin allocation versus the 1980 SES margin allocation of 7 percent plus 25 long tons. (See tables 2.2.4-II and -III.)

2.2.4.2 Volume Summary

The breakdown of ship volume by major categories is shown in table 2.2.4-IV.

TABLE 2.2.4-I

WEIGHT SUMMARY

SWBS	WEIGHT				
	SHORT TONS		METRIC TONS		w margin
Group 100 Structural System	1006.82		913.37		
Group 200 Propulsion System	264.06		239.55		
Group 300 Electrical System	47.48		43.07		
Group 400 Command & Surveillance	79.01		71.68		82.43
Group 500 Auxiliary System	252.50		229.06		
567: Lift System		128.71		116.76	
Group 600 Outfit & Furnishings	145.35		131.86		
Group 700 Armament	112.18		101.77		117.04
Design & Builder's Margin	286.11		259.55		
Empty Weight (Light Ship)	2193.51		1989.91		
Loads	1609.46		1460.09		
Crew		18.06		16.39	
Provisions		25.38		23.02	
Stores		6.56		5.95	
Freshwater		18.95		17.19	
Ordnance - Main Vehicle		93.25		84.59	84.59
- Secondary Vehicle		18.65		16.92	16.92
Secondary Vehicle (LAMPS & RPV)		26.50		24.04	24.04
Fuel, Including Mission, SSPU, **helo & residuals**		1402.11		1271.98	8.00
Full-Load Weight	3802.97		3450.0		

TABLE 2.2.4-II

WEIGHT BREAKDOWN - ARMAMENT GROUP

Launchers - Missiles			
Harpoon	16 required × 2500 lb	=	40,000 lb
ASAR	40 required × 2500 lb	=	100,000 lb
SDM	24 required × 450 lb	=	10,800 lb
Standoff Missile	16 required × 3500 lb	=	56,000 lb
ERAPS		=	3,700 lb
Launchers - Torpedo			
MK-48	4 required × 1000 lb	=	4,000 lb
Small Arms		=	372 lb
Small Arms Stowage		=	600 lb
Aircraft Weapons Handling		=	869 lb
Aircraft Weapons Stowage		=	7,150 lb
Miscellaneous - Wiring, etc		=	870 lb
TOTAL WEIGHT		=	224,361 lb
		=	112.18 short tons

TABLE 2.2.4-111

WEIGHT BREAKDOWN - ORDNANCE

Main Vehicle		(186,491 lb) (93.25 short tons)
Missiles		
ASAR	40 required × 1990 lb	= 79,600 lb
Harpoon	16 required × 1494 lb	= 23,904 lb
SDM	24 required × 300 lb	= 7,200 lb
Standoff	16 required × 3000 lb	= 48,000 lb
ERAPS	26 required × 500 lb	= 13,000 lb
Torpedoes		
MK-48	4 required × 3415 lb	= 13,660 lb
Small Arms - Expendables		= 935 lb
Pyrotechnics		= 192 lb
Secondary Vehicle		(37,300 lb) (18.65 short tons)
Torpedoes		
ALWT	36 required × 700 lb	= 25,200 lb
Other Stores		
Sonobuoys Type A		= 8,000 lb
Sonobuoys Type B		= 2,300 lb
ERAPS		= 1,800 lb

TABLE 2.2.4-IV

VOLUME SUMMARY

FUNCTION	INTERNAL VOLUME	
	FT^3	M^3
Main Propulsion (including main machinery box, uptakes, shafting)	84,992	2,407.0
Lift System	99,786	2,825.9
Personnel (including living, messing, and all personnel support and storage)	80,447	2,278.3
Auxiliary and Electrical (machinery spaces other than main propulsion and lift outside main machinery box)	56,881	1,610.8
Payload (internal volume only)	135,042	3,824.4
Other (including passageways, maintenance spaces, and all other spaces not included in above)	374,045	10,592.9
TOTAL ENCLOSED VOLUME	831,193	23,539.3

2.2.5 Stability

2.2.5.1 Stability at Zero Forward Speed Hullborne

The basic ship analyzed had a nominal gross weight of 3445 long tons (3500 metric tons) with the longitudinal center of gravity (Lcg) located at station 145.4 feet (44.4 m) from the bow hard structure, the transverse center of gravity located on the centerline, and the vertical center of gravity 25.4 feet (7.75 m) above the baseline, Lightweight conditions of 2340 long tons (2377 metric tons) and 2850 long tons (2896 metric tons) were also investigated,

At a gross weight of 3445 long tons, the service fuel tanks are full and the bow and stern transfer tanks are 92-percent full. In the damage analysis, when structural failure of a fuel tank occurred, it was assumed the fuel was replaced by water to a depth determined by the flooding water level, The analysis of the light ship (2340 long tons) assumed the fuel tanks to be IS-percent full, and thus any flood water entering the fuel tank by way of a structural rupture filled the tank to the flooding water level. At 2850 long tons, all service and transfer tanks are half full.

A plan view of the 1990 LSES, showing duct openings and various inlets on the weather deck, is shown in figure 2.2.5-l. Figures 2.2.5-2 and 2.2.5-3 show the watertight bulkhead arrangements for the third and second decks, respectively. The flotation box length is 257 feet (78.4 m) to the sidehull transom, with a 106-foot (32.5 m) beam. Several areas on the third deck, such as the IC and gyro room and anchor room, are considered vital areas and are enclosed in additional watertight compartments. The anchor handling room on the second deck is also enclosed by a pressure-tight compartment, since the anchor well is open to the water surface, The fan openings into the cushion are assumed to be free-flooding. The analysis assumed the duct areas and superstructure above the weather deck (waterline 35.5 feet, 10.8 m) do not contribute to buoyancy of the ship.

2.2.5.1.1 Intact Stability

The intact stability of the LSES was investigated to determine the reserve buoyancy and equilibrium pitch and heel angles. The study was performed using a computer program to determine buoyancy, restoring arms, and waterlines for the design configuration.

In this report, unless otherwise stated, all ship pitch angles are referenced to the main deck plane. The sidehull keel plane is 1.146 degrees bow-down from the main deck plane. The results of the study indicate that at the design weight of 3445 long tons, the intact ship (off cushion) will have a sidehull immersion (at the center of gravity station) of 19.4 feet (5.91 m) above the sidehull keel. The craft will trim 0.9 degree bow-down, and the swing rudder draft (at station 252) will be 25.1 feet (7.65 m), At 3445 long tons and a light weight of 2340 long tons, roll area ratios of 6.4 and 5.8, respectively, were calculated; both exceeded the criterion of 1.4.

2.2.5.1.1.1 Buoyancy and Waterlines

The sidehull immersion waterline of the intact ship versus craft weight is shown in figure 2.2.5-4, At a craft weight of 3445 long tons, the sidehull immersion (at the Lcg) relative to baseline (waterline 0) is 21.1 feet (6.44 m), with a bow-down trim of 0.9 degree. The reserve buoyancy is 288 percent.

At the gross weight of 2340 long tons, the sidehull immersion (at the Lcg) relative to waterline 0 is 19.4 feet (5.91 m), with a bow-down trim of 1.0 degree. The reserve buoyancy is 470 percent. Note that, because the LSES has a sloping wet deck, the sidehull keel at the Lcg station is at waterline 1.7. Therefore, 1.7 feet (0.52 m) should be subtracted from the sidehull immersion waterlines to obtain sidehull draft at the Lcg.

2.2.5.1.1.2 Intact Pitch Stability

Pitch-righting arm versus pitch angle is shown in figure 2.2.5-5 for the intact condition at weights of 3445 and 2340 long tons. The 3445-long-ton ship will have an equilibrium pitch angle of 0.9 degree bow-down, with a maximum righting arm of approximately 80 feet (24.4 m). The area ratios (A_1/A_2) are 5.6 and 5.7 for the 3445- and 2340-long-ton cases, respectively, Both these values exceed the criterion of 1.4. The pitch metacentric height is 750 feet (228 m) and 870 feet (265 m) for the 3445- and 2340-long-ton ships, respectively.

2.2.5.1.1.3 Intact Roll Stability

The roll-righting arm for the intact condition at ship weights of 3445 and 2340 long tons is shown in figure 2.2.5-6. A requirement of the LSES is to withstand a 100-knot (185.2 km/hr) beam wind (sea state 9), which for a 3445-long-ton ship results in a wind-heeling arm of 1.2 feet (0.36 m) as shown in the figure. The equilibrium roll angle is approximately zero degrees, with a maximum roll-righting arm of 34 feet (10.4 m) for the 3445-long-ton case, The area ratio (A_1/A_2) varies from 6.4 to 5.8 for the 3445- and 2340-long-ton conditions, respectively, and both exceed the criterion of 1.4. The roll metacentric height is 158 feet (48.1 m) and 240 feet (73 m) for the 3445- and 2340-long-ton ships, respectively. Fuel tank free surface effects were analyzed by assuming all service and fuel tanks are half full. The roll-restoring arm for this weight (2850 long tons), with free surface effects included, is very close to that at 3445 long tons.

2.2.5.1.2 Hullborne Damage Stability

An investigation to determine whether the 1990 LSES would meet the stringent requirements of NAVSEC DDS 079-1* was started by applying the criteria to several damage cases. Case 1 assumes longitudinal-side-up damage of 50 percent of DWL (128.5 feet, 39.2 m) with impact at station 89 and an inboard penetration of 10.6 feet (3.23 m). This damaged condition ruptures the watertight bulkheads at stations 25 and 153. The loss in buoyancy for the second deck is indicated by the shaded area in figure 2.2.5-7. The loss in buoyancy for the third deck is restricted outboard of butt 31 and, for the starboard sidehull, is from the sidehull bow to station 193, Figure 2.2.5-7 shows that the equilibrium roll angle is 8 degrees with a freeboard of 5.3 feet (1.62 m). The roll area ratio is 2.3 and is obtained from calculating area A_1 from 8 degrees to a 45-degree roll angle boundary. This value of area ratio (2.3) exceeds the minimum criteria value of 1.0. All other requirements for adequate stability (ie, freeboard, equilibrium heel angle, etc) are satisfied,

Case 2, shown in figures 2.2,5-8 and 2,2.5-9, has impact at station 105 with longitudinal damage of 46 feet (14 m) and inboard penetration to the centerline. The loss in buoyancy for the third deck is indicated by the shaded area in figure 2.2.5-8. The loss in buoyancy for the second deck is across the ship between stations 41 and 89 and from butt 31 to butt 53 between stations 89 and 137. The starboard sidehull has no buoyancy from the bow to station 153. The equilibrium pitch and roll angles are -2.6 and 2.7 degrees, respectively. The roll-restoring arm curves are shown in figure 2,2,5-8 with area ratio A_1/A_2 of 4.4 and a freeboard of 9.5 feet (2.9 m). The pitch area ratio is 1.9 with a freeboard (at the bow) of 6 feet (1.83 m) ,

A completely flooded version of case 2 is shown in figures 2.2.5-10 and 2.2.5-11. Figure 2.2.5-10 is a roll-righting arm plot with the area ratio equal to 2.78, while figure 2.2,5-11 shows the pitch-righting arm plot with an area ratio of 1.22. The equilibrium pitch and roll angles are -3.8 and 6.8 degrees, respectively, with freeboard of 0 feet at the bow for pitch and 3.5 feet (1.07 m) for roll. Note the criteria requirements specify that flooding to the waterline is sufficient, and therefore those cases are extreme flooding conditions. All criteria in NAVSEC DDS 079-l are met for this extreme damaged condition.

2.2.5.2 Stability Characteristics On-Cushion

Stable operation throughout the 1990 LSES operational envelope for pitch and roll is provided by passive means only. The 1990 LSES hull is directionally stable for normal maneuvering. However, two swing rudders may be rapidly

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*NAVSEC DDS 079-l Design Data Sheet, *Stability and Buoyancy of U.S. Naval Surface Ships, Part III Advanced Marine Vehicles (In Waterborne Displacement Mode),* August 1, 1975.

deployed to provide added directional stability, LSES stability characteristics predicted from the 2KSES design verification tests (DVT) and 6-degree-of-freedom simulation studies have shown that the 1990 LSES will meet all the stability and control requirements. The 1990 LSES structural and hydrodynamic design provides good stability when hullborne, at low and high speeds cushion-borne, and under damaged conditions,

This section presents the basic stability and control characteristics of the 1990 LSES while operating on cushion. Pitch stability data is based on LSES model performance testing at the David Taylor Naval Ship Research and Development Center (DTNSRDC), as are the static stability characteristics, in the sense that it is derived at various speeds under steady-state, calm-water conditions in which there are no dynamic heaving, pitching, or rolling motions. Data has been Froude-scaled to represent the LSES at 2700 long tons (2740 metric tons) and a total flow rate of 41,000 cfs. No roll or yaw stability data was obtained during LSES model performance tests. Therefore, the 1990 LSES roll and yaw stability characteristics are based on 2KSES DVT model stability tests, with adjustments to account for increased cushion pressure, increased cushion-length-to-cushion-beam ratio, increased sidehull-length-to-cushion-length ratio, and swing rudder area. The baseline configuration was designed to provide adequate inherent passive pitch and roll stability under all operational conditions without augmentation systems. The mean cushion-length-to-cushion-beam ratio of 2.46 resulted primarily from performance considerations, A bow cushion depth of 18 feet (5.49 m) was provided to minimize the bow and wet-deck slamming in sea state 6, while keeping within a lateral stability guideline that the vertical center-of-gravity-height-to-overall-beam ratio be less than 0.25. Further refinements of the lift and ride control system were developed to improve the ride quality in rough seas. For comparison, a full description of 2KSES stability characteristics is presented in Bell New Orleans Report 7446-950013, *Stability* and *Control (Z-3)*, dated March 1, 1976.

2.2.5.2.1 Pitch Stability

Pitch stability is obtained from the bow and stern seals and from the sidehull bow shaping. The cushion-pressure-to-water-dynamic-pressure ratio for the LSES is higher than that for smaller SESs, which aids in preventing bow seal tuck-under and the resulting plow-in. As the craft pitches down, the bow seal open fingers fold against the bag, thereby reducing the airflow between the bow seal and cushion. This increases the bow seal pressure and stiffness, and causes an increase in bow-seal-to-cushion-pressure ratio (P_b/P_c). The bow seal and side-hull hydrodynamic lifts now support a larger portion of the ship weight, while the cushion pressure decreases. Adequate pitch stability is required to prevent plow-in from occurring at high speeds and to prevent large changes in trim due to center-of-pressure transfers at all operating speeds, However, a ship with excessive pitch stability will provide a harsh ride, and will require a large transfer of ballast to trim the ship. Based on previous experience, the 1990 LSES is designed to provide a compromise pitch stiffness (M_θ) so that a

1-degree change in pitch attitude corresponds to approximately a 1-percent shift of the ship center of pressure along the characteristic length (cushion area divided by cushion beam).

Figure 2.2.5-12 shows pitch moment versus pitch angle at speeds of 40, 50, 60, 70, 80, and 100 knots, with roll angle (ϕ) and sideslip angle (β) equal to zero. At the nominal pitch attitudes for each speed, the pitch stiffness value ranges from -0.33 to -0.78 percent L_c/degree. Note that the pitch moment (-3×10^6 lb-ft) required to trim the ship for optimum performance at speeds from 40 to 100 knots (74.1 to 185.2 km/hr) is almost constant. Stable pitch moment slopes ($-M_\theta$) were obtained for all speeds and pitch angles. Pitch moments are referenced with respect to the model hovering at zero pitch attitude.

With respect to the 1980 LSES, pitch moment versus pitch angle at a weight of 2850 long tons (2896 metric tons), the 1990 LSES M_θ slopes are slightly reduced at the minimum drag attitude. Conversely, the 1990 LSES shows slightly less pitch stiffness at increased bow-down attitudes at higher speeds. However, stable operation is evident at all speeds, Stability tests of the 1990 LSES model should be conducted to define the pitch stability over an increased range of pitch attitudes.

2.2.5.2.2 Roll Stability

Roll stability for the 1990 LSES is obtained from the sidehulls and the bow and stern seals. At roll angles between ±4 degrees, more than 80 percent of the restoring roll moment comes from the sidehulls; the remaining 20 percent comes from the bow and stern seals. The sidehull hydrodynamic lift increases as speed increases, thus increasing the restoring moment. This restoring moment must be sufficient to overcome the destabilizing effects of the air cushion and rudder (if held at zero deflection). Based on previous experience, a roll stiffness (K_ϕ) of -0.5 percent B_c/degree was selected for the baseline design; ie, a lateral cg shift of 0.5 percent of the cushion beam (B_c) is equivalent to a 1-degree change in roll attitude, The baseline configuration, designed to meet this roll stiffness criterion, produces strong restoring moments throughout the normal operational range.

At the nominal pitch attitudes for each speed, figure 2.2.5-13 shows a calculated roll stiffness value of -0.51 percent B_c/degree for speeds from 65 to 105 knots (120.4 and 194.5 km/hr). Stability tests of the 1990 LSES model should be conducted to define the roll stability over the full operating range of ship attitudes.

2.2.5.2.3 Directional Stability

Directional stability for the 3500-metric-ton 1990 LSES is obtained from the partial-length (78-percent) sidehulls, the semiflush inlet and rudder fairings, and the extended swing rudders. The rudders, positioned at the transom, have a cambered section designed to exploit the strong control authority exhibited by a similar rudder split-flap in the water channel, cavitation-scaled model tests (table 2.2.5-I and figure 2.2.5-13). The geometric aspect ratio is 3.75 with no taper and side area of 30 square feet. The rudders provide the necessary additional directional stability and yaw control capability,

The lateral/directional stability of the baseline configuration provides strong yaw-restoring moments, roll into a turn, and stability to bow-down pitch attitudes greater than -2.0 degrees.

The swing rudders are retracted when the craft is holding course. In an emergency, both rudders can be extended to provide increased directional stability, as shown on figure 2.2.5-14. For maneuvers, only the appropriate rudder on one side is extended to supply maneuvering control. Notice that the directional stability increases as the single extended rudder unvents as it becomes unloaded,

At nominal pitch attitudes, the yaw stiffness increases with speed. Hull-alone directional instability may occur at 105 knots (194.5 km/hr) and bow-down pitch angles greater than -1.1 degree, However, the 1990 LSES yaw stiffness, with full-scale rudder effects included, overcomes the hull directional instabilities at bow-down attitudes.

2.2.5.3 Dynamic Stability

2.2.5.3.1 Damping Coefficients

Planar motion mechanism (PMM) tests (1/30-scale ship model) were performed at DTNSRDC to obtain on-cushion lateral dynamic stability data for the 2KSES design. The PMM test data showed that the lateral stability characteristics of the 2KSES design are satisfactory. Figure 2.2.5-15 shows the dimensionless roll-damping coefficients as a function of model speed for the ship with and without rudders. Figure 2.2.5-16 shows the dimensionless yaw-damping coefficients for the same conditions. Note that the rudders provide 80 percent of the yaw coefficient (N'_r) at high speeds. The swing rudder contribution is significantly reduced by the large reduction in rudder wetted area, and the damping coefficients for rudders off (2KSES data) will apply to the 1990 LSES.

Predicted results of linearized analyses are plotted in figure 2.2.5-17, where the low period and damping represents the roll mode, and the larger damping represents the yaw/sway mode. A damping factor of 0.11 is required for an oscillation to damp to one-half amplitude in one cycle; therfore, the PMM tests show the 1990 LSES has adequate roll and yaw damping. The 1990 LSES sidehull length has increased by 32 feet (9.75 m) over the 2KSES design; therefore, it is expected that the 1990 LSES damping characteristic, with the swing rudder, will be similar.

TABLE 2.2.5-I

SWING RUDDER SECTION OFFSETS

$\left(\frac{\pi}{2}\right)\left(\frac{x}{X}\right)$ (DEG)	$\frac{x}{X}$	INBOARD SIDE $\frac{y}{X}$	CAMBERED SIDE $\frac{y}{X}$
0	0	0.000000	0.000000
10	1/9	0.024890	0.025076
20	2/9	0.034611	0.033438
30	1/3	0.041229	0.032254
40	4/9	0.045990	0.021682
50	5/9	0.049479	0.009340
60	2/3	0.051966	0.008587
70	7/9	0.053528	0.031572
80	8/9	0.054232	0.081676
90	1	0.054350	0.150000

2.2.5.3.2 Control Yaw Moment

Directional control of the LSES is obtained from several sources, and is used either independently or in combination, Primary control is obtained swinging one rudder and/or four waterjets, Differential thrust may be used above hump in the 40- to 60-knot (74 to 111 km/hr) range without a loss of net thrust, since a thrust reserve is available. However, this is restricted to use for small course corrections where yaw rates less than 0.3 deg/sec are required. Yaw moments may also be developed by using the waterjet thrust reversers differentially (asymmetrically). The maximum positive moment is produced by applying maximum forward thrust on the port side, deflecting the two port sleeves 30 degrees, and applying maximum reverse thrust on the starboard side. The maximum achievable yaw moment for the various combinations is shown in figure 2.2.5-18 as a function of forward speed.

The yaw moment due to swinging one rudder shows that the moment increases with speed until 38 knots (70.3 km/hr), Above 38 knots, the maximum yaw moment prior to the rudders ventilating is 19.4 × 10^6 lb-ft. However, above 50 knots (92.5 km/hr) increased rudder control is available when sideslip angles increase the rudder flow angle to angles beyond the ventilation angle. The rudder yawing moment at a lo-degree toe-in angle is shown to increase rapidly with speed, reaching a value of about 55 × 10^6 lb-ft at 100 knots (185.2 km/hr). In normal operational use in turning, the maximum rudder loads and yawing moment above ventilation will be reduced by the relieving effects of ship sideslip and yaw rate once the turn has stabilized,

The propulsion system yawing moments shown on the figure include the effects from unsymmetrical inlet and momentum drag when appropriate.

Differential thrust is shown to be the least effective means of producing yawing moment from the propulsion system. A single curve is plotted, showing the yawing moment produced by both port engines at 40,000 bhp (limited by pump cavitation at low speed) with both starboard engines of the FT-9 idle (power of about 750 bhp) .

Deflection of all the steering sleeves to 30 degrees is shown to be more than twice as effective as differential thrust at low speeds, and the difference is greater at high speeds. Two curves are shown, one at the FT-9 maximum intermittent power of 40,000 bhp and the other at the LM2500 power of 27,000 bhp. The *two* curves join a common pump cavitation line at low speeds.

The combined use of full thrust reverser on the starboard side with 30-degree starboard deflection of the steering sleeves on the port side is shown to be 60-percent more effective than combined deflection of all four steering sleeves, but this would be at the expense of very great losses in net thrust.

In summary, it may be noted that as ship speed approaches zero, all propulsion steering techniques become more effective than rudder deflection, Above 30 knots (55.5 km/hr), rudder deflection is more effective than differential power, even at 40,000 bhp. At speeds close to and above hump, the yaw moment from 30 degrees of steering sleeve deflection at maximum power is greater than that from the rudder operating just below the ventilation angle. Above 50 knots the maximum yaw moment available from the ventilated rudder increases rapidly with speed. Near 100 knots, the yawing moment from the ventilated rudder is greater than that which can be produced by any propulsion control combination.

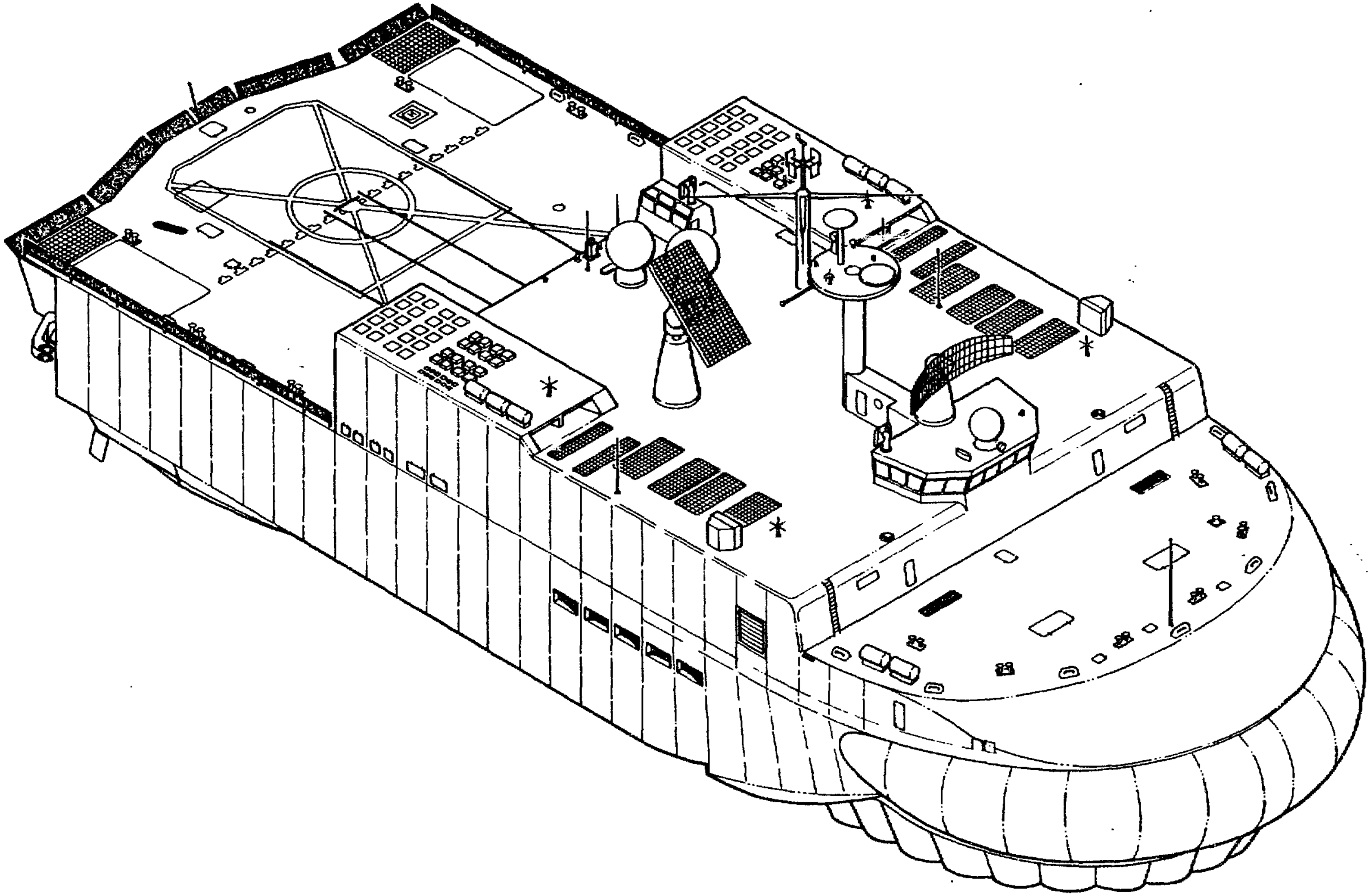


Figure 2.2.5-1 LOCATION OF INLETS AND EXHAUST OPENINGS ON WEATHER DECK AND SIDE FAIRING

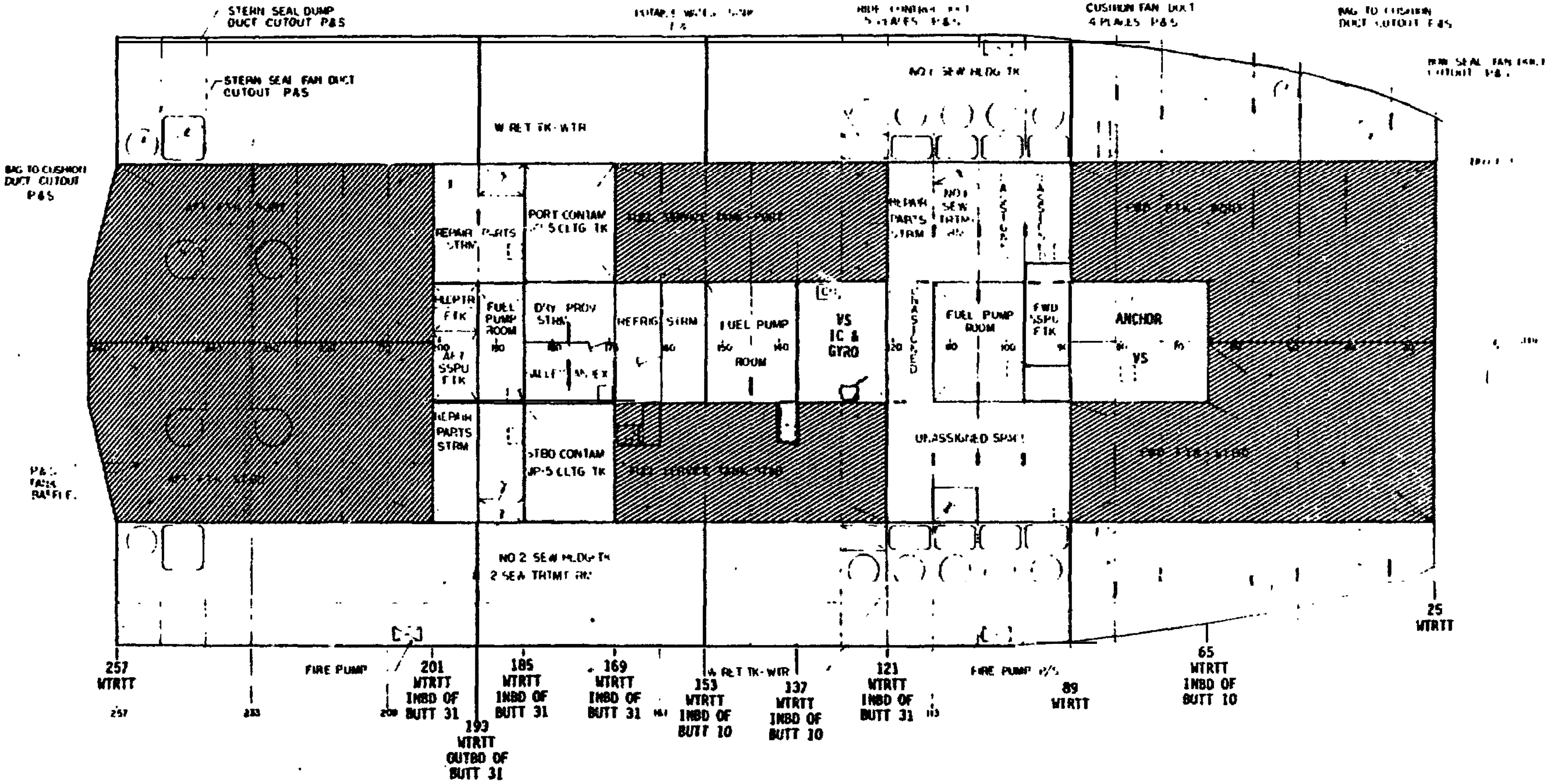


Figure 2.2.5-2 LOCATION OF WATERTIGHT BULKHEADS ON THIRD DECK

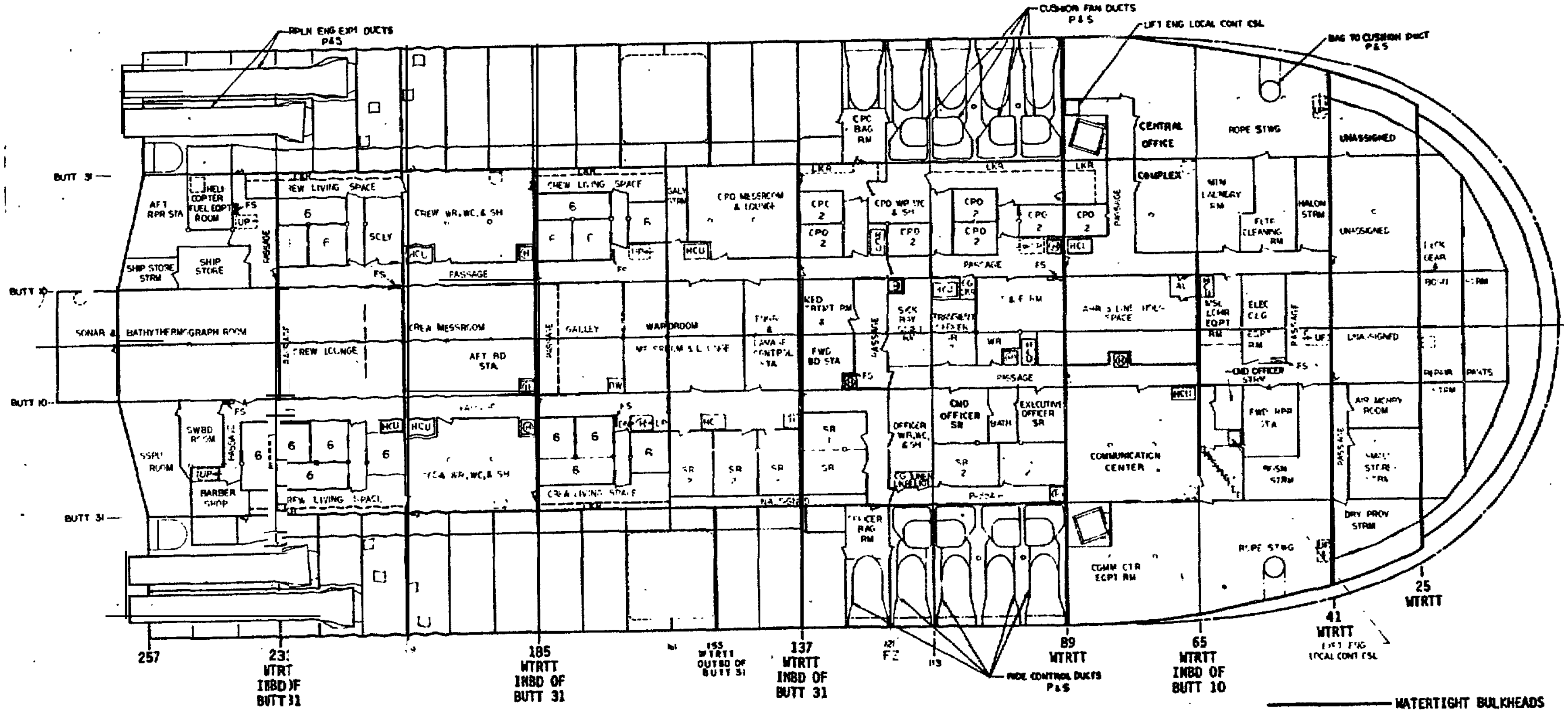


Figure 2.2.5-3 LOCATION OF WATERTIGHT BULKHEADS ON ND DECK

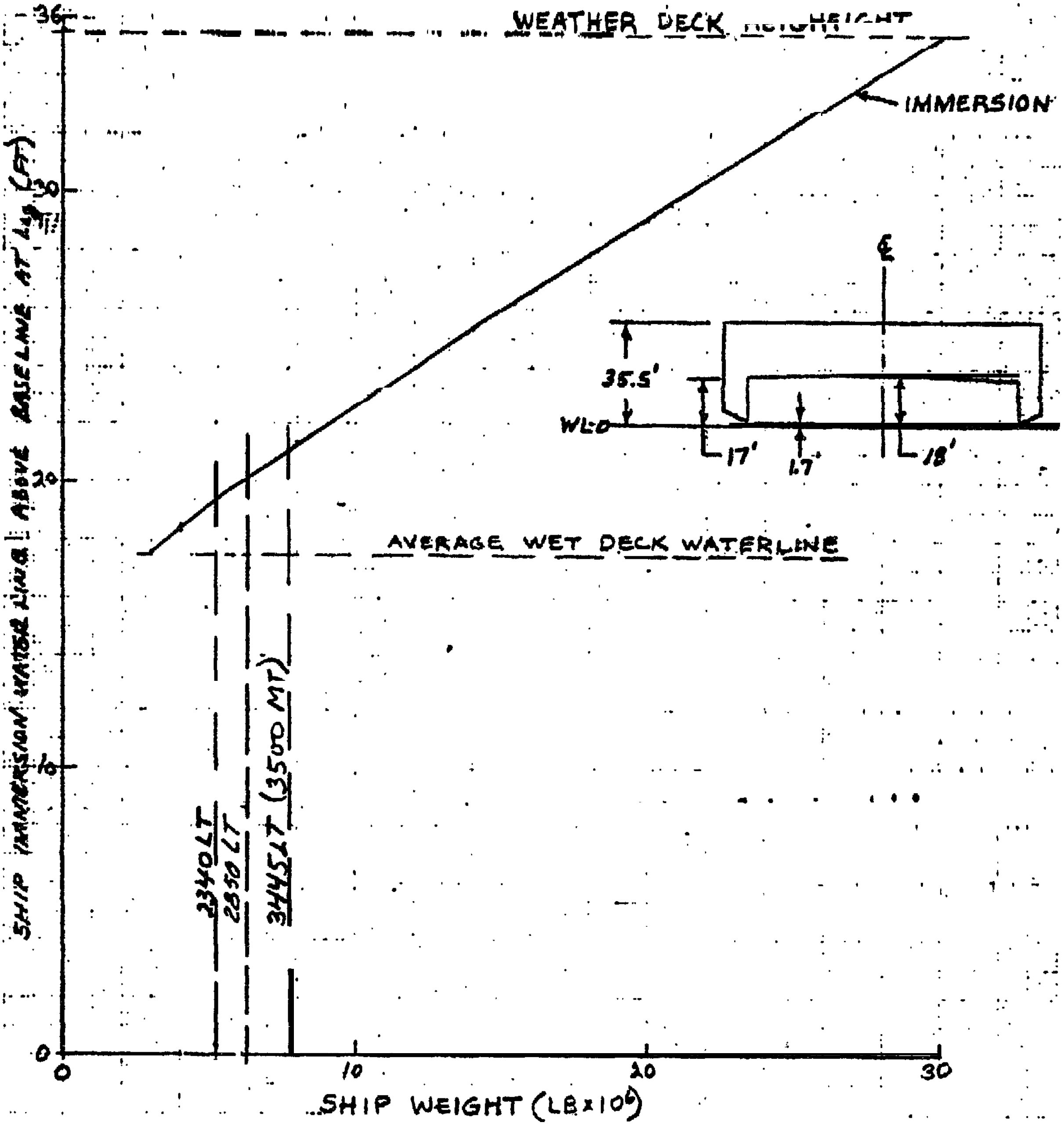


Figure 2.2.5-4 SHIP IMMERSION WATERLINE VERSUS SHIP WEIGHT

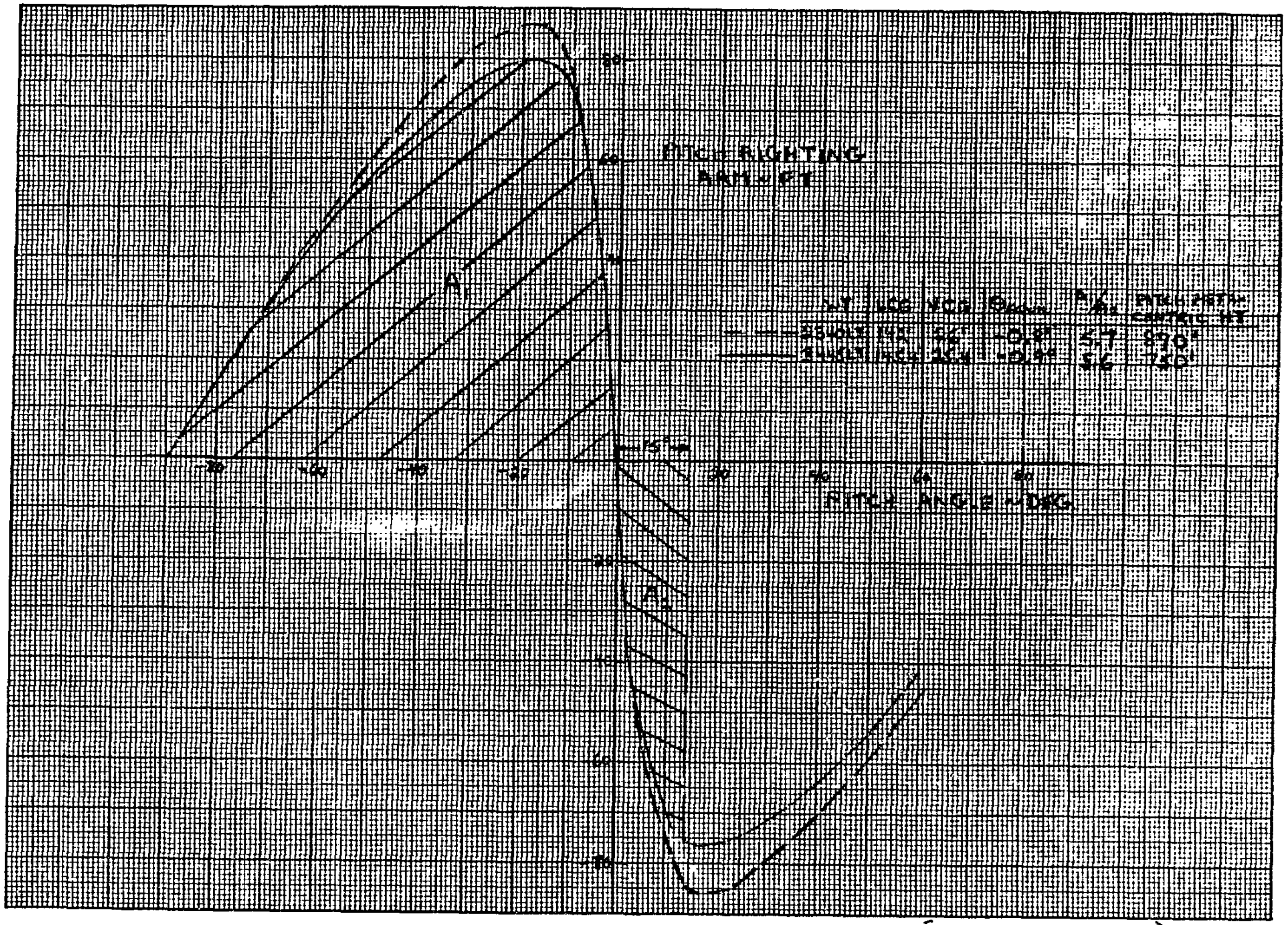


Figure 2.2.5-5 PITCH-RIGHTING ARM VERSUS PITCH ANGLE (INTACT CONDITION)

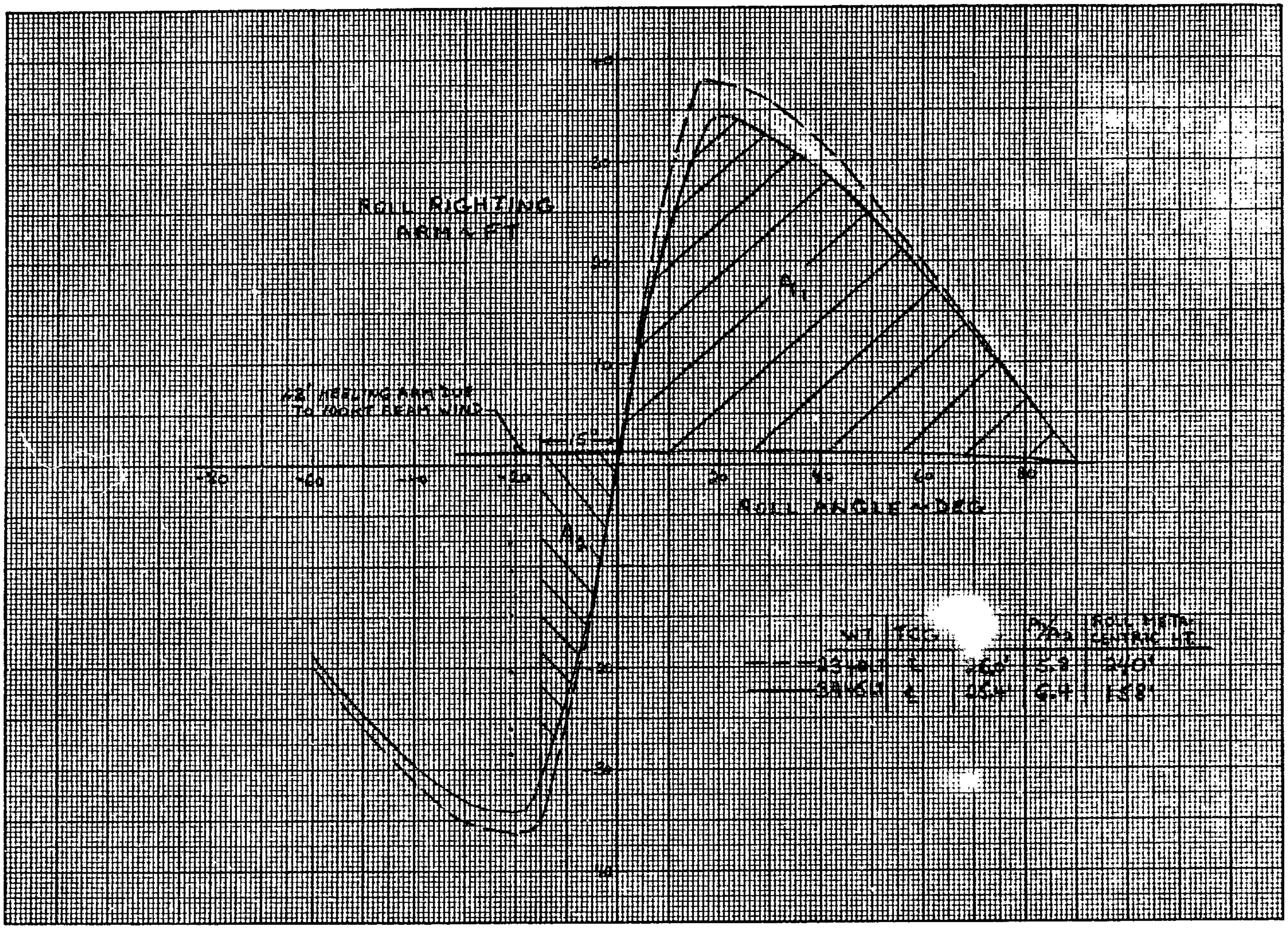


Figure 2.2.5-6 ROLL-RIGHTING ARM VERSUS ROLL ANGLE (INTACT CONDITION)

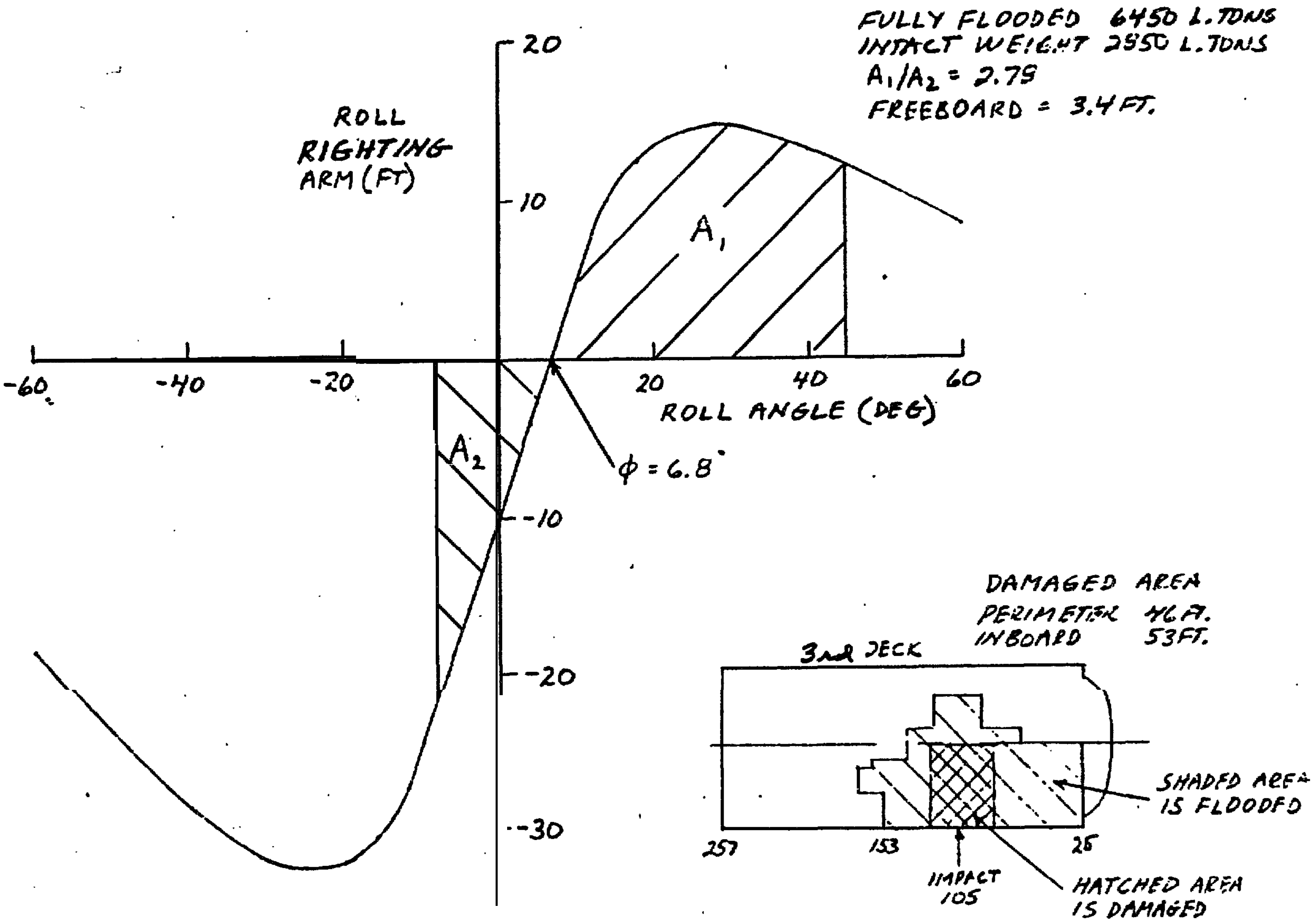


Figure 2.2.5-7 ROLL-RIGHTING ARM VERSUS ROLL ANGLE FOR IMPACT AT STATION 89 (**CASE** 1)

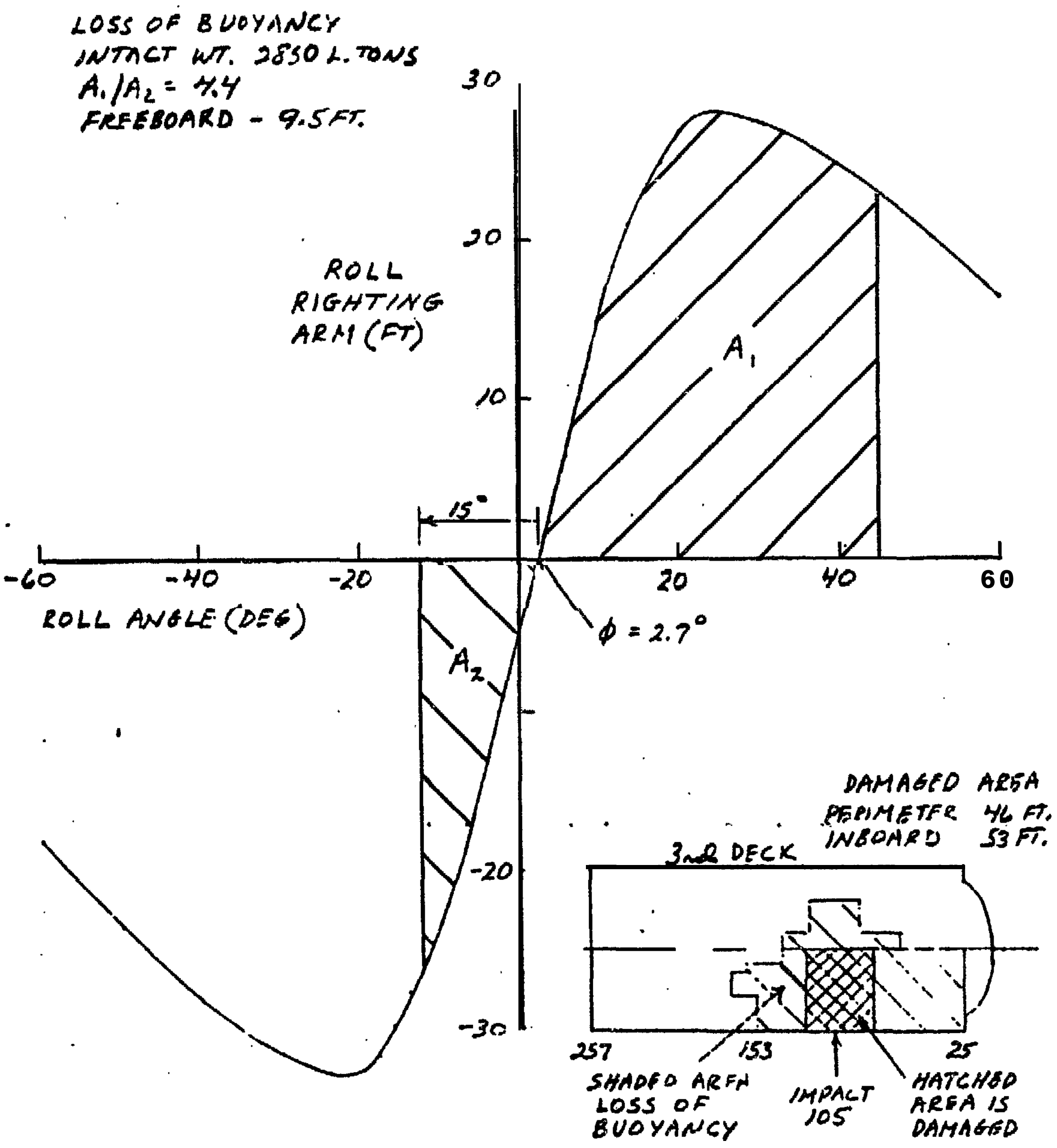


Figure 2.2.5-8 ROLL-RIGHTING ARM VERSUS ROLL ANGLE
FOR IMPACT AT STATION 105 (CASE 2)

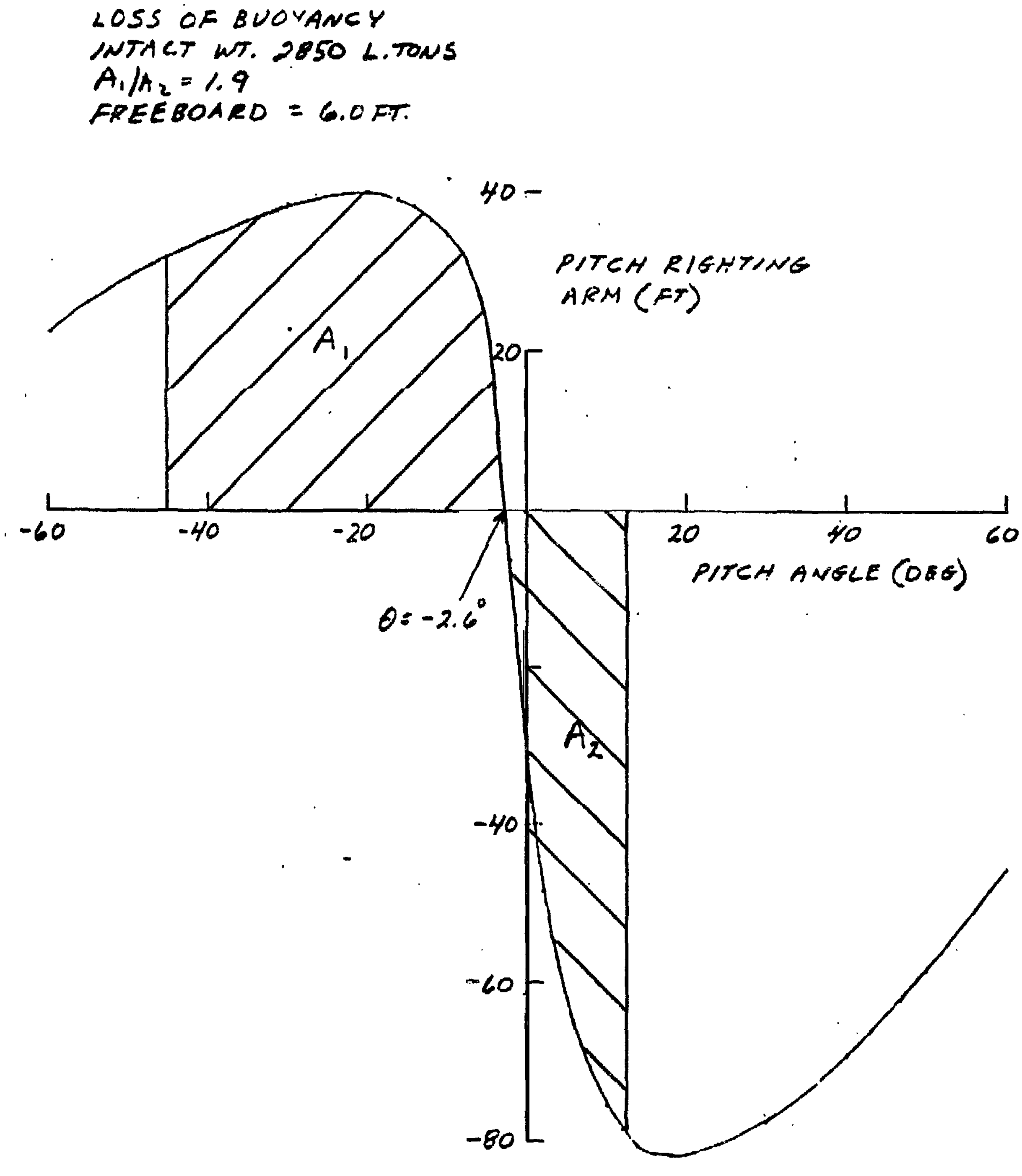


Figure 2.2.5-9 PITCH-RIGHTING ARM VERSUS PITCH ANGLE FOR IMPACT AT STATION 105 (CASE 2)

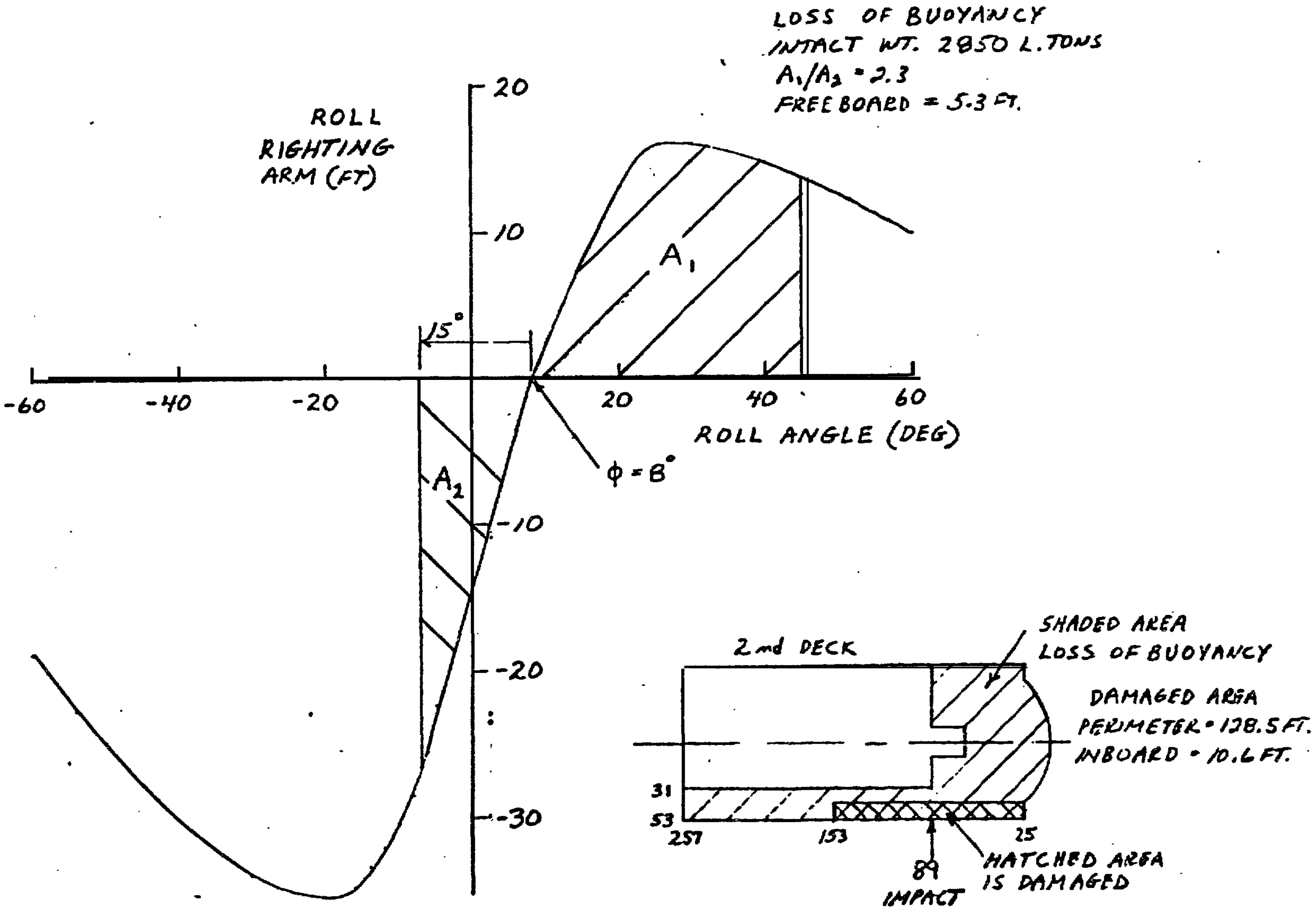


Figure 2.2.5-10 ROLL-RIGHTING ARM VERSUS ROLL ANGLE FOR IMPACT AT STATION 105 (FULLY FLOODED) CASE 2

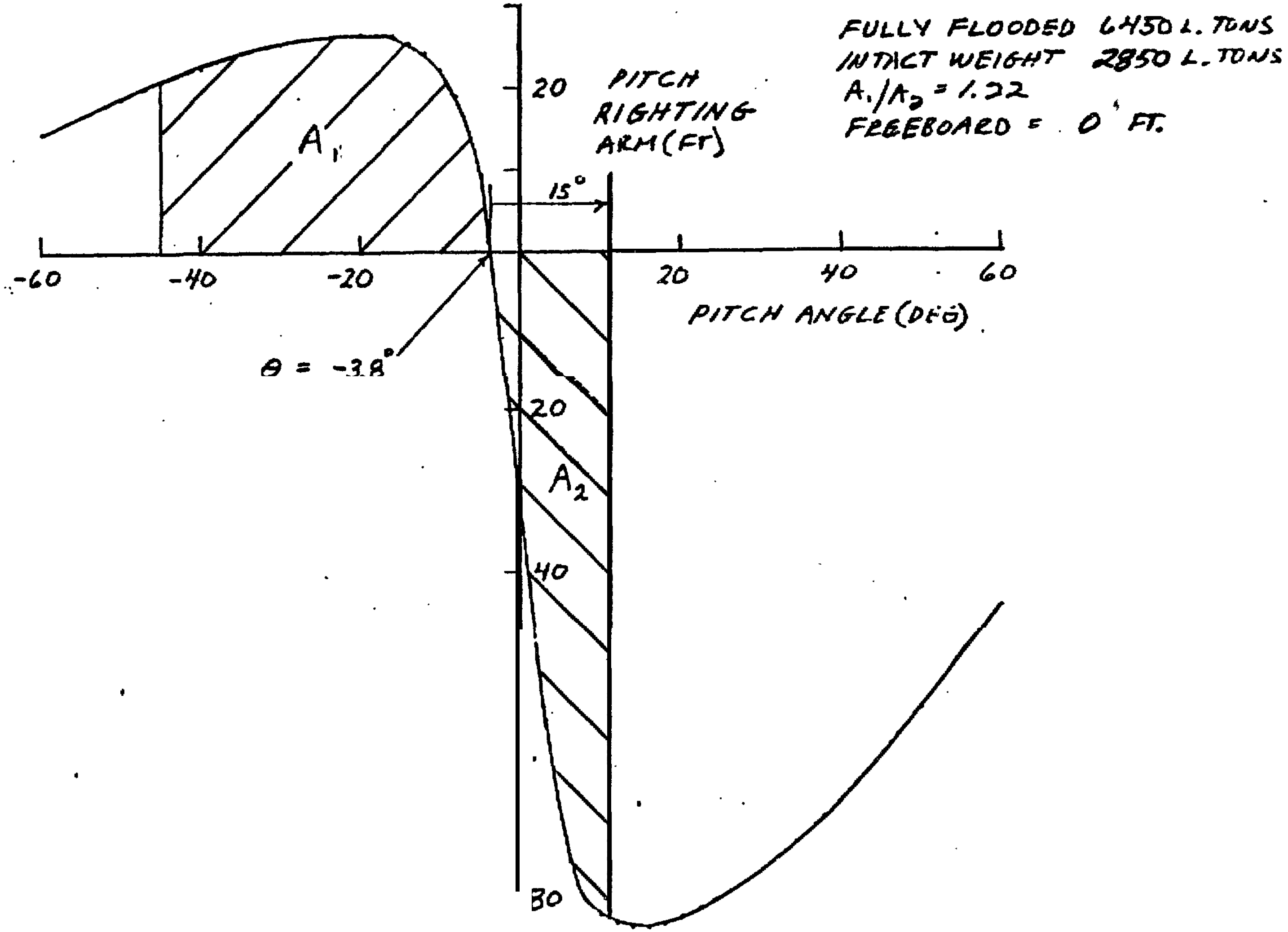


Figure 2.2.5-11 PITCH-RIGHTING ARM VERSUS PITCH ANGLE FOR IMPACT AT STATION 105 (FULLY FLOODED) CASE 2

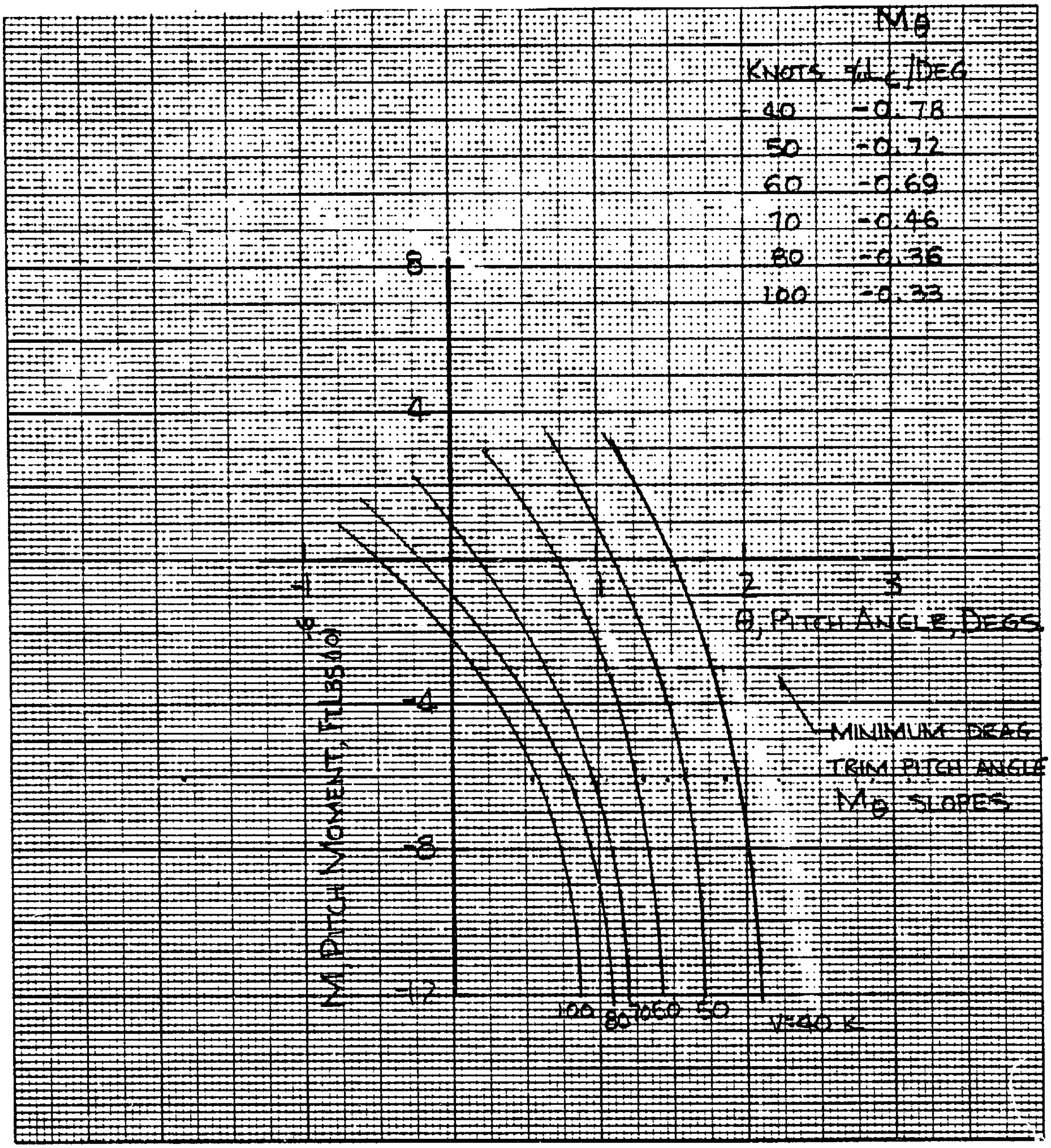


Figure 2.2.5-12 PITCH MOMENT VERSUS PITCH ANGLE FOR SELECTED SPEEDS

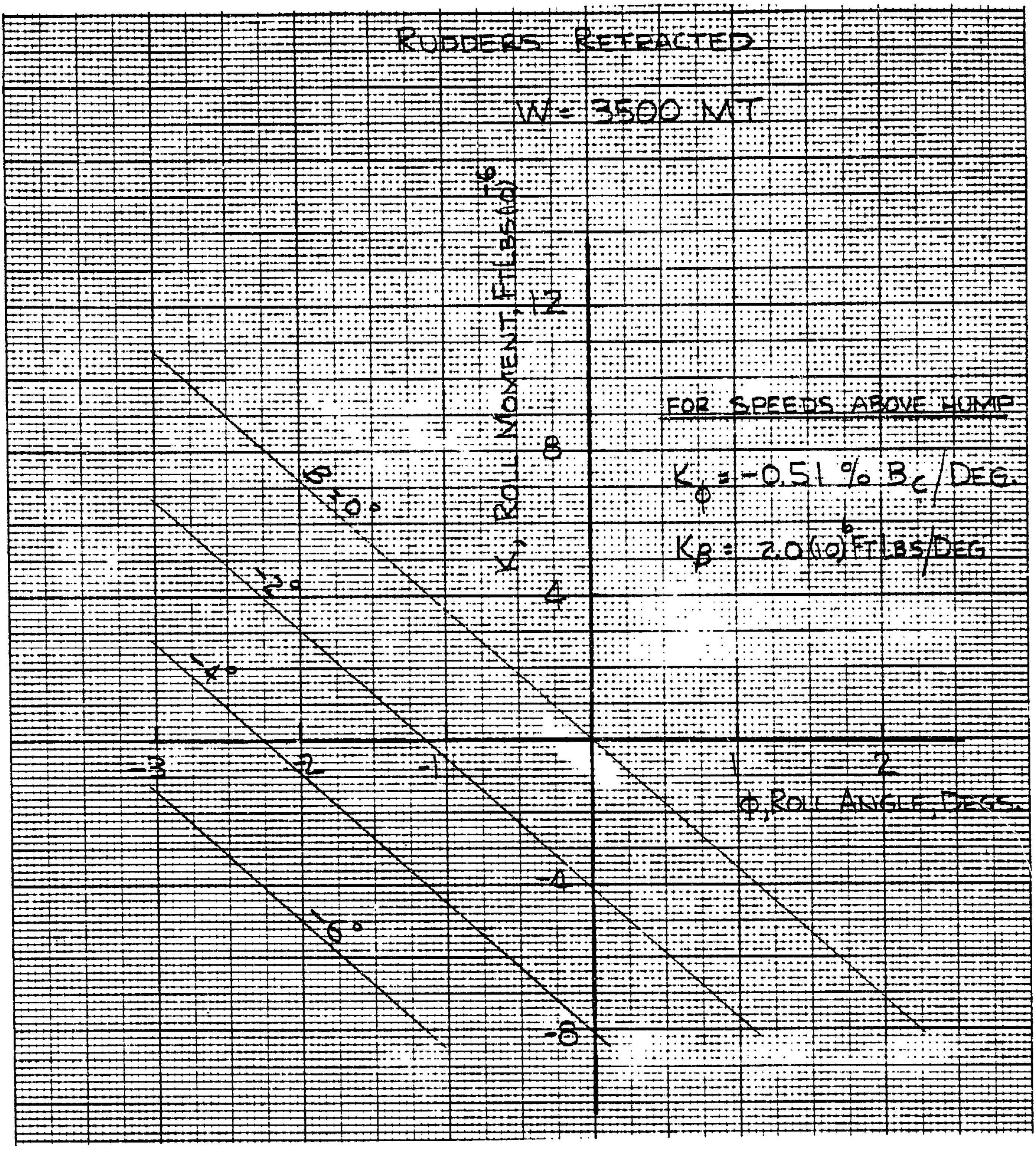


Figure 2.2.5-13 ROLL MOMENT VERSUS ROLL ANGLE FOR SELECTED SIDESLIP ANGLES

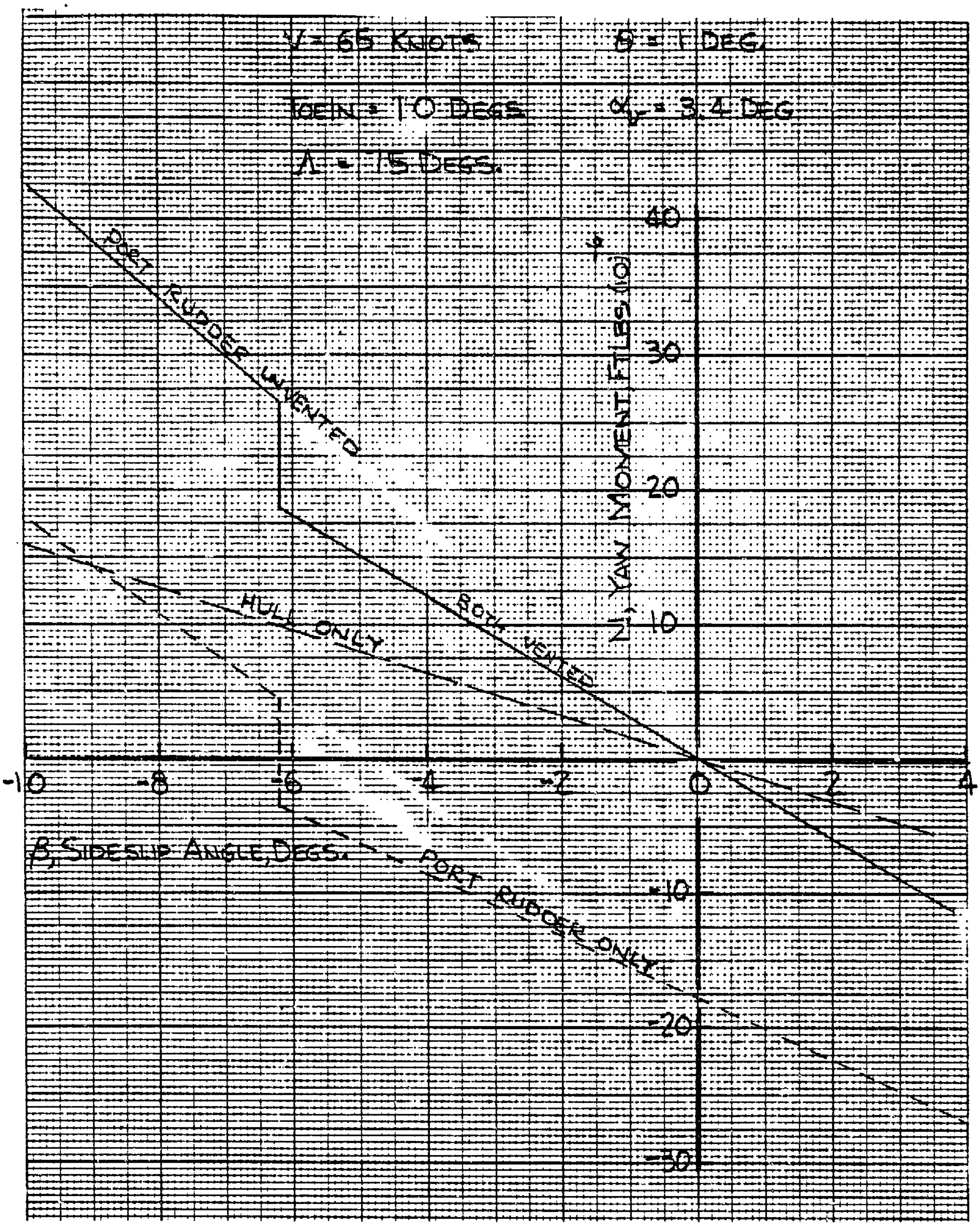


Figure 2.2.5-14 YAW MOMENT VERSUS SIDESLIP ANGLE

SIDE FORCE DAMPING
DUE TO
ROLL RATE

YAW DAMPING
DUE TO
ROLL RATE

ROLL DAMPING
DUE TO
ROLL RATE

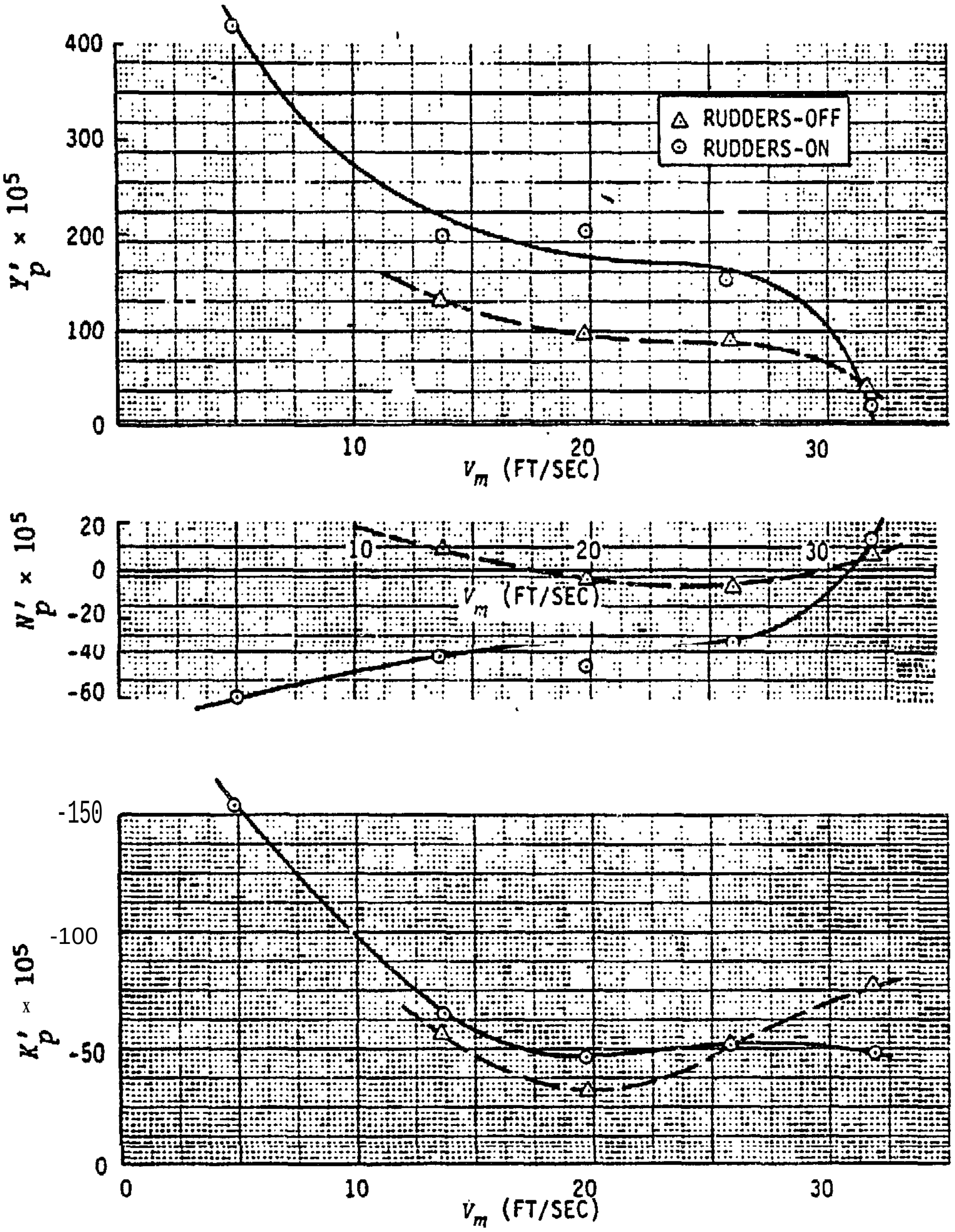


Figure 2.2.5-15 2KSES DIMENSIONLESS ROLL-DAMPING COEFFICIENTS VERSUS MODEL SPEED EVALUATED FROM DTNSRDC PMM TESTS

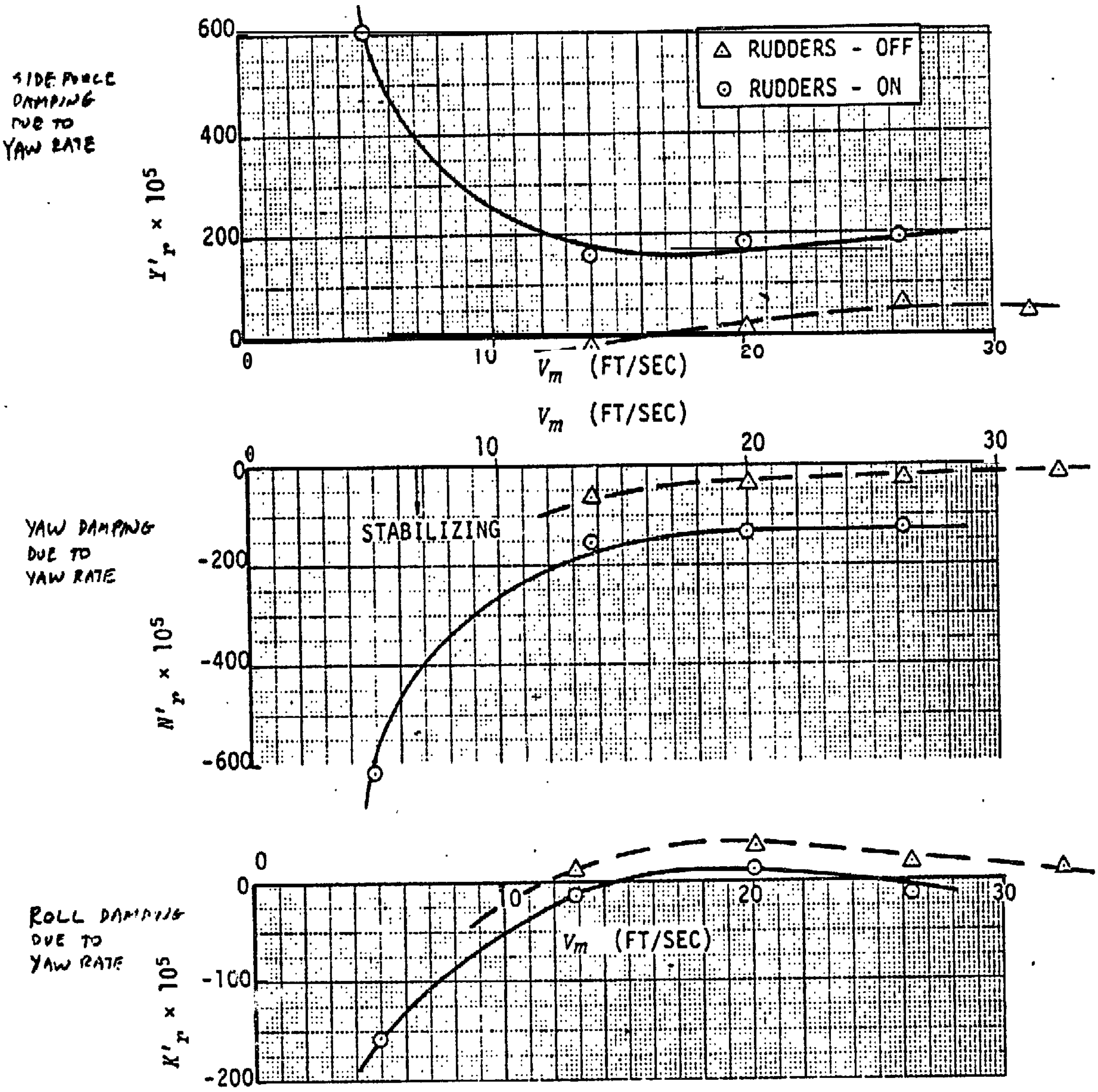


Figure 2.2.5-16 PURE YAW-DAMPING DIMENSIONLESS COEFFICIENTS VERSUS MODEL SPEED

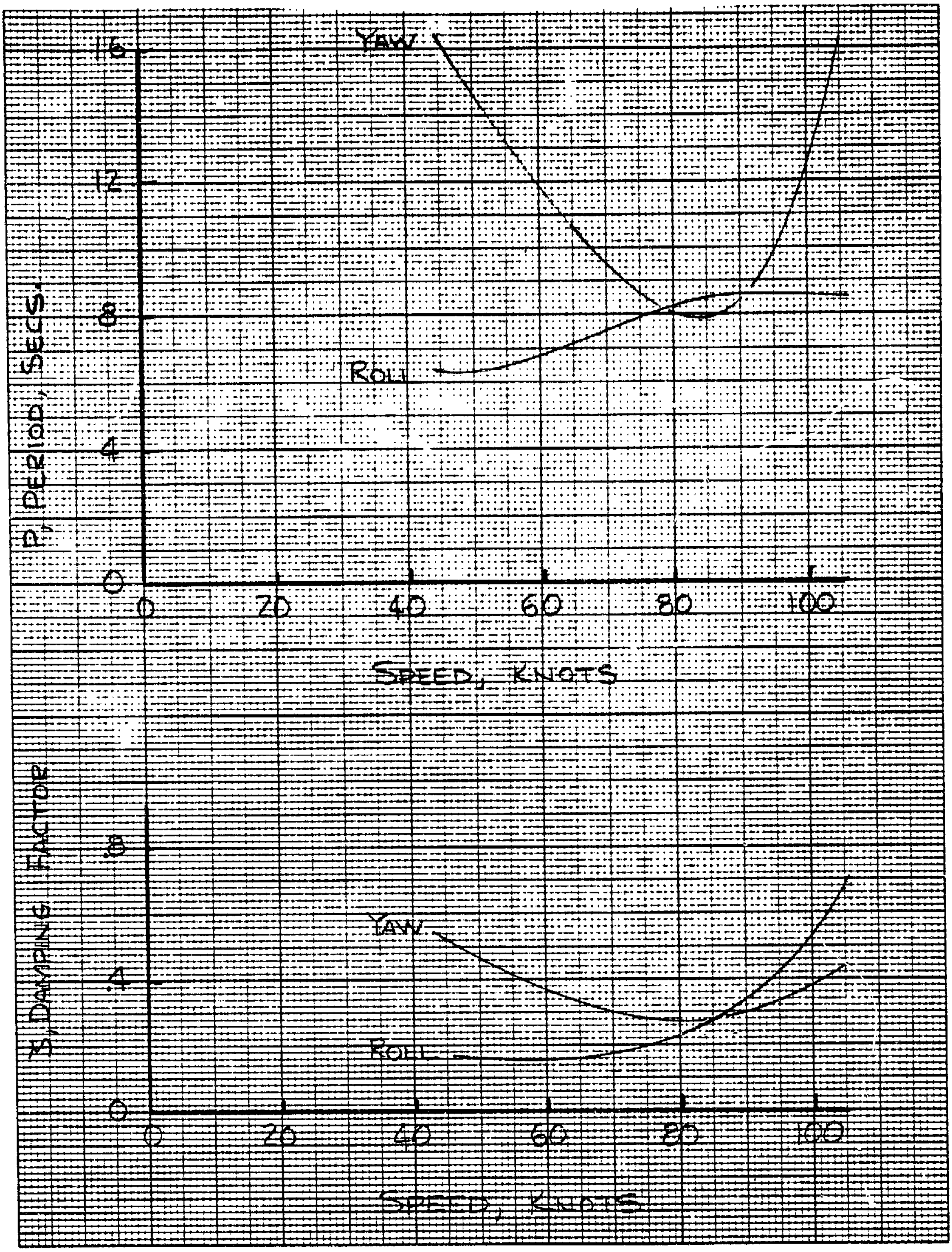


Figure 2.2.5-17 LATERAL STABILITY CHARACTERISTICS
BASED ON DTNSRDC PMM AND LOL TESTS

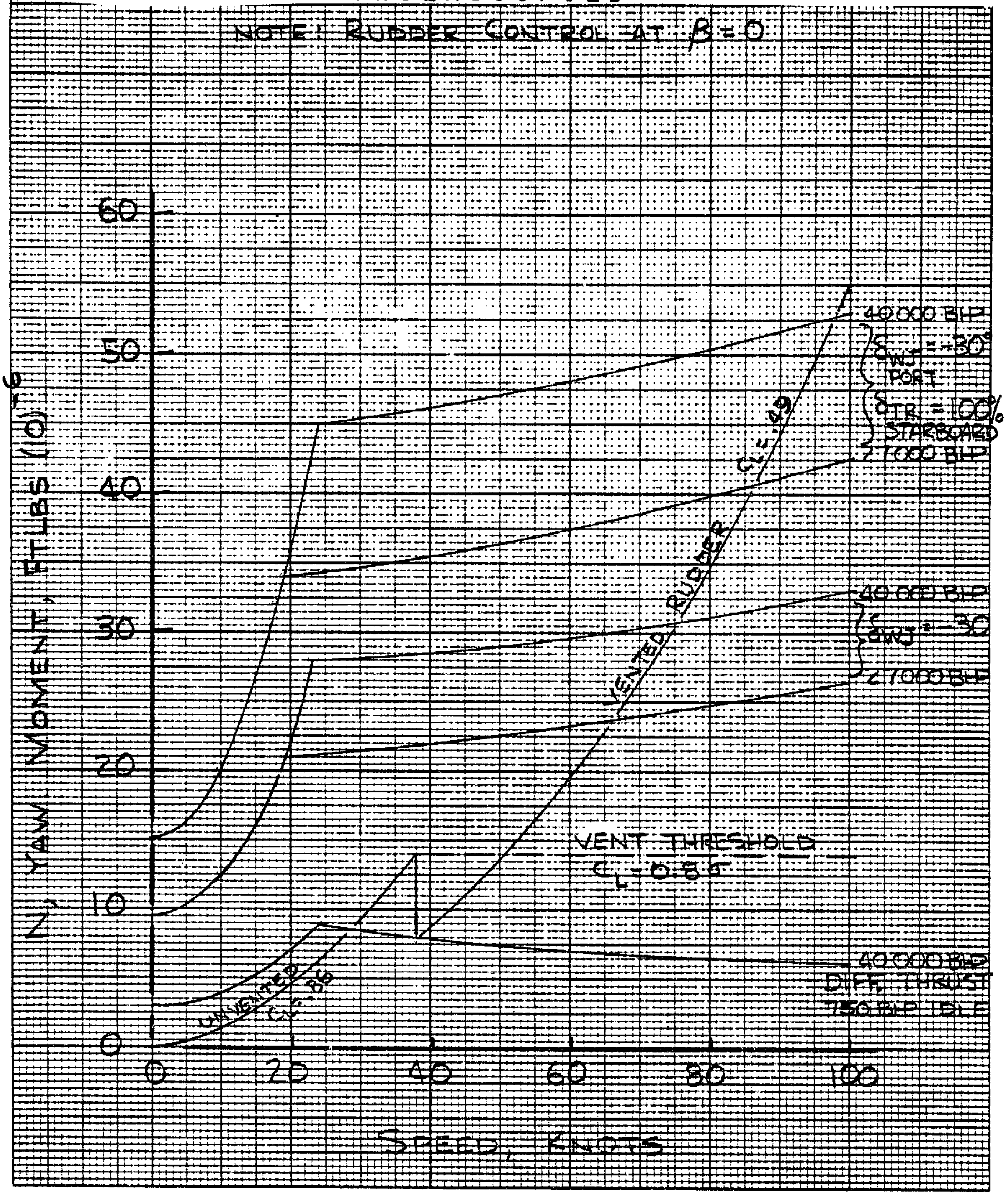


Figure 2.2.5-18 SWING RUDDER AND PROPULSION YAW CONTROL VERSUS SPEED

2.2.6 Geometric Form

The geometric form of the LSES has been selected to provide the best balance of performance and stability characteristics.

The center hull, which is 26 feet deep, contains ail the fuel, the crew hotelling, and the majority of the machinery.

The sidehulls have a width of 7.5 feet and a waterline length of approximately 78 percent of the mean cushion length,

Retractable rudders at the stern augment stability and provide steering forces at high speeds.

Inherent passive stability is provided over the entire speed/sea state envelope.

2.2.6.1 Hull Lines Drawing

The hull lines drawing (AD-76-52, 3KSES ANVCE Hull Lines - Waterjet) is provided in the appendix of drawings.

2.2.6.2 Control Surface Drawing

The rudder, which is geometrically similar to that successfully used on the SES-100B, is defined by figure 2.2.6-l and by general arrangement drawing AD-76-40 found in appendix B.

SWING RUDDER CAMBERED SECTION

$$\frac{\Delta Y}{X} = 0.15000$$

$$\frac{Y}{X} = 0.05435$$

$$\frac{R}{X} = 0.00281$$

CAMBERED CURVE

$$\frac{y}{\Delta Y} = \frac{1}{2}\left(\frac{x}{X}\right)^{\frac{1}{2}} - \frac{32}{9}\left[1-\left(\frac{73}{64}\right)\left(\frac{x}{X}\right)\right]\sin^2\frac{\pi}{2}\frac{x}{X} + \frac{8}{9}\left[1-(0.85225)\left(\frac{x}{X}\right)\right]\sin^2\pi\frac{x}{X}$$

TRIPARABOLIC CURVE

$$\frac{y}{Y} = 1.38\left(\frac{x}{X}\right)^{\frac{1}{2}} + 0.31\left(1-2.2255\frac{x}{X}\right)\sin^2\frac{\pi}{2}\frac{x}{X} - 0.0775\sin^2\pi\frac{x}{X}$$

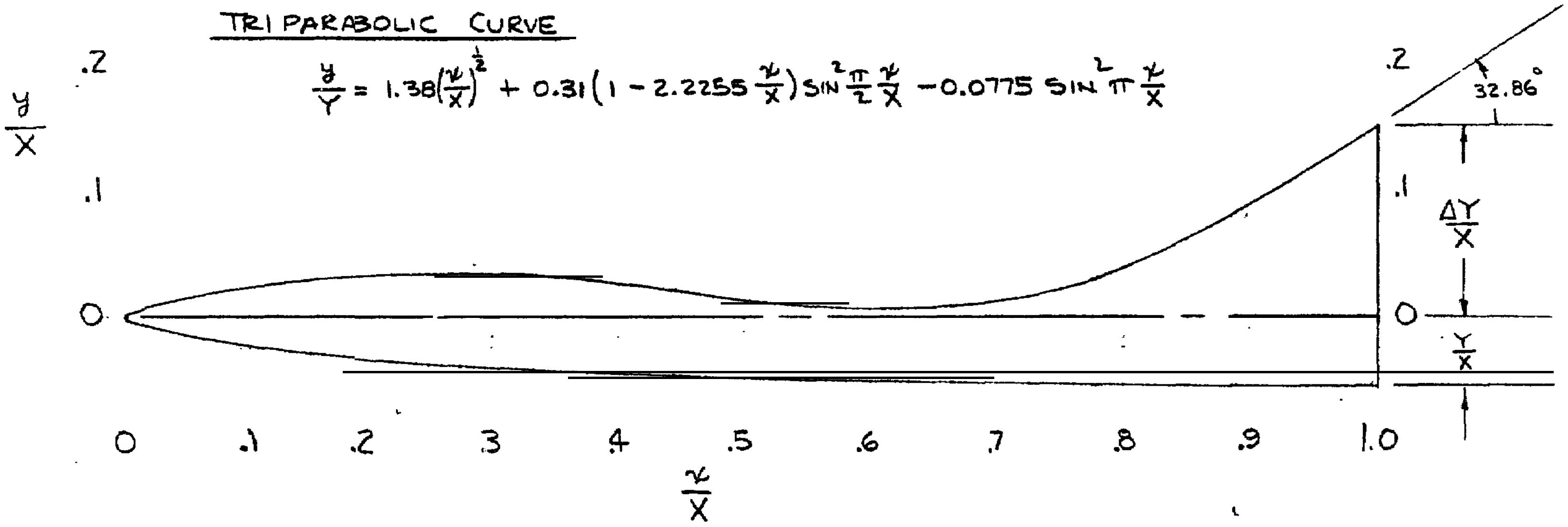


Figure 2.2.6-1 SWING RUDDER CAMBERED SECTION

2.2.7 Ride Quality

The effectiveness of the SES as a weapons system is affected by the ride quality of the ship. In order to aid in the assessment, estimated response data showing vertical and lateral accelerations is presented.

Figure 2.2.7-l shows the rms vertical acceleration in meters per second squared as a function of ship heading relative to wave direction, This data is presented for the cg and bridge locations for a speed of 40 knots. The trends are as expected, with the acceleration being maximum for the head sea (180 degrees) and near minimum for the beam sea (90 degrees). The ride control system (RCS) reduces the vertical accelerations by 20 to 30 percent.

An important feature of the ride control system is its active pitch control system. Pitch control is accomplished by vectoring the waterjet thrust in the vertical plane in response to pitch rate signals. It has been found through full ship motion simulation studies that such control can reduce pitch motions which induce additive vertical accelerations at the bow and stern. Although the improvement in ride is proportional to the distance from the center of pitch rotation, the rms vertical acceleration at the bow in sea state 6 is reduced by about 15 percent by using pitch control.

Figure 2.2.7-2 shows the rms lateral acceleration as a function of ship heading for the same conditions as figure 2.2.7-l. Two observations may be made here: (1) the maximum acceleration occurs at about 135-degree heading, and (2) the RCS-on condition generates higher accelerations than the RCS-off condition. The first observation is explained by the fact that lateral acceleration is a function of the yaw, sway, and roll motions. The worst combination of these motions in terms of the lateral acceleration might logically be expected to occur at some heading between head and beam seas. The second observation is attributed to the increased immersion of the sidehulls resulting from an RCS-on condition, The coupling of ship to water is increased, thereby increasing the lateral forces on the ship.

It should be noted, however, that these observations are academic, since a correlation study between maximum 1/3 octave band values and rms values shows that the 1/3 octave band values corresponding to the lateral rms values are well below the 8-hour exposure limit.

Estimates of the 1/3 octave band for vertical accelerations are shown in figures 2.2.7-3 and -4, and for lateral accelerations are shown in figures 2.2.7-5 and -6. This data is for the LSES at a capacity load displacement of 3100 tons. For the 1990 point design at 3500 tons, the vertical acceleration may increase up to 7 percent for head seas and may increase about 10 percent at a heading of 135 degrees. For the remaining headings, there is no significant change, nor is there any significant change in frequency.

Lateral accelerations can be expected to be less than or equal to the LSES and in any case better than the ISO 8-hour exposure criteria limit.

Overlays for the 1/3 octave band data are included for use with figures 2.2.7-3, -4, -5, and -6. They show the 4-hour exposure criteria called for in the Checklist for ANVCE Surface Point Design Reviews (WP 015).

Figure 2.2.7-7 is a typical time history of the vertical accelerations of an LSES in a head sea state 5 at 55 knots, It is typical with regard to wave form (crest factor, band width) of all the high-speed, high sea state accelerations.

The statistical acceleration data presented here was computed from time histories of lighter weight vehicles. Unfortunately, the statistical computation did not include the computation of exceedances. Therefore, we are unable to supply such information at this time.

Power changes for the lift and propulsion power for RCS operation have also been estimated. Results indicate that the propulsion system with RCS on will require about 5 percent more horsepower than RCS off for sea states 5 and 6 at 40 knots. For sea state 4 and below, there is no significant change in power.

The lift system power varies considerably with speed, sea state, and RCS bias positions. However, the worst case can be assumed to occur at sea state 6 at 40 knots, where it is estimated that a lift power increase of up to 20 percent will be required for RCS-on condition. For lower speeds and sea states, the increase will be proportionately less.

Sea spectrums with the following significant wave heights were used for generating the data submitted in this section:

SEA STATE	SIGNIFICANT WAVE HEIGHT
3	3.4
4	7.0
5	10.0
6	15.0

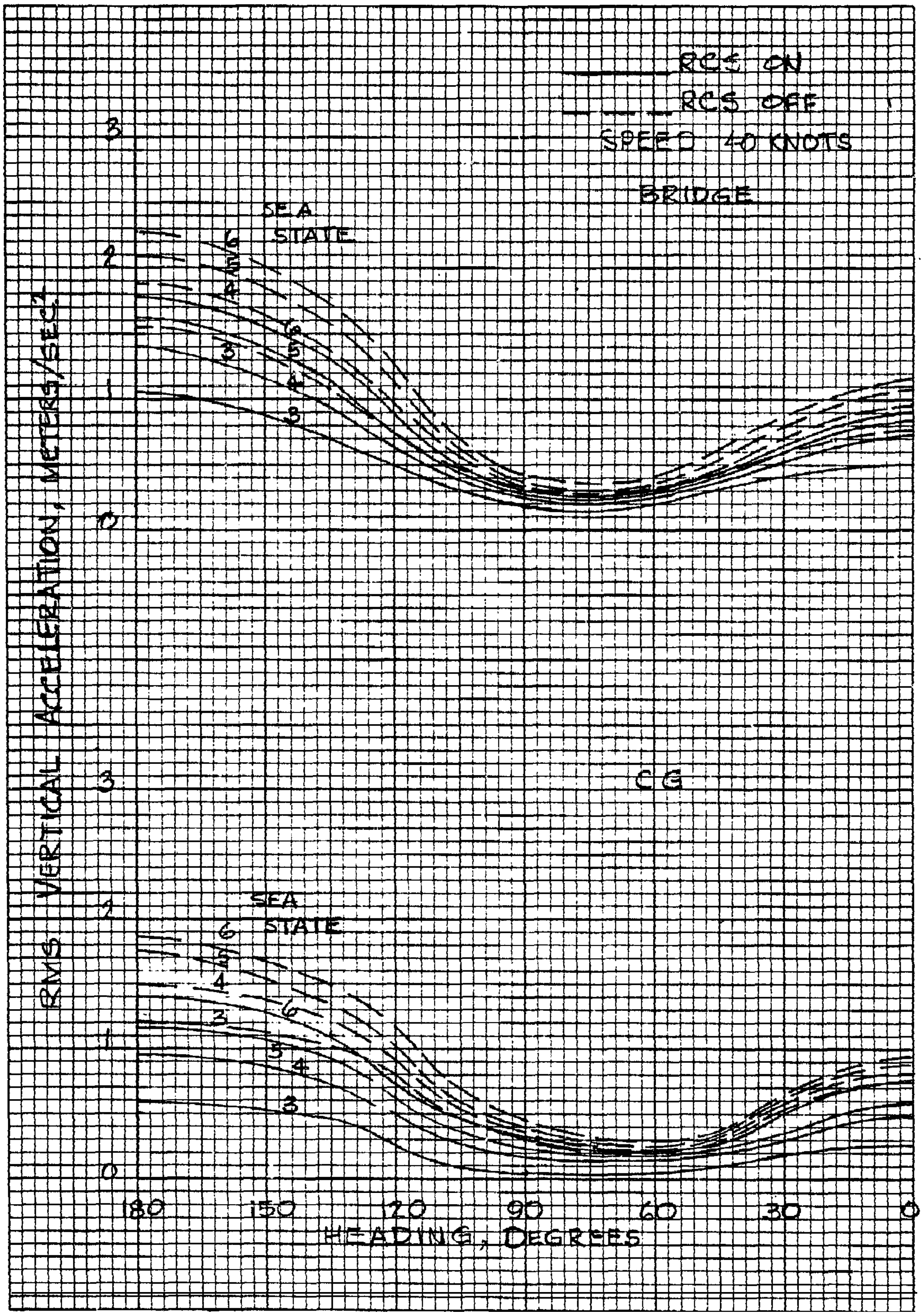


Figure 2.2.7-l VERTICAL ACCELERATION VERSUS HEADING AND SPEED, 40 KNOTS

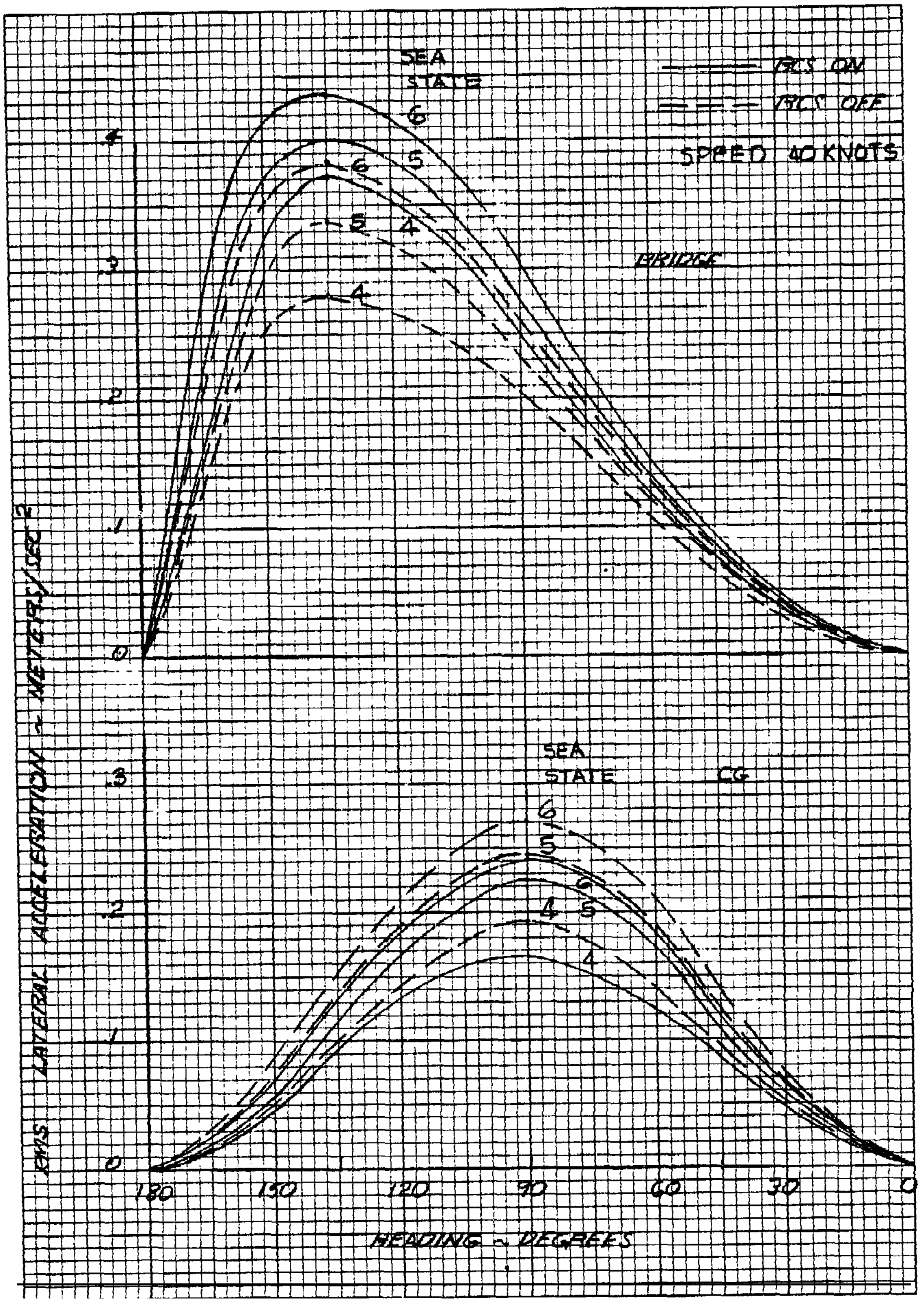
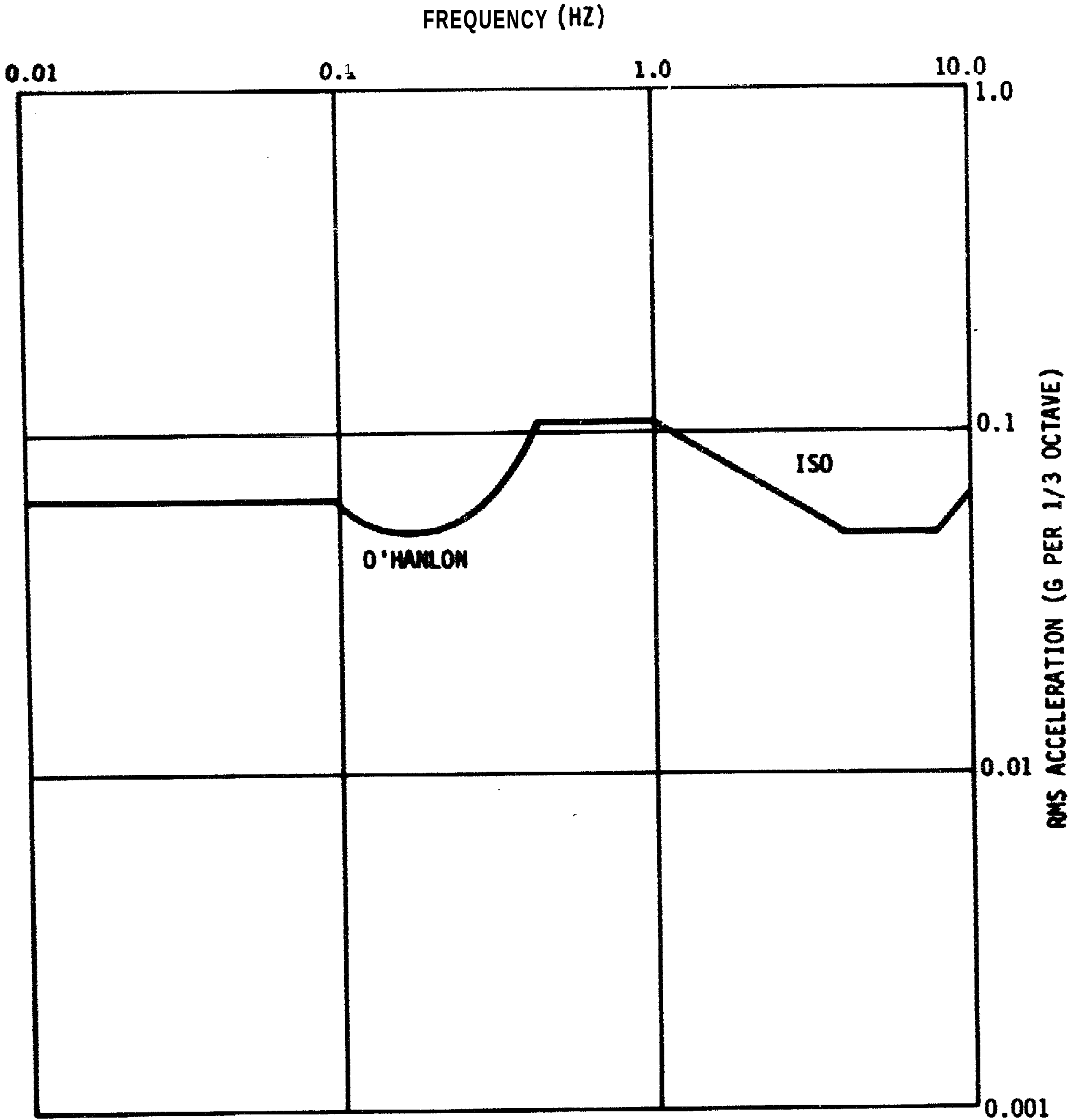
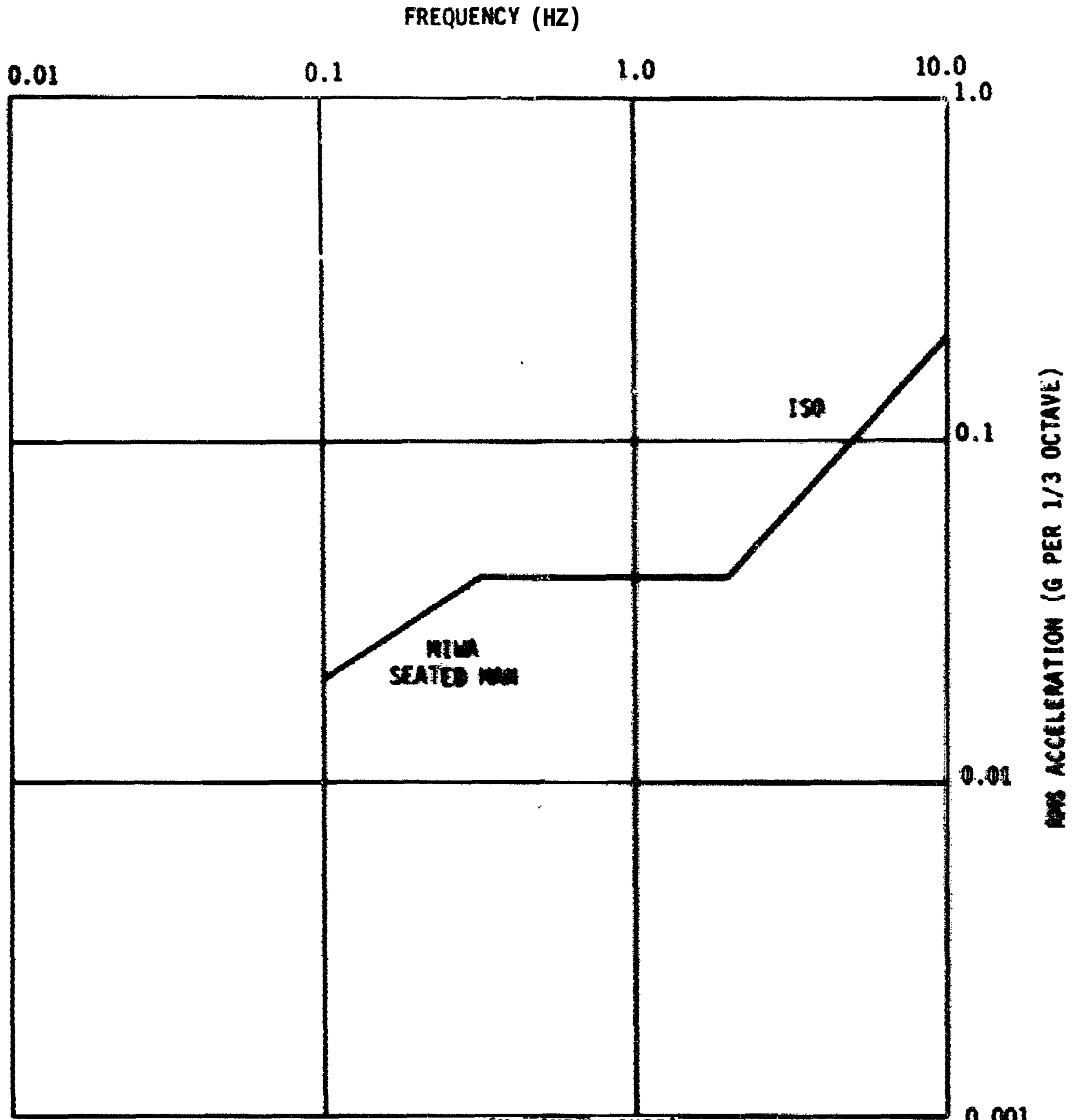


Figure 2.2.7-2 LATERAL ACCELERATION VERSUS HEADING, 40 KNOTS



VERTICAL (Z-AXIS) ACCELERATION
EXPOSURE LIMITS - 4 **HOURS**



TRANSVERSE (X- AND Y-AXIS)
ACCELERATION EXPOSURE LIMITS - 4 HOURS

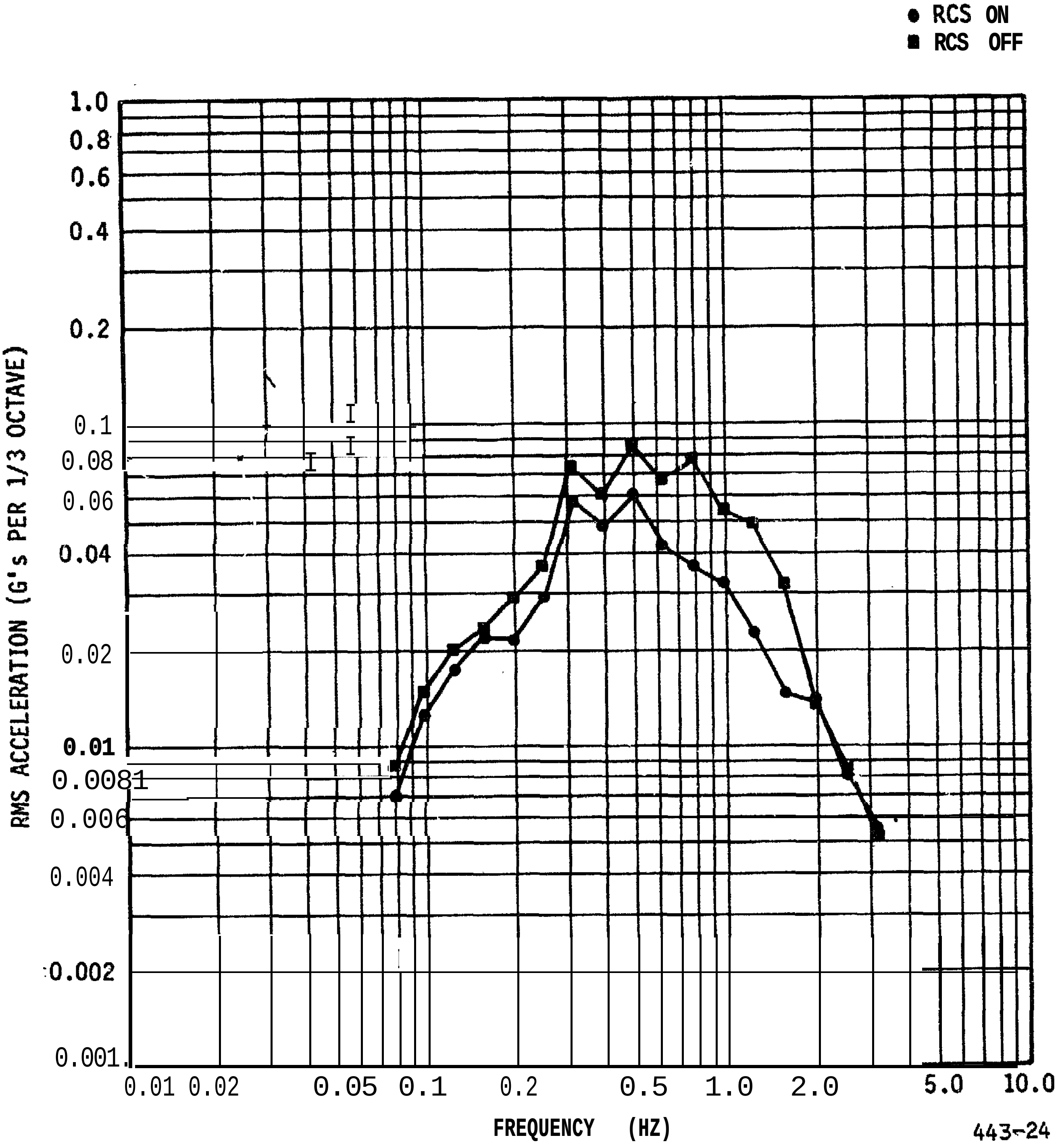


Figure 2.2.7-3 RMS VERTICAL ACCELERATION SPECTRUM,
LSES, CLD, BRIDGE, SEA STATE 5,
40 KNOTS, HEAD SEA

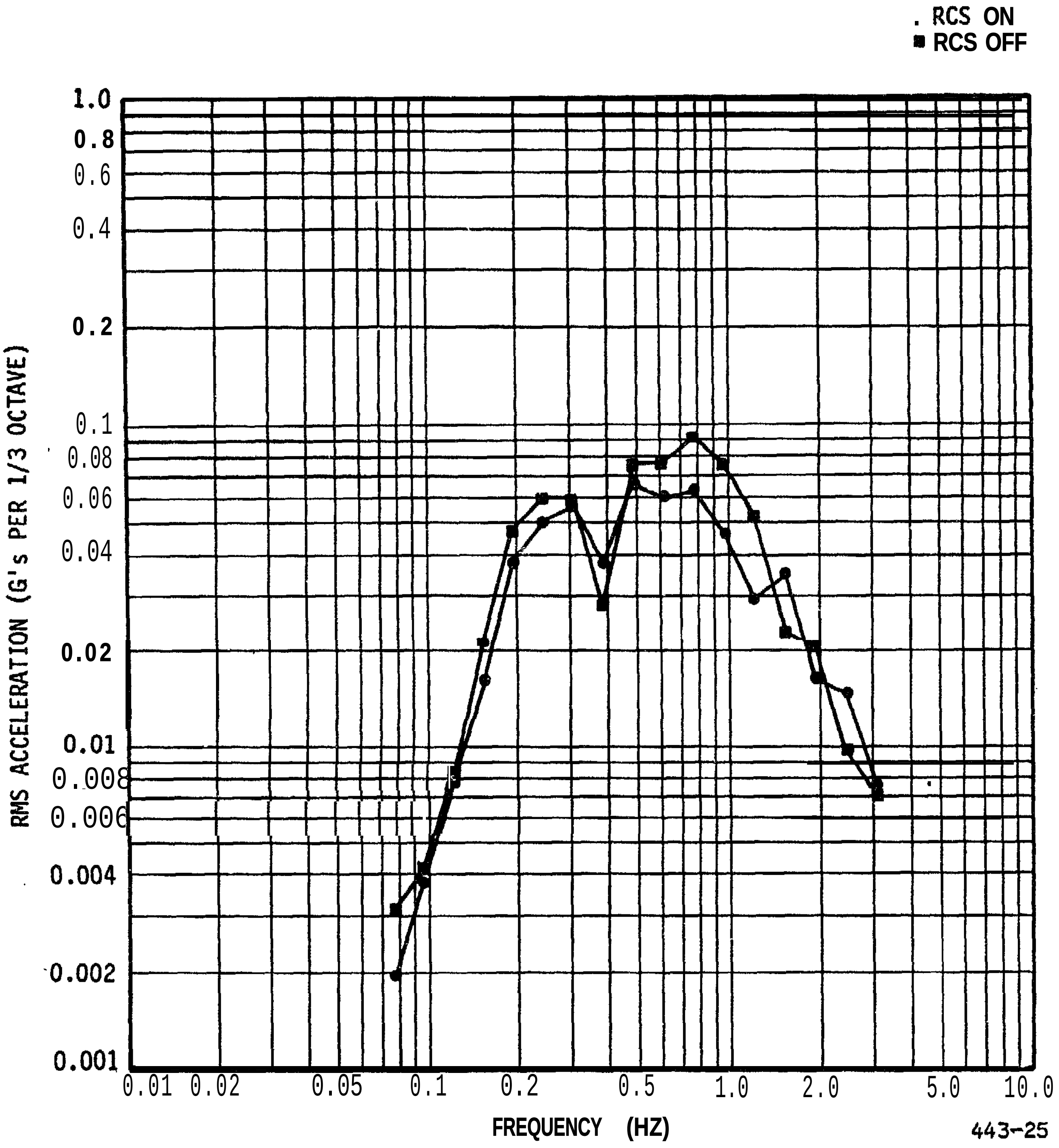


Figure 2.2.7-4 RMS VERTICAL ACCELERATION SPECTRUM, LSES, CLD, BRIDGE, SEA STATE 6, 40 KNOTS, HEAD SEA

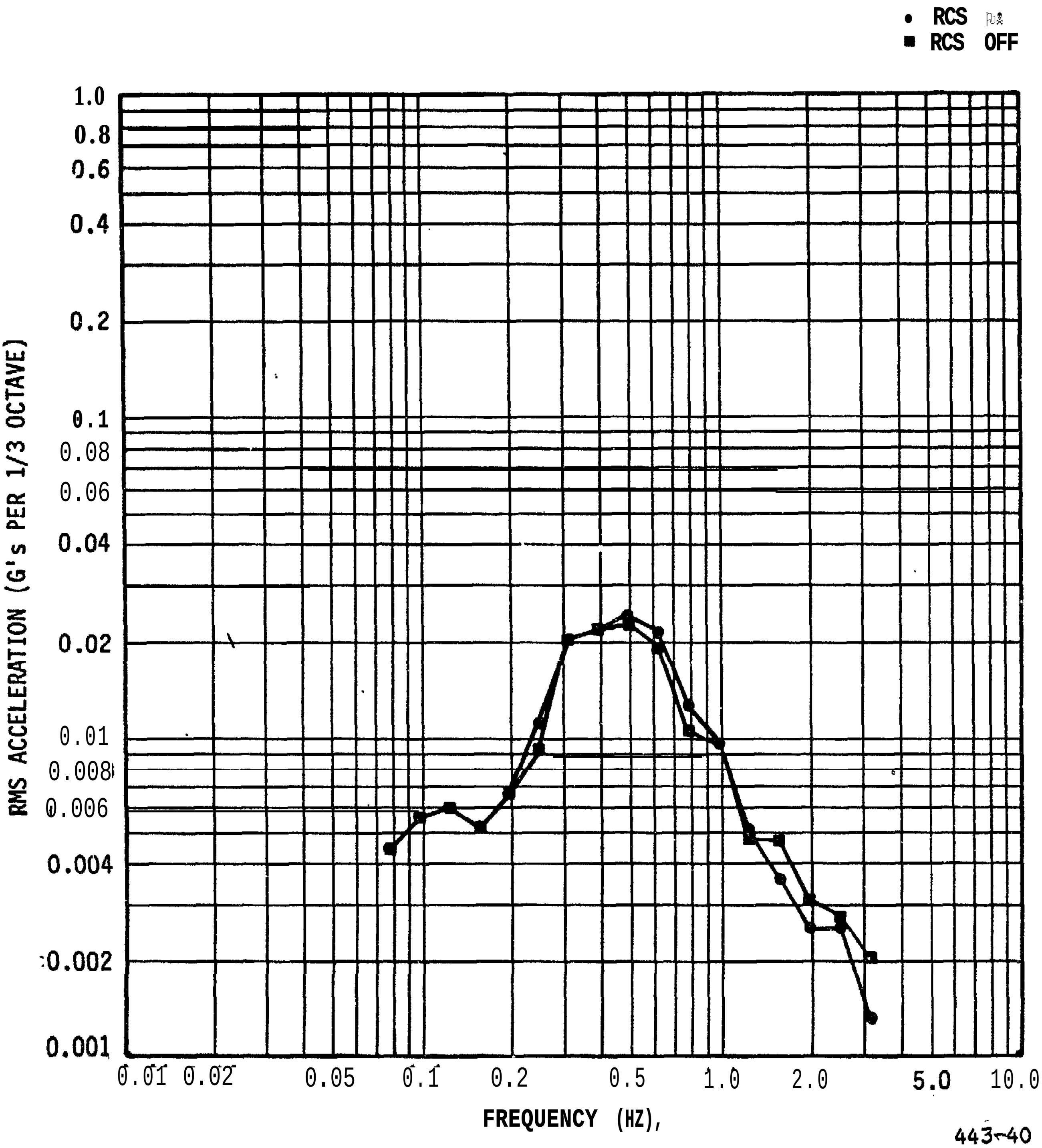


Figure 2.2.7-5 . RMS LATERAL ACCELERATION SPECTRUM,
LSES, CLD, BRIDGE, SEA STATE 5,
40 KNOTS, 135° HEADING

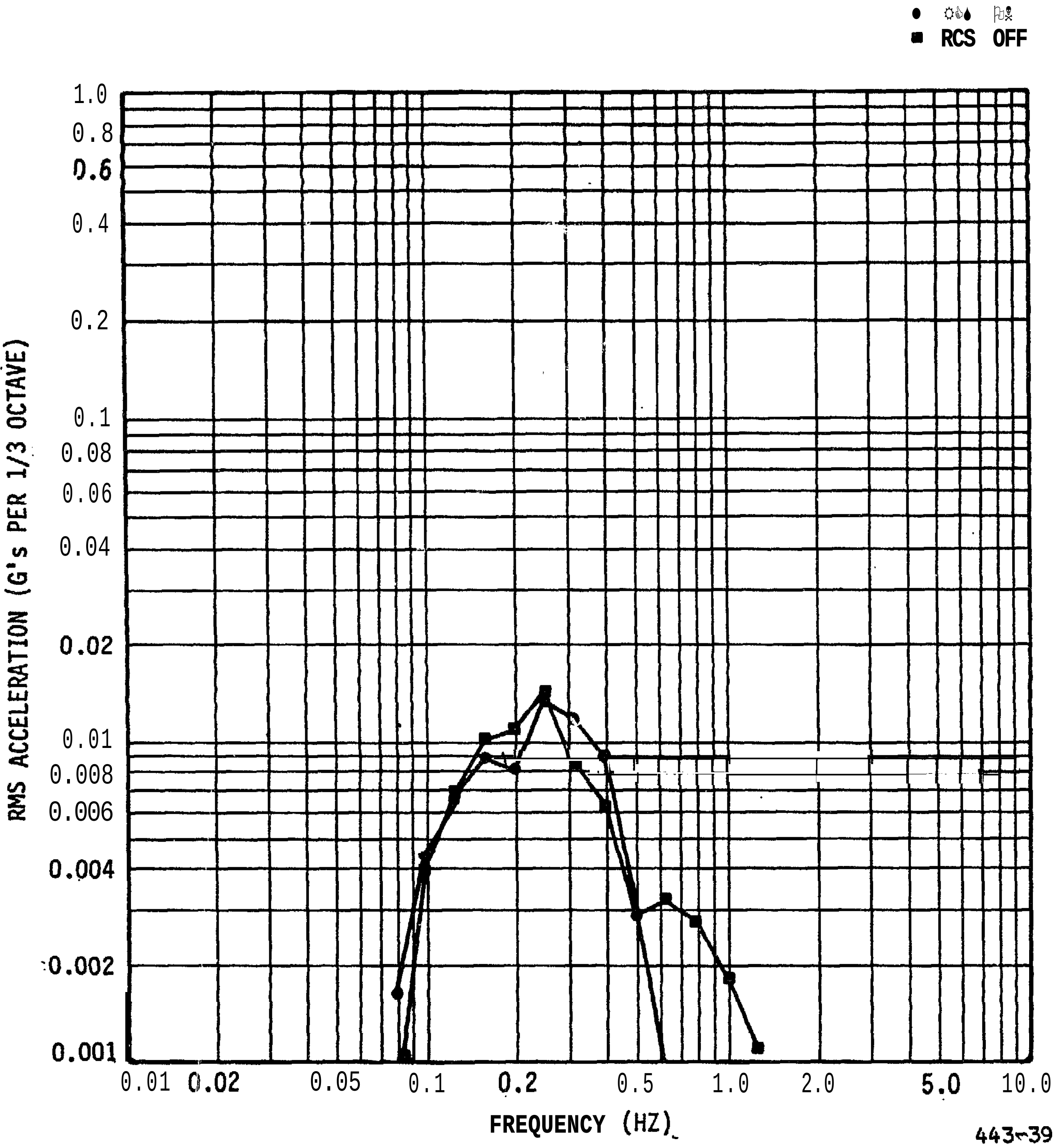
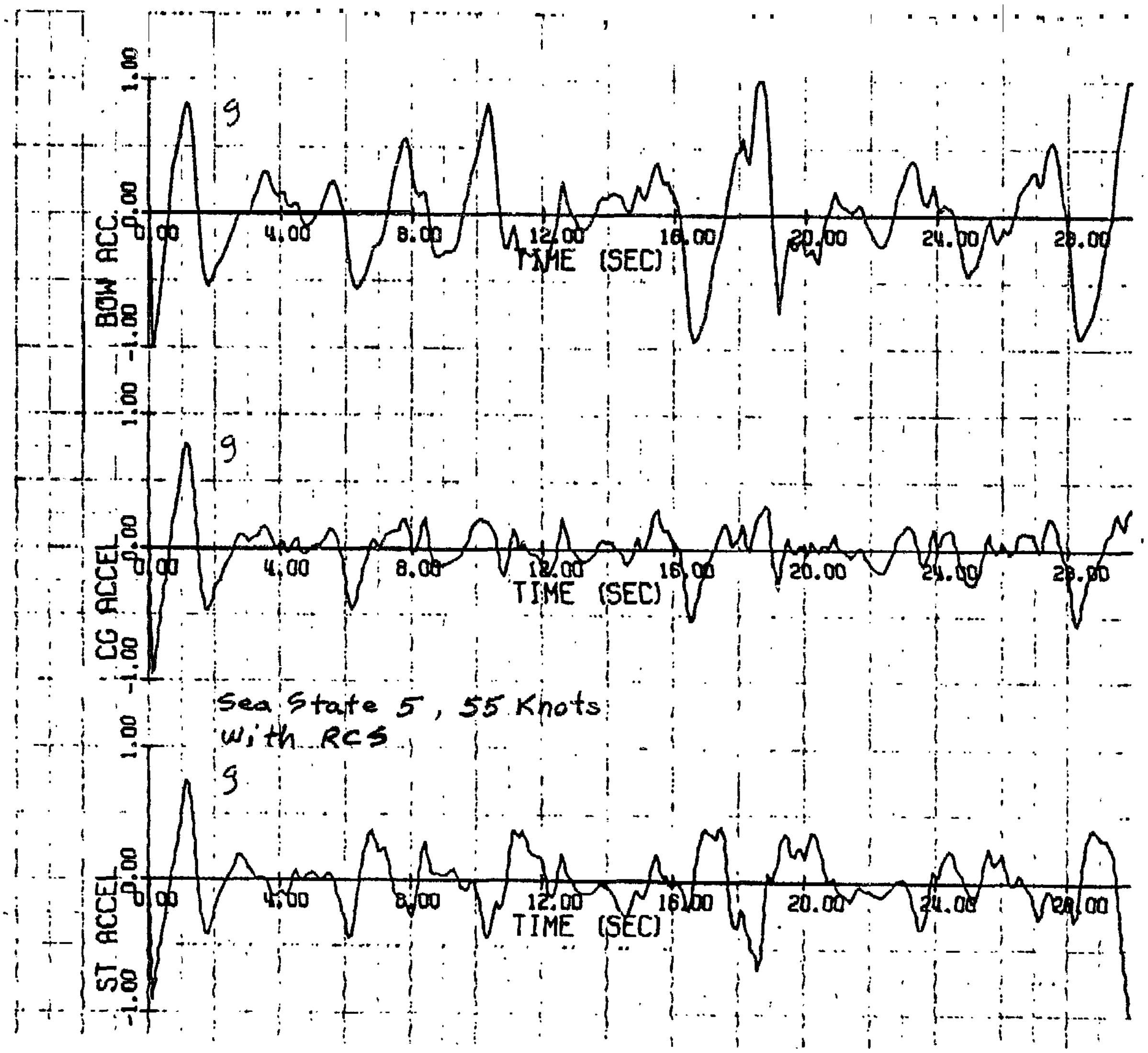


Figure 2.2.7-6 RMS LATERAL ACCELERATION SPECTRUM,
LSES, CLD, BRIDGE, SEA STATE 5,
40 KNOTS, 90° HEADING



Sea State 5, 55 Knots
with RCS

Figure 2.2.7-7 REPRESENTATIVE TIME RESPONSE OF AN LSES AT 55 KNOTS IN A HEAD SEA STATE 5

2.2.8 Manning

The philosophy underlying the far term LSES design was *to* minimize the number of crewmen on the ship while ensuring that the ship meets all functional and mission requirements imposed by the Top Level Requirements (TLR).

The organizational manning requirements for the LSES were developed in general accordance with OPNAV .10P-23 *Guide to the Preparation of Ship Manning Documents.*

The organizational manning requirements for the far term LSES are 16 officers, 11 chief petty officers, and 113 other enlisted men. Table 2.2.8-I presents the types and skill levels of the crew.

TABLE 2.2.8-I

MANNING FOR FAR-TERM 3000 TON SES

VEHICLE

OFFICERS	
Commanding Officer	1
Executive Officer	1
Operations Officer	1
CIC Ship Control Officer	1
Communications Officer	1
Electronics Readiness Officer	1
Engineering Officer	1
Engine Control Officer	1
Elect/Aux/Damage Control Officer	1
Weapons Officer	1
ASW Officer	1
Surface/AAW Officer	1
	12

CPO	
STGC	1
FTMC	1
OSC	1
RMC	1
ETC	1
ENC	3
EMC	1
MTC	1
	10

OTHER ENLISTED	
QM1	2
QM2	1
SM1	1
SM2	2
EW1	2
EW2	2
EW3	2
OS1	2
OS2	2
OS3	2
TM2	1
ST1	1
ST2	1
ST3	2
MT1	1
MT3	2
RM1	3
RM2	4
RM3	6
DS1	1
DS3	2
FT1	2
FT2	2
FT3	2
ET1	2
ET2	2
ET3	2
IC1	1
IC2	1
IC3	2
SN	7
EN1	3
EN2	3
EN3	4
EM1	2
EM3	3
FN	3
HT1	2
HT2	1

TABLE 2.2.8-I (Cont)

				OTHER ENLISTED	
				SK1	1
				SK3	2
				HM1	1
				MM1	2
				MR1	1
				MS1	1
				MS2	1
				MS3	2
				SH1	1
				SH2	1
				YN1	1
				BM1	1
				BM2	1
					61
SUB-VEHICLE					
Aviation Officers	2	ADJC	1	ADJ1	1
Assistant Aviation Officers	2			ADJ2	1
	4		1	AMS1	1
				AO1	1
				AX1	1
				AE1	1
				AE3	1
				AT1	1
				AW1	1
				AW2	1
					10
TOTAL COMPLEMENT	16		11		113

GRAND TOTAL 140

2.3 Ship Subsystem Description

2.3.1 Structure

2.3.1.1 Hull Materials and Method of Construction

The hull structural materials selected for the year 1990 3KSES are 5456-H343 and -H117 aluminum sheet and plate and 5456-H111 aluminum extrusions, Aluminum alloy 5456 was selected because of its high strength-to-weight ratio, It possesses the highest parent metal and as-welded strength properties of the marine aluminum alloys; it is readily weldable and machinable, highly resistant to corrosion in marine service, and low in cost. Tempers H343 and H117 were selected because of their inherent resistance to exfoliation corrosion. The other principal marine aluminum alloys, 5086 and 6061, are lower in both base metal and as-welded strength. Fatigue strength of 5456 is comparable to 5086.

This material selection is based on a SES structural optimization and hull materials tradeoff study performed in 1969-70 (reference 1). The results of this study show that a hull constructed of 6A1-2Cb-1Ta-1Mo titanium would yield the lightest structural weight. However, the fabrication cost tradeoff study shows that an all-welded titanium hull structure is cost-prohibitive at this time and will still be cost-prohibitive for 1990 hull construction. The next lowest structural weight fraction was obtained by using high strength 5xxx series aluminum alloy. This resulted in a relatively low fabrication cost, and it was, therefore, recommended for SES hull construction.

By the year 1990, it is anticipated that sufficient experience in fabrication and application will be available such that high strength composite laminate materials can be used to strengthen primary structural elements in selected areas of high local loads. The composite material considered at this time as best suited for local reinforcement is a uniaxial ply graphite-epoxy prepreg. This selection is based on a cost and weight tradeoff study performed under the 2KSES study contract (reference 23. The main advantages of this material are its high strength-to-weight ratio and its ease of application to structural members in local areas of high stress, thereby eliminating the need to machine off excess material. In the fully cured condition, this material can be obtained in the required thicknesses and widths and, when bonded to a structural member, it can be cured at room temperature. It will be cost-effective in 1990 when higher volume production results in low costs and its high strength, high modulus, low weight, and ease of application are considered.

The method of construction is a combination of both aerospace and ship building techniques. Because of the low structural weight fraction required for a high performance ship design such as the 3KSES, every advantage must be taken of the materials of construction and methods of structural analysis. Bulkhead webs are allowed to go into partial diagonal tension at high shear loads to take advantage of the closely spaced stiffeners on the bulkheads, Advantage is also taken of the membrane tension effects in flat plate bending for all structure designed by pressure.

Higher material allowable stresses are used for structural components analyzed by risk analysis methods and for multiple load path structure analyzed by non-statistical methods, thereby saving additional weight,

Allowable stresses of all plate, sheet, and extruded elements of primary structure analyzed by risk analysis methods, the single failure of which could result in the loss of either structural or watertight integrity of the subsystem, shall correspond to the mean-value material properties presented in table 2.3.1-I. This table includes typical coefficients of variatisn for various material properties that can be used in the absence of actual test data.

TABLE 2,3,1-I

MATERIAL STRENGTH PROPERTIES, 5456 ALUMINUM, MEAN VALUES

SYMBOL-MEAN STRESS	UNITS	5456 BASE METAL		5456 WELDED*	
		SHEET AND PLATE	EXTRUSION	SHEET AND PLATE	EXTRUSION
		-H116/117	H111	H116/117	H111
$\bar{\sigma}_{TU}$	KSI	53.4	48.7	48.7	47.5
$\bar{\sigma}_{TY}$	KSI	38.3	30.2	22.0	22.0
$\bar{\sigma}_{CY}$	KSI	31.3	25.5	22.0	22.0
t_{SU}	KSI	31.3	27.8	30.2	27.8

*Heat-affected zone only

1. COV for ultimate strength = 0.05
2. COV for yield strength = 0.07
3. Modulus of elasticity: $\bar{E} = 10 \times 10^6$ PSI; COV = 0.3 (approx)
4. Modulus of rigidity: $\bar{G} = 3.85 \times 10^6$ PSI
5. COV for fracture toughness of metallic materials: 0.07
6. The coefficients of variation (COV) were obtained from: Haugen, Edward B., and Wirsching, Paul H., *Probabilistic* Design, *Part 3*, (Machine Design, **May 15, 1975)**, pages 83-87.

Allowable stresses for all plate, sheet, and extruded single load path elements of primary structure, not analyzed by statistical methods, the single failure of which could result in the loss of structural or watertight integrity of the subsystem, shall correspond to the minimum guaranteed properties from MIL-HDBK-5, table 2.3.1-II, and material properties from NSRDC material information profile report (reference 3).

Allowable stresses for plate, sheet, and extruded multiple load path elements of redundant structure, not analyzed by statistical methods, in which the failure of an individual element results in a safe redistribution of load with no loss in watertight integrity, shall correspond to typical material properties established by manufacturer or MIL-HDBK-5 stress strain curves as shown in table 2.3.1-11.

All of these analytical techniques and the structural design criteria utilized result in thinner material gages than are normally used in conventional ship building. Therefore, welding techniques for an all-welded aluminum hull structure are more demanding than conventional ship building practices in that close attention must be paid to proper surface preparation, component alignment, inert gas shielding, and weld speed *to* assure high weld strengths and to minimize weld distortion, Close control of these parameters ensures that high strength welds are obtained consistently.

A weld development program was conducted on the 3KSES program to establish weld techniques and to determine their effects on distortion, strength, and tolerances. Automatic welds were successfully made on all plate sizes to be used on the 3KSES. Single-pass weld techniques developed in the program substantially reduce manufacturing time and improve weld quality. Test results show that porosity requirements and static and fatigue strengths had been met.

As a result of this program and the structural configuration selection, distortion will be minimized, Data from these tests was also used to establish criteria for acceptance of tolerances and weld distortions which might be encountered in the design and construction phases.

2.3.1.2 General Structural Arrangement

The internal structural configuration is a multi-deck compartmentalized structure consisting of three decks in the bow, four decks in the deckhouse area, and two decks in the hangar and helicopter pad area. Internal framing consists of transverse bulkheads on 24-foot centers, intermediate transverse frames on 8-foot centers, four full-depth longitudinal bulkheads spaced at approximately 20 feet, and two longitudinal sidehulls, This internal structure is covered with plating stiffened by longitudinal stringers on 12-inch centers. The internal decks are also stiffened by longitudinal stringers between transverse frames. The primary longitudinal bending and shear loads are carried by shell plating and the longitudinal bulkheads. The shell plating also carries all water pressure and deck loadings. All transverse bending and shear is resisted by the transverse bulkheads and frames. This is a significant loading condition in the 3KSES because of its large beam and because of the extended sidehulls.

TABLE 2.3.1-11

1990 3KSES

5456 ALUMINUM ALLOY MATERIAL PROPERTIES

ALLOY	5456 BASE METAL			5456 WELDED+		
FORM	SHEET	PLATE	EXTRUSION	SHEET	PLATE	EXTRUSION
TEMPER	H343***	H116/117	H111	H343***	H116/117	H111
F_{TU} (KS1)	63* / 53**	53 / 46	50 / 42	50 / 42	50 / 42	50 / 41
F_{TY} (KS1)	51 / 41	36 / 33	33 / 26	23 / 19	23 / 19	23 / 19
F_{CY} (KS1)	46 / 39	31 / 27	29 / 24	23 / 19	23 / 19	23 / 19
F_{SU} (KS1)	/ 31	/ 27	/ 24	/ 26	/ 26	/ 24

* Typical properties - redundant structure

** Minimum properties - single load path

*** 3/16-inch thick or less

† Heat-affected zone

Structural arrangement optimization studies for various size SESs were performed under a SESPO contract in 1969-70 (reference 1). These studies indicated that closely spaced bulkheads reduce the span of the shell longitudinal stringers carrying pressure loads. The closely spaced stringers make the plating more effective in compression, both with respect to hull bending and bending of the stringers under local water pressures. However, closely spaced bulkheads are in conflict with the internal accommodation requirements, and this problem was resolved at a small weight cost by selecting the bulkhead spacing at 24 feet and introducing shallow intermediate transverse frames to support the stringers and reduce their unsupported length. These transverse frames are full bulkheads between the second and third decks and 2-feet deep below the 01 deck at the bow, helicopter pad, and hangar areas, and 1-l/2-feet deep below the deckhouse roof.

The 12-inch stringer spacing, which is used throughout the ship, provides adequate access for welding of the skin-stringer panel sections. This spacing is based on a skin-stringer weight optimization study performed in Phase IIA of the 2KSES Design and Development Program (reference 4), which determined that minimum panel weight occurs at 8- to 12-inch stringer spacing depending on the type of loading the panel is designed to carry.

Structural continuity and stiffness are derived in the design of the panels by interconnecting both deck and bulkhead stiffeners with gusset plates thereby assuring joint strength and rigidity.

A preliminary structural analysis was performed to determine structural sizings of the stiffened shell plating, decks, and internal framing. Figures 2.3.1-1, 2.3.1-2, and 2.3.1-3 show the preliminary scantling sizes for a bow, midship, and aft section of the craft. Material corrosion allowances are not required because the hull material selected, 5456 aluminum alloy, is highly resistant to corrosion in a marine environment.

Advantage has been taken of the added depth of the 1990 ship in arriving .at the scantling sizes shown in figures 2.3.1-1, -2, and -3. Whereas the 1980 ship was a two-deck configuration, the three decks of the low area and four decks of the midship section provide considerably higher bending section moduli to the hull to resist the bending loads. This allows lighter-weight scantlings to be used in the main deck, keel, and sidewalls of the 1990 ship, offsetting the weight penalties of the added height surface areas and internal frames and bulkheads. Because the third and fourth decks are not continuous throughout the ship, a shear lag analysis was performed to determine the effectivity of the added decks in the hull bending section properties. Using a shear lag ratio of 3.5/1 for making a panel fully effective in resisting axial loads, it was shown that significant portions of the third and fourth decks were effective; full account of this is reflected in the overall ship sizing.

2.3.1.3 Key Structural Features

The stiffened shell demands particular attention because it represents approximately SO percent of the structural weight. It is the principal strength member of the hull girder in that it resists the primary longitudinal bending and shear loads, forms the torque box to resist hull torsional loads, and is designed to withstand water pressure loads.

Bell Aerospace Textron developed a skin-stringer optimization program under a 2KSES development contract (TADP H-S) for the Navy (references 5 and 6). This program is capable of optimizing skin-stringer configurations of various geometries and loadings, resulting in minimum weight skin-stringer panels.

Rapid computerized analysis permits evaluation of many geometric combinations and their effect on structural weight, such as stringer depth, stringer spacing, and skin-stringer thickness proportions. During the 2KSES development phase considerable parametric work was performed showing these effects and establishing minimum weight trends for a wide range; of panel loads.

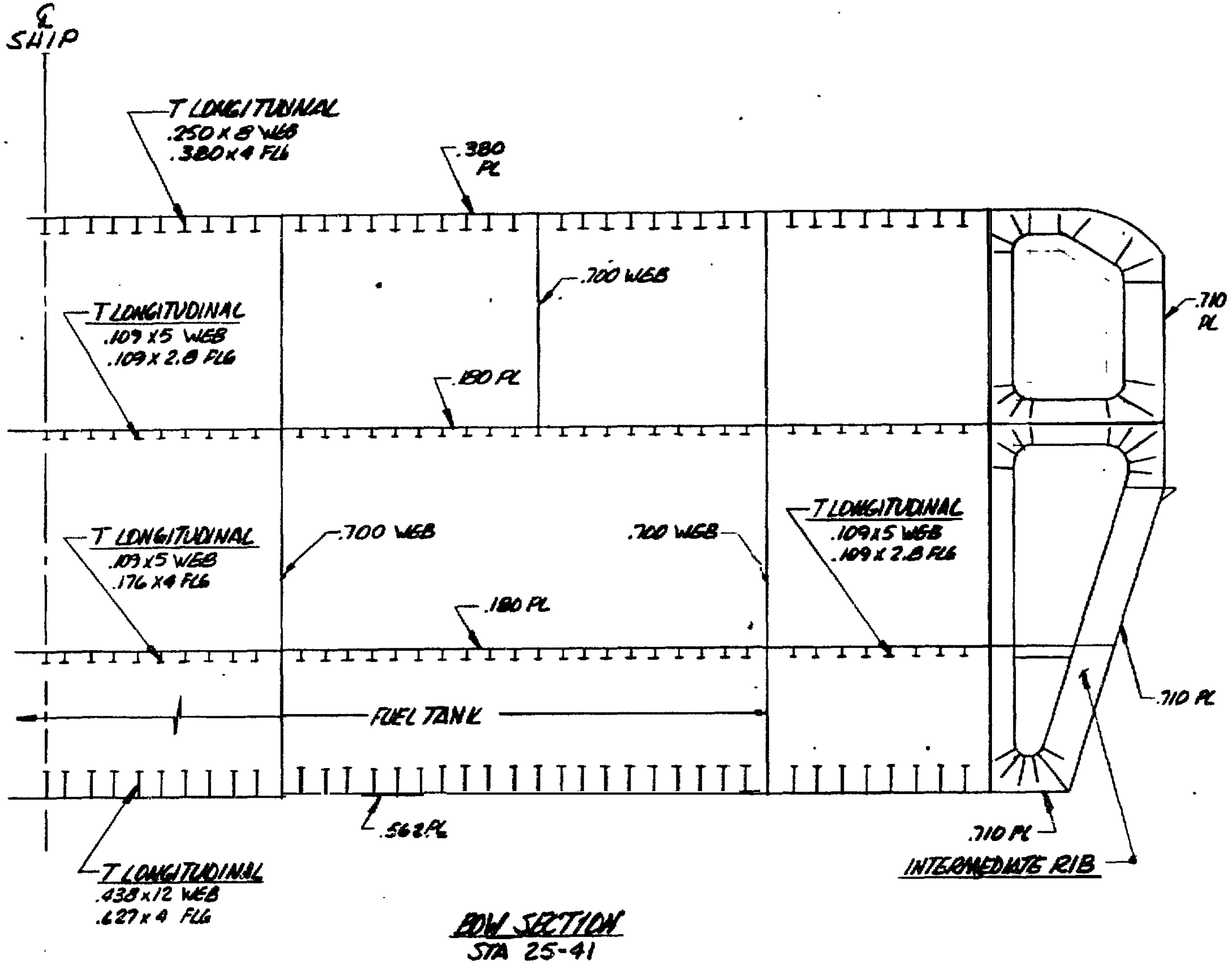


Figure 2.3.1-1 PRELIMINARY SCANTLING SIZES (BOW SECTION)

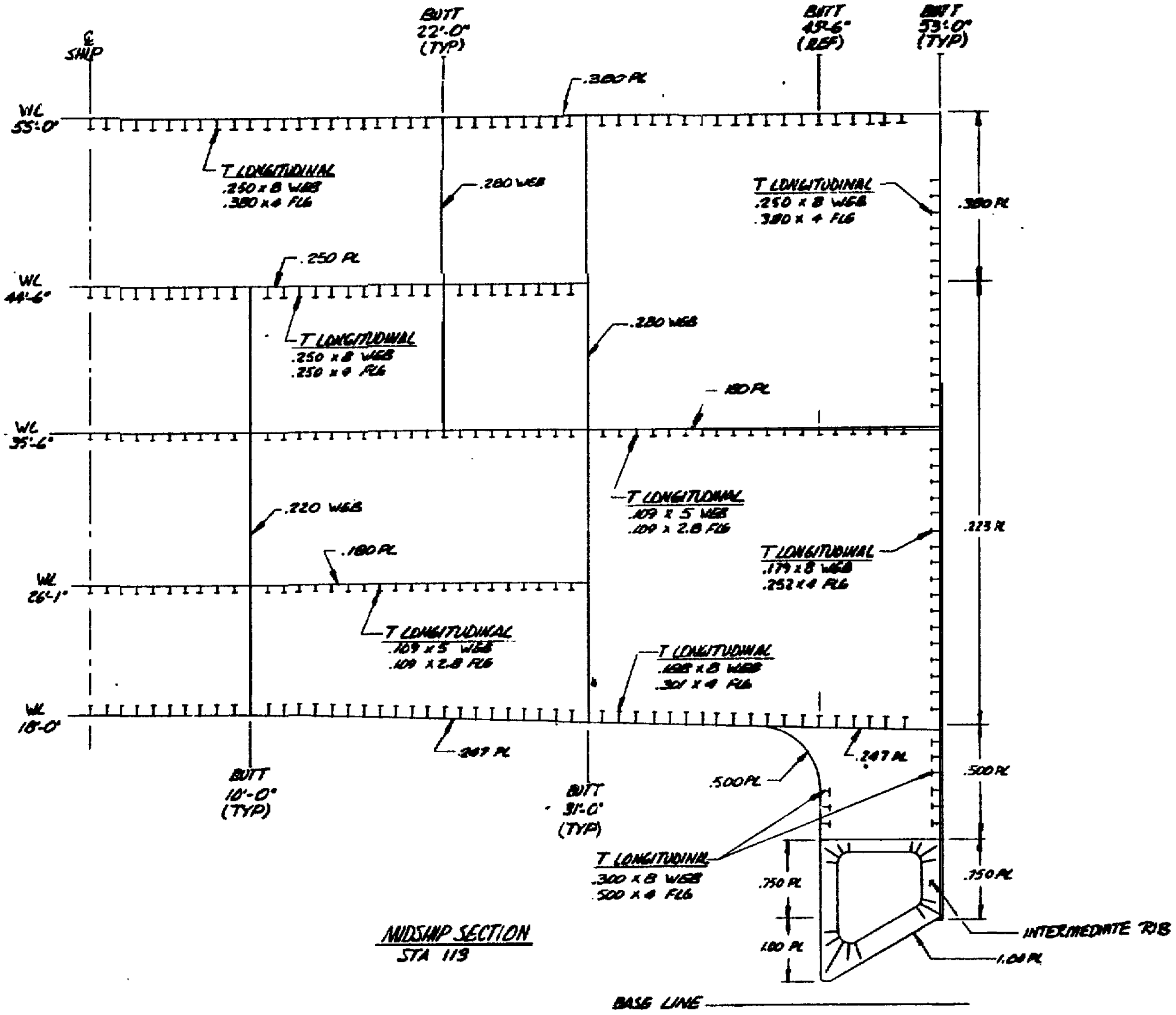


Figure 2.3.1-2 PRELIMINARY SCANTLING SIZES (MIDSHIP SECTION)

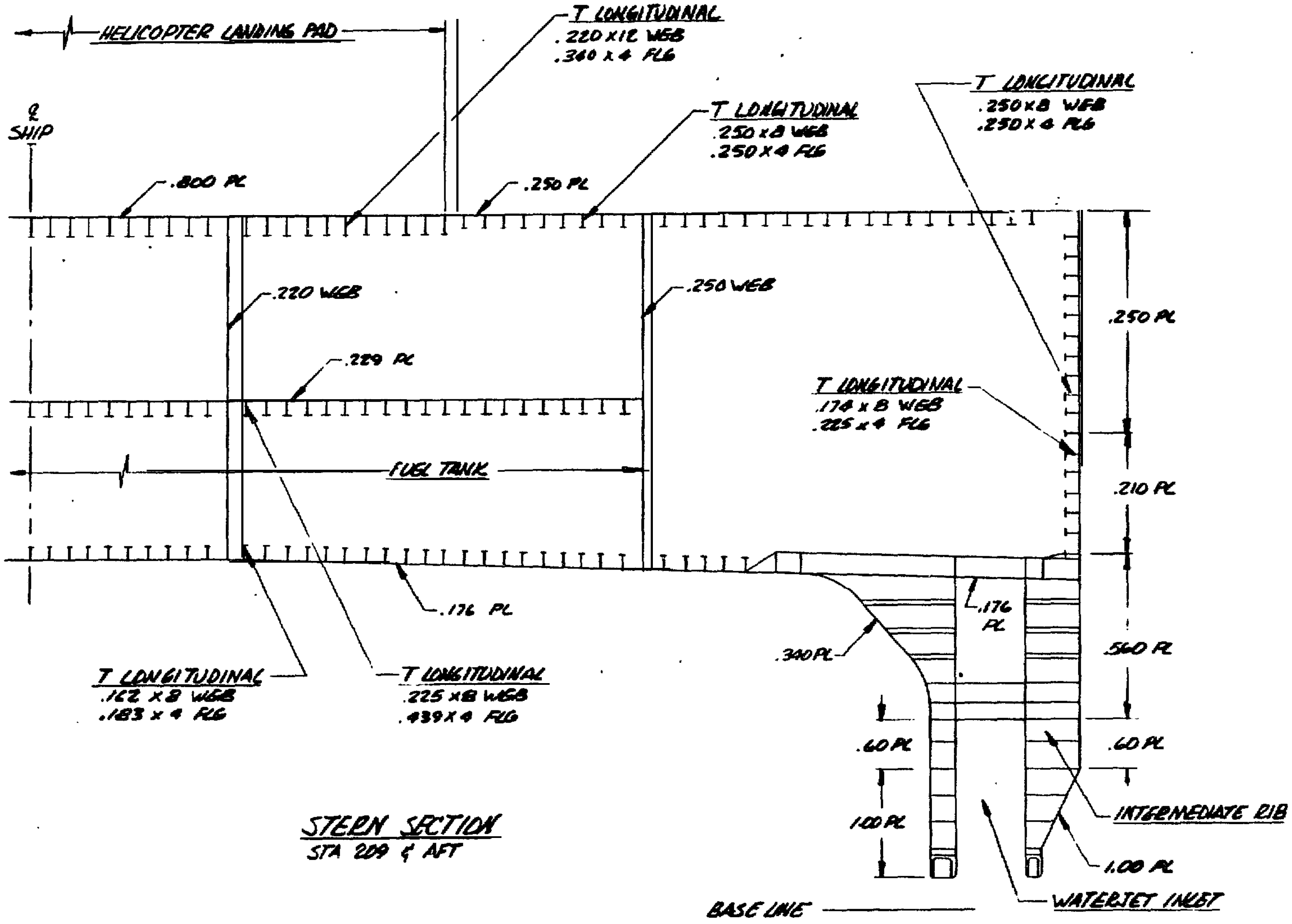


Figure 2.3.1-3 PRELIMINARY SCANTLING SIZES (STERN SECTION)

The longitudinally stiffened shell for the 3KSES consists of 5456-H111 integrally extruded skin-stringer sections joined by a continuous forge welding process to form skin-stringer panels. This process achieves a joint strength equal to the parent metal strength. The conventional method of MIG fillet welding of tee section extrusions to flat plate results in local annealling of the material at the joint. This has little effect on the allowable load of a panel designed for end-loading. However, there is a reduction in load capability for panels designed for normal pressure loading since plastic hinges are formed at the joint at a lower load than parent metal capability. Therefore, the forge welding process will allow a reduction in the required skin thickness from that required for the automatic MIG welding process. The nature of the process also allows joining of thinner gage sections with less distortion and reduces the amount of welding required, Figure 2.3.1-4 shows a comparison between the two methods.

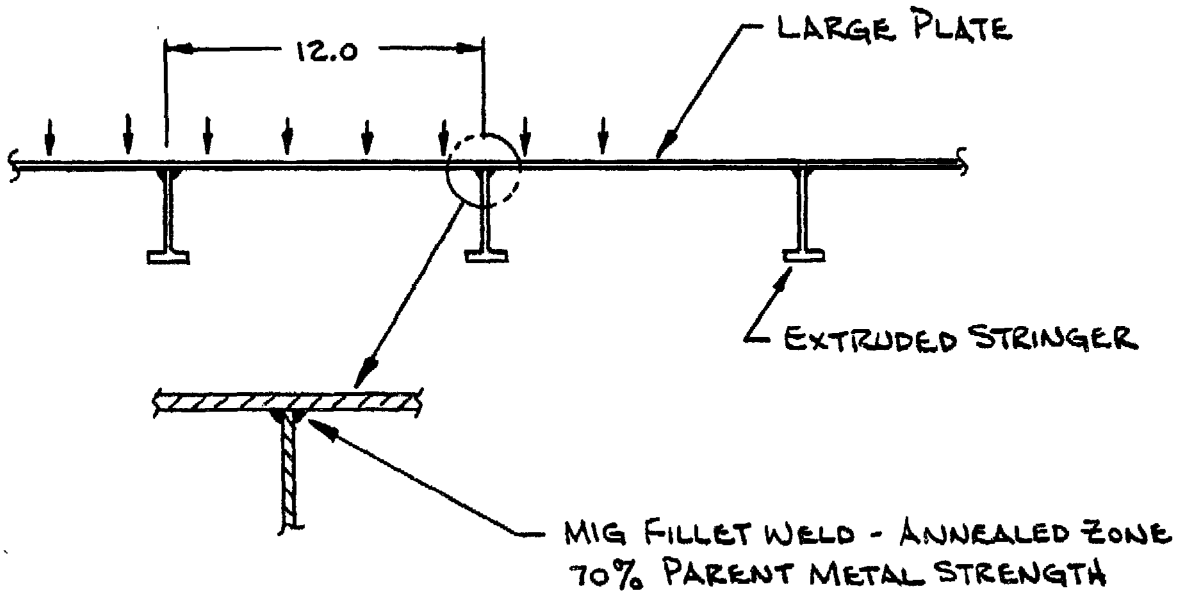
Bell conducted a structural refinement tradeoff study during the 2KSES development contract (reference 7). The results of this study show that weight savings can be achieved through various methods of structural refinement. Certain refinements, such as the use of semi-tension field bulkhead webs save considerable weight with no increase in manufacturing cost and have, therefore, been incorporated in the structural design of the 1980 and 1990 3KSES. Other structural refinements, such as high strength composite reinforcement of structural elements in areas of high local loads, high modulus composite reinforcement of frame stanchions, and machine removal of unnecessary material in areas of low local loads can save additional weight. Although most of these items were not cost-effective for the 1980 SES, they are considered to be cost-effective for the 1990 3KSES. Greater availability of the composite materials and experience in fabrication will bring their associated costs down to the range required for SES. These refinements are shown in figures 2.3.1-S and 2.3.1-6.

2.3.1.4 Weight Percentage Breakdown - Structure

The hull structure weight for the 1990 SES will differ in several aspects from the 1980 SES. Factors of safety will be reduced due to a lower uncertainty factor for structural load criteria and, in addition, increased structural depth through incorporation of a portion of deckhouse and sidefairing into the hull bending section are anticipated, The following is a percentage breakdown by SWBS code:

SWBS		PERCENTAGE
110	Shell and Supporting Structure	36.6
120	Hull Structural Bulkhead	17.9
130	Hull Decks	17.6
150	Deckhouse Structure	16.3
160	Special Structures	7.5
170	Masts, Kingposts, and Service Platforms	0.4
180	Foundations	3.6
190	Special Purpose Systems	0.1
	TOTAL	100.0%

1980 3KSES-MIG FILLET WELDED JOINT



1990 3KSES- FORGE WELDED JOINT

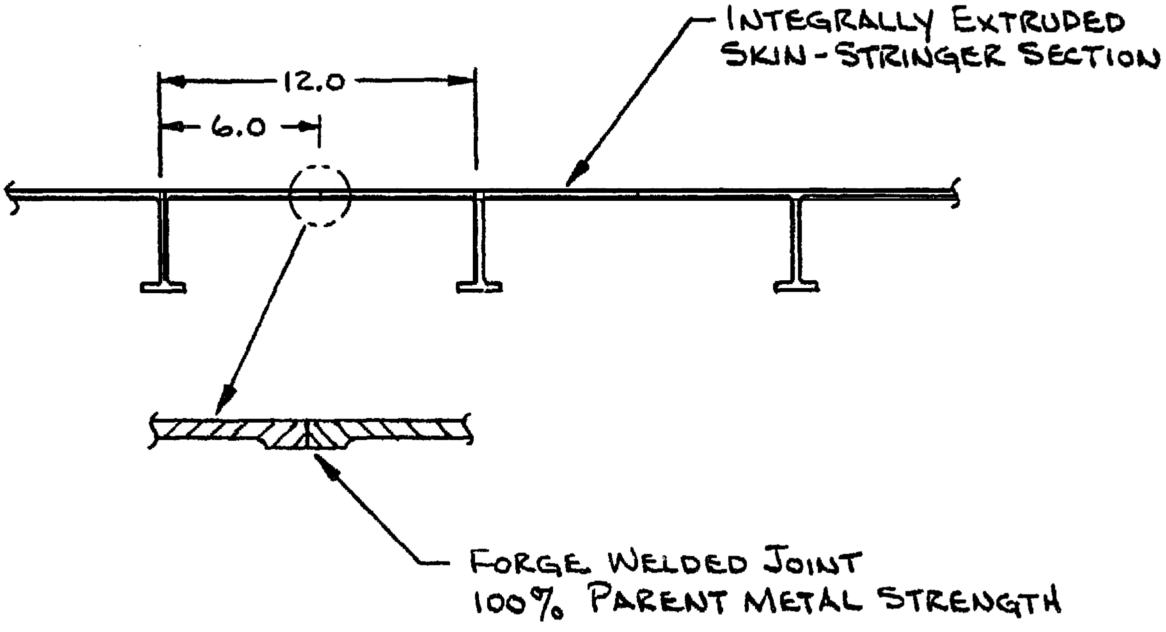
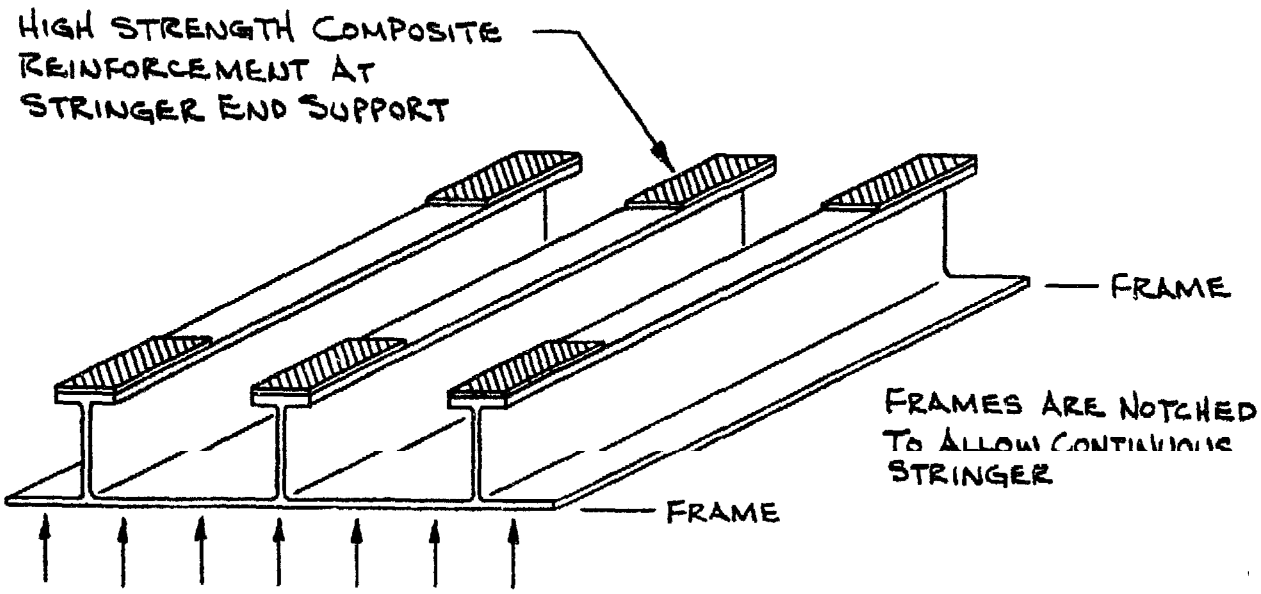


Figure 2.3.1-4 SKIN-STRINGER PANEL CONSTRUCTION



COMPOSITE REINFORCEMENT OF PRESSURE DESIGNED PLATING

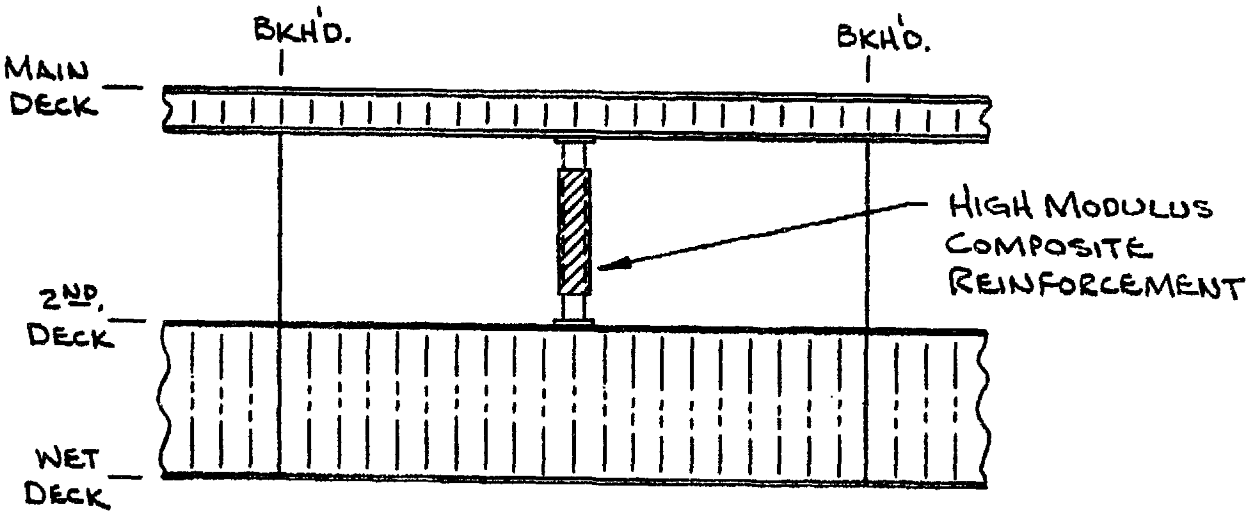
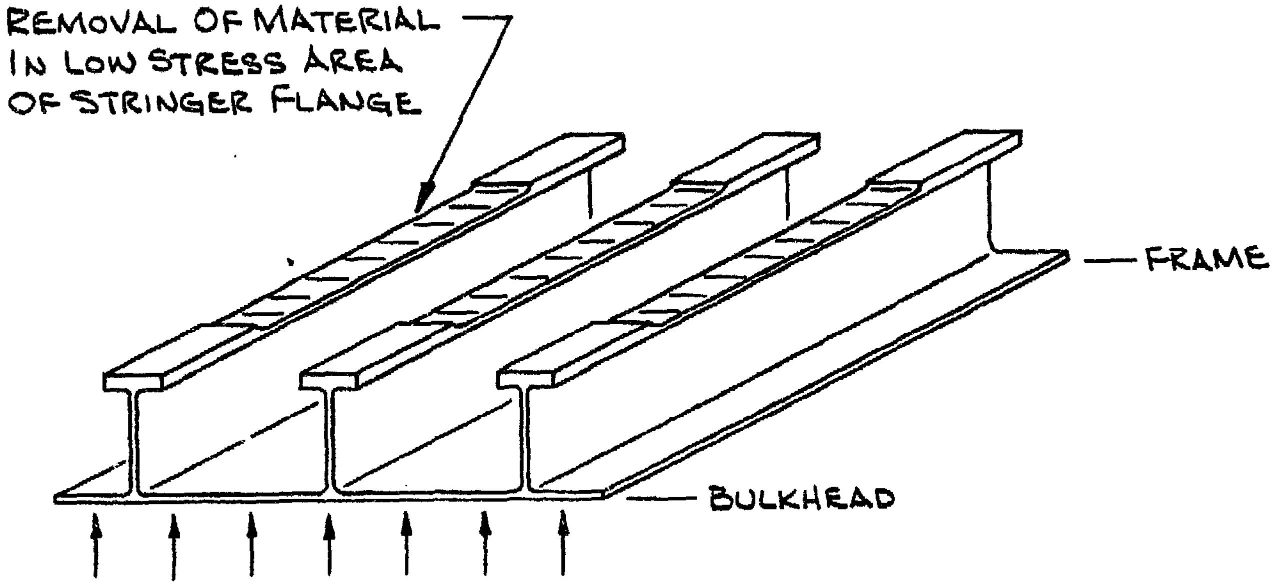
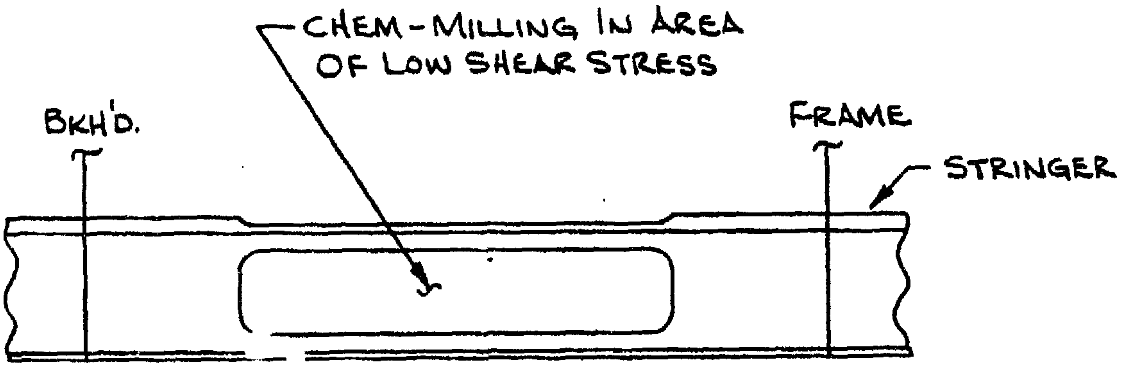


Figure 2.3.1-5 STRUCTURAL REFINEMENTS - COMPOSITE REINFORCEMENT



MACHINE MILLING OF

PRESSURE DESIGNED PLATING



CHEM-MILLING OF

PRESSURE DESIGNED PLATING

Figure 2.3.1-6 STRUCTURAL REFINEMENTS - MATERIAL REMOVAL

Armor weight of 56.1 short tons has been included in SWBS code 160 shown above.

2.3.1.5 Risk Assessment

The probabilistic theory of structural design recognizes that there is some probability or risk of failure during the life of a structural system. This theory is described in appendix A of reference 8, and applied to the design of 2KSES, for which both safety for extreme loads and fatigue reliability are evaluated,

Based on the probability-based structural design criteria, acceptance levels of risk and corresponding central safety factors have been established for each of four categories of ship structure as shown in table 2.3.1-III. These categories are as follows:

a. Category I. Structure that if failed by complete collapse, rupture, or other similar severe damage will endanger the safety of the ship in any operation. Examples falling in this category are:

(1) Collapse or fracture of the hull girder

(2) Extensive brittle fracture

(3) Extensive loss of watertight integrity.

b. Category II. Structure that if failed or damaged may interfere with the maximum operation of the ship but will not endanger the safety of the ship if reduced operation is maintained. It is intended that if failures in this category occur, the ship will be withdrawn from service for repair immediately. Examples in this category are:

(1) Excessive hull deflections or permanent set

(2) Minor structural collapse or failure

(3) Fatigue cracking

(4) Minor brittle fracture.

c. Category III (Secondary) . Structure that if failed or damaged would not cause curtailment of ship mission but would be scheduled for repair or replacement at the first opportunity. Examples in this category are:

(1) Secondary structural members not *carrying* primary loads or transferring primary loads to the main girder of the ship

(2) Equipment brackets and associated support structure of a minor nature

(3) Structure that could be temporarily reinforced or replaced while at sea

(4) Structure acting as fairings, either aerodynamic or water.

TABLE 2.3.1-III

RISK-BASED CENTRAL SAFETY FACTOR FOR LIFETIME MAXIMUM LOAD

CATEGORY		ACCEPTABLE RISK (PROBABILITY OF FAILURE)	CENTRAL SAFETY FACTOR	
			1980 3KSES	1990 3KSES
I	Main Hull Girder Weather Deck Wet Deck Sidehull Keel Outboard Long Bulkhead Web Transverse Bulkhead Web Transverse Frame Stanchions	≤0.001	2.0	1.5
II	Bow Plating (under bow bag) D/H Plating Middle Deck Foundations for Engines, Gearboxes and Propulsion System	≤0.05	1.5	1.5
III	Side Deck Fairing Radar Mast Hangar Door Foundations for Other Equipment			
IV	Partitions Soundproofing Panels Attachment Brackets Suspension Straps Railings	N/A	N/A	N/A

NOTE: The safety factors which are not determined by probabilistic methods are presented in the Structural Criteria Specification.

d. Category IV (Nonstructural). Structure not covered by the other three categories that, if failed, can be repaired or replaced at the discretion of the ship engineering officer. This structure is not intended to carry or transfer any primary loads into the hull. Examples in this category are:

(1) Nonstructural partitions

(2) Nonstructural brackets and attachments

(3) Insulation hangers or rails.

Associated with the risk levels and corresponding central safety factors for lifetime maximum loads (table 2.3.1-III) is the total design uncertainty, which is equal to the combination of the uncertainties in applied loads or internal stresses and strength (resistance). Of these two uncertainties, attention is directed to the uncertainty in applied loads as *it* is the greater of the two at the present time.

Currently, short-term histograms of applied loads or internal loads and/or stresses for various elements of the hull primary structure are obtained from a six degree of freedom (6DOF) computer program which extrapolates the long-term mean lifetime maximum loads and their coefficients of variation and associated uncertainties. Using the methods of extreme value statistics, the extreme loading is predicted on the basis of a small sample of short-term measured or predicted loads and results in a given value of uncertainty. Hence, the central safety factor of $\bar{\theta}$ = 2.0 shown for the 1980 3KSES Category I structures (table 2.3.1-III) includes the effect of the present loads uncertainty predicted by the present extrapolation of short-term data.

It is anticipated that as test data becomes available from testing of the 1980 3KSES, the loads will be better defined for longer periods of time and the predicted loads uncertainty will be reduced. With this future expectation of reduction in the loads uncertainty, the central safety factor for the 1990 3KSES Category I structures can be reduced for the same level of risk (0.001) (ie, one ship in 1,000 for the lifetime of the ships). The relationship of central safety factor and percentage reduction in both the loads uncertainty and the total design uncertainty, when the strength uncertainty and risk level are the same, is shown graphically in figure 2.3.1-7 for the 3KSES main deck and keel,

In figure 2.3.1-7 it is seen that if a 58 percent reduction in loads uncertainty is realized, the expected central safety factor will be 1.50 for the same risk level of 0.001. If a 41.5 percent reduction in the total design uncertainty can also be realized, the same value for the central safety factor can be expected, Based on the trend shown in figure 2.3.1-7 and the expectation of better loads data obtained from testing the 1980 3KSES, a central safety factor of 1.50 is considered acceptable for design of the Category I structures in the 1990 3KSES, as indicated in table 2.3.1-III. The central safety factors and levels of risk for the other categories noted in the table are presently considered to remain the same until better knowledge and definition of their environments is acquired.

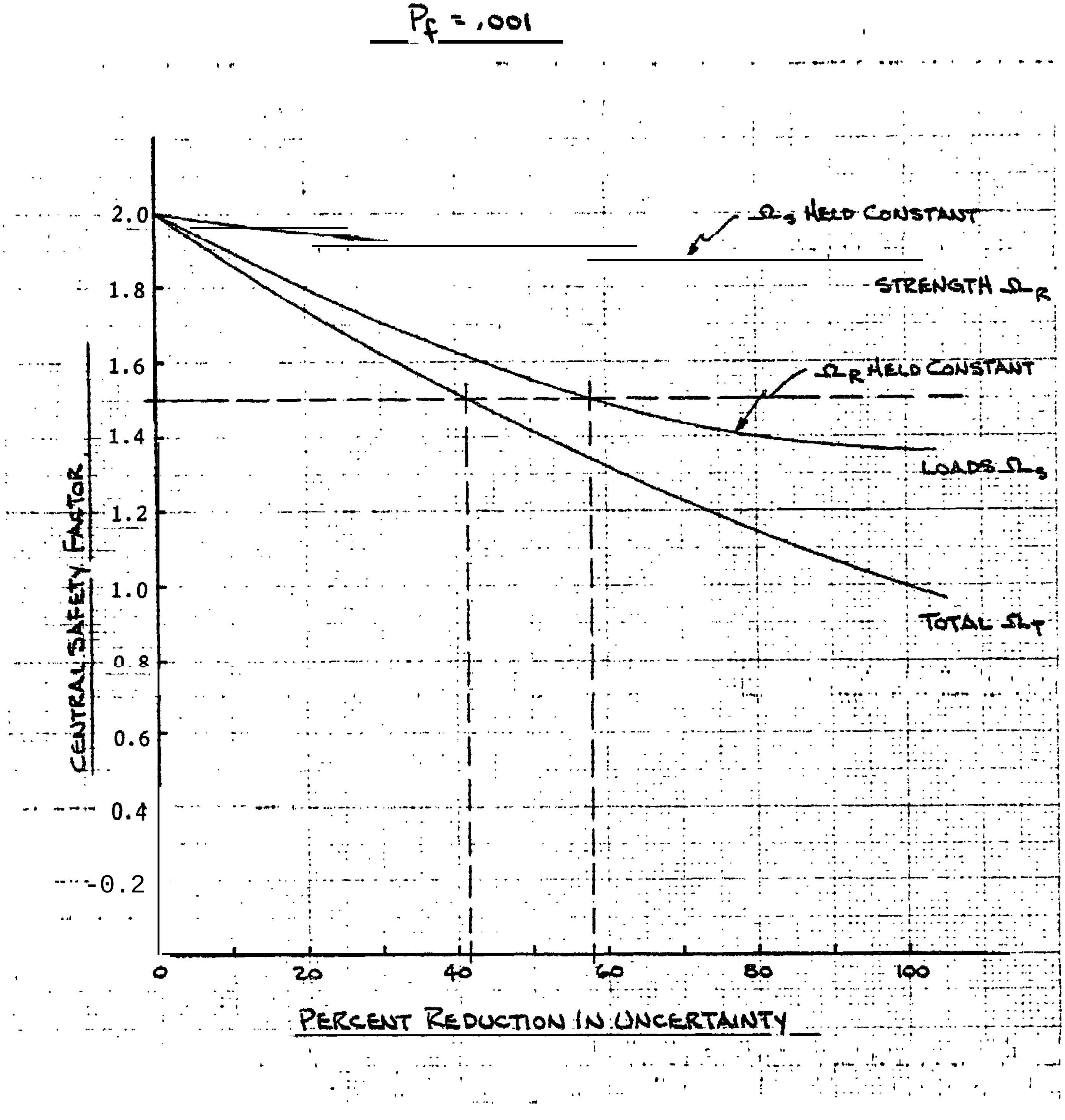


Figure 2.3.1-7 3KSES MAIN DECK AND KEEL $\overline{\theta}$ VERSUS REDUCTION IN UNCERTAINTY

In contrast to safety under the lifetime maximum load, reliability under repeated operational loading is not a question of strength versus load; but, rather, it is a question of the life, in terms of load cycles, that a structure can sustain prior to initiation of fatigue failure. Moreover, fatigue is a process of cumulative damage resulting from the repeated application of loads,

The evaluation of fatigue reliability, including its associated uncertainties, is presented in appendix A of reference 8, which predicts the allowable maximum stress range for design to achieve prescribed reliability for different inspection intervals.

As the fatigue loading spectrum becomes better defined through operational use of the 1980 3KSES, the expected cumulative damage should be predicted more realistically and confidently, thereby establishing the periods required between inspection intervals.

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2.3.2 Propulsion

The propulsion subsystem consists of the gas turbine engines, combustion air inlets and exhausts, transmissions, propulsors, and waterjet inlets. A brief description of each of the propulsion subsystem elements is contained herein.

2.3.2.1 Summary Description

2.3.2.1.1 General Description

The four propulsion power plants are gas turbines with a nominal 40,000 MCP and 50,000 MIP rating. Each engine drives a waterjet propulsor through a planetary reduction gearbox. Pairs of propulsors on either side of the ship are supplied water by a variable-area waterjet inlet. The general layout is similar to the Bell-proposed LSES configuration, but with the incorporation of anticipated advances in technology which will result in an increase in overall propulsion subsystem operating efficiency. Specific propulsion characteristics for the various subsystem elements are given in 2.3.2.2.

2.3.2.1.2 Propulsion Engine Inlet System

The propulsion engine installation features an integrated inlet and exhaust system. Salt-spray removal from the inlet air is maximized by incorporating a charged droplet scrubber (CDS) demister in series with Farr Aquavanes. Improvements in filter/demister state of the art allow for increased flow velocity through both the Farr Aquavanes and CDS demister. The higher airflow velocities create significant weight savings, because of more compact ducting and smaller demister units, Associated with increased airflow rates is increased pressure losses. However, by utilizing forward-facing inlets, the ram recovery will contribute to negating the higher pressure losses in the ducts. At high ship speeds, the forward-facing inlets will generate overall positive pressure at the engine face, thereby increasing installed engine performance.

The inlet contains a forward-facing entry into Farr Aquavanes. The Aquavanes turn the flow downward 90 degrees, where the flow is then diffused before entering the CDS demister. Downstream of the CDS, the flow is turned aft by a set of cascade turning vanes, and then flows into the engine. A long, smooth entry duct to the engine cancels flow turbulence and, along with the single-entry inlet system, provides for distortion-free inlet flow to the front face of the engine compressor. Blow-in doors are provided in the inlet diffuser, downstream of the Farr Aquavanes, to allow for proper airflow in the event of icing blockage of the Aquavanes.

AIRFLOW VELOCITIES (FT/SEC)
Propulsion Engine Airflow Plus Compartment
Cooling Air - $W_a = 362$ lb/sec

$V_{Farr} = 118$ ft/sec

$V_{CDS} \approx 45$ ft/sec

$V_{Engine\ Duct} = 77$ ft/sec

2.3.2.1.3 Propulsion Engine Exhaust System

The propulsion engines are moved aft to minimize shaft length between the power turbine and waterjet pump, and also to minimize the engine exhaust duct length. The exhaust gases are ducted out of the stern of the ship. Exhaust ducts straight out the stern provide for a minimum pressure loss installation. Also, exhaust plumes out the stern eliminate interference with helicopter operations. By the time the exhaust plume has expanded to within the helicopter approach path, it has diffused to low velocity and temperature. A weight allowance has been provided for a seawater spray system to reduce IR signature of the ship to a level equal to the ship radar signature.

2.3.2.1.4 Waterjet Propulsor/Transmission

The waterjet propulsor is assumed for parametric purposes to be a multistage, single-speed, axial-flow pump. The selected pump has an inducer diameter of 47.0 inches. Maximum absorbed power is 45,540 shp at 975 rpm. The pump is designed to minimize internal cavitation at low ship speeds. The transmission is assumed to be a single-speed planetary design. The selected design is capable of absorbing 46,000 shp with 99-percent efficiency.

2.3.2.1.5 Waterjet Inlet

The waterjet inlet for the 3450-metric-ton SES will be scaled up by a factor of approximately 12.5 percent (based on characteristic lengths) as compared with the current dimensions of the LSES. The bifurcated duct exit diameter, *or* pump inlet flange diameter, will be increased by only 3.5 percent (from 43 inches for the LSES to approximately 44.5 inches for the 1990 SES). The waterjet inlet will have a variable-area inlet.

2.3.2.2 Propulsion Characteristics

2.3.2.2.1 Engine Characteristics

The 40,000 hp maximum continuous rating and 50,000 maximum intermittent rating of the engine is achieved within current parameters of engine airflow and turbine inlet temperature. The physical configuration of the engine is identical to current engines.

ENGINE CHARACTERISTICS

Maximum Continuous Power (MCP)	40,000 hp
SFC at MCP	0.36 lb/hp-hr
Maximum Intermittent Power	50,000 hp
Turbine Inlet Temperature (max)	2,250°F
Airflow	302 lb/sec
Compression Ratio	32:1
Weight	18,900 lb
Length	300 in.
Diameter - inlet	50 in.
- exhaust	80 in.

ENGINE CHARACTERISTICS (Cont)

Number of Compressor Stages	12
Number of Turbine Stages.	6
Combustor Type	Annular

2.3.2.2.2 Propulsor Characteristics

Maximum Required Horsepower - Levels of 4 Engines:

MCP = 40,000 hp per engine
MIP = 46,000 hp per engine (50,000 available)

Vena Contracta Area = 1.5 ft^2 Inducer Diameter = 47 inches

	HUMP SPEED	83.8 KNOTS*	
Power Level (hp)	MIP	MCP	MIP
Flow Rate per Pump (cfs)	374.7	386.6	402.0
Inlet Area per Sidehull (ft^2)	19.39	8.1	8.4
Propulsive Efficiency	0.325	0.552	0.546
Developed Head (ft)	950.1	800.8	885.5
Pump Rotational Speed (rpm)	975.2	930.9	975.2

Maximum Suction Specific Speed = 27,700

*Maximum speed at MCP in sea state 3

2.3.2.2.3 Waterjet Inlet Characteristics

Width = 3.93 ft

SHIP SPEED (knots)	*INLET AREA (ft^2)	INLET HEIGHT (ft)	INLET VELOCITY RATIO
19	19.3	4.9	0.980
34	19.3	4.9	0.675
83.8	8.1	2.1	0.675
100	6.6	1.7	0.675

*At lip leading edge station

Variable Area Factor = 4.9/1.7 = 2.9

The variable area factor is only about lo-percent higher than that of the Bell LSES.

2.3.2.2.4 Transmission Characteristics

TYPE	GEAR RATIO	EFFICIENCY
Planetary	4.102	0.99

2.3.2.3 General Arrangement

A general arrangement of the propulsion subsystem is shown in figure 2.3.2-1, which indicates the main components and their relative locations.

2.3.2.4 Key Features

Key features of the propulsion subsystem air intake are shown in Bell drawing AD-76-61, which is contained in appendix B to this report.

2.3.2.5 Weight Percentage Breakdown - Propulsion System

SWBS		PERCENTAGE
230	Propulsion Units	18.1
240	Transmission & Propulsor Systems	32.0
250	Propulsion Support System	25.2
260	Propulsion Support System (Fuel & Lube Oil)	1.6
290	Special-Purpose Systems	17.7
	Shock Mounting (for Noise & Underwater Explosion)	5.4*
		100.0%

*Equivalent to 5.7 percent of group 200 machinery weight

2.3.2.6 Risk Assessment

The risks associated with the development of the 1990 SES propulsion subsystem are comparable to those associated with the development of the propulsion subsystem for the current LSES.

The 50,000 MIP engine prototypes currently available are the Pratt and Whitney (P&W) FT-9 A-2 and the General Electric (GE) LM5000. Both are capable of the required power, and the technology improvement needed for better fuel consumption is the subject of several intensive current development programs. Larger engines also exist in prototype form in the P&W FT-50 and the GE MS9001. However, these are industrial heavy-weight engines, and a relatively increased design and development gap exists to bring these engines down in weight. Aircraft programs, including the B1, Jumbo, and SST, do not seem to require core engines of the required size to provide this rating. Therefore, it appears less likely that this engine will come into existence; if it does, however, less advanced fuel consumption and weight requirements are likely, which are the reasons for the more conservative assumptions for this size class of power plant.

There is a moderate element of risk involved in the development of a 50,000 hp propulsor. The propulsor design developed by ALRC for the Navy LSES program is a two-stage, two-speed waterjet pump driven through an offset gearbox, and is based upon the waterjet pump presently installed in the Navy hydrofoil (PHM). Although much of the basic design is common, changes have been made to uprate the pump capability from 18,000 to 40,000 hp and to incorporate design improvements as a result of PHM testing and LSES model pump testing. Further uprating of this 40,000 hp propulsor to 50,000 hp represents a questionable undertaking, considering the substantial amount of uprating that has already been imposed upon this propulsor originally designed for PHM application.

The backup propulsor design for the LSES, designated as the Powerjet 46, is based on a modified scale Powerjet 20, which is a propulsor limited for commercial sales, In contrast to the ALRC propulsor, it is a single-speed design and is capable of producing 40,000 hp without resorting to uprating of a lower-power existing propulsor. One possible method of uprating this design to 50,000 hp is to include an additional axial stage. This involves a moderate degree of technical risk.

Development of a propulsor transmission capable of absorbing 50,000 hp also represents a moderate technical risk, due to the higher geartooth loads and transmission cooling problems.

The intake and exhaust systems are based on technology to be developed during the LSES program, and therefore represent a low technical risk. Higher filtration system efficiencies and higher flow velocities are projected for the 1990 SES. The selection of a ram-type air inlet is based on improved filtration efficiency and a better definition of spray environment to be obtained from the LSES program,

The waterjet inlet will be very similar to and only slightly larger than that proposed for the LSES, which was demonstrated to be fully satisfactory through extensive model-scale performance testing and full-scale ramp element structural testing, Development risks will be low.

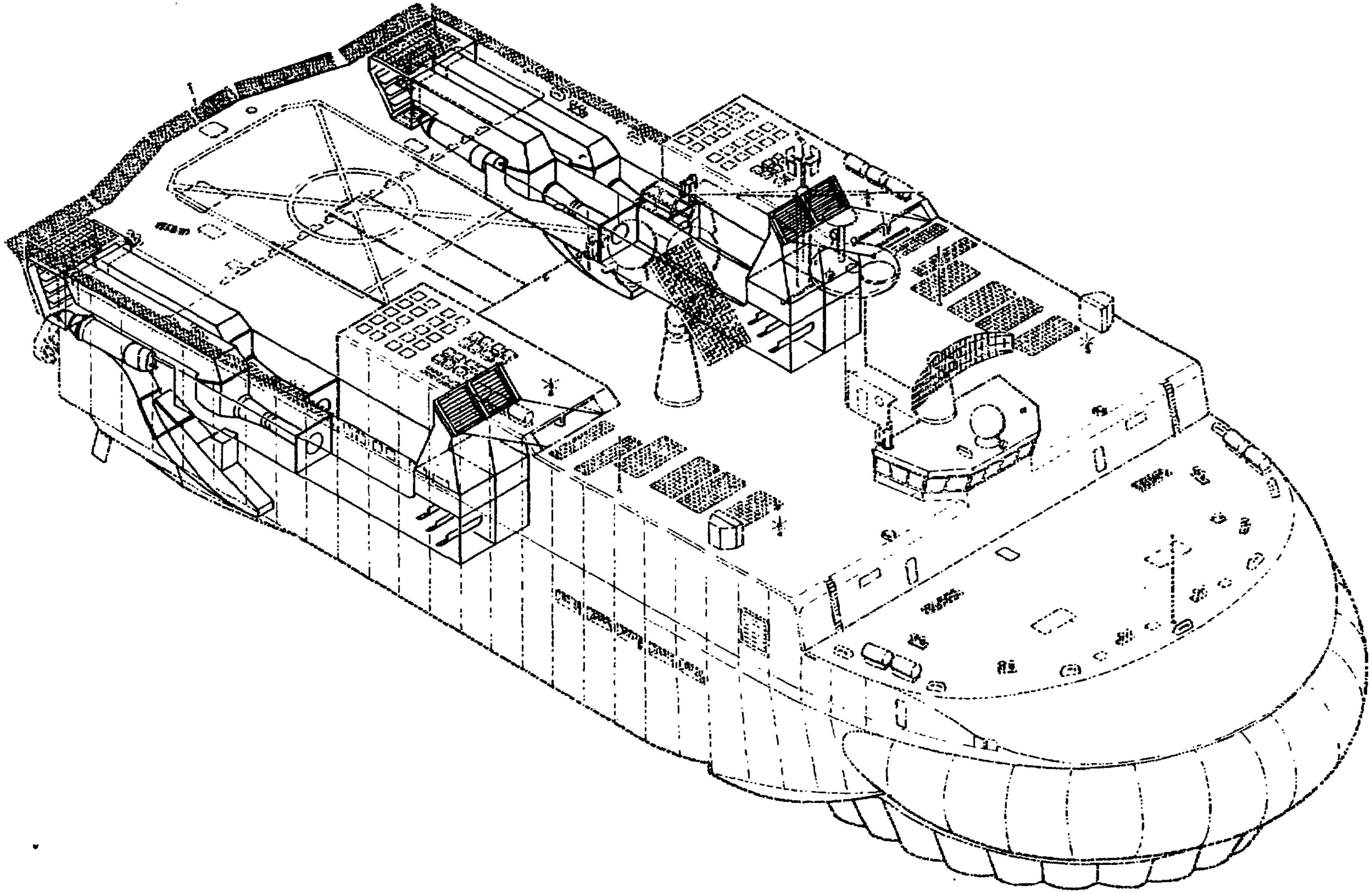


Figure 2.3.2-1 PROPULSION SYSTEM GENERAL ARRANGEMENT

2.3.3 Lift and Ride Control System

The basic elements of the lift and ride control system (LRCS) are as follows:

Lift power units
Transmission and fan system
Lift power support systems
Lift power support (fuel and lube)
Seal systems
Ride control system
Special purpose systems,

The location of the major elements of the LRCS of the LSES are shown in figures 2.3.3-l and 2.3.3-2.

The cushion of air under an SES provides it with the ability to achieve much higher speeds in a given sea state than a ship with a conventional hull. In lower sea states, the wave height is much less than the cushion depth, and a smooth ride is achieved at high speeds. As the sea state increases, more of the air in the cushion is compressed or displaced, and the hull experiences corresponding accelerations. In extreme sea states, the hull may contact the water, although this condition is minimized by the selected design of the bow seal.

It has been shown by analysis and ship simulations that the ride of the ship can be improved by the inclusion of ride control devices in the ship lift system. Two of these have been incorporated in the design of the LSES: variable flow centrifugal fans (VFCFs) and cushion vent doors (CVDs). The first modifies ship motion by controlling the flow of air to the cushion, the second by venting cushion air to atmosphere.

2.3.3.1 Summary Description

The LRCS is defined by figure 2.3.3-l and includes the lift power train, the seals, the ride control elements, and the integrated control equipment. The leading characteristics of the system are shown in table 2.3.3-I.

There are two independent lift power trains, one port and one starboard. Each train consists of one LM2500 engine driving two double-entry variable-flow cushion fans and one single-entry seal fan through a transmission unit composed of a gearbox with appropriate shafting and coupling. The engines are soft-mounted. Combustion air is taken in through forward-facing inlets located in the forward area of the ship superstructure as shown in figure 2.3.3-3. Salt-water spray is removed by filter/demister systems similar to the propulsion engines. The flow enters the forward-facing inlet and passes through Farr Aquavanes, where the Aquavanes turn the flow downward into a three-stage charged-droplet scrubber water separator manufactured by TRW, Inc. The flow is then turned forward by a set of 90-degree turning vanes; is diffused and turned aft 180 degrees by two sets of 90-degree turning vanes; passes through FOD screens, and then into the engine. Engine exhaust is ducted outboard through louvers in the ship superstructure.

TABLE 2.3.3-I

LIFT AND RIDE CONTROL SYSTEM MAJOR CHARACTERISTICS

Cushion Pressure at Design Gross Wt (3500 LT) (3500 metric tons)	352 psf (16,854 Pa)
Bow Seal Pressure at Design Gross Wt	422 psf (20,225 Pa)
Cushion Area	20,412 sq ft (1,896 m^2)
Mean Seal Clearance Height (Equivalent Air Gap, SS 0-3)	.442 ft. (0.135 m)

Lift Engine

Two General Electric LM2500 Marine Gas Turbine Engines

One Driving Each Independent, Half of the Total Lift System

Lift Fans

Custom Designed Cushion and Seal Fans, Centrifugal, Backward Curved Airfoil-Shaped Impeller Blades, Volute Casings

Fixed-Geometry, Fixed-Flow (at Constant Speed and Back Pressure) Seal Fans

Variable-Geometry, Variable-Flow (at Constant Speed and Back Pressure) Cushion Fans. Full 0 to 100% Flow Control at 2-3 Hz. Faster Response Available at Reduced Flow Control Range.

The engine gearbox takes drive directly from the engine. This gearbox drives both the seal fan and the cushion fans. Because of the common drive train, individual fan speed is dependent on the LM2500 power setting. Each fan will experience a proportionate gain or loss of speed, depending upon the engine power setting change.

To prevent lift fans from rotating while the lift engine is idling, a brake with 7000 lb-ft (9491 Nm) input torque is located on the input side of the two engine gearboxes.

The lift engines and gearboxes have separate lube oil supplies which are cooled by the lift system circulating and cooling seawater units.

The seal and cushion fans pull air through air grates located on the top side of the ship superstructure. The ducting from the fans has been designed and sized for the most efficient use of space and minimum flow losses,

'Ihe fans supply air to the cushion and the bow and stern seals. The cushion is contained by the sidehulls and seals. The cushion pressure is maintained at a nominal pressure of 352 psf (16,854 Pa). The seals are maintained at 432 psf (20,225 Pa). The 1.20 pressure ratio between the bow seal and the cushion is established by pressure control elements located in ducts between the seal and the cushion. In each duct between the seal fan and the seal, a control valve is used to close the duct should the fan be idle. These valves prevent loss of seal pressure and fan movement due to backflow, Should a cushion fan be lost, the fan unit sleeves will be closed to seal the cushion. A unity pressure ratio between the stern seal and the cushion is used in this design. Air flow to the stern seal is supplied directly from the cushion. No separate air supply or ducting system is needed.

The bow seal consists of a wrap-around bag of elastomer-coated fabric with reinforcing cables in regions of load concentration beneath the bag. Both the bag fabric and the reinforcing cables utilize Kevlar yarn to achieve a high strength-to-weight ratio. Bag weight is consequently between SO and 60 percent of current weights utilizing nylon yarns. Mechanical attachments are used for the hull and between bag segments. These attachments are designed to minimize load concentration in recognition of the low elongation properties of Kevlar.

The bow seal is provided with 22 fingers, also made of elastomer-coated fabric but utilizing nylon yarns in the interest of long life in a severe dynamic environment at the finger tips. The finger height is approximately 13 feet. This value was selected as a maximum to minimize bag contact in high sea states, while maintaining finger stability against premature collapse, and also maintaining sufficient bag stiffness to prevent seal tuck-under and plow-in.

The bow seal is 104-ft (31.7 m) wide, 101-feet (30.8 m) long, and 33-feet (10 m) deep. The bow seal bag operates at a nominal pressure of 352 lb/ft^2.

The stern seal is a three-lobe arrangement, also of coated fabric, with a flat lower surface maintained by internal fabric diaphragms. The seal has end lobes of conic and torodial shapes to seal against the sidehull and the fairings of the waterjet pump intake ducts (or propeller gearbox fairings). These seal end caps seal with line contact to minimize friction, and a wiping action occurs against the **sidehull** during wave action and ship motion. The stern seal fabric utilizes Kevlar yarns for minimum weight for the majority of the structure, but the lower regions, which are in frequent dynamic motion from water contact, utilize nylon yarns. The stern seal is 104-feet (31.7 m) wide, 14-feet (4.27 m) high, and 20-feet (6.1 m) long and also operates at a nominal pressure of 352 lb/ft^2.

In the bow bag there are 22 pressure operated vents which exhaust to atmosphere along the perimeter of the bow decking through the hull. These vent doors will operate to relieve over-pressure (1000 psf) (47,900 Pa) buildup in the seal.

The stern seal has two vents (port and starboard) to atmosphere which will be primarily used in obtaining partial cushion ($1/2\ P_c$) operation,

The LRCS must provide and maintain the proper flow of air to the cushion and to the seals to meet performance and habitability requirements. It does this by establishing nominal pressure flow conditions corresponding to selected lift engine settings. Pressure fluctuations about this nominal are minimized by modulating cushion fan flow and venting excess cushion pressure through cushion vent doors. The LRCS controls are on the bridge, the engineering and damage control center (EDCC) and at local stations. Engine throttles and parameter readouts are at the bridge. The bridge throttles have shutdown override for emergency conditions (ditching) , The bridge also has station in command switching capability. The EDCC has both engine (including engine starting) and LRCS control functions and readouts. Local engine controls and readouts are located at the engines for check and maintenance functions. Integrated circuits include appropriate interlocks associated with the LRCS functional controls.

2.3.3.2 System Characteristics

The LRCS contains most of the ship subsystems that are unique to an SES. The LRCS must provide and maintain the proper flow of air to and from the cushion and seals to satisfy the performance and ride quality requirements. The correct nominal pressure-flow conditions are achieved by adjusting engine power and valves in the air management system. Pressure fluctuations about this nominal condition are minimized by modulating the fan flow and by venting excess pressure through vents *to* the atmosphere.

In addition to providing an LRCS which meets the design point pressure and flow requirements, the system must have favorable dynamic response to fluctuating conditions of pressure and flow and must provide good off-design performance. Design features and philosophies, which are more specific to the subsystems, are discussed.

2.3.3.2.1 Fans

The ALRC VFCFs were selected due to their lowest development risk. Large-scale (approximately 1/4) models of similar fans have subsequently been tested in the XR-1D test craft. An exploded view of the VFCF is shown in figure 2.3.3-4.

The lift fans for the LSES have been the subject of an intensive development program which is nearing its completion. It is not considered likely that the presently claimed efficiency will be significantly exceeded in practice by

1990, but further design development resulting from production experience may lead to substantial weight savings in the area of the volute and support structure.

The seal fans are based on a series of fans which have successfully provided the cushion and seal air for the SES-100B and other successful Bell cushion craft. The design features of the single-entry seal fan are presented in figure 2.3.3-5.

Characteristics of both fans have been established at a large enough scale to ensure accurate full-scale predictions. The pressure-flow characteristics and efficiency of these fans is shown in figures 2.3.3-6 and -7. The structural arrangement and material selection of the fans satisfy the operational requirements of the fans in the open-ocean load and motion environments.

2.3.3.2.2 Seals

Critical subsystems of the LRCS are the bow and stern seals. They must contain the cushion while possessing performance characteristics that strike the proper compromise between ship drag and ship stability. The overall approach to the design of the bow and stern seals was to base it on previously successful seals. Tradeoff studies of seal configurational details were conducted and extensive material testing and joint and attachment testing has been conducted.

The studies included analysis and scale model tests. Using the 1980 seal configuration, initial tests were conducted to determine finger and seal stability, seal leakage characteristics, and comparative drag data. More extensive tests were then conducted on selected candidate seal configurations in a linear tow tank to quantitatively determine the effects on ship performance, seakeeping, and stability.

For the 1990 seal design three important functional changes were made. These will require verification by model testing. A smaller and flatter bow bag shape was used, as shown in figure 2.3.3-8. This shape exploits the available material strength properties more effectively than the 1980 seal to produce a bag which is smaller, lighter, and hence lower in cost to produce. Resistance to plow-in effects has been checked and is satisfactory. Taller fingers result, and these lead to lower drag in the high sea states because bag contact is reduced. Stability of the taller fingers is satisfactory.

Secondly, a curved finger leading edge configuration has been adopted since this results in shorter, lighter, and lower cost finger tails while retaining the geometric characteristics necessary for finger stability.

'Finally, the seal bag pressures have been reduced from 1980 values of 1.25 times cushion pressure to 1.20 for the bow bag and 1.0 for the stern bag. Reduced pressures result in a saving in lift system power and fuel and provide some simplification in machinery. The 1.25 pressure ratio of the 1980 seal was based on past satisfactory experience, but studies suggest that this can be reduced to 1.0, with some changes in seal geometry and attachment locations. However, conservatively, a 1.20 value has been retained for the bow bag.

The total effect of these seal configurational changes for the 1990 ship should be a reduction in weight, cost, and lift power requirements with no reduction in sealing effectiveness or increase in seal drag.

Structural aspects of the seal design are recognized as of importance in aiming at a low weight, low cost design, For the 1980 seal design sophisticated analytical methods were developed and extensive analyses, tests, and loads measurements on operational craft were made to ensure structural integrity. Tests were also conducted on materials, joints, attachments, and other details. For the 1990 seal system, extensive use of high-strength Kevlar fabrics is anticipated in bow and stern bags, with a potential for reducing bag weight by 50 percent. More sophisticated detail design methods will be needed since Kevlar is a stiffer material than nylon and is more sensitive to load concentration. Parallel testing programs will be needed.

Improvements in mechanical seams and joints are also under development, and these have been incorporated into the 1990 seal design to reduce cost. These schemes eliminate inserts in the fabric for efficient joining, and permit continuous coating of high-strength fabric in large widths. The combination of Kevlar fabric, the smaller bag shape, and the improved joints offers substantial reductions in both seal weight and cost, without compromise of structural integrity.

Changes will also be incorporated into the 1990 seal design to increase life. The life of the bags and finger attachments will be increased beyond the present 5000 hours by the refinements in detail design of attachments already mentioned. While Kevlar is not as forgiving of poor detail design as nylon, the result is that a design which has good static strength will have very good life because load and stress concentrations must be minimized.. Further refinement of both external and internal seals loads knowledge will also improve life.

Finger life, which is presently at about 700 hours for the 1980 seal system, will be substantially increased by a combination of material developments and proper design of the finger tips with respect to mass, stiffness, and geometry to control tip flagellation. This design will evolve from understanding of the finger tip dynamics which, in turn, becomes possible as a result of instrumentation developments recently accomplished. These developments now permit quantitative data on the finger tip environment to be obtained. A finger life of 1500 to 3500 hours is projected.

The baseline design shows bow and stern seals (figures 2.3.3-8 and 2.3.3-9 respectively) which are of a sufficiently low drag design to meet performance requirements, which provide stiffness to provide good pitch stability, and which are manufacturable and restorable with existing facilities. General arrangement drawings of the bow and stern seals are shown in the drawing appendix.

2.3.3.2.3 Air Control

Flow distribution to and from the seals and cushion is controlled by a series of ducts and control valves. The overall approach to lift system air control is to develop a machinery and ducting arrangement that will meet the following requirements:

a. Provide airflow to the cushion in a way that minimizes flow distribution lags within the cushion

b. Maintain a nominal bow seal-pressure-to-cushion-pressure ratio of 1.20 for all lift power settings

c. Provide sufficient air to the seals during wave action to ensure that the seals are reinflated prior to successive impacts

d. Provide pressure relief valves to protect the bow seal structure during wave impact events

e. Provide a means of reducing the stern seal pressure to a value equal to one-half the cushion pressure when transitioning secondary hump

f. Provide leakage paths to drain water trapped in the seals.

To satisfy the first requirement, the VFCF air flow is ducted directly into the cushion at a forward-of-midship location. Also, flow from the bow seal supplies the cushion at a forward location. Thus, flow into the cushion is well distributed. In achieving this requirement, the lift engines and fans are conveniently located amidship, and only short vertical ducts (with low losses) are required to direct the air to the cushion. Cushion flow from the bow seal not only minimizes lift system power requirements but also minimizes flow lags within the cushion.

A nominal bow seal pressure to cushion pressure ratio of 1.20 was selected as the best value to provide good seal geometry, performance, and pitch stiffness characteristics, while minimizing seal power requirements. This pressure ratio is controlled by valves between the seal plenum and the cushion plenum. Depending on the lift system power setting, the valves are controlled to provide the flow required to maintain the pressure ratio. A unity pressure ratio stern seal design provides good stern seal performance while minimizing lift power and reducing system design complexities.

Although the bow seal pressure is nominally 1.20 times the cushion pressure, it can transiently reach values that are several times larger, These transients occur during the combination of pitch, heave, and wave slope that create a bow bag/water impact. To protect the seal structure, a pressure relief valve is designed into the bow seal. This feature, by limiting the peak loads seen by the seal, will extend seal life and minimize repair requirements,

A feature that is designed into the stern seal is a relief valve to atmosphere. Opening this valve and modulating the valves in the stern seal/cushion ducts causes the stern seal pressure to drop to half the cushion pressure. The stern seal is maintained at the desired pressure by flow from the cushion entering the seal through the partially opened seal-to-cushion flow control valve, This reduction in pressure is useful in reducing overall ship drag for transitioning secondary hump on partial cushion, It also lowers the waterjet pump, thereby increasing its suction head and enabling it to produce more thrust during hump tranist, as well as minimizing broaching.

Another feature of the lift system, related to seal design, is the inclusion of drainage holes. This obvious feature provides a leakage path for water that is trapped in the seal (either due to-being off-cushion or due to heavy waves and spray).

2.3.3.2.4 Ride Control

The cushion vent doors (CVDs), together with the VFCFs, provide control of the cushion pressure during wave transits. This system selection was based on the successful operation of CVDs on the SES-100A and SES-100B test craft. Operational experience and ship simulations have been used to select system hardware. The designs of the control systems for CVDs draw heavily on test craft experience and simulation of ship responses.

An additional ride control feature, which will be particularly effective in reducing vertical acceleration at the bow and stern stations, is active pitch control. This is provided by gimballing the waterjet nozzles in the vertical plane in response to a pitch rate signal,

Such control reduces pitch excursions, thereby reducing pitch induced accelerations . Additional important benefits of pitch control is a reduction in the slam occurrences and the reduction of inlet broaching.

2.3.3.2.5 Lift Engines and Transmissions

As shown in figure 2.3.3-10, the lift system engines are arranged so that each provides half the lift system power requirements under normal operating conditions . Each engine powers two double-entry cushion fans and a single-entry seal fan. As with the case of the propulsion engine, particular attention has been paid to inlet and demister geometries to reduce saltwater ingestion.

The aim of the transmission design was to minimize the number of gearboxes and to select designs in which the critical parameters were within accepted limits for reliability and long life, The system contains only one gearbox on each side of the ship, which takes the output from the lift engine and transmits it to the cushion and seal fans.

2.3.3.2.6 Lift System Hydraulics

The lift system hydraulic arrangement provides dual systems, port and starboard. Four hydraulic pumps on each side of the ship are driven by the lift engine reduction gearbox. The 3000 psi (2.07×10^7 Pa) system pressure is used to control the LRCS valves in the VFCFs and the CVDs. These devices establish the system power requirements. Although the system also controls the various valves *to* achieve nominal pressure ratios, their duty cycle is insignificant compared to the LRCS requirements. These pressure control valves are also coupled to the ship service power unit hydraulic system to provide the proper lift system configuration when the engines are powered down.

2.3.3.3 Weights

Table 2.3.3-11 shows the weight breakdown of the LRCS. The total weight of 108.3 long tons (110.0 metric tons) includes all lift system machinery, working fluids, and seals.

TABLE 2.3.3-11

LIFT SYSTEM WEIGHTS

SWBS		%	SHORT TONS	METRIC TONS
L30	Lift System Power Units [Includes shock mounting equivalent to 5.7% of Lift System)	17.2	22.1	20.1
L40	Lift Fans and Transmission Systems	34.2	44.1	40.0
L50	Lift System Support	11.3	14.5	13.2
L60	Lubrication System	1.2	1.5	1.3
L70	Seal Systems	23.9	30.8	27.9
L80	Fan and Ride Control Systems	10.9	14.0	12.8
L90	Special Purpose Systems	1.3	1.7	1.5
	Total Life System	100.0	128.7	116.8

2.3.3.4 Technical Risk Summary

The LRCS is integrated into the LSES to provide a simple, straightforward design. The design contains identical independent systems, port and starboard, which separately will provide cushion and seal pressure/flow requirements in the event of a failure in either system.

All major aspects of the ride control system have been defined. Specific details related to sensor location and filter circuits must await test results of ship structural and acoustic modes. Both the variable-flow fans and the vent doors have been demonstrated in model scale and confirm analytical predictions. All major elements and design features in the LRCS have been tested at large model scale or use state-of-the-art design approaches. The LRCS does not represent a high-risk system,

The predicted LRCS performance has been based on simulations which have been correlated with test data. Further, the SES-100A, SES-100B, and XR-1D have operated in scaled seas and have shown the effectiveness of CVDs and variable-flow fans. Both 100-ton craft have logged many hours of CVD operation and have demonstrated the reliability of the rather straightforward system design. Furthermore, large scale models of the VFCF have operated successfully in the XR-1D test craft.

The predicted ride characteristics show that the recommended 4-hour criterion can be met at all speeds and headings in sea states 3 and 4. In sea states 5 and 6, a 2-hour criterion can be met, Even better ride is provided at slower speeds and at other headings.

In the seals area, an extensive development program has been conducted based on nylon yarn fabrics with Kevlar yarn reinforcements, which has produced high-strength seal bag coated fabrics, bow finger wear-resistant coated material, stern seal coated fabric, and high strength Kevlar reinforcing webbing. All of the strength requirements (tensile strength, tear strength, and weight) for the seal materials have been met or exceeded by specimen tests of the selected formulations. These tests demonstrate that the tensile and tear strength properties of seal materials meet the design requirements. Furthermore, the adequacy of the material developed for the seals has been demonstrated by showing that its strength exceeds design limit loads determined by the seal loads analysis methods (appropriate factors have been applied to allow for safety, material degradation, and joint efficiency). For the 1990 time period Kevlar fabrics have been substituted for nylon in the bags, and sufficient laboratory testing has been carried out with this material to ensure that the strength and integrity previously demonstrated with nylon can be repeated, The validity of the analysis methods employed to determine the loads has been verified by correlation of the analysis with model and full-scale seal loads measurements on the SES-100B test craft. Further correlations have been made between measured-load cases and predicted values on static and dynamic 2KSES models.

During design development of the seal system, the attachments and joints necessary to assemble the seal components and to install the seals were functionally determined. Full-size test specimens incorporating actual seal materials and attaching hardware were tested to prove the adequacy of the attachment and joint designs.

Seal design has also been verified by ship model tests on the l/30-scale and 1/10-scale tow tank models, as well as by static tests of a 1/6-scale bow seal on a large rig with a movable ground plane. Seal performance during these tests has been excellent.

Using seal loading histories developed for severe operating conditions by 6DOF ship motion simulation, together with experimentally verified fatigue properties for nylon fabric, a bag life exceeding 5000 hours has been predicted. For the Kevlar fabric projected for craft in the 1990 time period a similar life is expected since Kevlar fatigue data, relative to static strength, is similar to nylon.

Based upon SR.N4 and SES-100B finger wear data, measured properties of finger materials developed for the 1980 time period, and with corrections for the effects of craft velocity and cushion pressure levels, a finger life sufficient for one year of operation is predicted. Further development of finger materials along the lines already successfully followed can be expected during the next ten years, together with research into the mechanics of the finger tip dynamics which produce finger wear. As a consequence, a finger life corresponding to two years of ship operation can be confidently predicted for 3990 craft.

Seal development is not a high-risk technical area. The areas of risks in the LRCS which were addressed did not include the lift system transmission, However, an effort was made to design a simple, reliable system. This objective was achieved and the transmission contains only one gearbox and one accessory gearbox on each side of the ship. In each gearbox, the principal gear train is a parallel-shaft train of double helical gears transmitting about 22,500 hp (16.8 × 10^6 watts). Layout drawings have been made in sufficient detail to determine gear size, geartooth stresses, and bearing lives. All gears are well within the capacity of normal gear cutting and grinding machines. Since the latest baseline uses a transmission in which only spur gears are required, no bevel boxes need to be developed. Furthermore, all gear stresses are below the maximum values recommended by AGMA, With the reduction in the number of gearboxes, gears, bearings, and shafting, an increase in system reliability will also be realized,

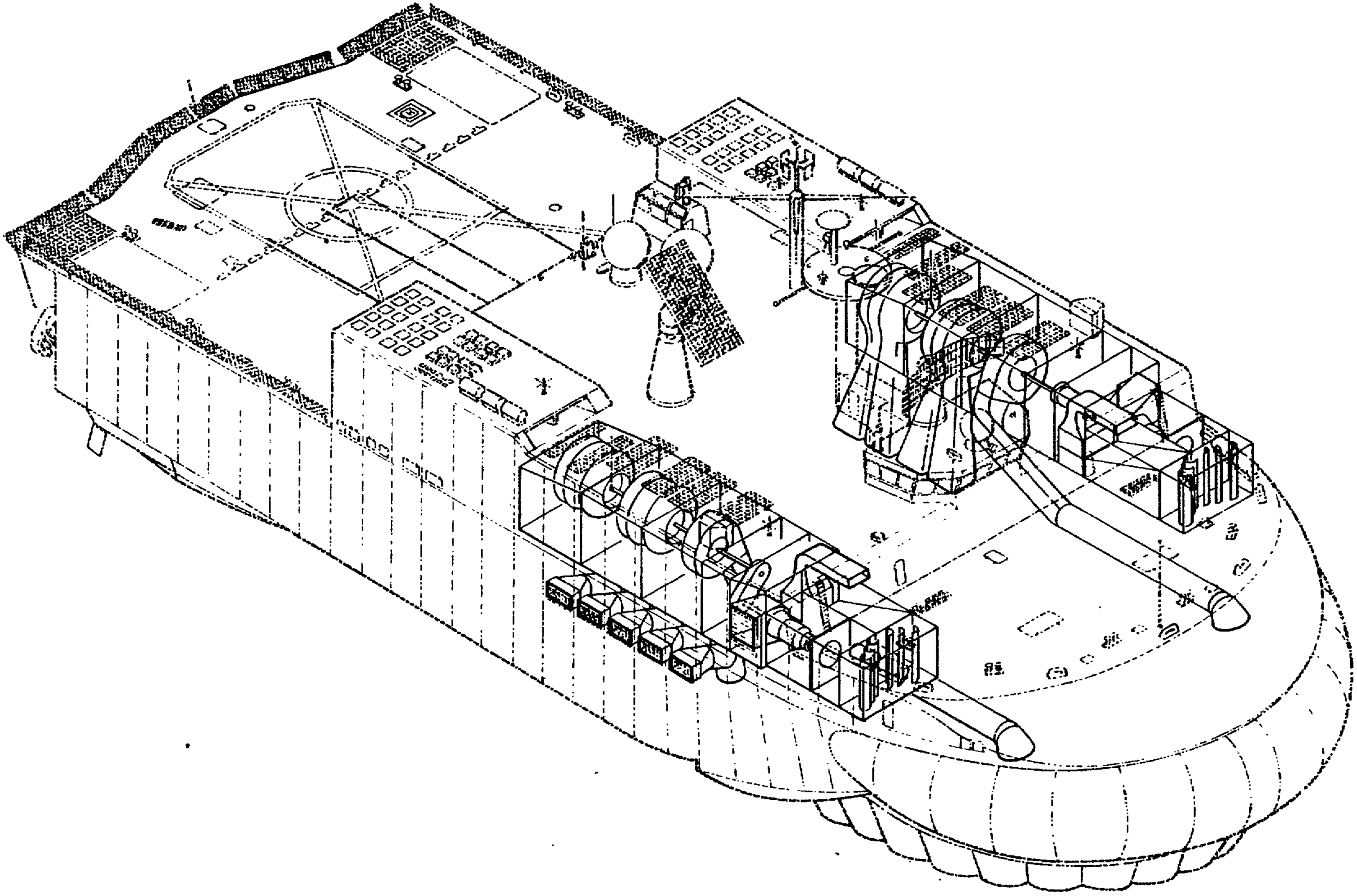


Figure 2.3.3-1 LIFT AND RIDE CONTROL SYSTEM (LESS SEALS)

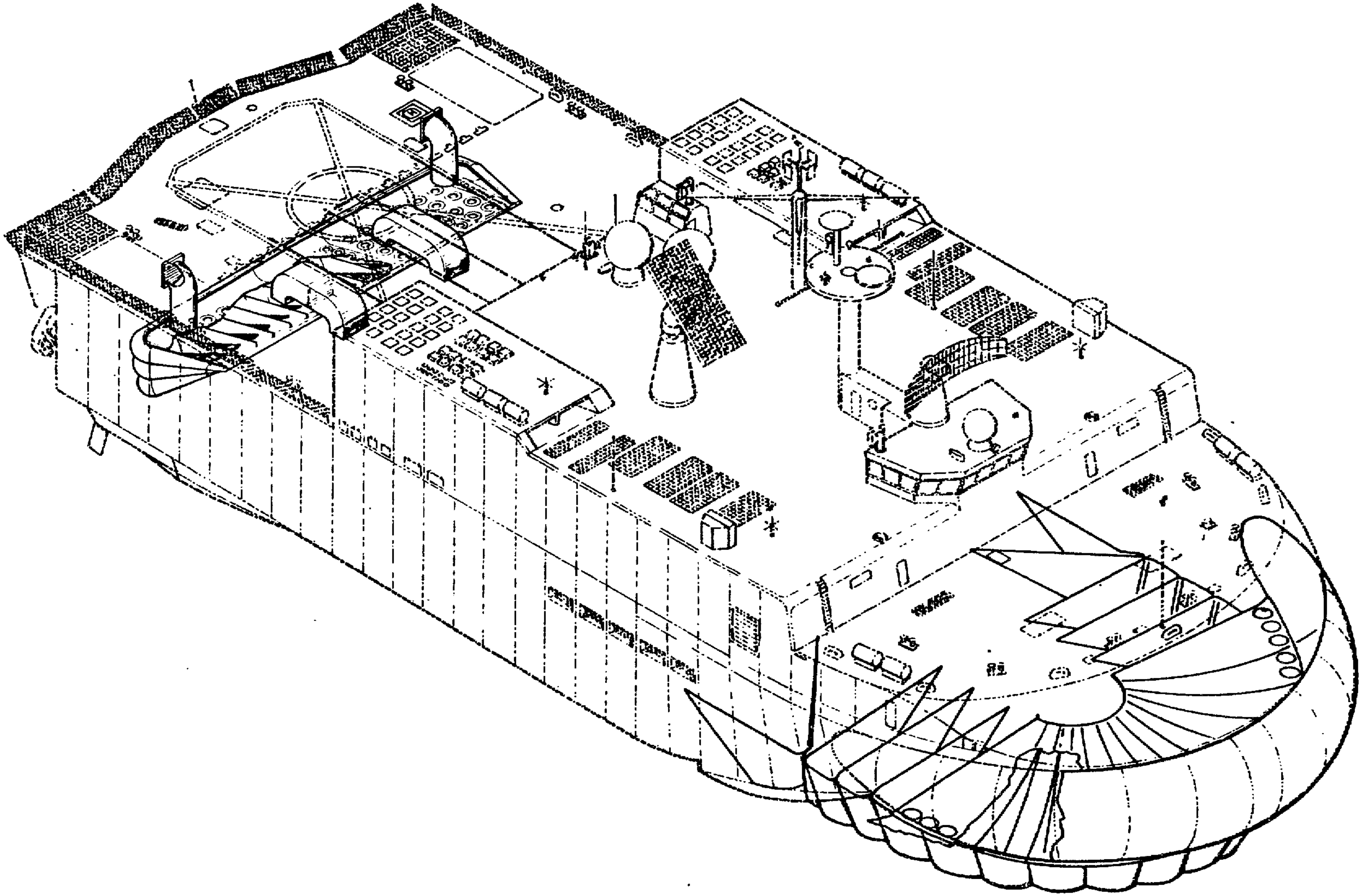


Figure 2.3.3-2 LIFT AND RIDE CONTROL SYSTEM (WITH SEALS)

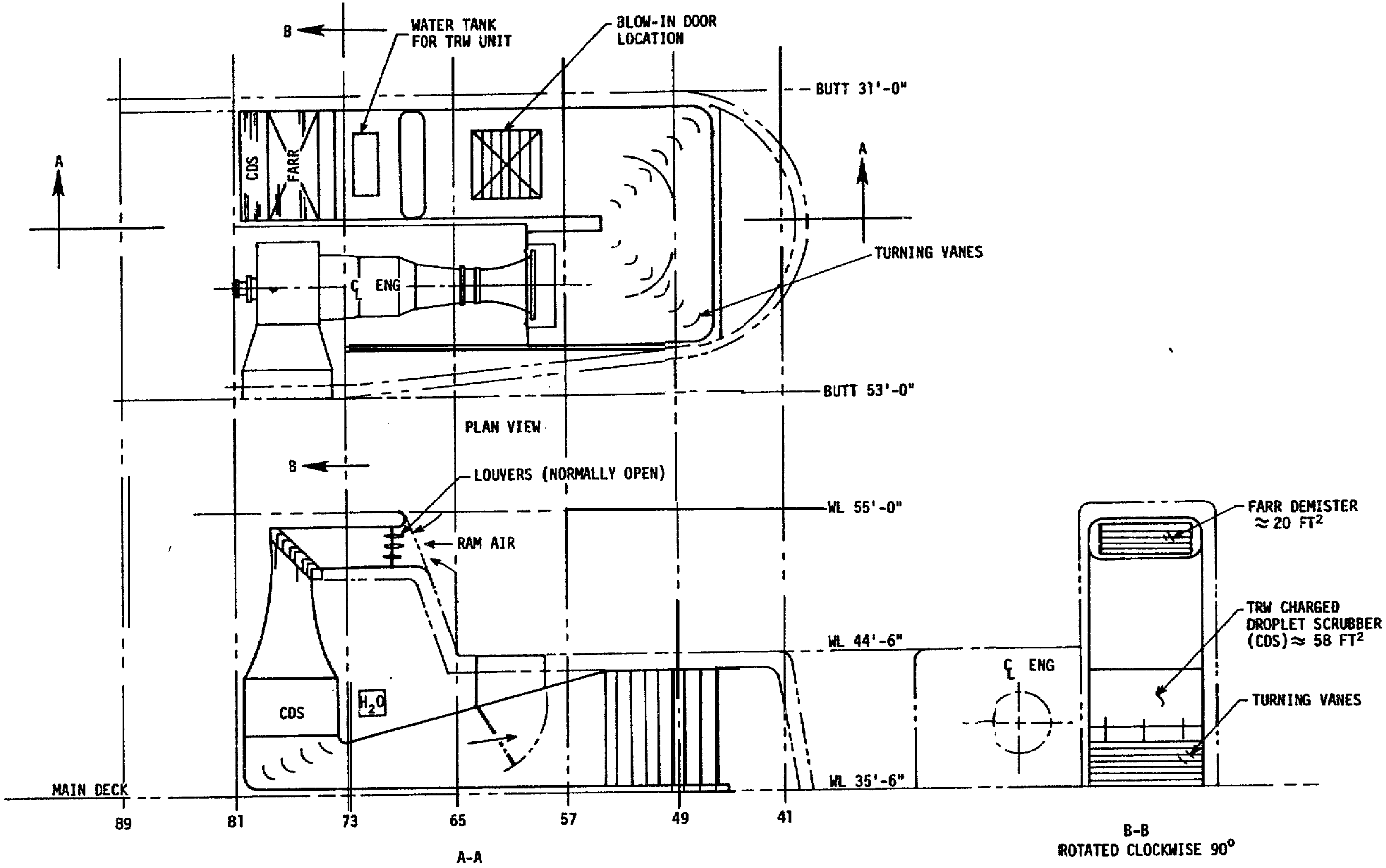


Figure 2.3.3-3 LSES LIFT ENGINE INLET ANVCE POINT DESIGN

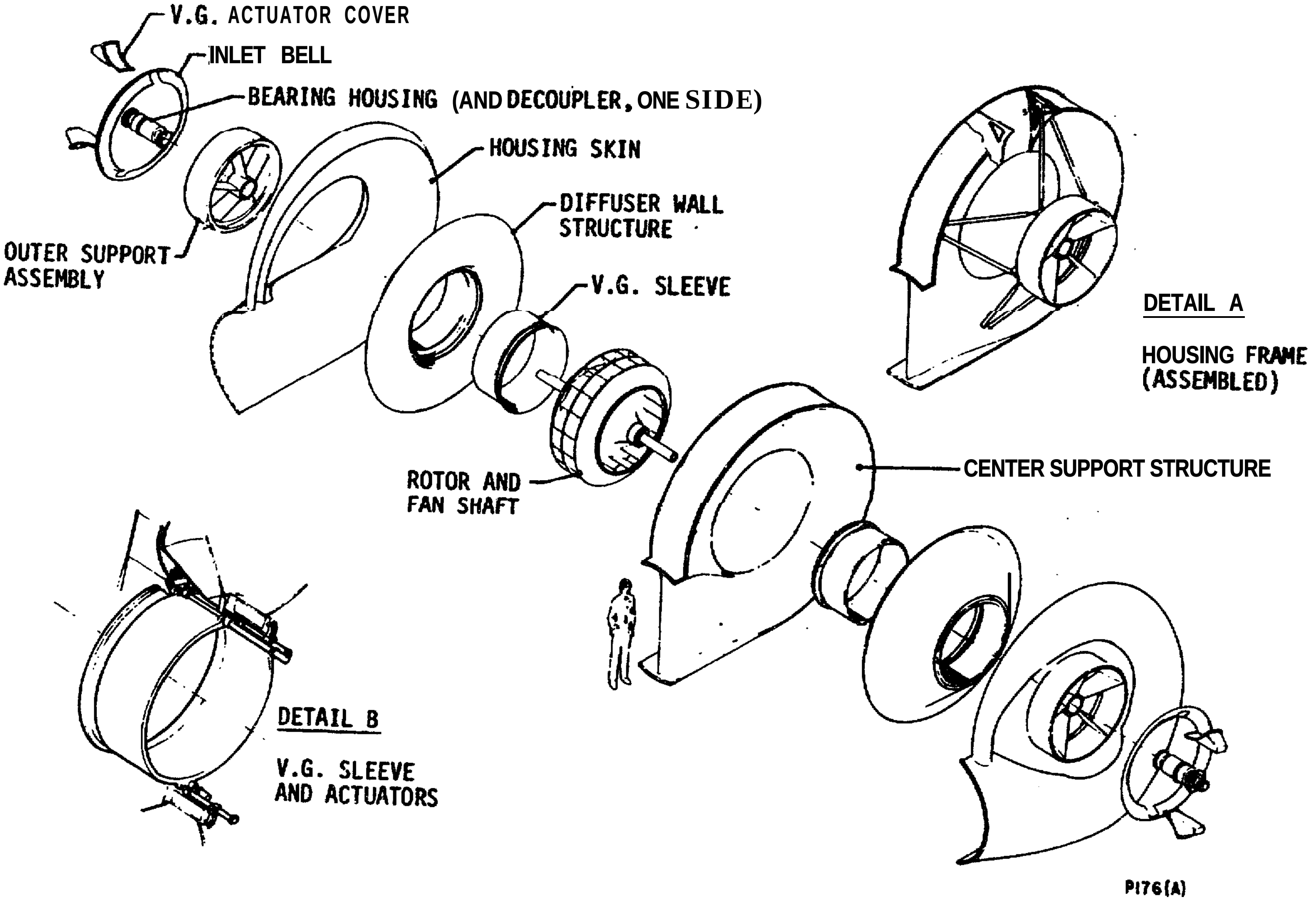
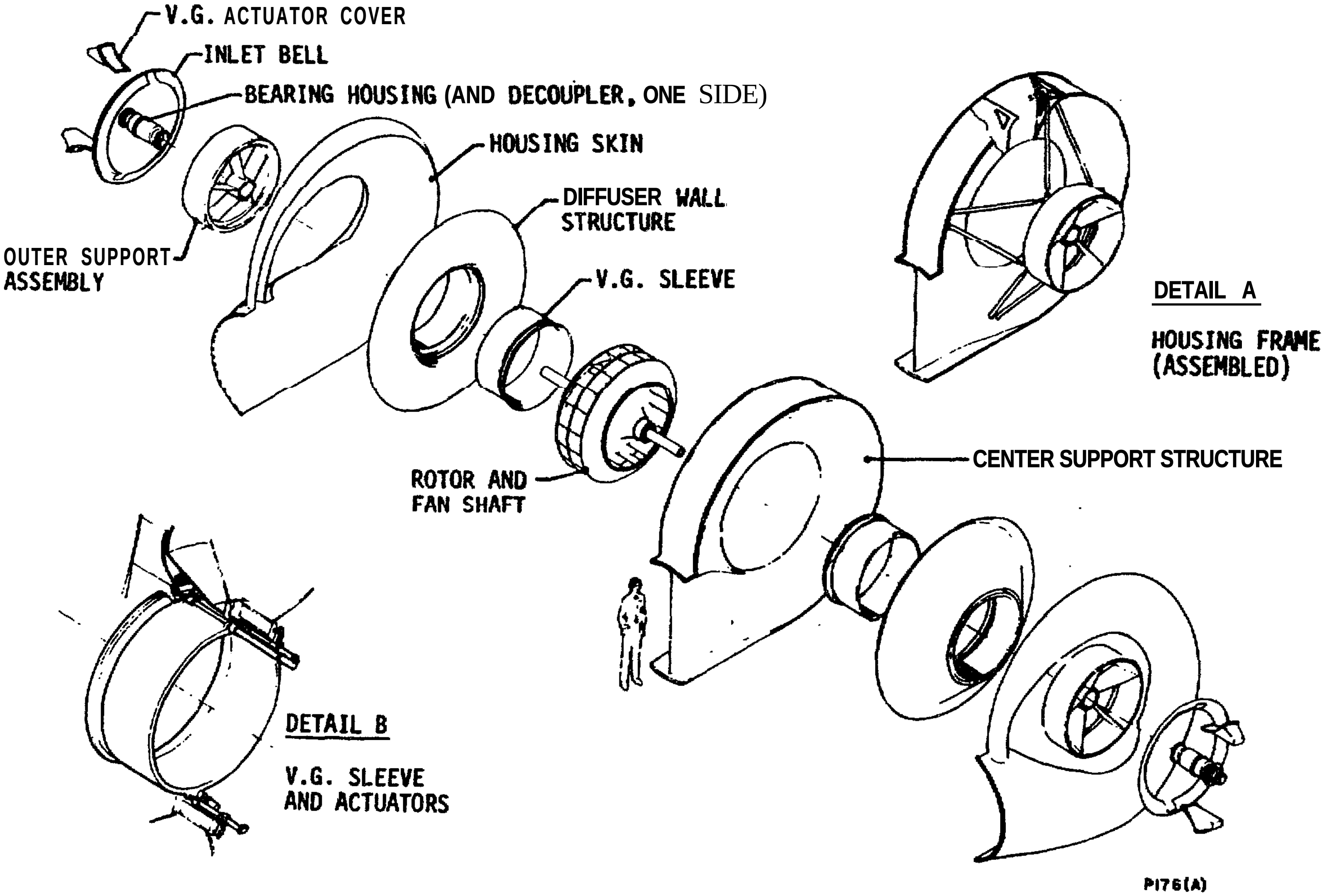


Figure 2.3.3-4 CUSHION FAN — EXPLODED VIEW



Fighre 2.3.3-4 CUSHION FAN — EXPLODED VIEW

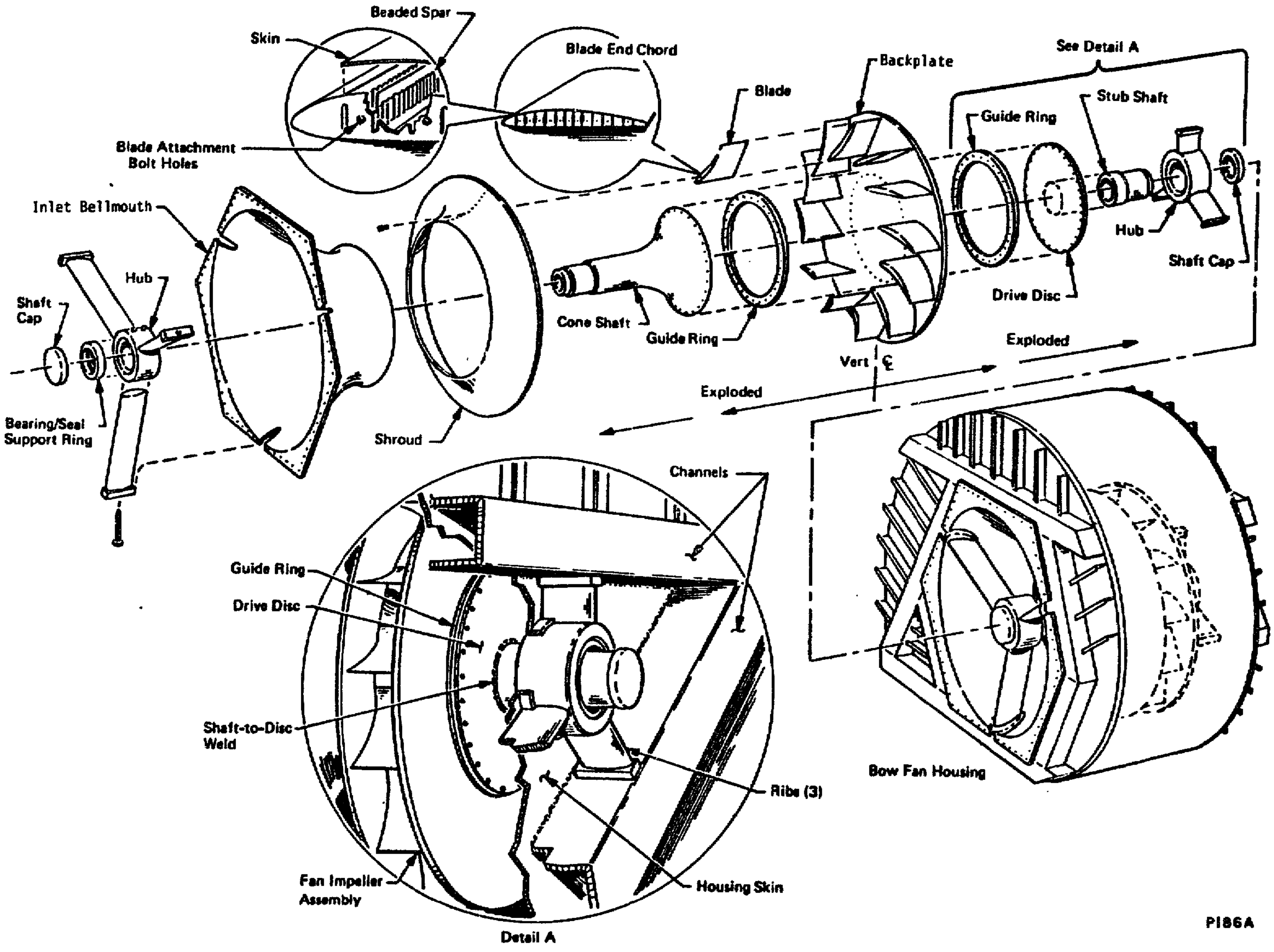


Figure 2.3.3-5 BOW SEAL FAN (SINGLE ENTRY)

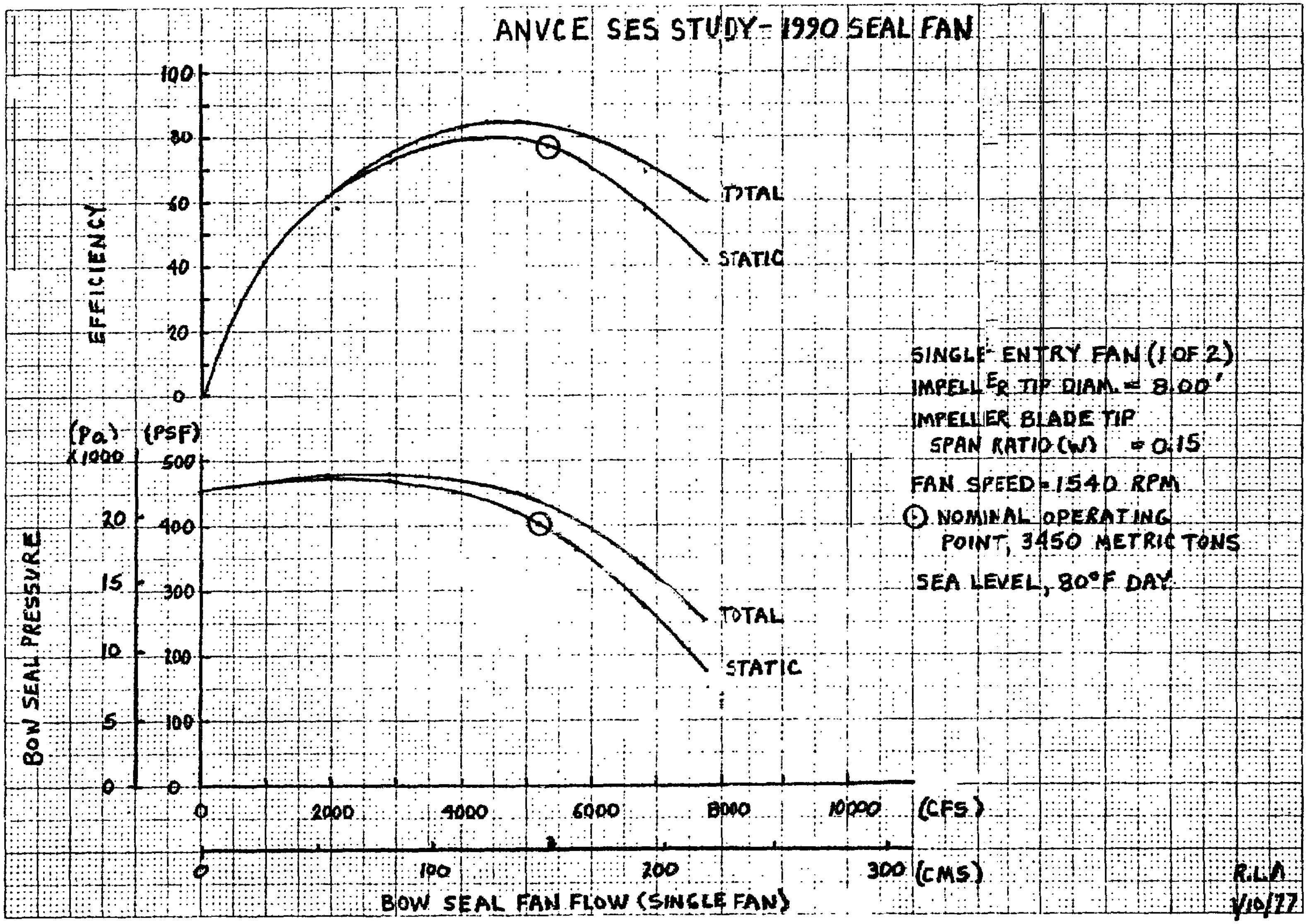


Figure 2.3.3-6 1990 SEAL FAN — PRESSURE-FLOW CHARACTERISTICS AND EFFICIENCY

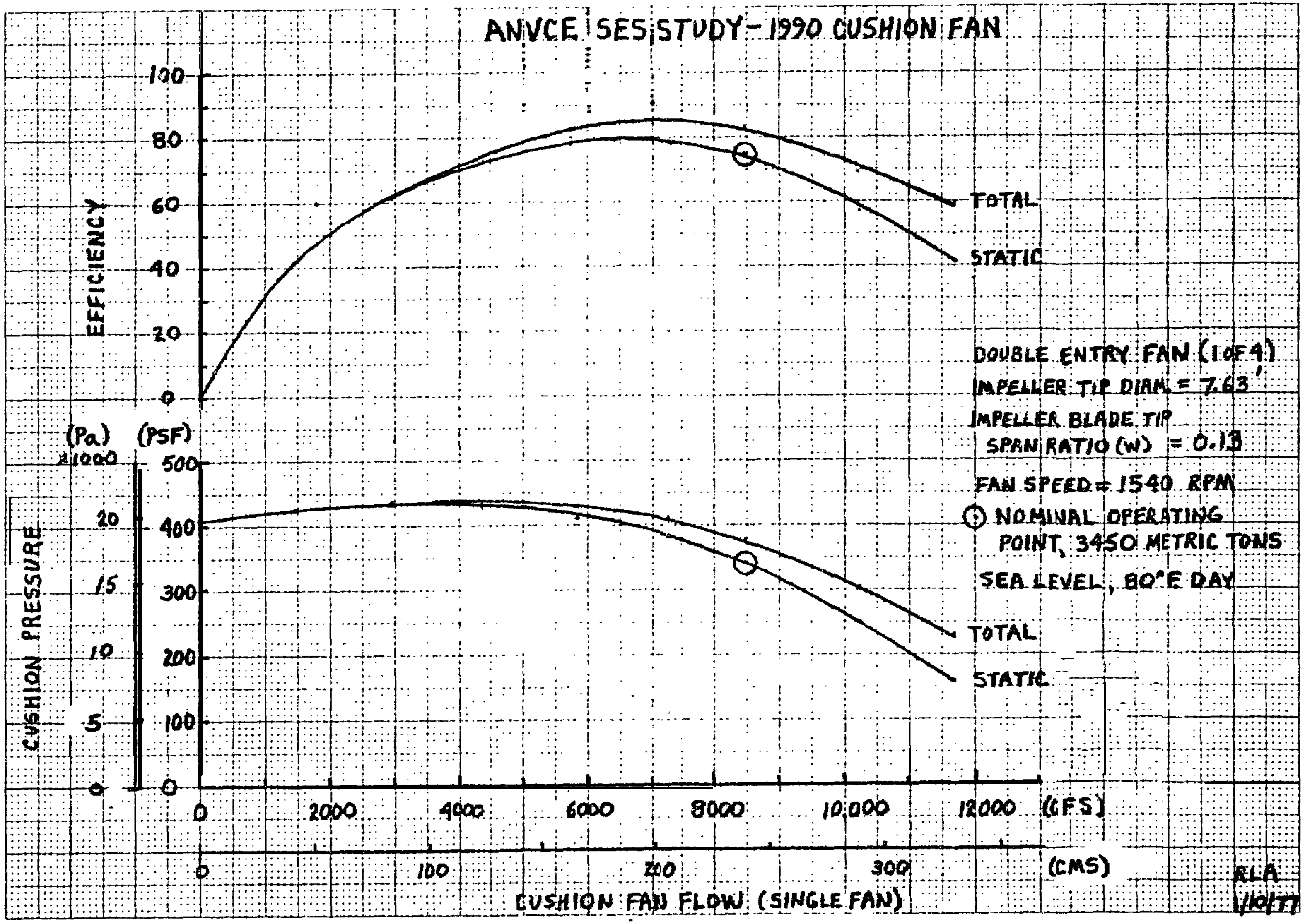


Figure 2.3.3-7 1990 CUSHION FAN — PRESSURE-FLOW CHARACTERISTICS AND EFFICIENCY

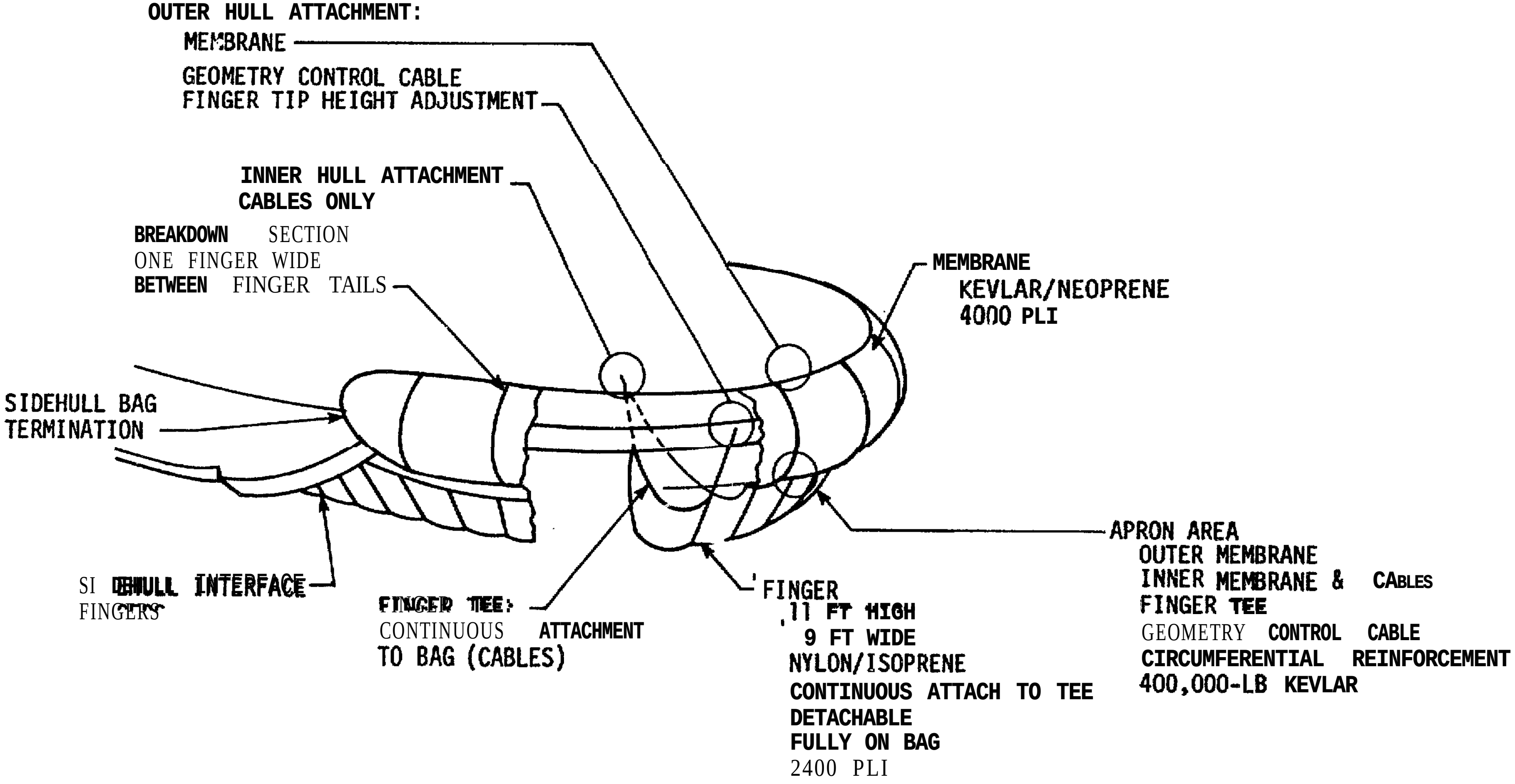


Figure 2.3.3-a BOW SEAL CONFIGURATION

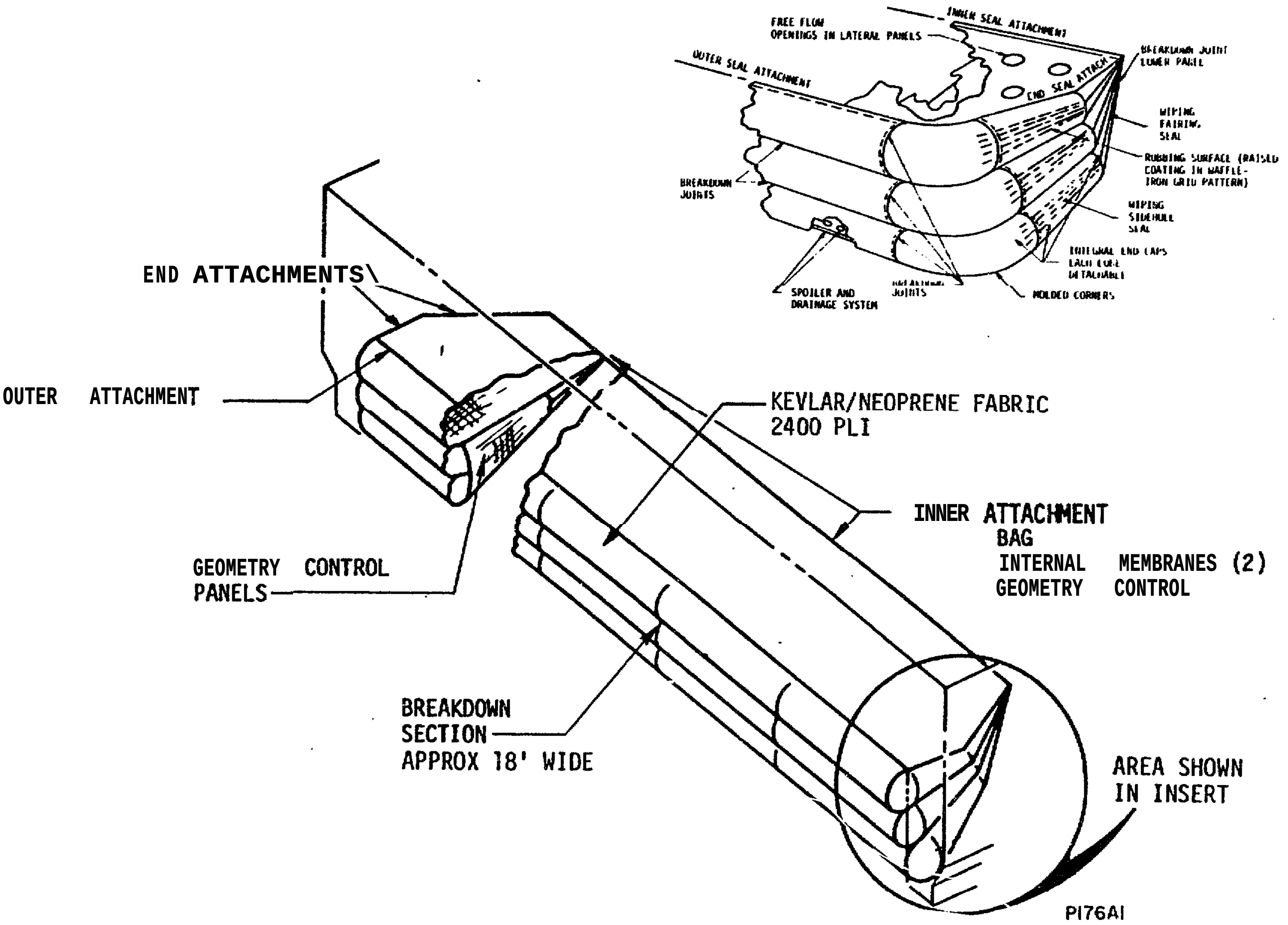


Figure 2.3.3-9 STERN SEAL CONFIGURATION

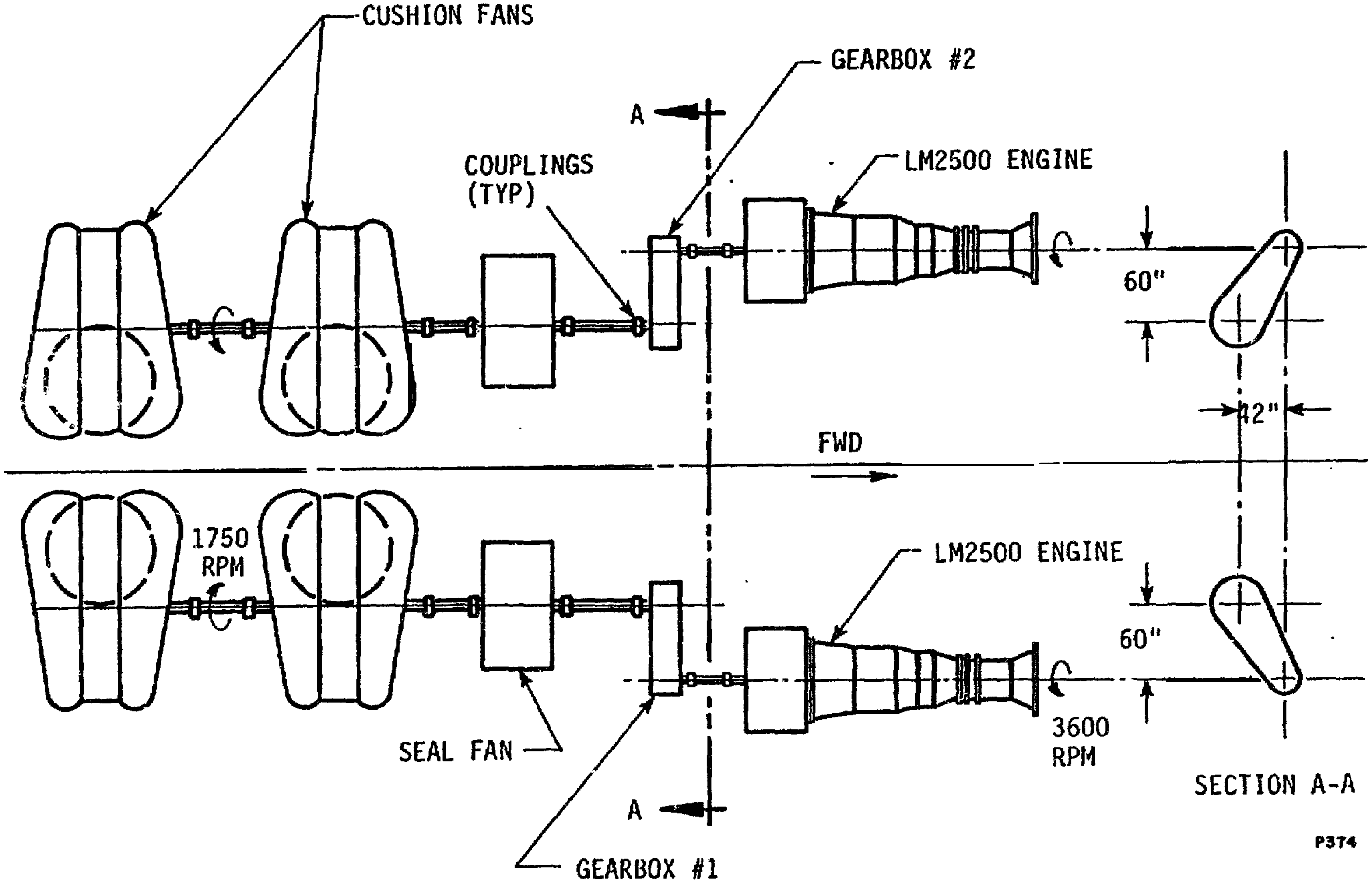


Figure 2.3.3-10 LIFT POWER AND FANS — PLAN VIEW

2.3.4 Electrical System

2.3.4.1 Summary of Key Features

The design of the LSES electric plant provides a safe, efficient, reliable and effective system, while accommodating the unique aspects of large surface effect ships.

Weight, which is the most prominent constraint in SES design, dictates the need for a lightweight electrical system. Second-generation aircraft electrical equipment, which has been adapted to the marine environment, is the means by which weight is being significantly reduced.

In keeping with the weight sensitivity of surface effect ships, the generating plant is a dual-purpose ship service/emergency generating system. Electrical power is generated by three ship service power units (SSPUs), as shown in figure 2.3.4-1. Each SSPU consists of a gas turbine directly coupled to a gearbox, which provides the drive to the generators and other equipment driven by a TF-25C gas turbine. Two 400-Hz generators are mounted on each SSPU, together with a 60-Hz air-cooled generator, two hydraulic pumps, and one load compressor.

The development progress of multi-megawatt 400-Hz generators is being monitored as a potential improvement on the two generator per SSPU design of the 1980 version. The multi-megawatt machines are considered very risky at this time, both from a cost and technology point of view, and consequently are being considered as a potential alternative pending successful development.

The electrical load analysis for the ship was derived from the 1980 ship configuration by assessing the load differentials between the two ship equipment complexes. Where definitive loads were not available, data from like equipments of today's inventories was used. This was felt to be a conservative load analysis, because in the 1990 time frame, electrical power consumption for the electronic and communications equipment should be significantly reduced with the further development of solid-state technology.

The generator size is adequate to provide for the normal and maximum electrical demands as well as for the safe and efficient operation of the ship. The 400-Hz ship service generators are operated in parallel, while the 60-Hz generators are operated split-bus. During anchor operations, any one of the three SSPUs is capable of providing power for the ship. During normal ship operation, two

SSPUs are required to be on-line to operate the total electrical load and to provide for 30-percent growth. This arrangement economizes fuel and allows for enough electrical power to operate the ship.

It is also possible for all six 400-Hz generators to operate in parallel. During operations where maximum operational load is required, it is standard practice to put all three SSPUs on-line. However, the total 400-Hz electrical load can be carried by any two. Additionally, any two SSPUs can provide all 60-Hz requirements with 100-percent backup, This design feature allows for total loss of any single source of generating capability with no loss of ship operational capability and with no momentary interruption of power. The system design also allows the ship to operate at a reduced capability on only one SSPU (ie, capable of maintaining course, direction, and speed). Separation of the SSPUs (two are located forward on the main deck, one on the port and one on the starboard side of the craft, with the third aft on the second deck) reduces the hazard of losing more than one SSPU as a result of physical damage.

The TF-25C is a two-shaft, free power turbine engine assembled in a modular configuration for easy maintenance. The engine is shown in figure 2.3.4-2, and the individual modules are shown in figure 2.3.4-3.

Mounted on top of the engine inlet housing assembly *is* the accessory gearbox module. This module has eight mounting pads, some of which are used for engine functions such as starter, fuel control, and governor. The engine has a self-contained lubrication system. An oil-sump module is attached to the bottom of the inlet housing, and serves as the engine oil reservoir. A separate lubrication system is provided for the main reduction gearbox and generators,

Fuel for the SSPU *is* provided from a system separate from the propulsion and lift fuel system. Particle and water filtration, together with pressure regulation, are provided. Filter servicing, coalescer drainage, low pump pressure, and high-pressure warnings are provided. An emergency fueling system has been provided which allows fuel from the main engine feed system to be fed to this SSPU via manually operated valves.

Compartment cooling is provided by 400-Hz cooling *fans.* The air is processed through a filter/demister prior *to* being injected into the compartment.

The SSPU anti-icing system is typical for all three locations. The load compressor driven by the SSPU serves two purposes. It provides air for air-starting the propulsion and lift engines, and is used for providing hot air for the SSPU air inlet anti-icing. When anti-icing is needed, the discharge from the load compressor is ducted through a selector valve to a point upstream on the filtration system, where it is discharged into the combustion air stream through a Riccolo manifold. By this means, the SSPU combustion air is maintained at a temperature above freezing.

An onboard water-wash system is provided. Water for this system is supplied from the distilling system and is stored and heated in a holding tank. A detergent tank is included in the system for detergent-wash purposes. Water to the SSPU water-wash nozzles is delivered by means of a 100 lb/in^2 pump.

Each SSPU has two separate lubrication systems; one supplies the ship service turbine (SST), and the other supplies the gearbox and shaft bearings on the 400-Hz generators. The possiblity of cross-contamination in the event of a failure was the compelling reason against an integrated system.

The SSPU gearbox and generator bearing lube system hardware is located in close proximity to each SSPU, but outside the SSPU firewall. Instrumentation is provided for remote sensing of oil-supply pressure, oil-return temperature, chip filter differential pressure, and tank oil level. The oil tank is sized to provide slightly more than 1 minute of oil dwell time to ensure sufficient deaeration. A single filter is proposed, since alternate SSPUs may be used to allow servicing of a clogged filter on a unit.

Salt removal from the air is achieved by filtration. A Farr Aquavane water separator and a charged droplet scrubber (CDS) demister are used in series. Ducting for the system also contains a silencer for air inlet noise reduction.

A weight allowance has been added for a seawater spray system in the turbine exhaust to reduce IR signature of the ship to a level equal to the ship radar signature.

Each ship service gas turbine (SSGT) is controlled by a sequencer/controller that accepts operator-initiated start/stop commands, with the sequencer/controller unit providing automatic start sequence and control of the unit to its run conditions. Operation of the SSGT is monitored continually by the sequencer, and automatic shutdown is accomplished for gas turbine conditions of overspeed, gas generator overtemperature, and any start sequence failure-to-complete condition.

The sequencer/controller provides automatic throttle control to achieve speed control of the turbine. This allows parallel operation of the 400-Hz generators being driven from the turbine.

Generator performance is governed by a generator control unit (GCU) that accepts the output of the generator built-in exciter and creates the field exciter current. This, in turn, generates field current in the rotating field for generation of power in the fixed stator. The GCU monitors frequency and voltage and, when preestablished limits have been met, allows the generators to be placed on- line.

Since electrical power is the very heart of the entire ship, continuity of power was a fundamental consideration in the system design. Vital ship functions (eg, steering, propulsion, communications, radar, fire maintenance, and lighting) are provided a more reliable distribution scheme than nonvital loads, because of their significance in normal and emergency operations. Each is connected to two sources of power, and an automatic bus transfer device allows automatic switching to the alternate source should the primary source fail.

The electrical distribution system is designed to minimize the number of feeders and length of cable runs. System protection is provided for the isolation of faults with a minimum of damage and disturbance to the remainder of the system. The distribution system, as well as the power generation system, is designed to maintain the voltage and frequency within specified tolerances at the terminals of the power-consuming equipment.

Electrical power (60 and 400 Hz] is generated at 450 volts line-to-line for distribution throughout the ship. The switchboards for the 400-Hz system are connected by a ring bus, which permits three switchboards to receive power from all six parallel generators. Each 60-Hz generator switchboard is connected to two generators by a split-bus system, which provides an alternate source of power for each switchboard from the isolated generators. Multiple feeders are provided in both bus systems to maximize system integrity. Bus ties are sized to carry the full rated output of the SSPU (900 kw for 400 Hz and 100 kw for 60 Hz). Details of this design are shown on figure 2.3.4-4. Power from the switchboards is distributed as required to the major vital and nonvital load centers located throughout the ship.

System protection is provided to isolate a fault with minimum disruption to the rest of the system, Coordination of devices will provide isolation at the lowest level within the system. Circuit breakers will be installed within the power panels for protection of the load feeders. Load-center breakers will be installed for protection between the load centers and power panels. The switchboards are equipped with circuit breakers for protection of the system between the switchboard and load centers.

The GCUs, in addition to providing voltage regulation and exciter controls, provide the following protection for the generators:

a. Reverse power
b. Over voltage
c. Under voltage
d. Over frequency
e. Under frequency
f. Over current
g. Differential current
h. Automatic parallel/dead-bus bypass
i. Over excitation
j. Under excitation.

In addition to generator protection, the GCU provides differential-current and over-current protection for the bus-tie contactors.

Control of the distribution switching is normally carried out remotely at the engineering and damage control center. However, direct local control can also be accomplished at the switchboards.

The electrical and control cables are the lightweight, highly flame-retardant type. This cable is approximately 25 percent lighter than standard Navy cable, and exhibits a degree of flame retardancy vastly superior to that of standard Navy cable. Additional weight savings will be realized by using aluminum conductors in cables with conductor sizes 8 and above. Adequate termination will be used to preclude the past problems experienced with aluminum conductors. These cables will result in a weight savings approaching 50 percent over standard Navy cable.

A cabling system that combines both aerospace wire technology and conventional marine cable technology will be used aboard the SES. For those applications where both ends of a conductor terminate within the same compartment, an aerospace-type harness will be used, For those applications where bulkheads must be penetrated, lightweight cable will be used, and will be either watertight or nonwatertight as the application dictates.

The lighting requirements are consistent with standard Navy practice, and are established using NAVSEA 0964-00-2000, Lighting on Naval Ships. Ship service power is provided by two vital load centers. Should both the normal and alternate supply to each load center fail, essential lighting will be provided by battery-operated lanterns. The batteries are continually supplied with charging power during normal operating conditions,

Equipment and enclosures are selected for compatibility with the environmental conditions anticipated and the locations. Equipment will be enclosed and self-cooled where it is exposed to the weather, explosive-proof where volatile frames can accumulate, and drip-proof for general compartment use.

2.3.4.2 Electrical System Characteristics

Tables 2.3.4-I and 2.3.4-11 list the system characteristics for both the 400-Hz and 60-Hz power.

2.3.4.3 Weight Percentage Breakdown - Electric Plant

SWBS		PERCENTAGE
310	Electric Power Generation	31.5
320	Power Distribution System	40.5.
330	Light System	15.7
340	Power Generation Support Systems	11.8
390	Special-Purpose Systems	0.5
	TOTAL	100.0

2.3.4.4 Risk Assessment

The load analysis for the 1990 SES showed no significant change in power requirements over the 1980 SES; therefore, the same SSPUs will be used for the 1990 SES. The use of this second-generation equipment ensures a minimum-risk approach and inherently indicates an improvement in design life and reliability.

As a contingency, should the electrical load increase beyond the capability of the presently proposed 400-Hz generators, multi-megawatt 400-Hz generators now under development for the Air Force should be available within the 1990 time frame and could be used aboard the 1990 SES.

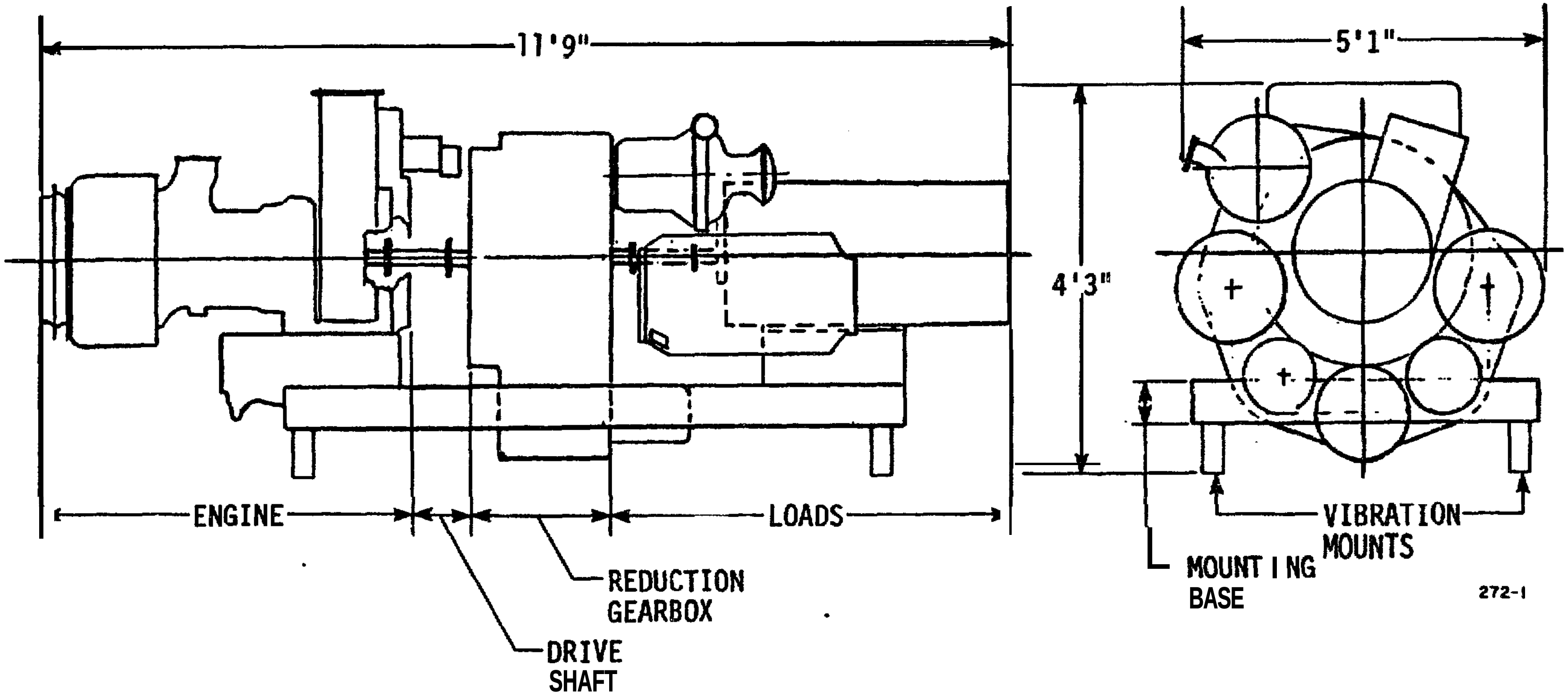


Figure 2.3.4-1 **BASIC** SHIP SERVICE POWER UNIT **(SSPU)**

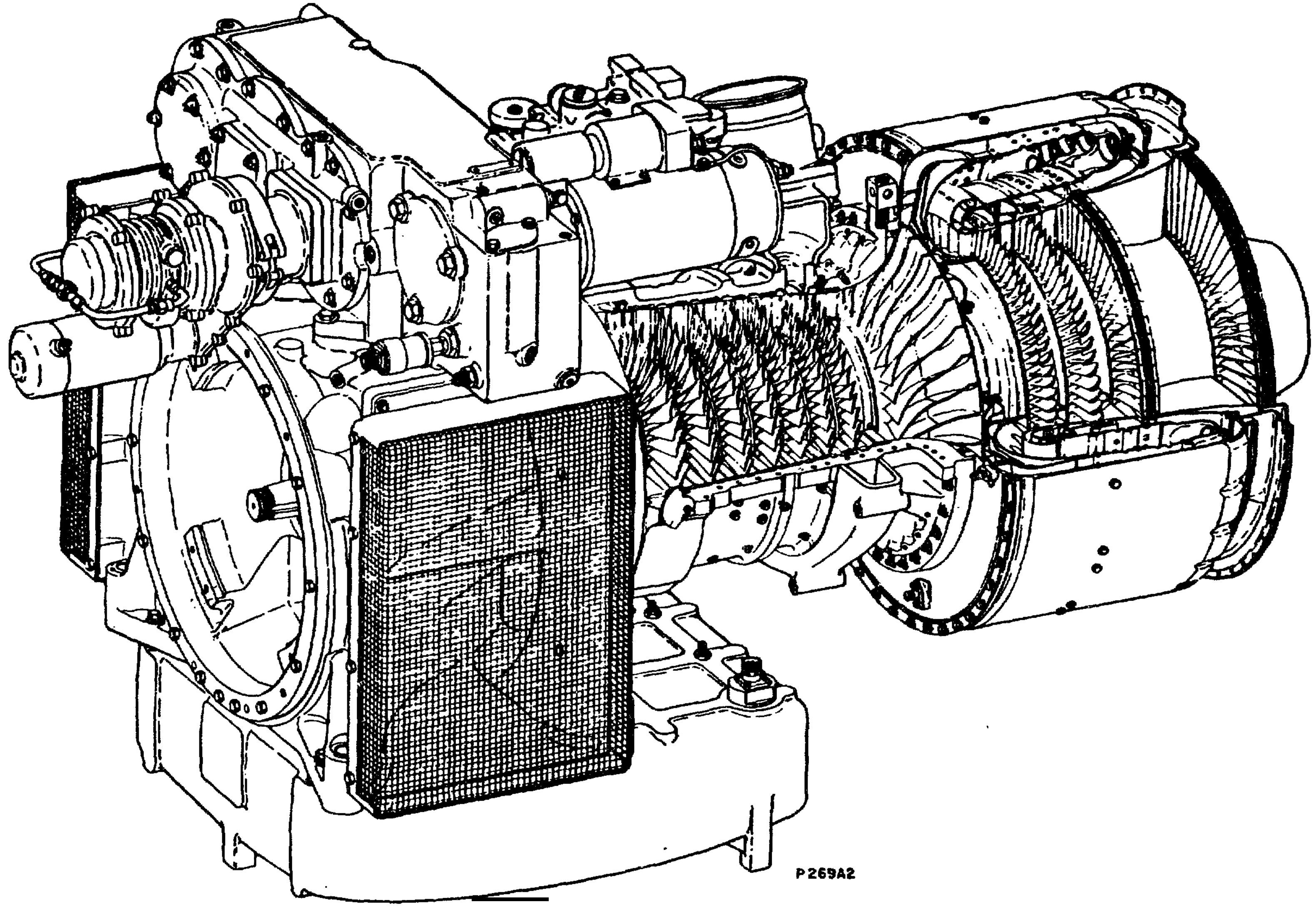


Figure 2.3.4-2 TF-25C TURBINE ENGINE ASSEMBLED

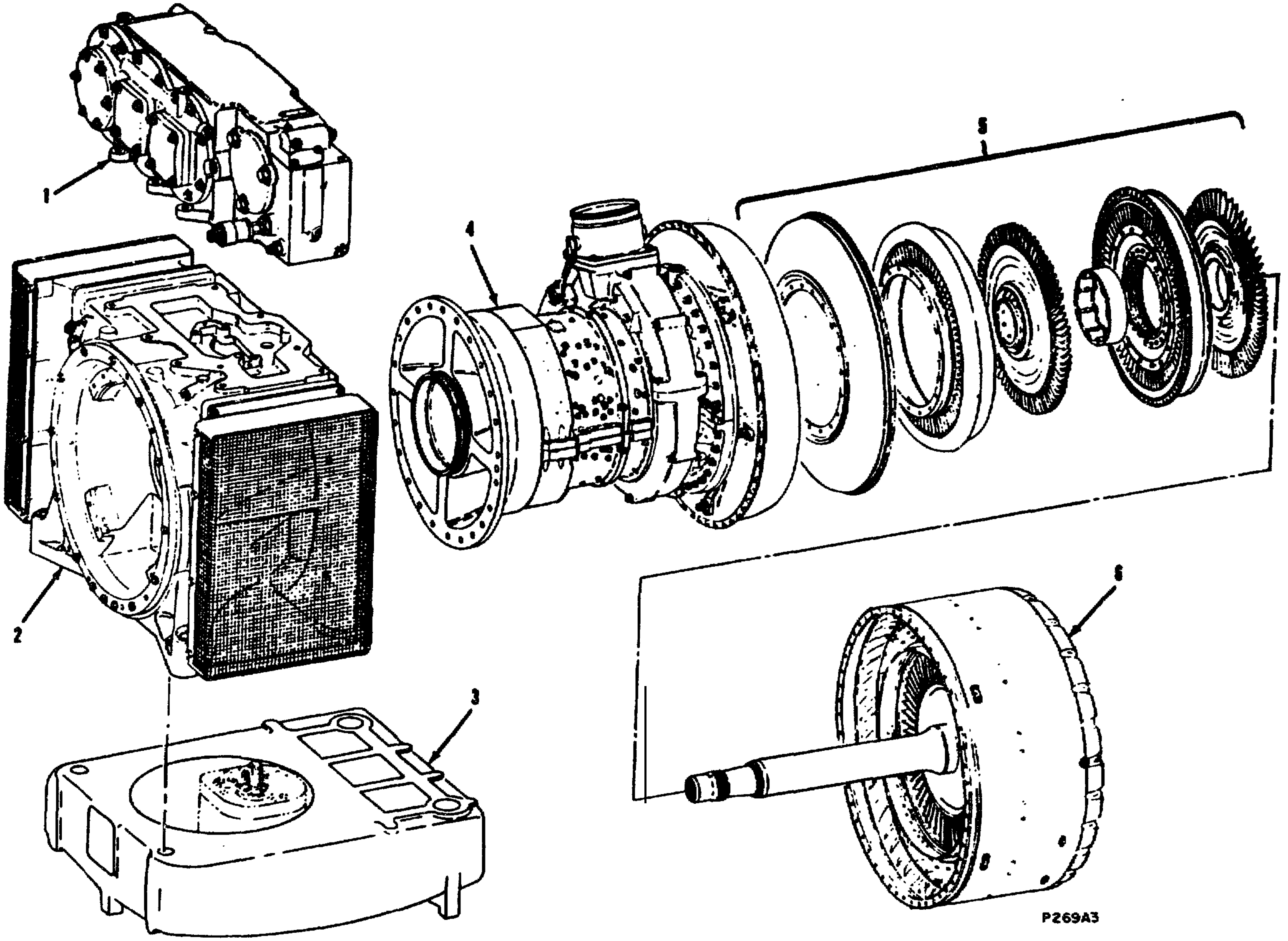


Figure 2.3.4-3 TF-25C TURBINE ENGINE MODULES

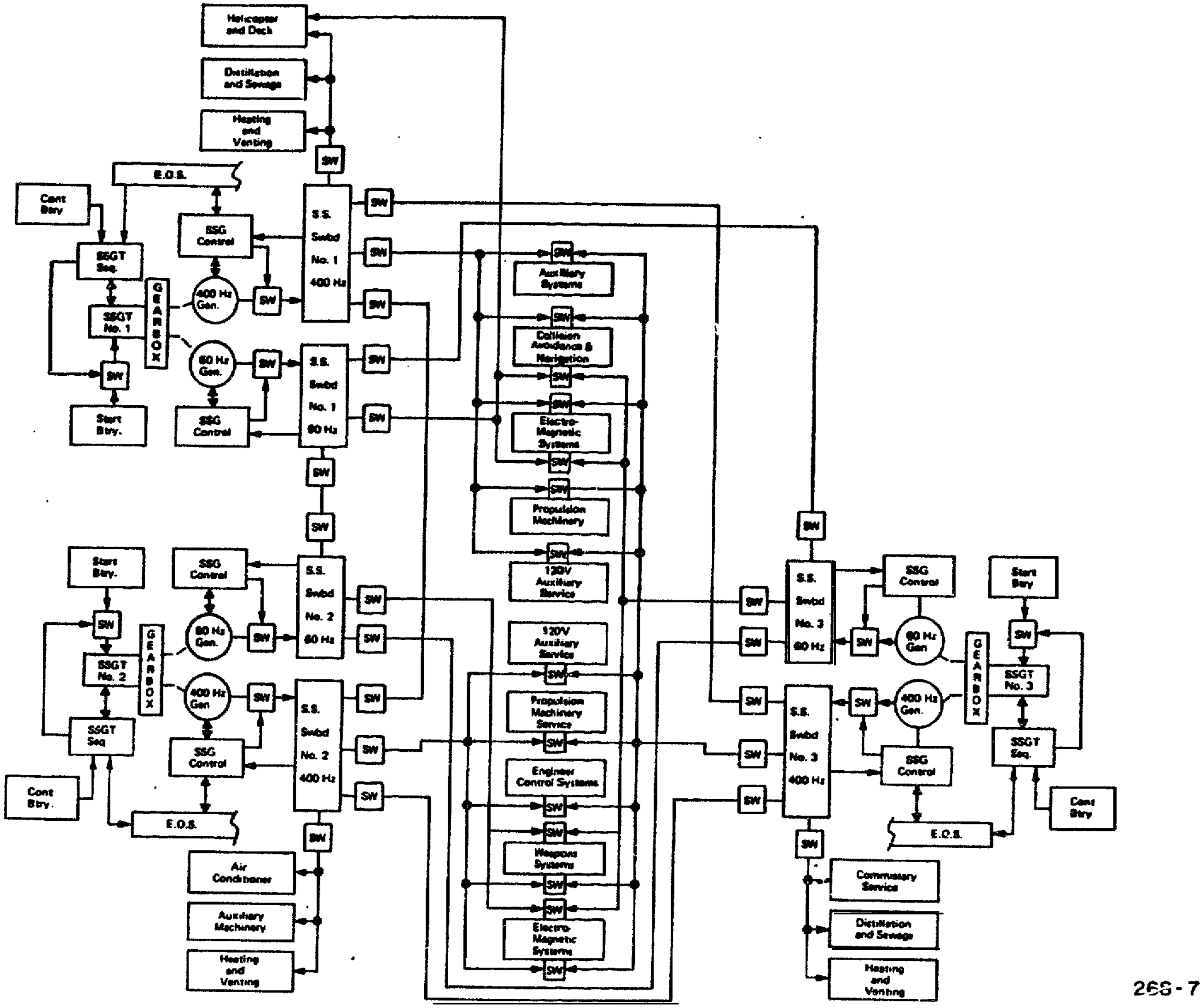


Figure 2.3.4-4 ELECTRICAL POWER GENERATION AND DISTRIBUTION SYSTEM BLOCK DIAGRAM

TABLE 2.3.4-I

PERFORMANCE OF THE 400-Hz SYSTEM

Nominal utilization voltage	400 or 115 volts
Nominal frequency	400 Ha
Steady-state voltage	
Average of the three-phase voltages (1)	±1%
Phase voltage for single phase	±2-1/3%
Unbalance	2%
Voltage modulation	2%
Waveform	
Total harmonic distortion	6%
Maximum single harmonic	4%
Deviation factor	5%
Voltage transients (2)	
200% load application	-24.3%
100% load removal	+18%
Recovery	0.1 sec
Steady-state frequency	
Tolerance band	±5%
Modulation units	0.5%
Frequency transient	
Frequency transient limits (only 1% will be outside the steady-state frequency tolerance band)	±3%
Recovery time	2 sec

(1) At point of regulation
(2) At generator terminals

TABLE 2.3.4-11

PERFORMANCE OF THE 60-Hz SYSTEM

Nominal utilization voltage	400 or 115 volts
Nominal frequency	60 Hz
Steady-state voltage	
Average of the three phases	±5%
Phase voltage for single phase	±7%
Unbalance	3%
Waveform	
Total harmonic distortion	5%
Maximum single harmonic	3%
Deviation factor	5%
Voltage transient	
Voltage transient limits	±18%
Recovery time	2 sec
Steady-state frequency	
Tolerance band	±5%
Modulation limits	0.5%
Frequency transients	
Frequency transient limits	±3%
Recovery time	2 sec

2.3.5 Command, Control, and Communications (C^3)

2.3.5.1 General Description

The key elements of the command, control, and communications (C^3) section are the command and control systems (SWBS 410), navigation system (SWBS 420), the internal communications system (SWBS 430), and the exterior communications system (SWBS 440).

The system design incorporates all the equipment directed by the TLR; new equipment development has been minimized, The system design draws extensively on the experience gained on the LSES program, with LSES hardware used wherever possible. In designing the systems for the LSES, the high-speed, unusual motion, and spray environment of the ship was taken into consideration. Additionally, sufficient automation was provided to accommodate the proposed manning while maintaining crew member normal task loading with a minimum of equipment sophistication, Redundant, below-deck control equipment has been provided to permit ship operation in the event of major damage.

The navigation equipment is identical to that used on the LSES, with the addition of a global positioning system. The collision-avoidance aspect of the navigation system was developed on the LSES program and provides the means by which the different aspects of a collision situation are displayed, monitored, and controlled. The system determines that a collision situation exists and commands the correct evasive action. The ship dynamic characteristics, and control capabilities, are automatically taken into consideration and the avoidance maneuver is displayed. It utilizes a dedicated anti-clutter radar and provides automatic target detection, target tracking, and maneuvering planning using a daylight TV-type display which includes a synthetic symbols generator.

The interior communications system consists of three major functional disciplines: voice communications, system data transfer, and the integrated control system. It utilizes systems developed for the LSES. The ship system data transfer is accomplished by the general data system which is an asynchronous time-division multiplex system derived from the Ship Data Multiplex System (SDMS). This reduces the ship cabling requirements by providing total data distribution throughout the ship by'three coaxial cables,

Significant integration of the ship control functions has been provided within the interior communications subsystem, to integrate the control of ship heading, speed, heave, ride, trim, and list. The control centers are the bridge and the engineering damage and control center (EDCC). Automation is provided where response exceeds the operator capability and where it would significantly reduce fatigue. This has resulted in a reduced operational manning requirement for some of the major ship systems.

The main machinery for propulsion and lift is operated remotely at a central location, the EDCC, as are the auxiliary systems, and damage control. Information pertinent *to* each major operating item is provided to the EDCC via the general data system and is displayed at one of three operator consoles: main machinery control, auxiliary systems control, or damage control.

The fire detection and extinguishing network is integrated into the damage control console located in the EDCC. Fire detection sensors are a mix of thermal and optical, providing redundancy in the high- and moderate-risk areas. The EDCC console provides the warning lights, alarms equipment and ventilation shutdown, extinguishing agent release, and built-in test capability,

Watertight bulkhead penetration status and compartment flooding is also displayed at the damage control console.

Included in these consoles are the control devices necessary to provide commands to operate the systems. Panel layouts on the consoles have been defined co provide for balanced operator workload, sit-down operation, and total viewability by the engineering officer, Data display uses limited real-time displays to reduce the amount of display hardware. A data processor is employed which senses out-of-tolerance conditions and selectively displays these on a common display.

This approach utilizes the display and control consoles developed and used on the LSES and is a minimum risk approach, However, an alternate at slightly higher risk utilizes the CRT graphic terminal displays more extensively for both data presentation and system monitoring and individual system control, The risk is minimized by providing backup displays. Following this approach, all the individual system display and control panels of the LSES design are eliminated . The CRT graphic terminal displays will display computer generated block diagrams of all systems which can be called up as desired. The computers will constantly monitor all systems and, if any system parameter is out of tolerance, will immediately display that parameter in a flashing format.

The EDCC will contain three consoles - the electrical/auxiliary console, the damage control console, and the engine control console, with the same basic distribution of signals as the corresponding LSES consoles. Each console will consist of two racks, each containing a CRT display and keyboard. It is expected that both CRTs will be normally utilized, with provision for one CRT handling the entire load of that console in case of malfunctions. In addition, redundancy will be provided by having one CRT at each console capable of handling the tasks of the other consoles.

With this approach, individual dedicated controls will be eliminated, with the exception of the fire extinguishing system and engine throttle levers. Also, all signals (both command, response, and display) will be transmitted using the shipboard data multiplex system, with the possible exception of the fire extinguishing system, which will be hard wired.

Further integration of the ship control system is evidenced in the bridge design. This appears in the merger of the ship bridge controls with the ship operational displays, navigational displays, and collision-avoidance displays.

Primary direct control of propulsion, lift, and contra1 devices is given to the helmsman. A backup set of controls is provided at the OOD stations, manned by either the OOD or a relief helmsman as required. Backup controls for emergency purposes are provided at the EDCC.

Both the helmsman and OOD positions are provided with the anti-clutter radar collision-avoidance display. This display provides dynamic ship steering information based upon the target evaluation and maneuver-planning computed in the NAVCAS. Unprocessed radar video data can be supplied to these displays as a backup function.

The OOD position on the bridge is provided with a multimode display which provides a visual display of the status of all of the ship systems on a system-by-system basis requiring only a single control command to acquire the display.

A navigator station is provided on the bridge. This station is located next to the OOD position providing access to the navigation plotting table. The navigation station provides all the controls and displays which satisfy the man-machine interface to the ship NAVCAS,

The ship voice communications function employs a multiplexed control which significantly reduces the number of control lines in its design. Further savings in system weight is achieved by integrating portions of access functions to the exterior communications system into the interior communications system, thereby reducing the number of communications switchboards required,

The exterior communications element is composed of equipment required for the exchange of intelligence between the LSES and any other vessel, aircraft, or land station, It includes the ship radio, underwater communications, visual and audible equipment, teletype and facsimile units, and security equipment as specified in the TLR. Mast of the exterior communications equipment differs from that used on the LSES. The equipment specified in the TLR was based on the following assumptions:

a. The ship will interface with the FLTSATCOM I for receipt of a multichannel broadcast and for ship-shore operation in a half-duplex mode.

b. The Naval Modular Automated Communications System (NAVMACS) family of message processing systems will be operational. The system will permit on-line record traffic operation far ship-shore satellite paths, ship-ship hf/uhf/vhf path and hf ship-shore as backup path to SATCOM.

c. An Automated Communications Control System (ACCS) will also be operational, This system will provide automatic circuit configuration, quality monitoring and control, fault isolation, processor-assisted frequency selection, and equipment status displays. System operation implies that all equipment tuning will be automatic and performed from a central console.

, Selection of the system control equipment was made to provide an integrated ship communication system, (both interior and exterior) with multiple-station access to the system. It would operate within the design constraints of a high-speed SES environment (ie, sit-down operation, limited manning, etc).

2.3.5.2 Equipment

The command, control, and communications (C^3) equipment, its weight, size, and ship service functions are given in table 2.3.5-I.-

2.3.5.3 General Arrangements

Figure 2.3.5-1 shows the general location of command and surveillance equipment on the ship.

Figures 2.3.5-2 and 2.3.5-3 show the bridge and EDCC console arrangements.

The room sizes required for the equipment in the command, control, communication, and combat systems were determined by modifying baseline room sizes established for the 1980 LSES to adapt for new equipment required by the 1990 TLR. The 1980 spare requirements were established by either preparing room area proving sketches or using FF6-7 room sizes where FF6-7 equipment was used.

TABLE 2.3.5-I

COMMAND, CONTROL, AND COMMUNICATION (C^3) EQUIPMENT

SWBS NUMBER	NAME	FART NUMBER	QUANTITY	SIZE	WEIGHT	POWER
SWBS 411 - Data Display Group	Operations summary console	OJ-197/UYA-4 (V)	1	303 ft^3	4.21 LT	7.5 kw
	PPI console	OJ-194(V)3/UYA-4(V)	4			
	Radar repeater	AN/SPA-25	1			
	Remote data readout	OA-8337(V) 1/UYA-4 (V)	1			
	Azimuth symbol converter group	OU-91 (V)/UYA-4 (V)	1			
	Radar data distribution siwtchboard	SB-2780/UYA-4(V)	1			
SWBS 412 - Data Processing Group	Digital computer	AN/UYK-7(V)	1	61 ft^3	1.13 LT	4.4 kw
	Data Exchange Auxiliary Console (DEAC)	OJ-172(V)/UYK-7(V)	1			
SWBS 513 - Digital Data Switchboards	Switchboard	SB-1299B/USQ-20(V)	1	18 ft^3	0.1 LT	I kw
SWBS 414 - Interface Equipment	Remote keyset	MS-8025	2	49 ft^3	0.45 LT	7 kw
	Interface unit for AN/APS-125 radar system	(TBD)	1			
	Signal data converter	AN/UYA-4(V)	(TBD)			
SWBS 415 - Digital Data Communications	Data terminal set control	C-9063/USQ-59	1	37.7 ft^3	0.4 LT	3.8 kw
	Data transfer switchboard	SB-3372/US	1			
	Data terminal	AN/USQ-59	1			
SWBS 416 - Command and Control Testing	Test message generator	SD-1051	1		0.03 LT	0.5 kw
	Test set, elect circuit plug-in	TS-2460/UYA-4	1			
SWBS 417 - Combat System switchboard	Switchboard	FFC-7	1	108 ft^3	2.0 LT	1 kw*
SWBS 421 - Non-electrical/electronic NAV Aids	Portable anemometer	(TBD)	1	a ft^3	0.03 LT	
	Chronometer	(TBD)	1			
	Sextant	(TBD)	1			
SWBS 423 - Electronic NAV Aids	TACAN-AN/URN- ( )			62.7 ft^3		
	Antenna	AN/URN-( )	1			
	Antenna control unit	AN/URN-( )	1			
	TACAN beacon	AN/URN- ( )	1			
	Status indicator	AN/URN-( )	1			

*Estimated

TABLE 2.3.5-I (Cont)

SWBS NUMBER	NAME	PART NUMBER	QUANTITY	SIZE	WEIGHT	POWER
SWBS 423 - (Cont)	OMEGA-AN/SRN-17					
	Antenna	AS-2960/SRN-17	1	5.96 ft³		
	Interconnecting group	ON-128/WRN	1			
	Receiver-computer	OR-133(V)/URN	1			
	Mount	MT-4610/WRN	1			
	Control-indicator	C-9462/SRN-17	1			
	Mount	MT-4611/WRN	1			
	Test Set	T-3389/URN	1			
	NAVSAT-AN/WRN-5 (V)					
	Antenna	(TBD)	1	94.26 ft³	1.38 LT	4.21 Kw
	Preamplifier	AM-6603/WRN-5(V)	1			
	Receiver computer	RT-1843/WRN-5(V)	1			
	Teletypewriter	TT-672/WRN-5 (V)	1			
	Global positioning system rcvr	(TBD)	1	TBD	TBD	TBD
SWBS 42-1 - Electronic NAV Systems	FATHOMETER-AN/UQN-1					
	Transducer	AT-2006/UQN-1	1	9.5 ft³	0.2 LT	0.1 Kw
	Receiver-transmitter	RT-888/UQN-4	1			
	Depth indicator	ID-1566/UQN-4	2			
	Depth indicator	(TBD)	1			
SWBS 426 - Electrical NAV Systems	WATER SPEED					
	Sensor	UL-204	2	2.3 ft³		
	Calibration-and-select unit	UL-701	1			
	Indicator-transmitter	UL-100-3	1			
	Synchro-converter	UL-502	1			
	Remote speed indicator	UL-101-M	4			
	Remote speed indicator	(TBD)	2			
	DRIFT ANGLE					
	Sensor	(TBD)	1	0.4 ft³		
	Sideslip indicator	(TBD)	2			
	NAVIGATION PLOTTER					
	DRAT-2	(TBD)	1	39 ft³		
	DRAT-2 Control	(TBD)	1			
	WIND SPEED/DIRECTION					
	Wind Speed and Direction Detector	Bendix 1135924-1	1	10.4 ft³		
	Wind Direction and Speed Transmitter	Bendix 1135925-1	1			
	Wind Direction and Speed Indicator	Bendix 1148595-2	3			
	Wind Direction Indicator	(TBD)	2			
	Wind Speed Indicator	(TBD)	1			
	(Total for SWBS 426)			52.1 ft³	0.43 LT	0.55 Kw

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TABLE 2.3.5-I (Cont)

SWBS NUMBER	NAME	PART NUMBER	QUANTITY	SIZE	WEIGHT	POWER
SWBS 427 • Intertial SAV Systems	Roll indicator	**(TBD)**	2		0.3 LT	0.4 kw
	Inertial unit	MK29 **MOD1**	1			
	Remote **position** indicator	(Part of **MK29 MOD1)**	1			
	Ownships head indicator	**(TBD)**	5			
	Heading indicators	**(TBD)**	2			
	Pitch indicator	(TBD)	2			
SWBS 428 - NAV Control **Monitoring**	Anti-clutter radar control panel	**(TBD)**	2	45.5 ft^3	0.4 LT	3.7 kw
	Anti-clutter radar display	**(TBD)**	2			
	Digital scan converter (ACR)	**(TBD)**	1			
	Digital scan converter (SPS-55)	**(TBD)**	1			
	Multimode display, 12 in.	(TBD)	2			
	Multimode display control panel, 12 in.	(TBD)	2			
	NAV/STEERING control panel	**(TBD)**	1			
	Navigation display	**AN/SPA-25B**	1			
	Computer	**AN/UYK-20**	**1**			
	Signal data converter	**(TBD)**	**1**			
	NAV collision avoidance symbol **generator**	**(TBD)**	2			
	Multimode display, 8 in.	(TBD)	1			
	Multimode display **cont** PNL (CO). 8 in.	(TBD)	1			
	Page printer	**AN/UGR-** 9	1			
	NAV/STEERING display	**(TBD)**	1			
SWBS 431 - **IC** Switchboards	Main IC switchboard	**(TBD)**	1	**132 ft^3**	1.04 LT	4.5 kw
	Local IC switchboard	(TBD)	3			
SWBS **432/433** • Telephone and Announcing Systems	Dist matrix/info tone gen	**622-2570-004**	2			
	Repackage of **DITM**		2			
	Bus power supplies	CPS **500-28/0 VP-4**	**12**			
	Shelves • PS mounting		6			
	Power supply	**CPS 120-28/0** VP-2	2			
	Shelf/breaker **MTG** panel		2			
	TTY/paper tape	33 ASK	1			
	Computer	**PDP-** 11 R20	**2**	(See next page for accumulated totals)		
	Rugged equip rack		**2**			
	Rack mod package		**2**			
	TTY mod		**2**			
	Power inserters		**8**			
	Bus amp		16			
	Switch over assy		2			
	I/C speaker	SAA	2			

TABLE 2.3.5-I (Cont)

SWBS NUMBER	NAME	PART NUMBER	QUANTITY	SIZE	WEIGHT	POWER
SWBS 432/433 • (Cont)	TAP units		132		1.2 LT*	2.0 kw*
	Handsets	H-273/U	54			
	Headsets	H-274/U	27			
	Phone terms (exposed)		7			
	Phone terms (interior)		71			
	Shelves W/4 IF units		2			
	Telco card cage	622-2410-001	1			
	Telco card cage mod		1			
	Pulse dial modules	622-2413-002	2			
	Intercom speakers	SAA	37			
	Intercom speakers	SBG	6			
	Extension speakers	SBA	24			
	Five-channel speakers	SAA	31			
SWBS 436 & 437 • Alarm. Safety Warning, and General Data System	Area multiplexer	(TBD)	4	108 ft^3	2.0 LT	5.2 kw
	Traffic control unit	(TBD)	3			
	Remote multiplexer-shared electronics	(TBD)	11			
	Remote multiplexer • in/out,	(TBD)	35			
	Keyset unit	(TBD)	1			
	Maintenance unit	(TBD)	1			
	Computer	AN/UYK-20	1			
	Data interface unit	(TBD)	1			
SWBS 438 • Ships Integrated Control System	Propulsion control system •	(TBD)	1	138 ft^3**	4.0 LT**	4.1 kw**
	Lift system control system	(TBD)	1			
	Ride control system	(TBD)	1			
	Waterjet inlet control System	(TBD)	1			
	Rudder & steering sleeve cont system	(TBD)	1			
	Aux machinery control system	(TBD)	1			
	Damage control system	(TBD)	1			
SWBS 439 • TV and Recording Systems	B&W TV camera and remote control	LDH-105/01	1	11.5 ft^3	0.2 LT	0.3 kw**
	TV camera stand	Type 230	1			
	RF splitters	PBB-2	3			
	TV monitor mounts		2			
	B&W TV monitor	CVM 960U	2			

*Totals are estimated and include items both on this page and preceding page (for SWBS 432/433)

**Estimated

TABLE 2.3.5-I (Cont)

SWBS NUMBER	NAME	PART NUMBER	QUANTITY	SIZE	WEIGHT	POWER
SWBS 441 - Radio Systems	JTIDS command Terminal Unit	(TBD)	1	4.9 ft^3		
	Control display unit	(TBD)	1		10	
	Power amplifier unit	(TBD)	1		28	
	Transmitter/Receiver unit	(TBD)	1		42	
	Signal processor unit	(TBD)	1		73	
	Terminal processor unit	(TBD)	1		24	
	Antenna	AS-2812	1		6	
	Medium speed printer	TT-624/UG	1	21 ft^3	270	
	SATCOM receiver	AN/SRR-1	1	3.4	90	
	Antenna	AS/2815	4		52	
	Amplifier converter	AM/65 34	4	.2	52	
	Bridge to bridge transceiver	AN/URC-80	1	.42	25	
	Antenna	AS-2809/SRL	1		7.5	
	HF Transceiver	AN/URC-81	5	8.74	270	
	Transmitter adapter	MX-8316/UR	5	.73	100	
	Antenna coupler	CU-938/URA-38	5	1.26	375	
	Antenna coupler control	C-3698/URA-38	5	.52	125	
	35-foot whip antenna	AS-2807/SRC	5		850	
	VHF/AM transceiver (115-156 MHz)	AN/ URC- 86	1	2.43	80	
	Control, radio set	C-9060/UR	1	.72	20	
	Antenna	AS-2809/SRC	1		7.5	
	UHF transceiver (100w)	AN/URC-93	4	8.74	640	
	Control, radio set	C-9059/URC	1	.25	6.5	
	Antenna	AT-390/SRC	4		18	
WBS 441 - (Cont)	HF receiver	AN/URR-67	4	2.43 ft^3	240	
	Antenna (35-foot whip)	NT-66047	1		100	
	VHF/FM transceiver	AN/VRC-46	1	.72	78	
	Control adapter	MX-1986A/SRC	1	1.57	30	
	Antenna matching unit	MX-6707/VRC	1	.18	10	
	Antenna	AS-1729/VRC	1		15	
	SATCOM Transceiver	AN/WSC- 3	1	7.96	148	
	Antenna	AS-2410/WSC-3	1	6.00	225	
	Processor	AN/UYK-20	1	5.44	220	
	Magnetic cassette unit	RD-396(v)/U	4	1.78	200	
	Paper tape reader/punch	RD-397(v)/U	1	7.51	150	
	Medium speed printer	TT-624/UG	1	12.76	270	
	Modem	AMF1-OM-43A	1	1.68	100	
	Crypto Device	T/SEC KG-36	1	.72	27	
	CRT display unit	CRT	4	5.44	800	
	Amplifier/converter	AM-6534	4	.75	52	
	Combiner/demodulator	MD-900	1	1.79	81	
	Deaultiplexer	TD-1063	1	1.40	72	
	Key generator	TSEC/KG-36	1	.72	110	

TABLE 2.3.5-I (Cont)

SUBS NUMBER	NAME	PART NUMBER	QUANTITY	SIZE	WEIGHT	POWER
SWBS 441 - (Cont)	**ACCS/NAVMACS** master control	(TBD)	1	54.00	4.50	
SWBS 442 - Underwater **Comm** system	Transducer **(LF)**	**TR-232/WQC-2**	1			
	Transducer (HF)	**TR-233/WQC-2**	1			
	Winch and cable assembly	**(TBD)**	**1**			
	Winch control box	**(TBD)**	1			
	RCVR/XMTR	**RT876/WCC-2**	1	0.7 **LT**	5.1 **Kw**	
	Control set, sonar communications	**C-7440/WQC-2**	1			
	Control set, sonar communications	**C-7441/WCC-2**	1			
SWBS 445 - Teletype and Facsimile System	Antenna patch panel	**AN/SRA-12**	1	1.57 **ft**^{3}	35	
	Highpass/lowpass filter	**CU2007/SRR**	1	**.20**	**8**	
	Receiver patch panel	**SB-2727/SRR**	1	1.30	44	
	Transmitter patch panel	**SB-863/SRT**	1	2.77	74	
	TTY patch panel (black)	**SB-1203/UG**	2	**.25**	24	
	TTY patch panel (red)	**SB-1210/UGQ**	2	**.25**	24	
	Modem	AN/UCC-1	1	1.26	67	
	FSK converter	**AN/URA-17**	2	1.57	70	
	Frequency standard	**AN/URQ-10**	1	**.46**	22	
	Teletypewriter	**AN/UGC-25**	1		50	
	Teletypewriter	**AN/UGC-6**	1		230	
	Radio set control (remote) VHF/UHF	**C-1207( )/UR**	4		120	
	Power Supply (red **TTY)**	**PP-1767A/UG**	2		80	
	Power supply (black **TTY)**	**PP-3494B/UG**	2		44	
SWBS 446 - Security **Equipment**	Covered voice CRYPT0	T/SEC-KY-R	2	2.11	160	
	Covered TTY **CRYPTO**	T/SEC-KW-7	2	1.40	148	
	Covered BCST **CRYPTO**	T/SEC-KWR-37	2	3.42	**258**	
	Covered BCST CRYPT0	T/SEC-KC-14	2	**2.88**	13s	

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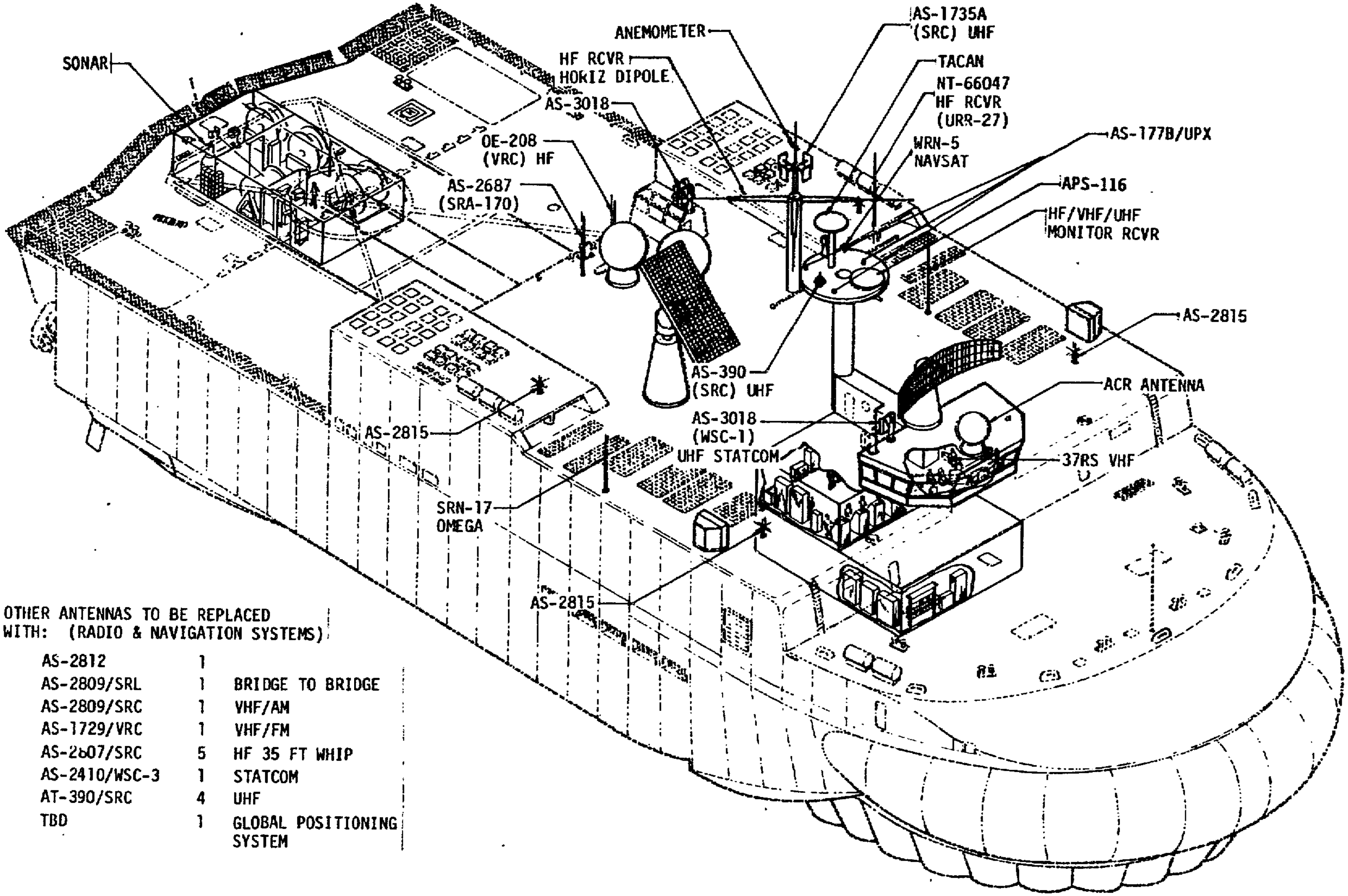

OTHER ANTENNAS TO BE REPLACED
WITH: (RADIO & NAVIGATION SYSTEMS)

AS-2812	1	
AS-2809/SRL	1	BRIDGE TO BRIDGE
AS-2809/SRC	1	VHF/AM
AS-1729/VRC	1	VHF/FM
AS-2807/SRC	5	HF 35 FT WHIP
AS-2410/WSC-3	1	STATCOM
AT-390/SRC	4	UHF
TBD	1	GLOBAL POSITIONING SYSTEM

Figure 2.3.5-1 COMMAND AND SURVEILLANCE SYSTEM
(OVERLAY OF ANTENNAS, BRIDGE, AND CIC)

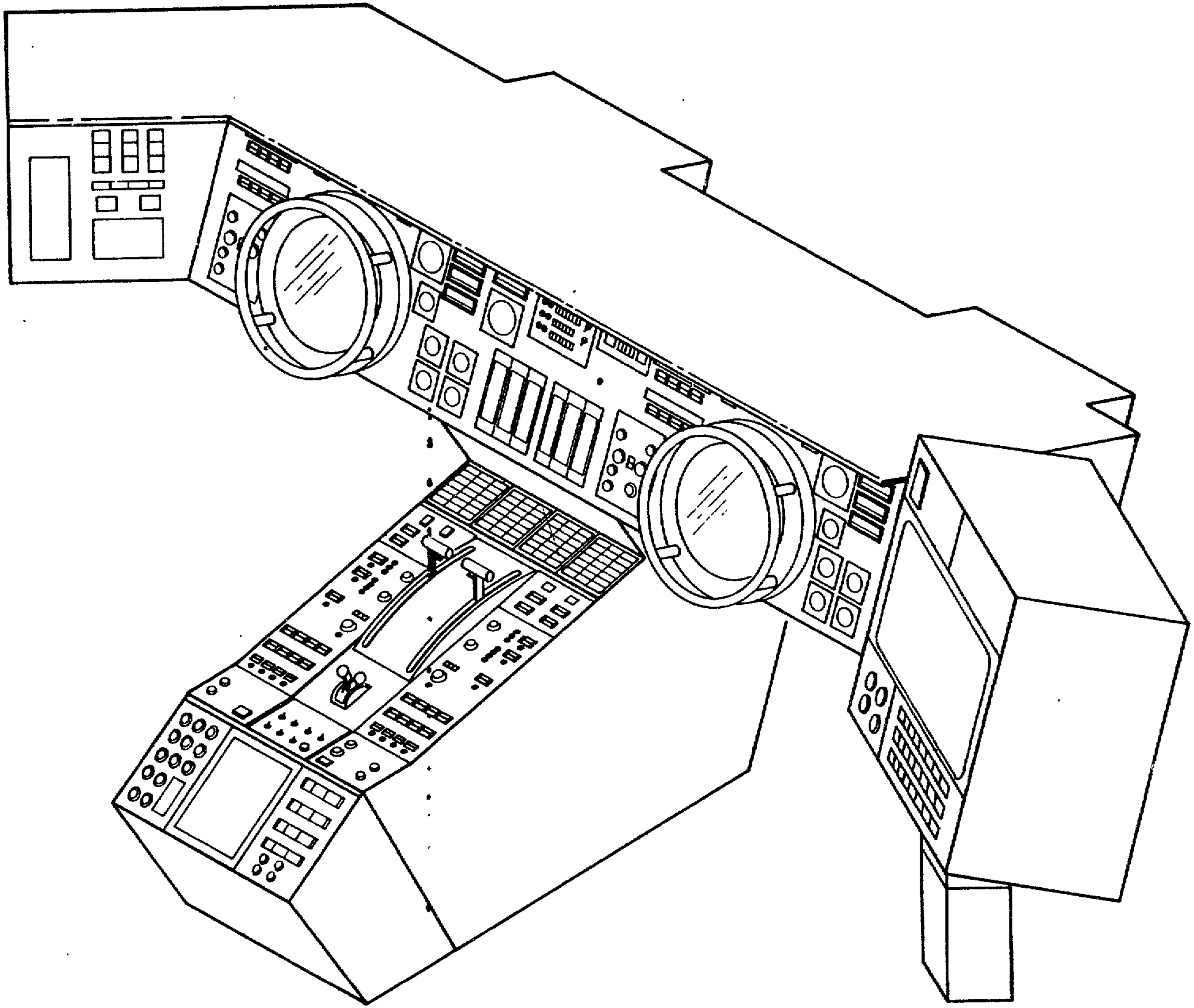

Figure 2.3.5-2 BRIDGE CONSOLE ARRANGEMENT (Sheet 1 of 2)

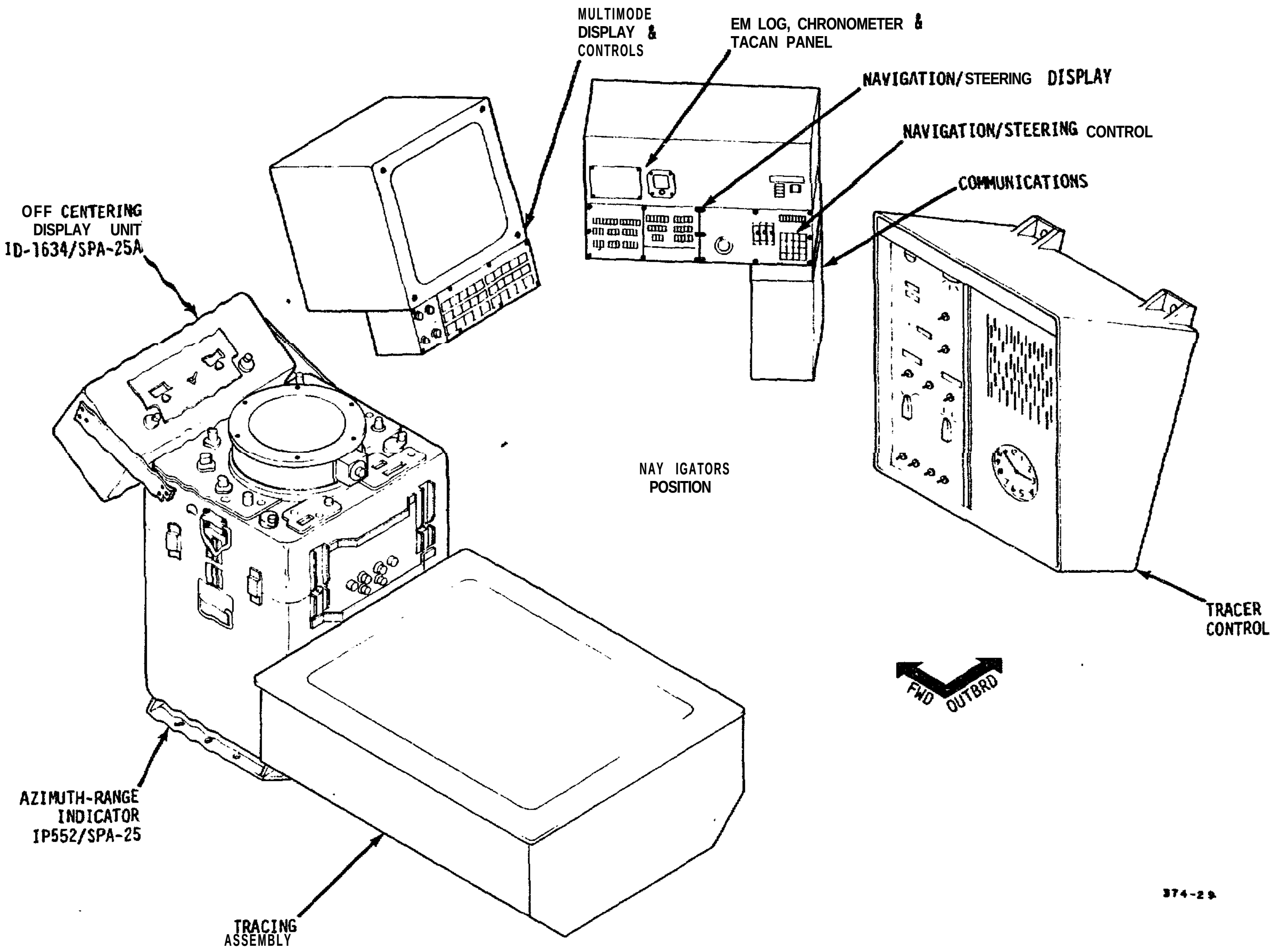

Figure 2.3.5-2 BRIDGE CONSOLE ARRANGEMENT (Sheet 2 of 2)

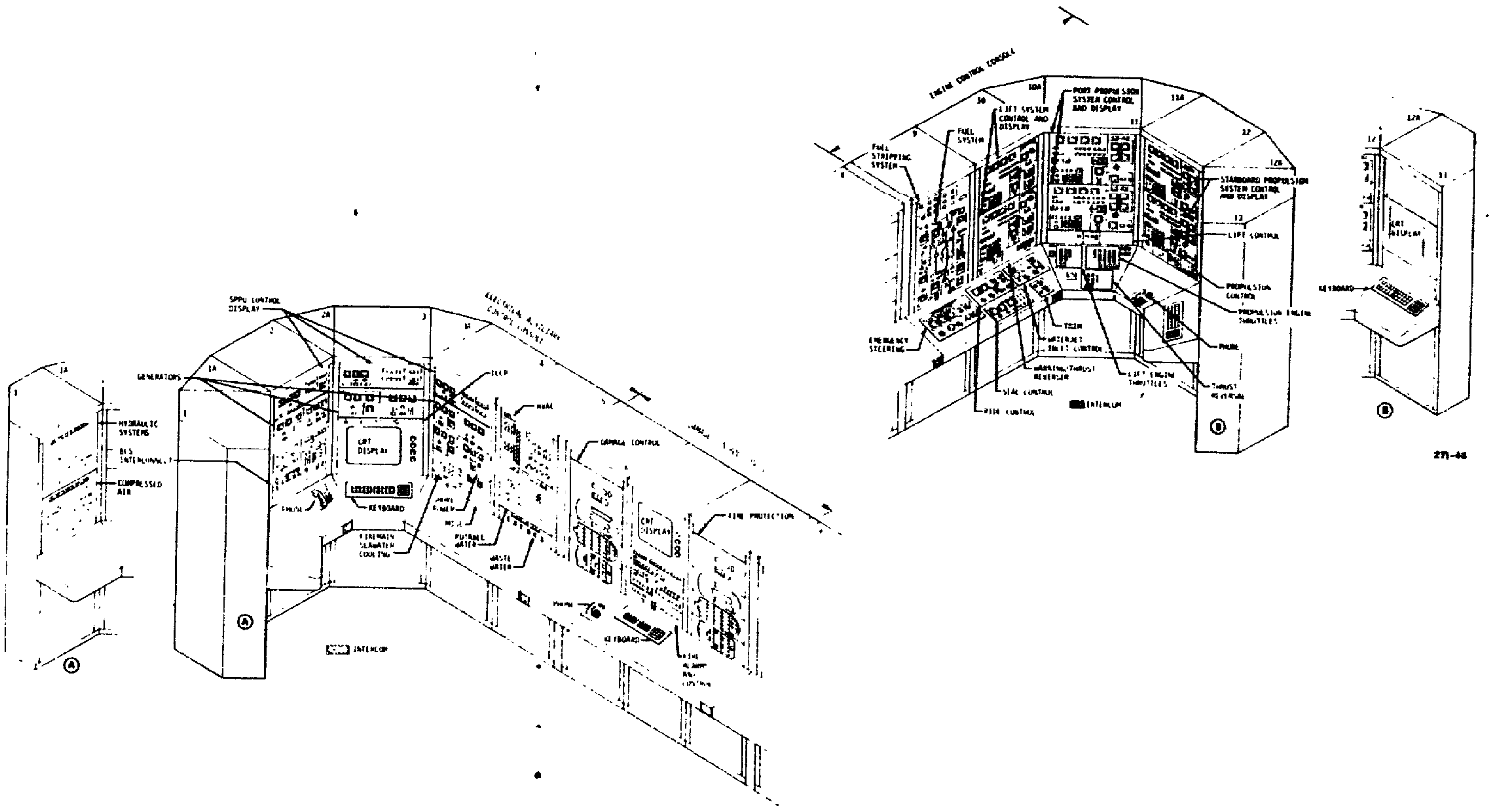

Figure 2.3.5-3 CONTROL CONSOLE ARRANGEMENT - EDCC

2.3.6 Auxiliary Systems

The auxiliary systems are similar to those used on all Navy ships, but are modified to satisfy the SES-unique requirements. In particular, lightweight systems are used wherever possible. This ship has the following auxiliary system improvements compared to the 1980 3000-ton SES:

a. Titanium alloy tubing is used in distribution systems in place of corrosion-resistant steel.

b. Waterjet thrust vector control in the vertical plane has been added to minimize the ship pitch response in high seas.

c. Reverse osmosis freshwater distillers have been selected to provide freshwater needs. These units are lighter and consume less power than alternate units of equivalent capacity.

d. Hydraulic system pressure has been increased from 3000 to 4000 psig to allow use of smaller components and reduce weight.

2.3.6.1 General Arrangement Drawings

Appendix B to this report includes four of the auxiliary system general arrangement drawings:

AD-76054	Potable Water System
AD-76-55	Human Waste Disposal System
AD-76-56	Climate Control System
AD-76-57	Hydraulic Systems.

General arrangement drawings of all of the auxiliary systems are in the booklet of drawings of the LSES.

2.3.6.2 Steering Devices

The rudder and steering sleeve control system is an electrohydraulic system that positions the ship rudders and waterjet steering sleeves in response to input steering and ride control commands.

In normal operation, system control is from the bridge. Emergency operation from the engineering and damage control center (EDCC) is provided.

Pour rudder/steering-sleeve system combinations are provided for steering control; rudder only, steering sleeve only, both, and blend. The blend system automatically provides steering-sleeve steering at low speeds, steering sleeve and rudder steering at moderate speeds, and rudder steering at high speeds. The steering sleeves are also vectored in the vertical plane to minimize the ship pitch response in high seas.

The rudders, positioned at the transom, have a cambered section designed to exploit the strong control authority exhibited by a similar rudder split-flap in the water channel, cavitation-scaled model test. The geometric aspect ratio is 3.75 with no taper and side areas of 30 square feet each, The rudders provide the necessary, additional directional stability and yaw control capability.

The swing rudders are retracted when the craft is holding course. In an emergency, both rudders can be extended to provide increased directional stability. For maneuvers, only the appropriate rudder on one side is extended to supply maneuvering control. The rudder system will employ hydraulic-powered servo actuation for deployment and positioning,

2.3.6.3 Fire Protection

The dangers associated with a fire at sea have been carefully evaluated during LSES design.

Care has been exercised in specifying compartment arrangements, construction materials, fire protection systems, and fire detection systems. Studies of smoke propagation, escape routes, and damage control have been made. Materials have been selected for the passive protection of the aluminum hull in conjunction with the noise and thermal insulation requirements for each compartment , The principle for minimizing the risk and effect of fire is speed in detection and activation of fire control systems. In areas of highest fire risk, such as engine compartments, fire-fighting measures are instantaneous for rapid and early application,

The entire detection and extinguishing network is integrated through the damage control console located in the EDCC, This console includes provisions for warning lights and audible alarms, equipment and venting shutdown, extinguishing agent release, override and inhibit functions, and built-in testing. Care has been taken in selecting extinguishing agents such that premature discharge does not cause damage to subsystems. The detection systems use proper combinations of thermal, optical, and smoke detectors,

2.3.6.4 Heating, Ventilating, and Air Conditioning

The heating, ventilating, and air conditioning (HVAC) system meets the habitability requirements of OPNAVINST 9330.7A. A temperature of 80 degrees is maintained during the cooling season and 70 degrees during the heating season under the most critical conditions, Watertight integrity and fire zoning have not been compromised.

The HVAC system uses lightweight, 400-Hz, seawater-cooled, modular unit air conditioners distributed about the ship in zones approximating the zones of watertightness. Small units (1-1/2 and 3-1/2-ton) wili be constructed such that they can be hidden in the overhead, thus freeing floor space. Electric heat will be provided by convectors, duct heaters, and heater elements within the air conditioner modules. Exhaust vent air heat recovery units will reduce winter intake air heat loads by 60 percent.

2.3.6.5 Underway Replenishment

The LSES can accept vertical replenishment on the helicopter deck. In addition,. means have been provided for rigging a highline for transfer of personnel or material at sea. Refueling stations are provided at port and starboard midship locations.

2.3.6.6 Anchoring, Mooring, and Towing

The anchor handling room is located forward on the second deck, The hawse pipe extends through the third deck and exits the ship within the cushion area. An air lock is provided for entry to the compartment while on cushion.

Bitts and chocks are located to allow use of eight breast lines and three spring lines forward and three aft with normal 30-foot spacing of dock bollards. Towing can be accomplished with a lo-inch nylon line.

2.3.6.7 Pollution Control System

The environmental pollution control plan is designed in compliance with OPNAVINST6249.3D. Sewage is disposed of by an evaporative toilet system. The sludge is sterilized, evaporated and stored until disposal. Oil/water separators are installed to separate oil from bilge water as it is pumped overboard from the bilge-water holding tanks.

2.3.6.8 Fluid Distribution Systems

The fluid distribution systems employ lightweight technology. Fluid distribution systems in the LSES are described in the following subparagraphs.

2.3.6.8.1 Seawater Systems

Seawater is tapped off the waterjet propulsors while underway to provide the ship firefighting, flushing, and cooling needs, Three electric-motor-driven fire pumps satisfy seawater needs at other times. A loop distribution system with multiple input points and isolation valving is used to ensure a continuous seawater supply in the event of system failure or partial damage.

The firemain supplies the torpedo and small arms magazine sprinklers, fire stations, and foam firefighting systems as part of the overall fire protection system, Water is also provided from the main supply loop for lubrication and hydraulic oil cooling, sanitary system flushing, compressed air cooling, fresh-water distillation plant supply, anchor washdown, air-conditioner cooling, and for cooling the freshwater in the electronics freshwater cooling system. During propulsion system start-up, seawater is tapped off the firemain to power the propulsor priming eductors and lubricate the propuisor rubber shaft bearings.

The plumbing drainage system is divided into three parts and is designed to comply with requirements for environmental pollution control, The human waste disposal drains are separated from other gravity drains to relieve the load on the evaporators. Pressure-fed drains, such as heat exchanger drains, are separated also to eliminate the risk of back-flowing into gravity drains.

Fourteen submersible bilge pumps route bilge water to two oily water holding tanks. The water is then pumped through oil/water separators and overboard. In the event of a leak rate that exceeds the separator capacity, the holding tank emergency overflow piping will accommodate the full capacity of the bilge pumps. Separated oil is stored in a waste holding tank for transfer to a shore facility.

2.3.6.8.2 Freshwater System

The freshwater system is designed to follow the intent of OPNAV 9330.7A. It is capable of supplying freshwater for 140 accommodations and supplying water for engine water wash and helicopter washdown every day.

Two independent, reverse osmosis desalinization plants of 2500 gallons per day capacity each provide a reliable source of freshwater, Each distiller has an associated 2500-gallon storage tank providing 36 gallons storage per accommodation. Screwed hose connectors are provided for ship-to-ship transfer of potable water in case of emergency. The distillers are of lightweight fiberglass construction and have an approximate 4500-pound weight advantage over vapor-compression units used in the 1980 3000-ton SES. Distiller electrical power requirements are reduced by approximately 80 percent.

A continuously circulating cold-water main supplies the ship potable water needs. Water is taken from the cold-water main to supply a separate, continuously circulating hot-water system with an electrically heated hot-water tank. Two separate closed-loop freshwater systems are provided for electronics cooling. Both systems are recirculating demineralized water loops; one system provides chilled water cooling,

2.3.6.8.3 Ship Fuel Distribution

Turbine fuel conforming to specification MIL-T-5624, Grade JP-5, is contained in four integral transfer tanks, two engine service tanks, and two helicopter service tanks. Fuel for the three port engines and the two forward SSPUs is taken from the port service tank. The three starboard engines and the aft SSPU is supplied by the starboard service tank. Fuel is pumped automatically from the transfer tanks to the service tanks on demand, to maintain the service tank fuel level. Duplex particle filters and coalescent filters are installed to remove solid contaminants and water from the fuel.

Pressure refueling may be carried out either in port or underway through a standard 7-inch receiver using the 7-inch standard Navy fueling hose and nozzle. Fueling at either side of the ship is possible. The design flow rate is 3000 gallons per minute with a nozzle pressure of 40 psig.

Defueling through the same piping system can be done using the LSES pumps. Attitude trimming of the ship is achieved by transferring fuel longitudinally or transversely between tanks as required, Tank stripping) open vent, and overflow systems are incorporated, Fuel tank quantity gaging units conform to MIL-L-23886, Class 1c/DPJALP,

All fuel system piping is titanium alloy, except inside fuel tanks where glass-reinforced plastic (GRP) is used,

2.3.6.8.4 Aviation Fuel System

A helicopter support fuel system is provided in accordance with NAEC 91122, Helicopter Facilities Bulletin No, 1C. Fuel is pumped from the aft port transfer tank through a particle filter and coalescent filter to two independent helicopter service tanks each of approximately 1646 gallons usable fuel capacity. A service pump delivers fuel through a second coalescent filter to the helicopter at flow rates up to 200 gallons per minute with a minimum nozzle pressure of 40 psig, This flow rate and pressure may be maintained with the helicopter on the deck or hovering up to a height of 60 feet, Either pressure fueling or gravity (overwing) fueling may be used on the deck, Provisions exist for defueling aircraft on the deck by means of a mobile air-driven pump, and also for flushing fueling hoses,

2.3.6.8.5 Compressed Air Systems

Two compressed air systems provide low-pressure ship service compressed air and high-pressure compressed air for charging torpedo launchers.

Two SS-cfm, 100-psig air compressors and receivers provide a reliable supply of ship service air even though the system supplies non-vital services only. The 100-psig system was chosen to enable use of standard air system equipment and conventional operating procedures and precautions, Low-pressure air is provided for tools, sea chest blowout, filter cleaning, helicopter servicing, and electrical/electronic machinery cleaning,

A separate 3000-psig air system supplies air for charging torpedo launchers.

2.3.6.8.6 Fire Extinguishing System

The fire extinguishing system uses rapid-response Halon 1301 systems as the primary firefighting system for high-risk areas such as engine rooms, with high expansion foam as secondary protection. An aqueous film-forming foam sprinkler system, with seawater fire station backup, is used in the hangar area where wind could render Halon or high-expansion foam ineffective. Moderate and low fire risk areas have portable fire extinguishers with seawater fire stations as secondary protection.

2.3.6.9 Hydraulic System

Three 4000-psig hydraulic systems supply ship hydraulic power. The propulsor hydraulic system has four pumps that are powered by the propulsor transmissions and provide hydraulics for all steering and reversing controls and propulsor variable inlet control. The ride control system has eight pumps powered by the lift transmissions for actuating the cushion vent doors and the sleeve actuators on the variable flow lift fans, The SSPU hydraulic system has three pumps powered by the SSPUs. This system supplies all the remaining ship hydraulic needs and is interconnected with the propulsar and ride control hydraulic systems to provide power for checkout and calibration when the main engines are not running.

Division of sections of the system into modular assemblies facilitates installation and maintenance and minimizes the number of lines, fittings, and potential leak joints. Titanium alloy tubing is used throughout to reduce weight,

2.3.6.10 Summary of Risk Areas

All of the auxiliary systems are considered to be low- to no-risk systems. Possible minimal hardware risks presently foreseen, such as the swing rudder, will be subjected to applicable test programs to eliminate all low-risk areas. Consequently, all auxiliary systems will be no-risk systems.

2.3.6.11 Auxiliary System Weights

The following tabulation shows the weight breakdown for elements of the auxiliary system,

SWBS		Percentage
510	Climate Control	14.5
520	Seawater Systems	7.5
530	Freshwater Systems	6.2
540	Fuels and Lubricants Handling and Storage	8.3
550	Air, Gas, and Miscellaneous Fluid Systems	7.8
560	Ship Control Systems	8.4
570	Underway Replenishment Systems	1.7
580	Mechanical Handling Systems	33.1
590	Special Purpose Systems	12.5
	TOTAL AUXILIARY SYSTEMS	100.0

2.3.6.12 Auxiliary Systems Characteristics

The system characteristics of the individual auxiliary systems are described in table 2.3.6-I.

TABLE 2.3.6-I
AUXILIARY SYSTEMS CHARACTERISTICS

SYSTEM	FLUID	PRESSURE	TANKS	PUMPS	TOTAL CAPACITY	NOTES
Steering Devices	Electrohydraulic, lateral positioning of rudder and waterjet steering sleeves Four steering modes: rudder only, steering sleeve only, both, and blend Electrohydraulic positioning of waterjet steering sleeves in vertical plane for ride control					
Fire Extinguisher System	Halon 1301	600 psig (4136.85 kPa)	(42) 45 lb (20.4 kg)			
	High-Expansion Foam		(2) 40 gal (151.4 1) concentrate tanks	7	23,000 ft^3/min (10.85 m^3/s)	
	Aqueous Film-Forming Foam	-	(5) 50 gal (189.3 1) concentrate tanks	(From seawater system)	900 gpm (56.8 l/s)	
	Seawater	150 psig (1034.21 kPa)		(From seawater system)		
Heating, Ventilating, & Air Conditioning	Heating and cooling units - 19 units, 1-3/4- to 10-ton capacity each, 95 tons total cooling capacity. 190 kw total heating capacity Duct heaters - 340 kw total capacity Ventilation fans - 20 fans, 0.3 to 11 kw each, 50 kw total 6 heat-recovery units - 64% recovery at -12°C Convection heaters - 7 units, 0.5 to 5.0 kw each, 17-1/2 kw total					
Underway Replenishment	Vertical replenishment Refueling rate 3000 gpm (189.3 l/s) Underway freshwater transfer Highline ship-to-ship					
Anchoring, Mooring, Towing	Anchoring - 3000 lb (1361 kg) anchor, 400 fathom (73[illegible] m) rode - 3-3/8-inch (8.57 cm) diameter synthetic Mooring - (16) S-inch (20.32 cm) circumference nylon lines for 70-knot (36 m/s) wind, 4-knot (2 m/s) current Towing - (1) 10-inch (25.4 cm) circumference nylon line for 30-knot (15 m/s) wind, 5-knot (2.6 m/s) speed					

TABLE 2.3.6-I (Cont)

SYSTEM	FLUID	PRESSURE	TANKS	PUMPS	TOTAL CAPACITY	NOTES
ollution Control System						
Human-Waste Disposal	Seawater Flush		(2) 80-gal (303 l) evaporators (2) 2000 gal (7571 l) sludge tanks	(5) macerators/pumps (2) sludge pumps	140 accommodations	
Bilge System	Bilge Water		(2) 1000 gal (3785 l) holding tanks (2) 200 gal (757 l) waste oil tanks	(14) 45 gpm (2.84 l/s) bilge pumps	630 gpm (39.76 l/s)	
eawater System	Seawater	150 psig (1034.21 kPa)		(3) 600 gpm (37.85 l/s) plus 4 waterjet tapoffs	1800 gpm (113.56 l/s) (fire pumps) >2100 gpm (132.49 l/s) (waterjet tapoff)	
reshwater System	Freshwater	50 psig (344.74 kPa)	(2) 2500 gal (9464 l) storage (1) 400 gal (1514 l) hot-water heater (1) 150 gal (568 l) distillate tank	(4) 5 gpm (0.32 l/s) (2) 20 gpm (1.26 l/s)	140 accommodations	
uel System						
Fuel Storage & Transfer	JP-5	40 psig (275.79 kPa) (transfer)	1163.5 short tons (1055.5 m tons) (4 tanks)	(4) 810 gpm (511.03 l/s)		lo-micron nom. filters. water separators

TABLE 2.3.6-I (Cant)

SYSTEM	FLUID	PRESSURE	TANKS	PUMPS	TOTAL CAPACITY	NOTES
Fuel System (Cont)						
Fuel Tank Stripping	JP-5	30 psig (206.843 kPa) (main tank sys) 10 psig (68.948 kPa) (Helo sys) 30 psig (206.843 kPa)		(6) 60 gpm (3.785 l/s) stripping (main tanks) (1) 20 gpm (1.262 l/s) stripping (Helo tanks) (2) 180 gpm (11.356 l/s) (strip tank dump)		
Main Engine Fuel Service	JP-5	50 psig (344.738 kPa)	359.5 short tons (326.14 m tons) (2 tanks)	(4) 120 gpm (7.571 l/s)		lo-micron nom. filters, water separators
SSPU Fuel Service	JP-5	50 psig (344.738 kPa)	(From main storage tanks)	(2) 6 gpm (0.378 l/s)		↓
Helo Fuel Service	JP-5	80 psig (551.581 kPa) (fueling) 5 psig (34.474 kPa) (defueling)	11.6 short tons (10.52 m tons) (2 tanks)	(1) 200 gpm (12.618 l/s) (fueling) (1) 35 gpm (2.208 l/s) (defueling)		↓
Helo Fuel Transfer	JP-5	25 psig (172.37 kPa)	From aft main tank	(1) 200 gpm (12.618 l/s)		lo-micron nom. filters, water separators
ompressed Air System						
Low-Pressure System	Air	100 psig (689.48 kPa)	(2) 12 ft^3 (0.34 m^3) receivers	(2) 55.5 ft^3/min (0.0262 m^3/s)	111 ft^3/min (0.0524 m^3/s) (standard)	
High-Pressure System	Air	3000 psig (20684.27 kPa)	(2) 10 ft^3 (0.283 m^3) receivers	(2) 60 ft^3/min (0.0283 m^3/s)	120 ft^3/min (0.0566 m^3/s) (standard)	

TABLE 2.3.6-I (Cont)

SYSTEM	FLUID	PRESSURE	TANKS	PUMPS	TOTAL CAPACITY	NOTES
Hydraulic Systems						
SSPU Hydraulic System	Oil per MIL-H-83232	4000 psig (27579.03 kPa)	(3) 15 gal (56.78 l)	(3) 20 gpm (1.262 l/s)	60 gpm (3.785 l/s)	
Lift & Ride Control Hydraulic System	Oil per MIL-H-83232	4000 psig (27579.03 kPa)	(4) 15 gal (56.78 l)	(8) 60 gpm (3.785 l/s)	480 gpm (30.28 l/s)	
Propulsor Hydraulic System	Oil per MIL-H-83232	4000 psig (27579.03 kPa)	(4) 15 gal (56.78 l)	(4) 60 gpm (3.785 l/s)	240 gpm (15.14 l/s)	

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2.3.7 Outfit and Furnishings

2.3.7.1 Summary Description

Investigations were made into all systems in sufficient depth to ensure the validity of the ship weight statement. The overall philosophy of system selection was to meet Navy requirements and to use existing lightweight marine components wherever possible. As far as accommodations are concerned, the latest Navy philosophy on outfitting the Patrol Frigate was studied, and the 1990 LSES arrangement meets or exceeds those standards,

The locations of the living and working spaces are shown in the deck plans (paragraph 2.1.2) . The major machinery control spaces are the bridge, the EDCC, and local engine control centers. Experience gained with the SES-100B and Bell ACVs contributed significantly to the selection of materials and protection systems.

Based on acoustical data derived from the Bell SES-100B, an acoustical model of the LSES was used to identify control measures required to reduce airborne and structureborne noise. Measures incorporated in the 1990 LSES include treatment of the major noise sources and sound treatment of the manned areas. The ship has been arranged to make the best use of lockers, dead storage, etc, to minimize noise in manned spaces.

The hull insulation system is based on the special requirements of protecting an aluminum structure and recognizes the weight sensitivity of a high performance ship. The materials and techniques to be used in the hull insulation system are a part of a rapidly advancing technology which, by 1987, will have become almost commonplace.

The acoustic insulation, which represents 32.5 percent of the total insulation system, also satisfies thermal insulation requirements for the heating, ventilating, and air conditioning system where required. (Reference drawing AD-77-2 sheet 1, in appendix B.) The insulations listed under the acoustic column are installed in the areas shown on the deck plan sheets. Noise criteria per OPNAVINST 9330.7A were used to determine the types and amounts of insulation installed in all areas of the ship. The following is a breakdown of the insulation required.

Thermal	4.1%	3.1 tons
Fire	63.4%	47.9 tons
Acoustic	32.5%	24.5 tons
Total		75.5 tons

The main fire zone bulkhead insulation is applied to and in contact with **all** exposed surfaces of the structure. Application of insulation to both sides of the fire zone bulkhead ensures that the bulkhead will be a barrier to fire risk from either direction,

The hull insulation, which provides an integrated acoustic, fire, and thermal insulation is a Fiberfrax insulation for high-risk areas (engine rooms, etc) and a fibrous glass insulation for low fire risk areas. The high fire risk insulation system also contains an integral steel plate to form a positive fire barrier. In low fire risk areas where the insulation cannot be installed in direct contact with the smooth uncluttered side of a bulkhead the insulation will be installed across the stringers or stiffeners. Location of the insulation across the stringers or stiffeners saves approximately 15 tons that would be required to insulate around the complete contour of the stringers. The air gap should also help reduce bulkhead skin temperature. In each location where insulation is placed over vertical stringers, at least two fire stops are incorporated in the dead space between the stringers. The horizontal fire stops in vertical dead spaces behind insulation provide additional insurance that these spaces or tunnels will not become conduits for fire between levels. The additional fire stops will form a backup in the event of a deck burn-through.

To ensure that visual inspection and maintenance criteria is maintained, the insulation will be installed between the bulkhead and the fuel lines, electrical conductors, etc.

Overhead insulation is supported by 2-inch hullboard and the insulation system is attached to the stringers by steel hangers.

For the bulkheads where the insulation is not already covered with a perforated metal for acoustic reasons, and where it could be damaged, it will be protected by a light-gage fiberglass laminate sheathing. The sheathing, like the perforated metal acoustic covers, will also serve as a means of support. The insulation will be bonded to the sheathing and the assembly attached by means of welded-on studs to the ship structure. In areas where sheathing and perforated metal covers are not used, the insulation will be covered with impregnated fiberglass cloth and the assembly will be attached to the structure by a combination of bonding and studs. Bonding materials will be suitable for exposure to 800°F.

The 1990 LSES has accommodations for 141 men, Compliance with all applicable standards contained in the U.S. Navy habitability document, OPNAVINST 9330.7A, is the design goal. The effectiveness of the ship depends, to a significant extent, upon the physical and mental condition of the personnel who man it;

their condition, in turn, is strongly influenced by the physical environment in which they live and work. Careful design will produce pleasant surroundings within the boundaries of acceptable cost and weight. Consideration for the mission duration influences the requirements of recreational and associated off-duty activities.

A re-examination of the commissary concept was conducted to determine whether a frozen and reconstituted food service or the more conventional onboard food preparation system would better serve the 1990 LSES.

The well being and effectiveness of the crew is a prime consideration for high performance ships. The desire to improve living conditions for all Navy personnel, as evidenced by OPNAVINST 9330.7A (Habitability Standard), leaves the question of weight penalties. The difference in weight for the two concepts is approximately 2.13 metric tons. It is felt that this is not an unreasonable penalty. Therefore, a conventional food service is recommended.

In the arrangement of the second deck, the living spaces have been located in areas of best ride and least noise. Living quarters are not located in the forward third of the ship. The propulsion and lift engines, which are the major source of noise, are all located outboard of longitudinal bulkhead 31, which acts as a noise and fire barrier between the machinery and living spaces. Inboard of that longitudinal bulkhead, either a passageway, locker room, or a void space is used as a further sound barrier between the noise sources and the living and working spaces. Two longitudinal and three athwartship passageways provide traffic flow about the second deck between living, mess, sanitation, and work spaces.

Living quarters and mess and sanitary spaces for the crew are grouped together; the CPO spaces are similarly arranged. The officers' staterooms and sanitary facilities are grouped together, and the officers' wardroom is nearby. The commanding officer's stateroom, washroom, watercloset, and showerroom are located on the 01 deck near the bridge and CIC.

The furnishings to be provided may be lightweight Navy standard equipment, but it is believed that even lighter-weight serviceable furnishings are both feasible and desirable. All living spaces are air-conditioned and have, with few exceptions, sound-attenuating carpeted decks and suspended ceilings.

The following accommodations are provided for the crew, including aviation personnel:

TYPE	MANNING
Enlisted	114
CPO	11
Officer	16
	141

Adequate service spaces compatible with requirements for a compact, lightweight ship and consistent with its cruise duration are provided. The main galley is centrally located to the crew mess and wardrooms. A galley annex for food preparation is located on the third deck. Prepared food is transported by dumbwaiter to the galley for final finishing and serving. The food storage area located adjacent to the galley annex contains adequate space for dry, chilled, and frozen foods. A scullery is provided adjacent to the crew mess.

The officers' wardroom is located on the ship centerline just forward of the galley on the second deck. This space is divided into serving, seating, and lounge areas. The serving area has a dresser with a service window connected to the galley, a coffeemaker, a toaster, and a refrigerator. Officers are messed family style with steward service: china, stainless-steel flatware, and so on. The seating area has three tables and 17 chairs, The arrangement is in compliance with OPNAVINST 9330.7A, which specifies one seat per officer for ships having an officer complement of fewer than 20. The lounge space is separated from the mess area by a traveling privacy curtain. The area has a transom, two lounge chairs, dresser, bookcase, coffee table, and hi-fi equipment. This area is carpeted and has an acoustical suspended ceiling.

'The CPO mess and lounge is located on the port side aft of the CPO living space. This space is divided into serving, eating, and lounge areas, is fully carpeted, and has a noise-attenuating suspended ceiling. CPOs are messed family style with steward service. Optional cafeteria-style messing using food trays is also provided. A small service dresser has a coffeemaker, toaster, storage area, and sink. A table with bench seats and two booths provide seating for 11 men. A TV set is installed in this area. A traveling curtain separates the mess and lounge areas. The lounge seats five men, has a coffeetable, corner table with bookcase, and hi-fi cabinet.

The crew mess and lounge is located about the ship centerline between port and starboard longitudinal bulkheads 10 and between frames 185 and 230. This space has a cafeteria line forward, a mess section, and a lounge space. The lounge space is separated by a folding partition. The mess section has accommodations for 38. The lounge section of the messroom has 6 writing surfaces and chairs for 19 men. A second crew lounge is located on the centerline immediately forward of the officers' washroom. In this space 6 writing surfaces and seating for 19 men are provided. To minimize cleanup (stowage of plates, etc), meals will be served in conventional trays. Soup bowls, cereal bowls, and cups will be available from a dispenser? The crew mess is also used for showing motion pictures and as a training facility. The mess room. decking is vinyl asbestos tile, and the suspended ceilings are acoustic.

After completing his meal, the crewman disposes of leftovers in a container lined with a plastic bag and his tray, utensils, and cups in suitable racks. This area is serviced by galley help, and the garbage is taken to the garbage compactor. In addition to the lounge chairs and transoms, a TV and hi-fi are installed. Noise-attenuating carpeting and acoustical ceilings are installed in the lounge areas.

All sanitary spaces have vinyl asbestos floor tile, suspended ceilings, and sheathed walls. Vanity-style lavatories are provided. Fixture quantities conform to the requirements of OPNAVINST 9330.7A.

Deck gear lockers and the boatswain’s storeroom are located on the main deck forward of frame 41. Access to these spaces is by main deck hatches and vertical ladders. The portable bow stanchions and rails are stored in this area, as well as the jackstaff.

Rope lockers are located fore and aft. The forward lockers are located on the main deck, port and starboard, between bulkheads 25 and 41 and inboard of longitudinal bulkhead 31. Access is through deck hatches and vertical ladders. Aft rope stowage is provided inboard of bulkhead 31 on the main deck. Baggage stowage for the ship’s company is provided in separate [officer, CPO, and crew) compartments forward of bulkhead 41 on the port side of the second deck. In addition, a commanding officers’ storeroom is provided near the commanding officers’ stateroom on the 01 deck.

Combined cleaning gear and linen lockers located on the second deck include two lockers each, port and starboard, near bulkheads 113 and 121, which service the officers’ and CPO quarters and other spaces forward of frame 161. Cleaning lockers are also installed in each of the sanitary spaces on this deck.

A foul-weather-gear locker is located in the starboard main deck enclosure, as well as a crash and rescue locker that contains fire-fighting clothing, oxygen masks and tanks, and wet suits and scuba gear. A flight suit locker is part of the flight office and ready room. There is also a small ship's store located aft of bulkhead 233 on the port side. The repair parts storerooms are located on the third deck aft of bulkhead 193, Additional storeroom area is available on the third deck between bulkheads 113 and 121, and on the starboard side in the bow on the second deck.

A flammable-liquids storeroom is located on the 01 deck on the starboard side.

2.3.7.2 General Arrangement

See paragraph 2.1.2 for the general arrangement drawings.

2.3.7.3 Weight Estimate

SWBS NO.	DESCRIPTION	PERCENT OF SWBS 600 WEIGHT
610	Hull Fittings	2.3
620	Hull Compartmentation	18.8
630	Preservatives & Coverings	51.9
640	Living Spaces	12.8
650	Service Spaces	4.4
660	Working Spaces	6.0
670	Stowage Spaces	3.5
690	Special-Purpose Systems	0.3
		100.0%

~~NOTE: PARAGRAPH MARKING INAPPROPRIATE~~
~~SEE SECURITY STATEMENT.~~

2.3.8 Combat System

2.3.8.1 Summary Description

The combat system description covers the following Ship Work Breakdown Structure (SWBS) groups: SWBS 450, Surveillance Systems (Surface); SWBS 460, Surveillance Systems (Underwater); SWBS 470, Countermeasures; and SWBS 480, Fire Control Systems. Additionally, several areas of SWBS 700, Armament, have been included, because of its close association with combat systems. Notably, SWBS 720, Missiles and Rockets, SWBS 750, Torpedoes, and SWBS 780, Aircraft-Related Weapons, are included,

The combat system for the 1990 SES, as taken from the TLR, consists of 40 k&urn-range multimode guided missiles for antiaircraft warfare, 24 advanced self-defense missiles for defense against antiship missiles, 16 Harpoon missiles for antiship warfare, and 4 MK-48 torpedoes [improved) for antisubmarine warfare. Additional ASW capability is provided by 16 standoff missiles with the Advanced Lightweight Torpedo (ALWT), and the two Light Airborne Multipurpose Systems (LAMPS) carrying the ALWT. Thirty-six ALWTs are carried. (See figure 2.3.8-I.)

Detection of airborne targets is accomplished with the advanced dual-band 2D radar and the rotating phased-array radar. Surface detection is accomplished with the AN/APS-116 radar. ASW detection and surveillance is accomplished by a combination of deployed arrays, towed arrays, APRAPS, ERAPS, and sonobuoys.

Fire control is provided by the MK-74 MOD XX fire control system, the advanced lightweight track-while-scan fire control system, and the improved mini-RPV for long-range weapons.

Additional self-defense against air and surface threats is provided by the advanced electronic warfare suite (ASMD EW MK XX), which is capable of RF and IR surveillance, automatic detection and identification of threat-associated emitters, threat-reactive deceptive ECM and jamming, and chaff launching with selectable mixture of active, IR, RF, and hybrid decoys.

The missiles have been located aft of the engine inlets to preclude the ingestion of blast gases and debris. In consideration of the weight sensitivity of SESs, lightweight vertical missile launchers have been provided. The launchers utilize blast ports to deflect the missile blast away from the deck area. Locating the missiles aft of the engine inlets and forward of the flight deck inherently provides for a future reload capability.

The recovery devices for the RPVs and the replenishment-at-sea facilities have been integrated to reduce weight and provide for greater utilization. Stowage of the RPVs has been located close to the flight deck, which allows easy utilization. The integration of the RPVs has been accomplished with limited restriction to LAMPS operations. Simultaneous launch or recovery of LAMPS and recovery of the RPV is not possible,

[redacted]

The antennas are located to provide good coverage and to minimize screening while providing for maximum weapon effectivity. The antennas for the electronic warfare equipment have been located on the port and starboard side of the ship, near the edge. This provides excellant coverage for the passive and active portions of the system and facilitates the use of decoys (chaff, IR, etc).

As noted previously, the combat system was taken from the TLR. However, same items critical to the combat system were found to be missing and were subsequently added. These items, which included the identification system, video blanker, navigational radar, and the anticlutter radar, have been added and are identical to the units used aboard the 1980 SES.

2.3.8.2 Weight and Volume Estimates

Table 2.3.8-I contains this combat system weight and volume summary.

2.3.8.3 Risk Assessment

Cost and schedule risk assessments are contained in the *ANVCE Study Combat System Data Sheets* for *AAW, ASW, and SSW,* Serial no, 8760653, Volumes I and II, dated June 30, 1976.

-Additional risk ‘factors that involve the sensor/weapon versus craft interface have been uncovered. The advanced dual-band 2D radar and the rotating phased-array antennas are both depicted as not requiring a dome; however, this is assuming that these antennas can meet the SES wind loads, Use of the linear towed array requires craft speed to be reduced to 15 knots while deploying and to 10 knots during recovery of the array, which tends to negate a strategic aspect of the SES, namely speed. In addition to the towed array, the APRAPS, MK-48 torpedo, and ALWT impose speed restrictions for their use. In the case of APRAPS, the craft must maintain a relative drift of less than 3 knots. The MK-48 torpedo restricts the craft speed to 15 knots during the wire-guided mode, and limits craft maneuverability. The ALWT restricts craft speed at launch to no more than 30 knots.

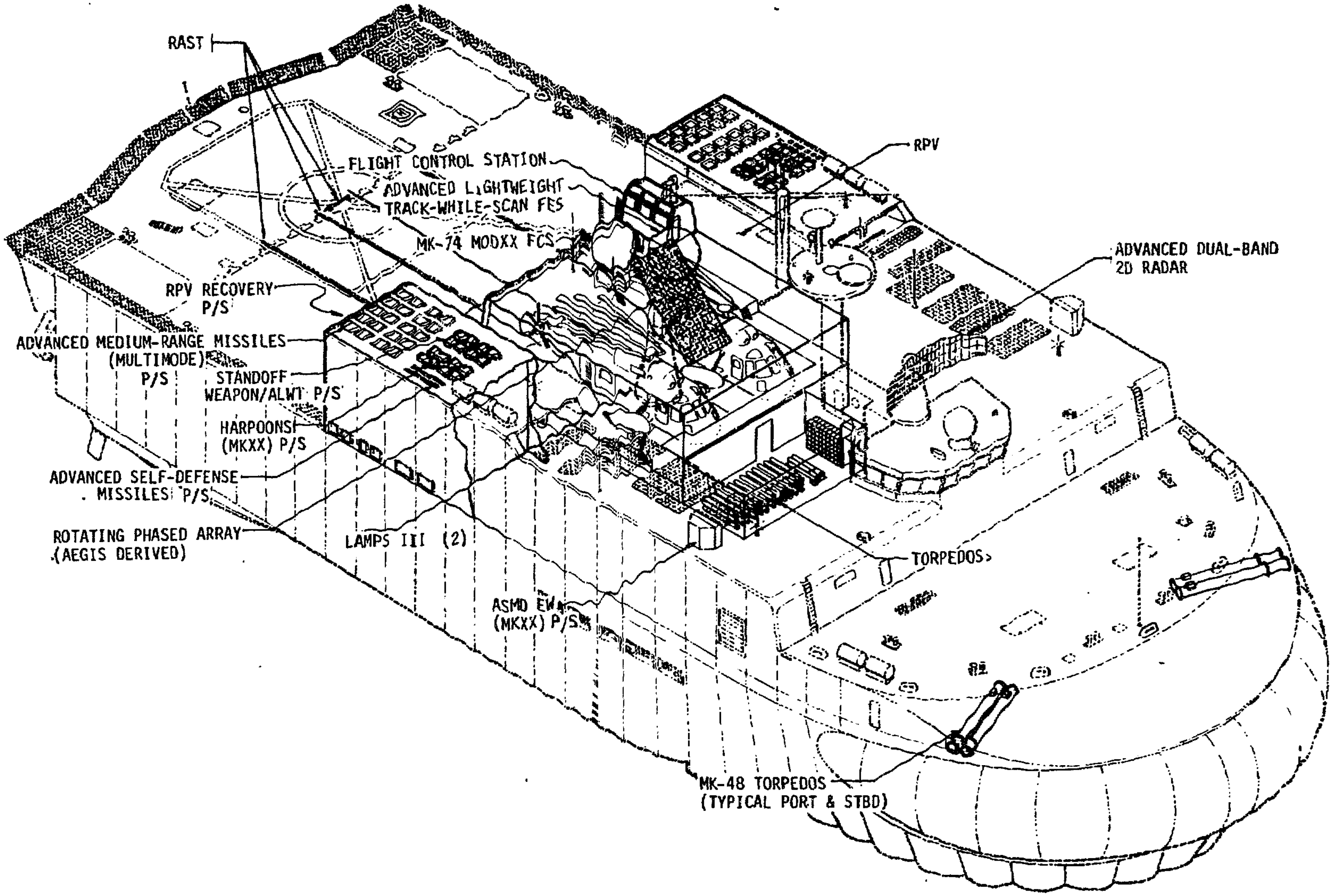

Figure 2.3.8-L COMBAT SYSTEM ARRANGEMENT

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TABLE 2.3.8-I

COMBAT SYSTEM WEIGHT AND VOLUME SUMMARY

SYSTEM	QUANTITY	TOTAL SYSTEM WEIGHT (LB)	VOLUME (BELOW DECK) (FT^3)
Advanced Dual-Beam 2D Radar	1	11,000	1,900
Rotating Phased Array (AEGIS-Derived)	1	26,000	1,400
ASMD EW MK-XX	1	4,000	100
Advanced Lightweight Track-while-Scan FCS	1	1,700	40
MK-74 MOD XX FCS	1	5,000	200
AN/APS-116	1	443	33
Deployed Linear Array	6	9,161	261*
Towed Array with Depressor & Spare Array	1	8,000	1,300
APRAPS	1	12,810	840
ERAPS	10	1,800	120
ERAPS/Rocket-Projected	26	13,000	1,080
ERAPS Launcher	1	3,700	133
Sonobuoy - Type A	200	7,800	150
Sonobuoy - Type B	10	390	8
ASW Electronics	1	14,502	910
**LAMPS MK-XX	2	43,460	29,200***
Standard Ship-Launched RPV	12	3,000	375†
RPV Launch/Recovery/Support	1	8,100	--

*18' × 25' compartment

**Does not include fuel, ammunition, and spares

***Aircraft only - processing and maintenance 3450 ft^3 additional

†Total system volume - RPVs/RPV Launch/Recovery/Support

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[redacted]

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TABLE 2.3.8-I **(Cont)**

SYSTEM	QUANTITY	TOTAL SYSTEM WEIGHT (LB)	VOLUME (BELOW DECK) **(FT^3)**
***AMRM** Multimode/with Launchers	40	200,000	5,000
*Advanced Self-Defense Missile with Launcher	24	7,200	415
*Harpoon MK-XX with Lightweight Launcher	16	33,006	9.5
*MK-48 Improved Torpedo	4	13,660	**
*Advanced Lightweight Torpedo **(ALWT)**	36	25,200	540
MK-48 Ejection Launch Container	4	7,600	***
*Standoff **Weapon/ALWT** with Launcher	16	85,996	550
Need AN/SLA-10 Blanking Unit	1	38	0.8
IFF Equipment			
Transponder AN/UPX-25	1	750	16
Decoder **AN/UPA-59A**	4	162	3
Antenna **AS-177B/UPX**	3	21	1.5
AIMS Test Set AN/UPM-137A	1	190	9
Anticlutter Radar	1	826	101
Navigational Radar **AN/SPS-55**	1	785	52

*Does not include fuel, ammunition, and spares
**Stowed in launcher
***Located on deck

~~NOTE: PARAGRAPH MARKING INAPPROPRIATE~~

~~SEE SECURITY STATEMENT~~

~~CONFIDENTIAL~~

2.4 Survivability

2.4.1 Signature Characteristics

2.4.1.1 Radar Cross Section (Not provided by Bell)

2.4.1.2 Microwave Signature (Not provided by Bell)

2.4.1.3 Infrared Signature (Not provided by Bell)

2.4.1.4 Visibility (Not provided by Bell)

2.4.1.5 Acoustic Signature (Not provided by Bell)

2.4.1.5.1 General (Not provided by Bell)

2.4.1.5.2 Airborne Noise Signature

Overall, the airborne noise levels to which personnel on board and in the vicinity of far term ANVCE SES will be exposed should be reduced somewhat from that experienced on earlier large surface effect ships. The major reason for the reduction in noise levels is the increase in efficiency of the prime noise makers. It is expected that the improved 50,000 horsepower engine (LM5000) will have a somewhat lower noise profile for a given power requirement than the earlier large engines such as the FT-9. Likewise, the lift fan efficiency improvement will result in lower sound power levels for a given airflow. This improvement coupled with the reduction in air losses due to seal improvements will produce significant reduction in lift system noise which will more than offset any increase caused by ship growth.

Other improvements in the noise source levels will result from reductions in electrical and auxiliary power requirements. Improvements in the efficiency of heating, cooling, and other auxiliary systems will reduce the demands on the SSPU resulting in lower noise outputs from the prime movers, generators, gears, pumps, and compressors. Another possible method whereby source levels may be reduced is lowering the redundancy in several noncritical systems in the far term ship. Operational experience and confidence gained from operation of earlier large SESs should permit the elimination of some excess capacity in noise producing systems.

Detailed on deck and off ship noise predictions have not been made for this ship configuration as they were for the 2KSES in 1975. However, some changes in noise level and noise exposure due to the revisions in ship arrangement can be expected. While making the 01 deck the forward weather deck will have some beneficial effects on interior noise levels, it will put people on the forward weather deck closer to and increase exposure to some engine and fan inlet. As was mentioned in the near term ANVCE report, people on the weather decks will have to wear ear protection devices during some shipboard evaluations. No change in this requirement is foreseen at this time. Improvements in the state of the art of silencers and silencing materials should result in noise exposure no worse and in some areas better than that predicted for earlier SESs.

The near-field airborne noise will affect operations alongside a pier, transfers at sea, and tug-assisted moves. The acoustic power levels of the major noise sources will be reduced considerably below the maximum levels due to both distance attenuation and possible reductions in machinery operating power levels. However, even with the reduced noise levels taken into consideration, there will be times when some off-ship personnel will require ear protection devices.

For refueling at sea or in similar situations, the LSES should not present any danger to personnel on the other ship relative to hearing loss/damage risk considerations. Furthermore, the LSES under most in-port operating conditions should not present a problem relative to environmental noise pollution.

The off-ship noise levels predicted for the FT-9 configured ship in 1975 are shown in the following two figures. Figure 2.4.1-l shows overall and A-weighted levels 500 feet from the ship at approximately maximum power. Figure 2.4.1-2 shows overall noise levels to starboard and A-weight levels to port at reduced power settings. Under similar conditions the far term ship levels should be somewhat lower than these.

2.4.1.5.3 Target Strength (Not provided by Bell)

2.4.1.5.4 Underwater Radiated Noise (Not provided by Bell)

2.4.2 Hardness

2.4.2.1 Armor

The armor system shown on drawing AD-77-3 in appendix B was designed to protect against the cheap kill threat from a 30-caliber AP projectile and fragmentation from a S-inch shell. Vertical armor was sized by the 30-caliber threat, and horizontal armor was sized for fragmentation from the S-inch shell. To minimize weight, a ceramic-faced composite armor was used. Throughout, advantage was taken of the aluminum structure to reduce the weight of armor required. No protection was required against the 250-pound contact torpedo, since it would pass under the on-cushion SES. Protection was not possible for defense against the 500-pound semi-armor-piercing missile, so none was attempted.

Areas protected by the armor system include the following:

a. CIC equipment room

b. Torpedo storage room

c. Missile launcher area

d. Lift engines and transmissions

e. Communication center

f. Communication center equipment room

g. Sonar and bathythermograph room

h. IC and gyro room

i. Propulsion engines and gearboxes.

A local belt of armor is used around the torpedo tubes.

Armor was not considered necessary on the propulsors, because their heavy casing is inherently resistant to ballistic damage. No armor is required on the SSPUs because of their redundancy. Fans are also not armored because of redundancy. Loss of a single cushion fan would not reduce range and speed. Loss of two cushion fans would reduce speed to 70 knots in calm water. The ride control system is not armored, since it is redundant and is also not vital to the mobility of the craft. Steering nozzle and rudder hydraulics are not protected because of the inherent redundancy in having both systems for steering.

The methodology given in the *Survivability/Vulnerability Methodology*, Working Paper 013 dated November 15, 1976, was followed in preparing the armor drawing. The design followed the design recommendations made to Bell by J. Hawkins of DTNSRDC.

2.4.2.2 Shock Protection

Lift and propulsion group machinery has been designed for underwater shock anticipated for 3000-ton SESs in Working Paper 013.

To account for this design requirement, the weight allowance for propulsion and lift machinery has been increased by 5.7 percent to cover shock mounting.

3. LOGISTICS CONSIDERATIONS

3.1 Reliability (Not provided by Bell)

3.2 Maintenance Concept (Not provided by Bell)

3.3 Overhaul Concept (Not provided by Bell)

3.4 Supply Support Concept (Not provided by Bell)

3.5 Human Engineering

Human engineering has been an integral part of the far-term 3000-ton SES design effort. The objectives of the human engineering effort have been to improve the man/machine interface, to achieve the required effectiveness of personnel performance during ship operation, and to ensure that demands upon manpower resources, skills, and training are economical. A human engineering program based upon MIL-H-46855A, *Human Engineering Requirements for Military Systems, Equipment, and Facilities*, was undertaken to ensure successful accomplishment of these objectives. Major emphasis in achieving the stated. objectives has been placed on work station design, design for maintenance access, and design for habitability.

3.6 System Safety

The safety and survivability analysis conducted for the 1990 point design indicated that no Category IV Catastrophic Failure as specified by Mil Standard 882 existed.

Adequate margins of structural safety have been incorporated and stability and buoyances developed in accordance with DDS 079-l so that the ship is an inherently safe design. In addition, the built-in characteristics of the lift system provide buoyancy redundancy. The feature of low cg-to-beam ratio enhances stability, thereby making a safer than conventional ship design.

In addition, control redundancies and shorter stopping distances coupled with smaller turn radius make maneuvering in unsafe waters much safer than conventional ships of the same class and weight.

Operating procedures and performance criteria have been established that assure achievement of mission objectives within safe operational limits of the LSES man/machine system.

3.6.1 Preliminary Hazard Analysis

The preliminary hazard analysis for the 1990 ship indicated fire as one of the major hazards. However, extensive fire-protection systems reduce this hazard to a minimum level. The systems provide a rapid detection of and response to fires, combined with passive protection of the aluminum hull, The high-risk fire hazard is due to a potential major fuel, hydraulic oil, or lubricating oil leak. A major leak is not expected because of maintenance procedures which will result in detecting and preventing hazardous leaks. Any fire resulting in critical ship damage would require a double failure; for example, an item leak and subsequent multiple failures of fire-protection items.

Major ship damage hazards would most likely be the result of a collision, Small object hazards such as logs, debris, etc, would not cause any safety hazard even at top speeds.

Radiation hazards from ship radar and radios were evaluated and no adverse effects were noted (see 3.6.8 on radar antennas),

3.6.2 Safety Tradeoff Studies

Where possible, known hazards that could not be eliminated through design were reduced to an acceptable level through the use of appropriate safety devices as part of the system, subsystem, or equipment (eg, high-temperature cutout switches, relief valves, etc). See table 3.6-I.

TABLE 3.6-X

PRELIMINARY SAFETY INPUTS IN DESIGN TRADEOFFS

GROUP	INPUT REQUIREMENT	CONSTRAINT	TRADEOFF EFFECTED	RATIONALE	SAFETY CRITERIA
1 Hull Structure	A. Remaining afloat after damage. B. Structural survival in sea state 9. C. Structure as armor protection.	A. Ship size and utilization. B. Ship weight critical. C. Ship weight critical.	A. Additional watertight bulkheads. B. Additional structural members. C. Increased scantlings.	Additional bulkheads and structural material will improve flotation capability and sea state 9 survivability (provided not being blown ashore). Material additions provide more limited armor protection.	Require critical hull structure areas to be easily inspected and maintained or specify methods of doing so. Specified fire insulation (2000°F 15 minutes with maximum 300°F rise in temperature).
2 Propulsion Plant	A. Propulsion failure.	A. State of the art.	A. From propellers to waterjets.	A change from propellers to waterjets reduced the number of components required providing improved reliability and maintainability.	Either propulsion system to be able to propel ship without tow.
5 Auxiliary Systems and Lift System	A. Fire protection. B. Lift system failure. C. Bow seal failure. D. Stern seal failure. E. Non-redundant control device.	A. Ship weight critical. B. State of the art. C. Material limitations. D. Material limitations. E. State of the art.	A. Increased use of semiautomatic chemical fire extinguishers. B. Increased use of chemical hand fire extinguishers. C. Minimal fire main installations. D. Independently operating lift systems. E. Seal configurations and materials. F. Controls redundancy.	Areas with limited access and availability such as the engine compartments compel the use of semiautomatic chemical fire extinguishers. Large amount of electrical controls and electronics require added hand chemical extinguishers to prevent personnel injury and minimize circuitry damage. Increase in chemicals reduces need for fire mains and decreases water damage.	Number of fire curtains, semiautomatic fire extinguishers, firemains, fire walls and fire resistant insulation. Number of bilge pumps and locations. Hydraulic arrangement to minimize being damaged, ease of maintenance and maximum separation from electrical/electronic components. Either lift system to be able to maintain cushion. Use of the latest state of the art in seal material.
6 Outfit and urnishings	A. Personnel placement.	A. Ship size and utilization.	A. Environmental control. B. Impact of reduced manning.	Personnel reduction reduces space requirements for use in other ship operational requirements.	Personnel arrangement for minimum noise level and possible injury from propulsion and lift machinery. If necessary, provide sound insulation and protective shields. Also, electrical insulation to prevent electrical shock.
7 Armament	A. Magazine placement	A. Ship size and utilization.	A. Magazine and weapon placement.	Magazine and weapon placement changes are dependent upon other ship requirements.	Magazines are located in the less hazardous areas of the ship.

Where it was not possible to preclude the existence or occurrence of a known hazard, devices were employed for the timely detection of the condition and for the generation of an adequate warning signal. Warning signals and their application were designed to minimize the probability of incorrect signals or of improper reaction by personnel to the signals,

Where it was not possible to reduce the magnitude of an existing or potential hazard through design, or through the use of safety and warning devices, special procedures were developed to counter hazardous conditions and enhance LSES crew safety. In the event of a fire in the engine room, for example, all the hazards associated with fighting that fire, keeping fumes from spreading, keeping the crew safe, and minimizing ship damage, were analyzed and the best procedures developed. The systems safety group established standard definitions and notations to be used for this purpose,

3.6.3 Fire Protection

During the subsystem development phase of the LSES Program, fire studies have continued as described in TADP F-l. (See Technical Area Development Plan (F-l), *Fire Protection,* Bell report 7446-940834, September 4, 1974,) The results of previous passive protection test programs were evaluated and additional fire tests have been conducted. Materials have been selected for the passive protection of the hull in conjunction with the noise and thermal insulation requirements for each compartment.

The fire load of each compartment of the ship was computed and the fire risk identified. Fire-detection and fire-protection systems were defined accordingly. (See Analysis Report, *Fire Protection System* (F-l), Bell report 7446-917020, December 10, 1975.) The principle of minimizing the risk and effect of fire on the 1990 SES is to achieve speed in detection and activation of fire-control systems. In areas of highest fire risk, such as engine comparment, fire-fighting measures are instantaneous, and fire in these compartments can be rapidly extinguished, Care was taken in selecting extinguishing agents such that premature discharge will not cause unreasonable damage to subsystems. The following systems ensure that any fire will be rapidly detected, localized, and extinguished with minimum damage.

The high-risk machinery spaces utilize total-flooding fire-suppression techniques, with Halon 1301 as the prime system and high-expension foam as the backup system. The detection system uses a combination of thermal and optical detectors in each space. The entire detection and extinguishing network for the high-risk spaces is integrated through the damage-control console located in the engineering damage control center (EDCC). This console includes provisions for warning lights and audible alarms, equipment and venting shutdown, extinguishing agent release, override and inhibit functions, and built-in testing.

The high-risk hangar area utilizes an aqueous, film-forming, foam-sprinkling system as the primary system, and seawater and portable potassium bicarbonate extinguishers as the backup system. The torpedo stowage space utilizes a seawater sprinkling system as the primary system and portable potassium bicarbonate extinguishers as a backup, The detection system uses a combination of thermal and smoke detectors. This entire detection and extinguishing network is integrated through the damage--control console,

Unmanned moderate-risk spaces utilize total-flooding fire-suppression techniques, with Halon 1301 as the primary system and seawater and portable potassium bicarbonate extinguishers as the backup system. The detection system uses a combination of smoke and thermal detectors in each space, This entire detection and extinguishing network is integrated through the damage-control console.

All areas on the open deck and side fairings use aqueous film-forming foam as the primary system. The lift engine and SSPU compartment uses the Halon 1301 as the primary system, and seawater and portable potassium bicarbonate extinguishers as the backup system. The detection system for the side fairings is integrated through the damage-control console.

All other spaces (crew quarters, galley, machine shops, radar room, pump rooms, etc) use portable potassium bicarbonate extinguishers and portable CO, extinguishers as the primary system, and seawater as the backup system,

Fire protection measures in the 1990 SES configuration include minimal use of flammable or toxic, gas-producing magerials. Also, containers and lines carrying combustible liquids, gases, or other explosives are identified and given maximum separation and shielding from potential ignition sources; control valves are provided to control fluid flow; and compartments are vented to prevent excessive concentrations of toxic or explosive gases,

The insulation selected is based on the special requirements of protecting an aluminum structure and corresponding weight sensitivity of a high performance ship.

The main fire zone bulkhead insulation is located around stringers and tion is applied to both sides. Application of insulation to both sides of the main fire zone bulkhead is to ensure that the bulkhead will serve as a barrier to fire in either direction. In the main fire zone, bulkhead insulation is wrapped around stringers following conventional ship practice.

In each room where insulation is placed over vertical stringers, at least two fire stops are incorporated in the dead space between the stringers.

The insulation is located behind all fuel and hydraulic lines and electrical conductors to provide access for inspection,or maintenance.

The horizontal fire stops in vertical dead spaces behind insulation provide additional insurance that these spaces or tunnels will not become conduits for fire between levels. The additional fire stops will form a backup in the event of a floor burn-through.

The insulation installed behind fuel, hydraulic, and electrical conductor lines can be readily formed into the space between and around stringers. This will ensure that conductors can be readily reached for maintenance and allow ready visual inspection of fuel and conductor line conditions,

Location of the insulation across the stringers or stiffeners saves approximately 15 tons that would be required to insulate around the complete contour of the stringers. The air gap should also help reduce bulkhead skin temperature.

Suspended overhead insulation, where installed, is supported by 2-inch hullboard and the insulation system is attached to the stringers by steel hangers.

For the bulkheads where lightweight insulation is not already covered with a perforated metal for acoustic reasons, and where it could be damaged, it will be protected by a light-gage fiberglass laminate sheathing. The sheathing, like the perforated metal acoustic covers, will also serve as a means of support. The insulation will be bonded to the sheating and the assembly attached by means of welded-on studs to the ship structure, In areas where sheathing and perforated metal covers are not used, the insulation will be covered with impregnated fiberglass cloth and the assembly will be attached to the structure by a combination of bonding and studs. Bonding materials will be suitable for exposure to 800°F.

Several insulation types are employed to allow for differences in fire insulation probability and intensity and for acoustics in various ship areas, The high fire-risk areas insulation also contains an integral steel plate to form a positive fire barrier in propulsion engine areas. (The latter area also incorporates automated fire-detection and control systems,) Fire insulation with shorter protection-time capability is employed in low fire-risk areas.

The hull insulation, which is provided for integrated acoustic, fire, and thermal insulation is a Fiberfrax insulation selected for high-risk areas (engine rooms, etc) and a fibrous glass insulation selected for low fire-risk areas.

3.6.4 Lift System and Seals

The LSES is safe when operating either off or on cushion, therefore, system safety was evaluated only when operating on cushion and with some hazard causing cushion loss, or for some operating condition where the hazard was introduced.

System failures revealed by failure mode effects and criticality analysis did not include a single hazard that would cause a problem on the ship as the cushion generation system is partially redundant. A loss of one complete fan system would reduce the ship performance but would not place the ship in the unsafe mode.

The seal system can sustain a loss of at least 20 percent of the fingers or bag segments before performance loss occurs.

The bow seal is provided with pressure-operated vents which exhaust to atmosphere through the hull and serve to limit pressure buildup during severe ship motions in waves. Each seal is provided with bypass ducting to the cushion region, the bypass flow being controlled by valves operated from the EDCC. These bypass systems are used to achieve the required cushion-to-bag pressure ratios and they are also used to maintain seal pressures in the event of failure of one side of the lift fan system.

Pressure sensing instrumentation is provided so that correct bag pressures can be established and ship operating mode kept safe and constant.

3.6.5 Ride Control

A ride control system has been developed which greatly expands the speed/sea-state envelope in which the crew can safely and efficiently operate. This system has been described in 2.3.3. With the use of ride control, the ship can operate anywhere within the goals envelope and within the ambient conditions specified in the Top Level Requirements document. This system is not required for normal operation, and the system is used for operational envelope expansion. Even in extreme cases the crew can still operate for short periods of time with the system out.

Predicted ship motions with the ride control system in operation were compared to the human tolerance limits specified in the ride criteria report to ensure that no conditions exist where crew performance would degrade to levels where the ship and ship crew would be endangered.

Analysis of 1990 point design SES ride can be summarized as follows:

a. The ride does not exceed the 4-hour endurance criterion for vertical accelerations at the bridge, at any speed within its operational capability, for any sea direction in sea state 6 or less. Xn sea state 3, the ride does not exceed the 8-hour endurance criterion even at the highest speeds.

b. Headings other than head and bow seas offer considerable improvement in the ride characteristics, providing endurance limits in excess of 24 hours for most speed/sea-state conditions.

c. The use of active pitch control improves the ride at all ship locations.

d. Lateral and longitudinal accelerations do not exceed the 8-hour tolerance limits under any conditions analyzed to date,

e. The highest accelerations in the ship occur at the bow, although active pitch reduces these levels, In head or bow seas in sea states 6 and above, reduced duration habitability may be required with respect to the standard Navy watch in the far forward section of the ship,

f. Due to the mission-critical tasks performed at the bridge and combat information center, and also because the motion levels at the bridge are representative of the near-maximum motion levels at most other inhabited areas of the ship, task performance and well-being at the bridge will establish limiting conditions for ship operation and watch rotation. Nevertheless, the more favorable ride characteristics at other ship locations will allow extended operation at high speeds and sea states with watch schedules that are consistent with current Navy practice for rough-sea operations,

3.6.6 Helicopter Control System

The flight contact station overlooking the flight deck is fully equipped to direct helicopter operations, and has an unobstructed view of the whole flight pattern. The helicopter landing, operating, and support facilities are designed to meet the requirements of NAVMATINST 3120.1 and Bulletin 1C.

3.6.7 Deck Edge Curvature

The LSES structures design is such that there are few areas where hazards due to deck edge curvature exist, On the bow, however, there are some surfaces where firm footing is not established with solid flat surface and anti-skid paint. Life/safety lines will be used for all maintenance and servicing conducted here or when line handling operations are conducted in this area,

When the ship is in port, or for short at-sea mission, temporary safety rails will be placed in areas of heavy personnel travel to assure ultimate crew safety.

3. 6.8 Antenna Relocation

The safety evaluation of all ship antennas and radiation transmission across the ship did not indicate a need for any major radar or radio antenna relocation,

The LSES design considered all known radiation hazards and ship operating hazards and placed the antennas accordingly, If, however, in the final analysis there is an indication that the antennas cause an obstruction, produce radiation hazards, or in any other way affect safe ship operation, the design can be changed to remedy the situation,

4. TECHNICAL RISK ASSESSMENT

The Bell Aerospace Textron, New Orleans Operations, approach to large SES design has been to carry forward as much basic technology as possible from the near-term LSES in order to minimize risk. However, where new developments are required, these have been identified.

The Bell approach is to ensure that the LSES possesses the inherent availability and endurance to successfully carry out its mission. To this end, system and subsystem design selection emphasized the use of highly reliable and maintainable components within the weight limitations.

The overall Bell design philosophy was to take the maximum advantage of existing SES technology and operational experience. The ship configuration and systems have been selected to minimize risk and any substantial subsequent development programs; therefore, the overall configuration of the ship is an evolution of the LSES and the SES-100B configuration. In addition, the subsystem design rationale was based upon previous high-speed craft experience and the extensive subsystem development results obtained during Phase IIA of the LSES program.

The far-term LSES uses the same overall philosophy of providing inherent passive stability over the entire speed range as that successfully demonstrated by the SES-100B.

Numerous and extensive series of model tests and calculations to examine ship performance, seakeeping, maneuverability, and stability show that the hull will meet the TLR requirements over the full range of LSES displacements and sea states. Adequate power margins exist at hump, with full displacement, and at the maximum required speeds. Ship motions in severe sea states do not exceed levels considered acceptable for long-term retention of personnel efficiency. Questions of inlet broaching and inlet unwetting by sidehull flow separation have been carefully examined during the numerous model programs, and also by using SES-100A data. Sidehull shaping and fencer, at the intake location have been designed to minimize flow separation and the occurrence of broaching. The ship hydrodynamics and aerodynamics are considered to be a low-risk area.

A major element of the far-term ship that has considerable influence on its oceangoing capability is the bow and stern seal design. The Bell bow and stern seals are based on the successful configuration of the SES-100B with significant improvements in load reduction, sealing, and hull and finger attachment. These improvements over the SES-100B have been verified by extensive model test rigs and tow tank model programs. Further improvements to the near- term ship, based on recent test data, have been incorporated.

The validity of analytical techniques to predict seal loads has been verified by correlation with model and full-scale seal load measurements on the SES-100B test craft. Full-size test specimens incorporating seal materials and attachment hardware have proven the adequacy of attachment and joint designs.

For the 1990 ship, Kevlar fabrics have been substituted for nylon in the bags, and sufficient laboratory testing has been carried out with the material to ensure that the strength and integrity previously demonstrated with nylon can be repeated.

The risks associated with the development of the 1990 SES propulsion subsystem are comparable to those associated with the development of the propulsion subsystem for the current LSES.

The 50,000 MIP engine prototypes currently available are the Pratt and Whitney (P&W) FT-9 A-Z and the General Electric (GE) LM5000. Both are capable of the required power, and the technology improvement needed for better fuel consumption is the subject of several intensive current development programs.

There is a moderate element of risk involved in the development of a 50,000 hp propulsor. The propulsor design developed by ALRC for the Navy LSES program is a two-stage, two-speed waterjet pump driven through an offset gearbox, and is based upon the waterjet pump presently installed in the Navy hydrofoil (PHM). Although much of the basic design is common, changes have been made to uprate the pump capability from 18,000 to 40,000 hp and to incorporate design improvements as a result of PHM testing and LSES model pump testing. Further uprating of this 40,000 hp propulsor to 50,000 hp represents a questionable undertaking, considering the substantial amount of uprating that has already been imposed upon this propulsor originally designed for PHM application.

The backup propulsor design for the LSES, designated as the Powerjet 46, is based on a modified scale Powerjet 20, which is a propulsor limited for commercial sales. In contrast to the ALRC propulsor, it is a single-speed design and is capable of producing 40,000 hp without resorting to uprating of a lower-power existing propulsor . One possible method of uprating this design to 50,000 hp is to include an additional axial stage. This involves a moderate degree of technical risk.

Development of a propulsor transmission capable of absorbing 50,000 hp also represents a moderate technical risk, due to the higher geartooth loads and transmission cooling problems.

The intake and exhaust systems are based on technology to be developed during the LSES program, and therefore represent a low technical risk. Higher filtration system efficiencies and higher flow velocities are projected for the 1990 SES. The selection of a ram-type air inlet is based on improved filtration efficiency and a better definition of spray environment to be obtained from the LSES program.

The waterjet inlet will be very similar to and only slightly larger than that proposed for the LSES, which was demonstrated to be fully satisfactory through extensive model-scale performance testing and full-scale ramp element structural testing. Development risks will be low.

A risk assessment of the remaining major systems is presented in table 4-I. Development required during the next 10 years for 1987 design start on the ship described in this document is given in table 4-11.

TABLE 4-I

SYSTEMS DESIGN
SUMMARY OF LOW-RISK APPROACH

SYSTEM	RISK LEVEL	COMMENTS
Hull	Low	Highly compartmented - multiple load path design. Construction principle proven by extensive weld development program and SES-100B operations. In-depth knowledge of loads from 100-ton test craft, model test, and analysis. Reduced design factors of safety used as a result of near-term ship operation and further analysis.
Engine Air Filtration	LOW	TRW Charged Droplet Scrubber (CDS) is a new development for ship application, but is considered a moderately low risk in view of considerable commercial application experience, Peerless system will be carried as a parallel design effort.
Lift	Low	Cushion fan program at ALRC and LSES operation will provide substantial test and design development. Basic concept fully proven. Seal fan - within state of the art - used for near-term ship. Simple transmission - one gearbox for each system (port and starboard). No bevel gears, short shafts.
Combat	Low	Incorporation of significant amount of previous ship combat system design, physical and functional layouts. All other systems based on operational hardware and software.
Electrical Auxiliary Instrumentation	Low	All systems utilize to maximum extent existing hardware and proven experience. Many systems will have been proven on near-term ship. Navy specifications and requirements will be met to the maximum possible extent.
Swing Rudder	Minimum	Since the swing rudders effectiveness has not been verified by model tests as yet, risk is greater than with the conventional rudder used on the 1980 LSES.

TABLE 4-11

DEVELOPMENT REQUIRED DURING NEXT 10 YEARS

SYSTEM	DEVELOPMENT
Hull	Increase plate size capability for forge welding
Propulsion	Complete development of P&W FT-9 A-Z or GE LMSOOO
	Uprated Roeketdyne propulsor and transmission
	Develop low-cost, lightweight IR suppression system
Lift	Model tests to demonstrate reinflation from the cushion of a l/l pressure ratio stern seal
	Demonstration of seal life using a Kevlar bag and finger seal and simplified joints on the SES-100B test craft
Auxiliary	Complete development of low-cost reverse-osmosis distiller
	Demonstrate the effectiveness of the swing rudder with model tests

APPENDIX A

DESIGN PROCESS

A.1 APPROACH

The configuration of the far-term 3KSES point design is based on the technology developed at Bell Aerospace Textron over a period of approximately 10 years, and specifically upon the successful SES-100B test craft. A design philosophy was adopted which established an order of priority for the principal characteristics of the ship. This order of priority may be summarized as follows:

a. High-speed stability and safety
b. Thrust margin at primary and secondary hump
c. Range performance
d. Speed performance
e. Maneuverability.

It was recognized that the primary objective of the SES concept is ship performance. However, this performance is of little use unless the ship is safe and stable throughout its possible operating envelope. Also, the ability to accelerate readily through primary and secondary hump is vital if the ship is not to suffer operational limitations that materially detract from its high-speed performance.

The basic elements of the configuration reflect the priorities listed above. High-speed stability is ensured through the selection of partial-length sidehulls, which in turn requires a three-dimensional bow seal. The rounded bow planform also assists in minimizing the magnitude of the secondary hump drag, since the critical induced wave condition does not occur simultaneously across the beam of the ship. The low deadrise sidehulls ensure good lateral stability, roll into turns, and minimize the additional drag penalty for the installation of the propulsion system, be it waterjets or propellers. All of these features have been thoroughly proven on the SES-100B.

The performance, stability, maneuverability, and seakeeping characteristics of the design have been predicted using methods established and verified through correlation with a wide range of model and full-scale experimental measurements.

Performance predictions are based upon drag values calculated by the Bell performance math model. This math model agrees well with drag measurements from the SES-100B, as illustrated in figures A.1-1, A.1-2, and A.1-3, which show comparisons between measured and predicted drag levels in low, intermediate, and high sea states, respectively. It has been assumed that some improvement in a number of drag components can be realized through technology development prior to 1990, amounting to a total drag reduction of 16 percent relative to the math model portrayed in the figures. Since the experimental results are generally somewhat under the math model predictions, this is considered a reasonable assumption. Similar small improvements are assumed in various component efficiencies, and are described in more detail in section A.4. All assumptions are based to a significant extent upon test data accumulated from the 100-ton SES and from the Advanced Development Phase of the LSES Program.

The predictions of ship stability have been extrapolated directly from model tests of the Bell LSES having essentially the same hull form. The maneuverability of the ship in the low-speed hullborne or partial-cushion modes has been predicted by a simplified 3-degree-of-freedom math model developed for the LSES. Turning characteristics in the high-speed, full-cushion model have been generated by a comprehensive 6-degree-of-freedom simulation, which was also used to predict ship motions in a range of sea state, speed, and heading condition. This simulation was also correlated extensively with both towing tank models and SES-100B test data.

It is considered that this point design is based firmly on proven SES technology, with only modest improvements resulting from normal engineering development being required to realize the performance described in the body of this report.

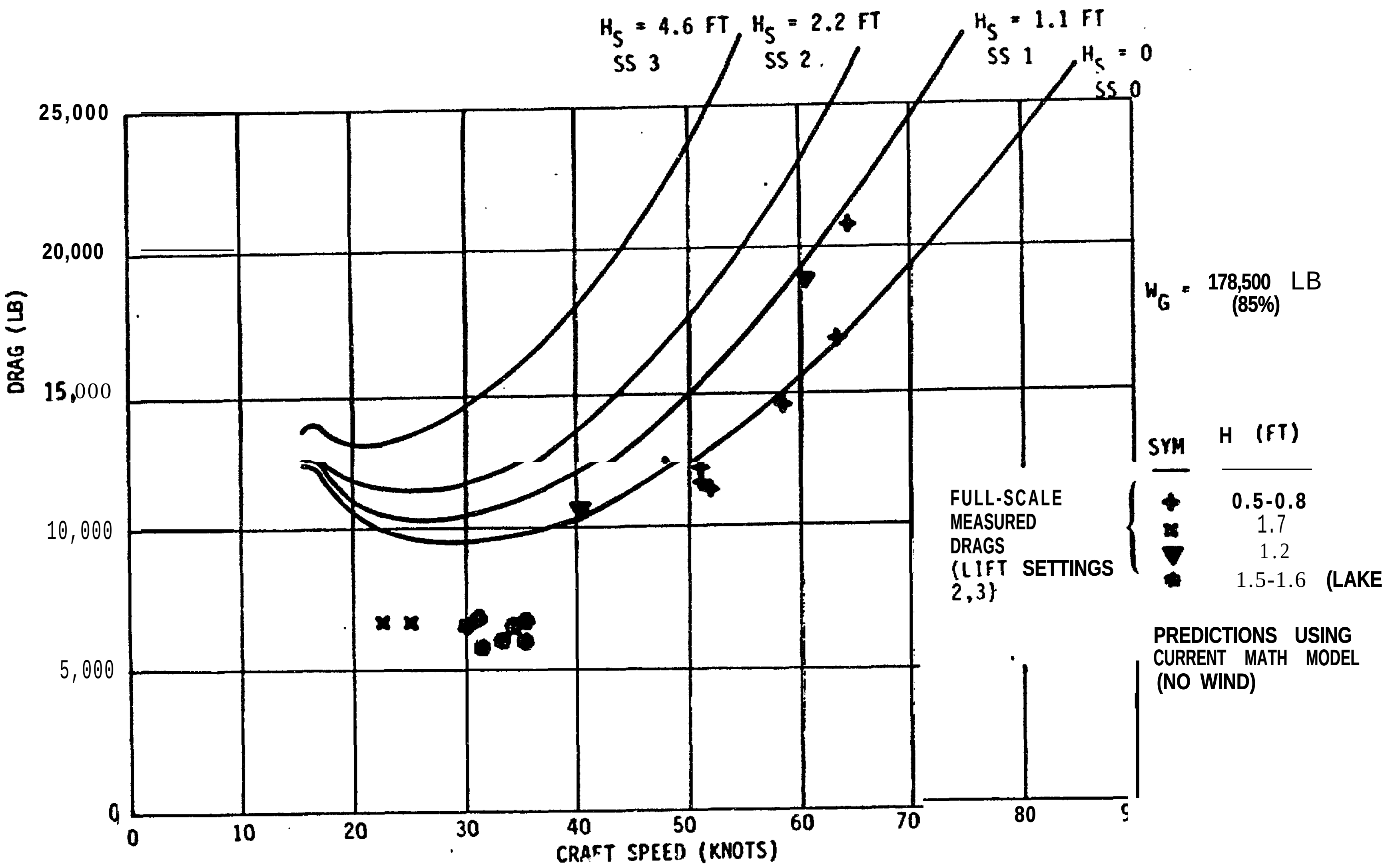

Figure A.l-1 SES-100B DRAG VERSUS CRAFT SPEED
COMPARISON OF MATH MODEL PREDICTIONS WITH FULL-SCALE DATA

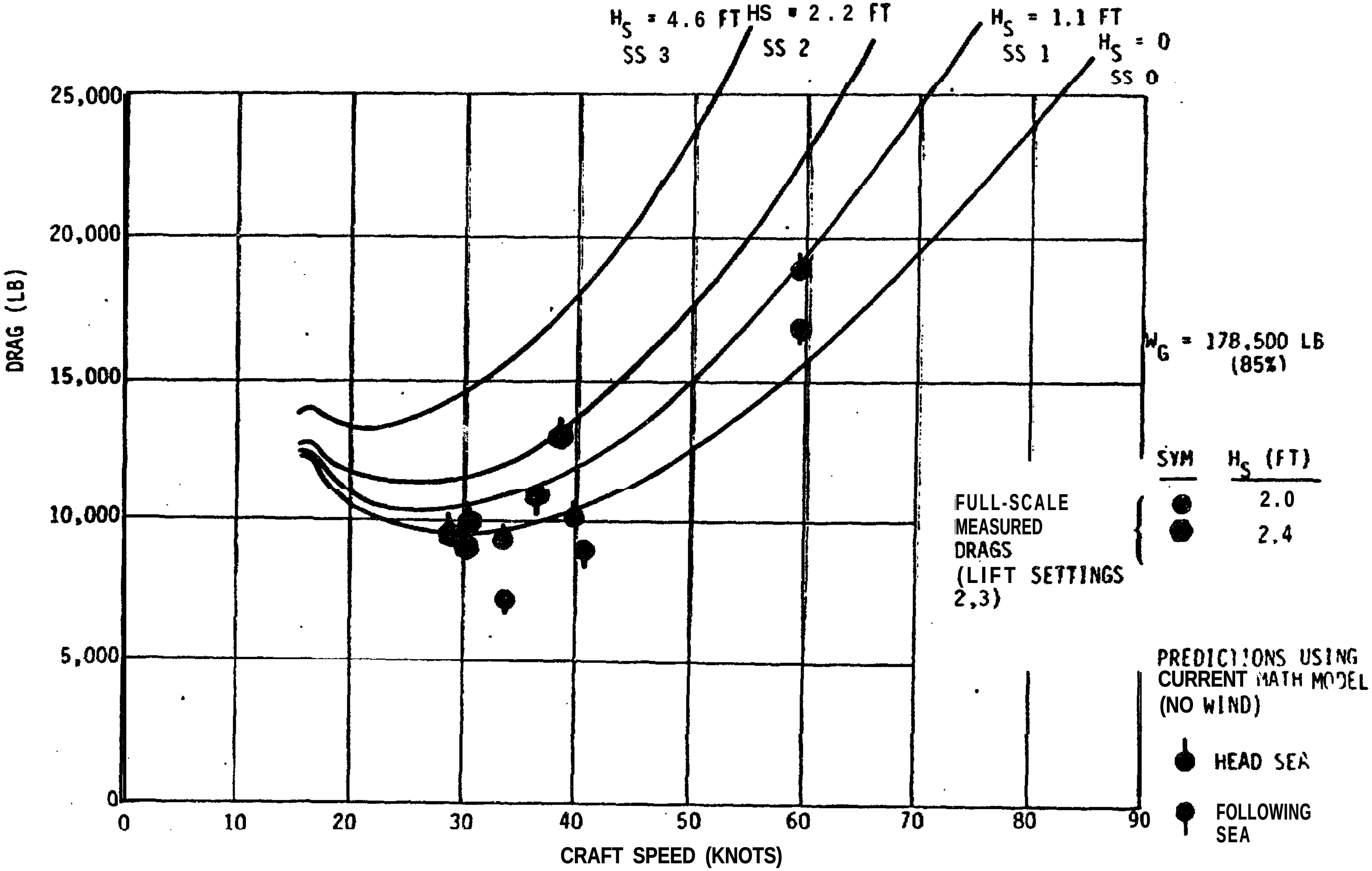

Figure A.1-2 SES-100B DRAG VERSUS CRAFT SPEED
COMPARISON OF MATH MODEL PREDICTIONS WITH FULL-SCALE DATA

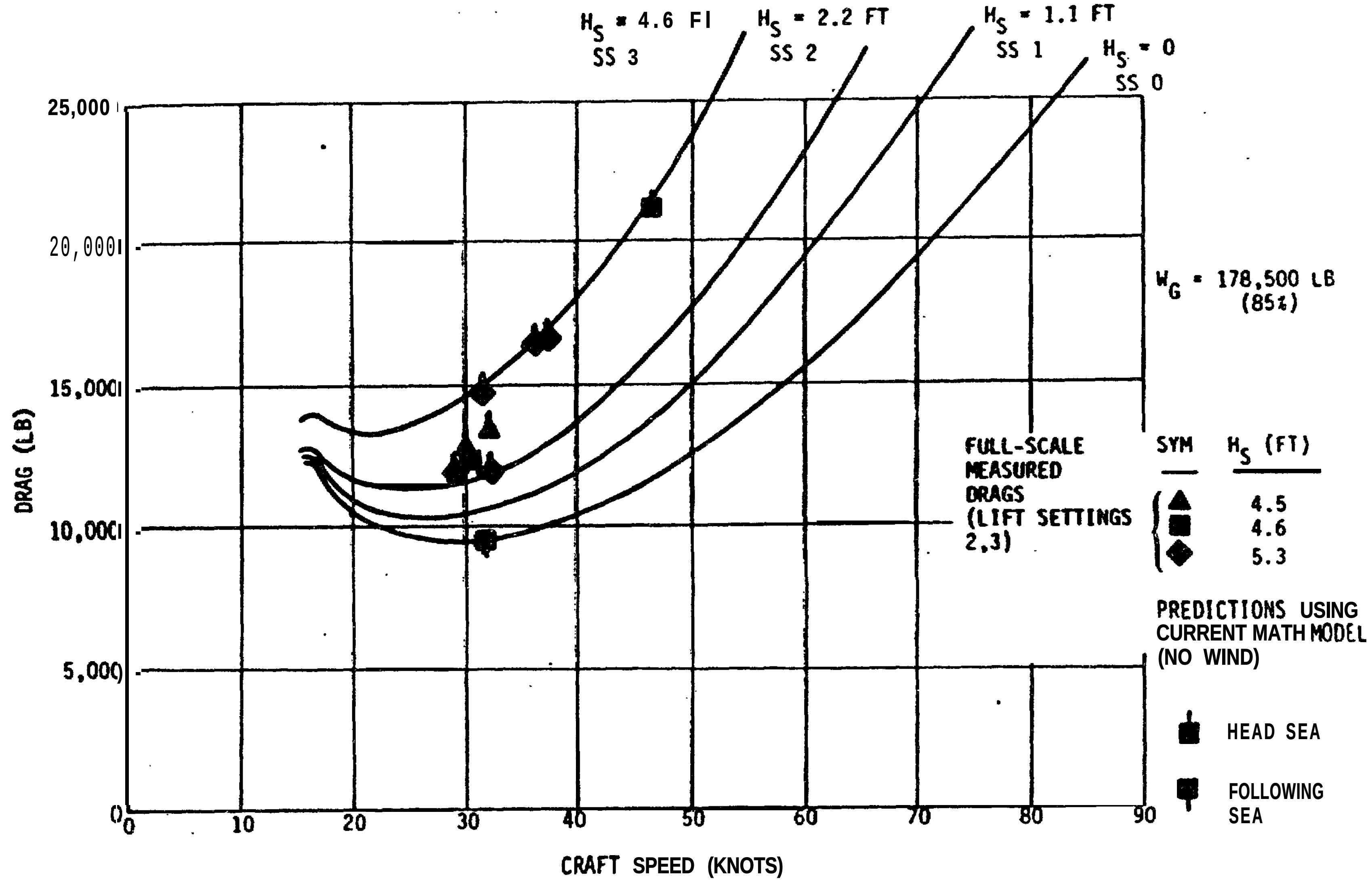

Figure A.1-3 SES-100B DRAG VERSUS CRAFT SPEED
COMPARISON OF MATH MODEL PREDICTIONS WITH FULL-SCALE DATA

A.2 DESIGN CRITERIA

A.2.a Hull Structure

HULL - 1980 3KSES

Structural design and loads criteria are specified in *Structural Criteria Specification, Large Surface Effect Ship,* bell New Orleans report 7446-SC-110001, revision A, June, 1976.

Structural reliability analysis development is shown in *Criteria Development Analysis Report - Structural Design Criteria (H-11),* Bell New Orleans, report 7446-917036, May, 1976.

HULL - 1990 3KSES

Structural design and loads criteria are the same as for the 1980 3KSES, except that all category I primary structure analyzed by reliability methods has a central safety factor of 1.5 instead of the 2.0 factor specified. The rationale for this reduction is discussed in paragraph 2.3.1.5 of the basic document.

A.2.b Propulsion

The propulsion system has the following characteristics:

Waterjet propulsor efficiency = 0.91

Waterjet inlet efficiency = 0.90 up to 60 knots, decreasing to 0.75 at 100 knots

Transmission efficiency = 0.99

Thrust margin = 1.262 (based on hump-speed drag under calm-water conditions).

The engine inlet system will contain Farr and TRW charged droplet scrubber (CDS) demister systems, which will satisfy the following gas turbine engine manufacturer's requirements: the inlet air flow will have no more than 0.0006 ppm of salt (concentration by weight), and no more than the **maximum** engine inlet flow pressure depression of 4 inches of water will occur in the engine inlet system.

A.2.c Electrical Plant

a. This design approach used was that of minimizing risk and improving product reliability, design life, and efficiency,

b. Generator sizing allows growth margin of 30 percent in cruise and 20 percent in combat conditions.

c. Generator sizing will allow the loss of one SSPU without affecting servise.

d. Distribution of power was accomplished such that critical loads were provided two sources of power.

e. Expansion of automation over what was established in the 1980 version would be accomplished only if it would impact manning.

A.2.d Command and Surveillance

a. Integrate TLR specified requirements into a functional high-speed SES environment.

b. Provide optimum system reliability as constrained by SES lightweight system requirements.

c. Provide an acceptable level of system automation to reduce the condition III manning requirements without over-sophistication.

d. Integrate SES operational aspects into standard Navy fleet operational procedures with as little change as possible without adverse effect on the SES-unique capabilities.

A.2.e Auxiliary Systems

A.2.e.1 Design Criteria - Fuel System

The following criteria have been assumed in the projected design of the 1990 SES:

a, Fuel flow rates: 15 ft/sec maximum for shipboard transfer; 25 ft/sec maximum for fueling and defueling.

b. Engine fuel inlet pressures: 5 to 50 psig for FT-9 propulsion engines and LM2500 lift engines; 5 to 15 psig for ship service power units (SSPUs).

c. Maximum engine fuel flow rates: 45 gpm for FT-9 propulsion engines; 24 gpm for LM2500 lift engines; 3 gpm for the Super TF-25 SSPUs.

d. Fuel: in accordance with specification MIL-T-5624, grade JP-5. Aircraft fuel conforms to NAVAIRINST 10340.3. Ship engine and SSPU fuel is filtered through 10-micron nominal, 25-micron absolute particle filters and filter-separators conforming to MIL-F-8901 or MIL-F-15618.

e. Fuel temperature; 0° to 100°F. Ambient temperature 0° to 160°F.

f. Helicopter fueling provisions: in accordance with NAEC 91122, Helicopter Facilities, bulletin no. 1C.

g. Maximum distance between forward and aft transfer tanks to provide maximum trim capability.

h. Automatic changeover from a failed primary service pump to a backup pump. Automatically activated backup feed for SSPUs.

i. Incorporation of warning of abnormal fuel pressure, tank levels, and filter condition indicated at control station for quick troubleshooting,

j. Maximum accessibility to all components, particularly those requiring scheduled maintenance.

k. Components will be lightweight qualified hardware proven in previous marine use.

A.2.e.2 Heating, Ventilating, and Air Conditioning

Design Points

Weather Temperature

90°F, 65% RH - Summer
+10°F - Winter

Seawater Temperature

85°F - Summer
28°F - Winter

Space Design Temperature

80°F, 50% RH - Summer
70°F - Winter

(per NAVSHIPS 0938-018-0010 for Non-Air Conditioned Spaces)

Chilled Provisions for 15 days

Frozen Provisions for 30 days

A.2.e.3 Seawater Systems

Fireplug spacing and capacity
Magazine sprinkler capacity = 0.8 gpm/ft^2
150 psig firemain
per General specifications for ships of U.S. Navy

Gearbox oil cooling = 1% of meshed horsepower

Electronics cooling = 100 kw plus

20 ft/sec maximum flow velocity

Waterjet tapoff flow capacity = 2000 gpm each

A.2.e.4 Freshwater System

Personnel accommodations per OPNAV 9330.7A

140 personnel

30 gallons freshwater per day per man (minimum)

One engine wash per day per engine

One helo wash per day per helo

5 parts per million maximum salinity content

Electronic cooling system per Navy standard drawing 810-2251137

Transfer capability per general specifications for ships of U.S. Navy

A.2.e.5 Compressed Air System

Low-pressure system at 100 psig

High-pressure system at 3000 psig

Air receiver capacities

low pressure - 12 ft^3
high pressure - 10 ft^3

per general specifications for ships of U.S. Navy

A.2.e.6 Fire Extinguisher System

Insulation requirements - NSRDC report SER 74-174-91, April 5, 1974, used as guide

Fire hazard evaluation - NSRDC report SER 74-174-133, May 10, 1974, used as guide

Fire loadings
Fire risk
Technical Area Development Plan, Bell report 7446-948034 used as guide

A.2.e.7 Hydraulic System

General system design per MIL-H-5440,	*Hydraulic Systems, Aircraft, Types I & II, Design and Installation, Requirement for*
Component design per MIL-H-8775,	*Hydraulic System Components, Aircraft and Missiles, General Specification for*

A.2.e.8 Ship Control System

Waterjet steering sleeve control

±30° deflection
6° per second

Rudder steering

200,000 ft-lb torque
±30° deflection

Thrust reverser

Full travel in 3 seconds

Underway Replenishment

Refueling at sea

3000 gpm at 40 psig

Vertical replenishment

High-line replenishment

Freshwater transfer

Anchoring, Mooring, Towing

Anchor in 70-knot wind, 4-knot current

Moor in 70-knot wind, 4-knot current

Warping capacity - 30-knot wind, l-knot current, broadside

Towing - 30-knot wind, S-knot speed

A.2.e.9 Human Waste Disposal System

140 Accommodations

1 to 1.5 pints of water/flush

Personal accommodations per OPNAVINST 9330.7A

No discharge of oily wastes, sewage

A.2.f Lift System

Design criteria for the most significant items of the lift system are presented herein. They are based on years of testing, analysis, and related experience.

A.2.f.1 Lift System Transmission

The LSES lift fan system arrangement uses a very simple parallel-shaft, offset transmission to drive the fans at optimum rotational speed, using the LM2500 gas turbine engine as the prime mover. The design of the fan transmission strikes a balance between the extremely sophisticated lightweight aircraft transmissions using gearsets having substantial shaft, housing and geartooth deflections, and the robust, heavy, stiff, and very conservative marine systems. The selected limits for the design parameters resultantly provide a moderately lightweight, lightly deflected transmission operating conservatively at the designated power spectrum and expected life requirements with the least risk possible,

Gearing is held to conservative limits established by American Gear Manufacturers Association (AGMA) standards, and is within the capability of manufacturing equipment presently available, The AGMA limits within which stresses have been held are shown in table A.2.f-I.

Scoring indices and flash temperatures are determined by use of AGMA 217.01, and the fundamental geartooth bending and compressive stress are per AGMA 211.02, 221.02, 225.01, 226.01, and 411.02.

Specifications are written to establish the design criteria for the transmission based on the needs of the ship and the experience developed by past designs for other ships and craft of similar (high-performance) nature. The exclusive use of 9310 CEVM material for gearing on transmission is established based on a material departure on the SES-100B resulting in ring gear failure due to material impurities. This caused lessening of fatigue life capabilities.

The gearing stress levels selected are based on a near-infinite life capability at the maximum speed and torque output. Although the transmission will operate for only 1 percent of its total life at this point, it does represent more than 10^8 loading cycles on the gearteeth for the 54,000 hours cumulative running time encountered during the life of the transmission at the specified speeds and power levels. Superimposed on this maximum loading is the consideration of a 3 Hz alternating torque equal to ±15 percent of the steady torque for 40 percent of the time.

In order to ensure that the transmission has a low airborne and structural noise characteristic with design features producing the minimum dynamic load variation and a smooth and quiet operation to the fullest extent possible, class 12 or better gearing is utilized. Rotating elements are dynamically balanced so that the residual imbalance meets MIL-STD-167, Avoidance of the whirl-mode frequency in the operating range is also accomplished by proportioning the rotating shaft assemblies so that the lateral frequency is at least 130-percent higher than the maximum design rated speed. Oil churning is kept to a minimum by ample internal space and localized baffling, use of an air/oil scavenge ratio of 2.5 to 1 or greater, and by maintaining design delta temperature rise conditions. Corrective geartooth modification is made in the form of crowning or profile correction to

TABLE A.2.f-I

CONSERVATIVE TRANSMISSION CRITERIA

	AGMA MAX TOOTH BENDING STRESS RECOM (PSI)	AGMA MAX TOOTH CONTACT PRESSURE RECOM (PSI)
Helical Gears	60,000	200,000
Spiral Bevel Gears*	40,000	200,000

*Note the 1990 SES lift system transmission does not use spiral bevel gears.

provide compensation for tooth, shaft, and housing deflections under loaded conditions. The exclusive use of anti-friction bearings of class 5 or better quality is deemed necessary with a positive means of race retention to prevent race creepage, rotation, and/or fretting. The skip-tooth principle is applied to ensure full hunting of the gearteeth and equalization of wear,

Other salient requirements include isolation of dissimilar metals as defined in MIL-STD.880 by use of sealants, paints, oil immersion, encapsulation or potting; black oxide protection of all ferrous components wetted by the lubricating oil, with the exception of bearings; and use of hermetically sealed electrical connectors of a specific type based on field experience.

A.2.f.2 Lift Fans

The lift fan design criteria were established to produce a sound fan design that meets the pressure-flow requirements at a high operating efficiency. In addition, a design requirement of the cushion fans was to provide a capability for modulating the flow at a fixed fan speed,

The design criteria developed and the ensuing design presents a low-risk ship subsystem for the ship functional requirement. The following subsections address the various aspects of fan design criteria.

A.2.f.2.1 Performance

Performance requirements drive the overall size of the fan. For a given fan type, airflow and pressure strongly influence the fan width and diameter respectively. Specific requirements for the cushion and seal fans are as follows :

	Cushion	Seal
Nominal operating pressure (lb/ft^2)	353	422
Flow modulation required (% nominal)	+10,-50	

A.2.f.2.2 Structural Design

Impeller

The functional design for pressure-flow rate, flow characteristics, high efficiency, and minimum space results in an impeller of specified geometry and speed. The dynamic loads induced by centrifugal action applied to this design must be considered in selecting fan materials. Materials of high strength-to-weight ratio and marine environmental corrosion resistance are mandatory. Impeller disc and shroud stresses require the use of titanium. The blades have material selections that suit the design detail.

The seal fan has an airfoil of ample thickness such that extruded aluminum blades similar to those successful elements of the SES-100B are used. The cushion fan, with more blades of thinner section, requires the structural usage of a welded titanium blade.

Housing

Housing design is geared to minimal weight requirements. Both the seal and cushion fans take advantage of a blown shape with the high structural efficiency feature of membrane tension. The seal fan design specifies a 5000 series of aluminum weldment, The cushion fan has a fiberglass sandwich construction. Either material is technically recommended.

Shafting

Individual fan decoupling while running is a significant design feature, since full system shutdown is not necessary. The system must be stopped to achieve a recoupling, however, since a powered recoupling device is costly and has unacceptable weight.

Variable Flow Device

This mechanism has been designed for hydraulic oil actuation. It has the sensitivity and high-frequency response necessary to achieve a significant ride control input. Significant studies of variable flow device failure mode possibilities have demonstrated that secondary failure of the impeller is unlikely.

Structural criteria considerations are detailed as follows:

a. Environmental Loadings. Fan survival extremes in singular extreme wave impacts are accounted for. They do not entail considerations of fatigue, since occurrences are infrequent. Aside from local attachment concern, their magnitude does not affect design.

	Vertical	Lateral	Axial
Seal Fan	+10g -5g	±2.0g	2.0g -0.5g
Cushion Fan	+6g -4g	0.7g	+2.0g -0.4g

Certain ship loadings are of fatigue-frequency occurrence; therefore, fatigue considerations are included.

	Vertical	Lateral	Axial
Seal Fan	+5g -2.5g	±1g	+1g -0.5g
Lift Fan	TBD	TBD	TBD

b. Environmental Motion Loadings, Impeller Tests. Angular rates of ship motion and their frequencies impose a gyroscopic load on complex rotary machinery. The fatigue stresses imposed upon high basic centrifugal stresses provide a failure source mechanism of such significance that high load cycle demonstration testing of this fatigue resistance is a criterion by Bell for both impeller designs for design qualification.

Shaft axis orientation of the fans in the ship is such that pitch and yaw only contribute to impeller gyroscopic loading. Extreme low-cycle gyroscopic action is considered as well, but is not of fatiguing significance.

	Pitch	Yaw	Roll	RPM
Extreme Values				
Seal fan	24°	4°	24°	1755
Cushion fan	24°			1880
Fatigue Unlimited Values				
Seal fan	15°/sec	-		1.564
Lift fan	15°/sec	2°/sec	33°/sec	1450

A shaft oscillating test of each fan will be run for SO hours, subjecting the fan to the fatigue pitch rates and concurrent fatigue rpm shown in the table. Other than the impeller, these motions have insignificant effect on the fan static components.

Impeller Spin Requirements and Test

The energy content, and therefore the damage potential of a failed rotor, is significant. Prior to acceptance, each deliverable rotor is spun to a speed in excess of its maximum operating speed.

In turn, to demonstrate the impeller design margin, a design qualification rotor is subjected to a speed still higher than the production acceptance value. The criteria is that there shall be no yield or significant unbalance created by this extreme test.

	Max Operating Speed (rpm)	Acceptance Test Speed (rpm)	Qualification Test Speed (rpm)
Seal Fan	1755	1910	2100
Lift Fan	1880	2200	2200

The impeller design margins required are as follows:

Yield - 1.5 × limit load

Ultimate - 2.0 × limit load.

Housing Pressurized Design, Test

Wave impact and hull slamming supply fan housing back-pressure extremes that must be considered in the criteria. Subjected to such a loading, the air inlet fairings to the aft fans of the Bell SES-100B suffered collapse failures.

These failures, of low-margin design and subjected to pressures not locally measured, focus on the requirement for extreme pressure criteria and static test.

Pressure-relief doors to the air spaces connected to the fans limit the back pressure to 1000 psf, or 6.8 psi, on the Bell ship. The fan housing structural criteria is as follows:

	Design Criteria Pressure (psi)	Bell Max Load Pressure (psi)	Proof Pressure (psi)
Seal Fan	1000	6.8	7.0
Lift Fan	907	6.3	6.3

The design criteria pressures differ for the two fans, but the design strength safety factors are the same:

1.5 on yield strength

2.0 on ultimate strength,

This anomaly resulted from a time lag between lift fan hardened design and maximum load establishment by Bell. It is felt that the equal proof-pressure requirement, however, levels out the criteria difference.

Fatigue loadings to the pressurized housings result from varying cushion back pressures induced by wave encounter. The action of the ride control system (RCS) with further attenuation by the VF fan system should minimize such pressure excursions. The best estimate of the predicted situation for unlimited life structural fatigue capability is as follows:

	Mean Pressure (psi)	Fluctuating Pressure (psi)
Seal Fan	2.50	+1.5 -0.5
Lift Fan	2.0	TBD

Structural Dynamic Considerations

The effects of random or spaced fan back pressures, the heave alleviation inputs, the variable-flow lift fan system effects, and the turbine power fluctuations all combine *to* disturb the torsional mass elastic constants of the combined mechanical system. In summary, the principal torsional inertia components are the power turbine of the prime mover, the reduction gearing, the two aft fans, and the single seal fan. All of these elements are connected by shafting of limited torsional stiffnesses. A dynamic study of the system has led to an integrated design that will suffer no critical resonant conditions within the operating speed spectrum and that will, for fatigue strength purposes, be satisfied by the following criteria:

	Max Power Torque	RPM	Fatigue Torque
Seal Fan			±15%
Lift Fan	9000	1880	TBD

The discrepant power sums shown reflect the power magnitude and split differences between the Rohr and Bell requirements for the lift system. Conservatism is maintained, however.

A.2.f.3 Seal Systems

The structural design requirements used for the seal system design result from a combination of requirements presented in the LSES TLR. These include the nominal pressures required by the lift system, experience with the SES-100B and a number of air cushion vehicles, and the use of the 6DOF mathematical simulation used to predict motions, loads, and pressures of the ship. This ship motion simulation program and its correlation are described in the LSES seal system DDR.

The nominal pressures required by the lift system and upon which the structural design of the seal system is based are as follows:

Cushion pressure	352 psf
Bag pressure	422 psf.

These values correspond to a maximum design weight of 3450 long tons, a cushion area of 20,412 square feet, a bow seal-to-cushion pressure ratio of 1.20 and a stern seal-to-cushion ratio of 1.0. These are current baseline ship values.

Experience with various air cushion vehicles and with the SES-100B has shown a number of potentially critical structural design conditions for seals. These have been examined and confirmed in some detail by using instrumented bow seals on the SES-100B and the SR.N4 to measure loads and hence determine critical conditions. These test programs and the analysis and conclusions were reported under the LSES program.

Based on this experience, the important design cases include :

a. Various combinations of bag and cushion pressure resulting from ship motions in waves

b. Drag loadings

c. Dynamic loadings due to rapid reinflation of a partially collapsed bag or finger

d. Liftoff of the craft with water in the seal bags

e. Water scooping loads, applicable to the bow fingers.

In order to establish the combinations of bag and cushion pressure to be examined, the mathematical simulation has been used to examine all potentially important combinations of speed and sea state at the boundaries of the operating envelope of the TLR. For each speed/sea state combination, the ship motion program was exercised, in the appropriate random sea environment, for a sufficient length of time to generate a statistical sample of peak pressures and pressure differences. From this small statistical sample (typically 4 minutes of real time), rms peak pressure levels and deviation values corresponding to a Rayleigh distribution were obtained and extrapolated to give peak operating life of the seal. The resulting peak pressures and pressure differences are used to define limit loads, to which the required safety factor of 2.0 is subsequently applied, It should be noted that both bow and stern seals involve pressure-relief systems that are simulated in the mathematical model. Thus, any significant increase of bag pressures above those selected as limit values is very unlikely, however small a probability of occurrence is selected.

Pressure loadings in the seal bags are associated with some water level and some degree of bag compression or shape change so that, in determining loadings in the bag, maximum pressures are not necessarily associated with the fully inflated shape. Definition of water height has been taken from the mathematical simulation results, but without using any type of statistical extrapolation. Thus, the maximum bag compression for any particular speed and sea state is the maximum value taken from the 4-minute real-time ship motion analysis, whereas the associated pressures are once in a lifetime values. This procedure is simple and conservative.

For seal life design, internal loadings in the seal membranes have been taken directly from the mathematical simulation results at various velocities and random sea conditions. The simulation output permits loading rates to be determined for each loading level; from these rates, the total number of loadings at each level throughout the seal life can be determined.

For design cases in which drag is critical, drag forces on fingers or bags have been determined using the product of wetted area (defined by water level and seal geometry), dynamic pressure, and a drag coefficient of 0.0045.

For finger drag loads, full immersion of the finger has been assumed possible at any operating speed up to maximum, Orientation of the fingers around the bow requires consideration of drag loads in any direction from parallel to perpendicular to the plane of symmetry of the finger.

For bag drag loads, full immersion of the bags has been assumed only in conditions greater than sea state 3, and thus only at speeds below 80 knots. All headings from head to beam are considered.

For design cases in which reinflation dynamics are important, a completely collapsed initial bag or finger shape is assumed. Bag reinflation is based on either maximum seal fan flow or a constant pressure equal to the nominal bag pressure. The latter represents the case of a partial bag collapse, where a large volume of air remains in the uncollapsed sections of the bag. Finger reinflation is examined for a cushion pressure of 2.0 times nominal,

For liftoff with water in the seal bags, the bags are assumed to be filled to a level corresponding to the hullborne condition of the craft, with the bag configuration deformed by water and seal pressures.

Water-scooping loads for finger design are based on the dynamic pressure loading of the scooping region using a coefficient derived from test data. This criteria was developed by Bell using British Hovercraft Corporation (BHC) data associated with failures and successes of SR.N4 and SR.N6 fingers. Its purpose, however, has been to force a finger attachment design that makes scooping loads small, so that water scooping does not dictate extremely high materials strength.

All of these structural criteria are summarized in table A.2.f-II.

The seals are designed to minimize weight within the geometric constraints imposed by the requirements and with consideration for life, maintenance, fabricability, and avoiding dependence on major advances in the state of the art of coated textile materials.

The internal loads, within the various seal elements for the critical design cases, are tabulated in tables A.2.f-III and A.2.f-IV for the bow seal and the stern seal respectively. All values shown are limit values. All conditions, including a matrix of pressure combinations for the wave impact cases, have been examined for each element of the seal structures. Descriptions of these load analyses were reported under the LSES program,

From a summary of worst-case loadings, the critical loading for each major element of the seal system can be determined. In order to establish margins of safety for the materials of the seal, these limit loads are combined with the required ultimate factor of safety of 2.0, and another factor of 2.0 is included to account for material degradation during its life and to account for inefficiencies at joints.

The critical loading for each attachment is determine? for each of the basic attachment types by combining the maximum limit load with the required safety factor of 2.0 and a factor of 1.5 to account for material degradation during seal life. A joint efficiency factor is not included since it is inherent in the joint strength test data.

TABLE A.2.f-II

SUMMARY OF SEAL STRUCTURAL CRITERIA

Nominal Cushion Pressure 352 psf
Nominal Bag Pressure 422 psf

Design Cases:

1. Water Impact

   For rational combinations of cushion and bag pressures with maximum bag pressures equal to 1200 psf.

2. Maximum Cushion Pressure for Finger Design

   1440 psf

3. Drag

   Fingers - wetted area corresponding to full immersion; drag coefficient of 0.0045; dynamic pressure corresponding to 80 knots; drag loads in any direction from parallel to perpendicular to finger plane of symmetry.

   Bags - wetted area corresponding to full immersion; drag coefficient of 0.0045; dynamic pressure corresponding to 60 knots; drag loads in any direction from head to beam.

4. Reinflation

   Fingers - from completely collapsed to fully inflated under a constant pressure of 700 psf.

   Bags - from various collapsed states to fully inflated under pressure and flow conditions which correspond to the capability of the fan.

5. Water Carry During Liftoff

   Bags assumed filled with water to wet deck level and also pressurized to nominal pressure. Bag shapes to correspond with these conditions.

6. Safety Factor

   All of the above cases are limit conditions, and loads are to be combined with a safety factor of 2.0.

7. Life

   A 2000-hour seal bag life based upon loads versus number of occurrences for the specified TLR duty cycle.

   The lower section of the finger, which is in continuous contact with the water, must have a life corresponding to 2 years of ship operation without incurring sufficient wear that the ship will not achieve minimum TLR performance.

TABLE A.2.f-III

BOW SEAL LIMIT LOADS

ELEMENT	LOAD	CONDITION
Outer Bag Attachment		
Normal Inflation	1,200 pli	Overpressure
+90° Upward	600 pli	Water impact
-90° Downward	650 pli	Water carry
Inner Cable Attachment		
At Finger Tail	98,000 lb	Overpressure
Between Finger Tails	60,000 lb	Overpressure
Outer Bag Membrane		
Radial (Vertical)	1,200 pli	Over-pressure
Peripheral (Lateral)	1,200 pli	Water impact
Inner Bag Membrane		
Radial (Vertical)	250 pli	Water carry
Peripheral (Lateral)	310 pli	Overpressure
Inner Bag Cables		
At Finger Tails	98,000 lb	Overpressure
Between Finger Tails	60,000 lb	Overpressure
Apron		
Peripheral Reinforcement	120,000 lb	Overpessure Minimum ratio
Geometry Control Cables and Attachments		
At Finger Tails	50,000 lb	Water carry
Between Finger Tails	50,000 lb	Water carry
Finger-to-Bag Attachment	780 lb/attach	Reinflation
Finger Membrane (1 - 9)	720 pli	Reinflation
Finger Membrane (10 - 11)	720 pli	Reinflation

TABLE A.2.f-IV

STERN SEAL LIMIT LOADS

ELEMENT	LOAD	CONDITION
Outer Bag Attachment	600 pli	Water carry
Inner Bag Attachment	925 pli	Overpressure with drag
Upper Lobe Membrane	600 pli	Water carry
Middle Lobe Membrane	600 pli	Water carry
Lower Lobe Membrane	600 pli	Water carry
Upper Lateral Membrane	525 pli	Overpressure with drag
Middle Lateral Membrane	410 pli	Overpressure with extended segment
Lower Lateral Membrane	600 pli	Water carry
Internal Vertical Membrane	600 pli	Water carry
End Cap Membrane	320 pli	Overpressure

A.2.g Outfit and Furnishings

The criteria chosen is consistent with the standards set forth in NAVSHIPS 0902-01-5000, *General Specification* for U.S. *Navy Ships,* and OPNAVINST *9330.7, U.S. Navy Shipboard Habitability Design Standards.* The FFG-7 Patrol Frigate and the DD963 designs were studied and compared with the 1990 LSES. The latter was found to compare favorably with each of these designs.

Design criteria on which the insulation system design is based are found in the following reports:

a. Summary Report, *Fire Protection System (F-1)* (Bell New Orleans report 7446-950038, July, 1976).

b. Summary Report, Noise *Reduction* (N-2) (Bell New Orleans report 7446-950006 and addenda, May, 1976).

c. *LSES Baseline Description Report* (Bell New Orleans report 7588-RE-000004, July 19, 1976).

d. *Best and Final Offer Design Proposal* (Bell New Orleans report 7588-RE-800004, October 12, 1976).

In addition to the above reports, the fire insulation specified in the TLR (1 pound per square foot) is shown on the bulkheads designated by the Navy. Deck plans of the ship were sent to J. Hawkins of DTNSRDC and returned to Bell with bulkheads requiring fire insulation designated. The purpose of this Navy-directed procedure was to ensure that the fire insulation design was consistent from ship to ship for all ships in the ANVCE study. In a few areas, the reasoning followed in the Navy fire insulation design was not apparent to Bell; however, in the interest of maintaining uniformity for all ships in the ANVCE study, the insulation system drawing (AD-77-2) in appendix B reflects the Navy design.

A, 2. h' Armament

a. Integrate the TLR armament requirements such that they do not restrict weapons effectiveness on conflict with the SES operations.

b. Vertical-launch weapons will be used to facilitate locations and reduce weight.

c. Multiple use of facilities will be stressed.

d. Maximum sensor coverage will be provided.

A.2.i Loads

Crew

Personnel Allowance	200 lb/man
Carry-on Baggage Allowance	
CO/Exec Officer	125 lb/man
Officers	100 lb/man
CPOs	75 lb/man
Enlisted	50 lb/man

Stores

Chilled Provisions	1.69 lb/man/day
Frozen Provisions	1.61 lb/man/day
Dry Provisions	3.2 lb/man/day
Ship Stores Tobacco, Beverages, etc	1.5 lb/man/day
Medical Supplies	1,250 lb
General Supplies Photographic, Hardware, etc	1,500 lb
Lube and Hydraulic Oils	11,610 lb

Helo Fuel

All ship mission fuel is available as helo fuel, but an allowance of 8 metric tons has been made for helo use per ship refueling period.

A.2. j Weight Margins

A weight margin of 15 percent has been used per the requirements of WP-015 dated November 15, 1976, for preliminary, contract, detailed design, and construction margins.

A.2.k Vehicle and Personal Safety Requirements and Damage Stability

The 1990 point design will utilize the following ship safety design criteria:

a. Failure minimization through redundancy

b. Avoid use of hazardous materials

c. Design systems fail-safe

d. Adequate lock-outs and lock-ins

e. Hazards eliminated when recognized in design

f. Isolation of energy sources

g. Safe design practices

No burrs of sharp edges

Protective covers

Handrails and safety nets

Safety workways, nonskid surface

Blackout/blackout emergency procedures

Development of red-line limits

Stability and buoyancy in accordance with Design Data Sheet - Stability and Buoyancy of U.S. Naval Surface Ship, dated August 1, 1975, DDS 079-1, Part III Advance Marine Vehicles [in Waterborne and Displacement Mode)

One-hour fire protection time for uncontrolled fire

Adequate structural safety margins as specified in Bell specification 7446-SC-110001A, dated June 25, 1976.

In addition to the above, the following detailed design criteria will be used by all designers to help establish the maximum achievable safety for system assemblies and components.

a. Provide a means to isolate all power from specific equipment to allow maintenance or removal.

b. Ensure that maximum continuous RF exposure to which personnel will be subjected does not exceed 10 mw/cm^2.

c. Design all toxic detection systems to receive power from the vital bus.

d. Provide critical instruments with positive failure warnings.

e. Specify toxic vapor detectors to be used wherever toxic gases can enter inhabited spaces,

f. Ensure that emergency conditions that require immediate action initiate an audible warning in addition to a visual warning.

g. Ensure that volume controls do not reduce warnings to an inaudible level.

h. Provide audible warning override where prolonged warning will interfere with effective correction action.

i. Design and locate operating controls to minimize inadvertent activation.

j. Design displays such that reading errors are minimized.

k. Ensure that the shape and location of emergency controls are such that they can be operated under conditions of poor visibility.

1. Locate emergency controls to be readily visible and accessible under normal conditions.

m. Ensure that color coding is used in accordance with the specifications.

n. Provide protection for personnel from moving parts, sharp corners, high temperatures, high-pressure fluid and gas vents, and corrosive or toxic spray.

o. Provide handrails, hand grabs, etc, to aid personnel in maintaining footing.

p. Provide self-locking or other foolproof features on deck hatches, heavy doors, chain barriers, etc.

q. Provide adequate access routes from hazardous areas.

r. Provide area isolation for critical areas for use in event of fire, explosion, or other disaster.

s. Locate fire extinguishers to afford maximum availability for fires.

t. Separate systems employing incompatible fluids to prevent inadvertent mixing.

u. Design adjacent systems employing incompatible fluids so that it is impossible to interconnect.

v. Use components that are qualified for use with system liquid or gas.

w. Establish procedures to ensure that cleaning agents are not retained within the system.

x. Design the system so that pressure will relieve prior to exceeding structural limits.

y. Locate components to minimize danger of ignition of flammable materials.

z. Route lines to minimize effects of leakage.

aa. Provide ventilation and drainage where leakage of toxic and/or flammable **fluids** into confined areas is possible.

ab. Design vent systems to safely dispose of hazardous vapors.

ac. Ensure that check valves will not be installed in reverse.

ad. Provide bypasses for filters where filter failure would constitute an operational hazard,

ae. Ensure that emergency modes of operation are completely independent of primary modes.

af. Provide a backup seal where pressures can cause O-ring extrusion.

ag. Provide system protection so that a regulator malfunction will not cause downstream system failure.

ah. Include provisions for bleeding pressure off systems for maintenance purposes.

ai. Use pressure reliefs that are sized to exceed the maximum flow capacity of the pressure source where practicable.

aj. Where step regulation is specified, select regulators that operate in the center 50 percent of their total range and locate a pressure-sensing device on the low pressure side of each regulator.

ak. Ensure that selection of materials for use in electrical/electronic systems has been made with due consideration of operational environment such as explosive or corrosive atmospheres.

al. Select materials that will not emit toxic or explosive gases when operated at the anticipated temperatures..

am. Ensure that system operation is not degraded by anticipated temperature extremes.

an. Route wires and locate components such that they do not create interference with adjacent systems.

ao. Deisgn electrical/electronic systems with a minimum of connections and terminations.

ap. Route wires and locate components such that they will not impose undue mechanical strain on termination points under any combination of anticipated service conditions.

aq. Design electrical equipment so that receptacles (female socket type) are not hot and the plugs (male pin type) are cold when disconnected.

ar. Provide positive protection for terminal blocks to prevent shorts resulting from contact with miscellaneous debris or from elements of the environment.

as, Ensure that elements of a redundant system do not pass through the same connector as elements of the primary system.

at, Ensure that primary and redundant system circuits are not supplied from the same power bus or circuit breaker.

au. Specify electrical shielding whenever it is necessary to suppress RF energy or other sources of spurious energy.

av. Provide protection from the hazards of loose articles, tools, and debris.

aw. Specify interlocks, shielding, safety guards, barriers, and warning markings where a personnel hazard can exist.

ax. Route wires that are attached to normally moving parts to twist rather than bend across adjacent moving parts.

A.2.1 Manning

The philosophy underlying the far-term design was to minimize the number of crewmen on the ship while ensuring that the LSES meets all functional and mission requirements imposed by the TLR.

The organizational manning requirements for the LSES were developed in accordance with OPNAV 10P-23, *Guide to the Preparation of Ship Manning Documents.*

Conditions of Readiness I and III were used to establish manning requirements.

Military Standard 14728 was used to establish human engineering design criteria.

A.2.m Performance Criteria

The installed propulsion power is based on the following conditions:

a. 1.25 thrust-to-drag ratio at secondary hump, calm water

b. 1.25 thrust-to-drag ratio at primary hump, calm water

c. 70 knots in sea state 3 (h_{sig} = 4.6 ft, 1.4 m), lo-knot headwind

d. Optimum cruise speed in sea state 3, lo-knot headwind

All cases were evaluated at design gross weight. The installed power is selected as the greatest of these requirements. Maximum intermittent power (MIP) is assumed for hump, and maximum continuous power (MCP) for top and cruise speed.

A.3 DESIGN PHILOSPHY

The design philosphy for the Bell point design for the 1990 SES is to achieve a proper balance of design improvement features while using the Bell LSES of the 1980's (reference Bell report number 7588-950047) as a baseline reference and point of departure. This approach provides minimum risk with respect to technology and cost, while meeting or exceeding all minimum levels of the TLR for craft performance.

Attainment of a ship gross weight of 3500 tons with increases in ship volume provided the necessary major design improvements that permitted the ship to be chosen as the first LSES operational lead ship. The gross weight improvement, coupled with increased ship volume, provides for additional space and weight for improved operational combat suites and additional personnel. This has been achieved without compromising safety and survivability, while retaining or exceeding the ship performance of the 1980's.

Tradeoff studies for design rationale have been made at the system level to ensure that the thrust, drag, stability and control, and ride qualities were consistent with design goals. For each specific requirement, a careful balance between speed and range has been achieved.

The improvements to the baseline LSES of the 1980's result from normal engineering improvements based on recent historical trends not requiring technological breakthroughs. The major areas considered in this design study have been centered around the following:

a. Increased propulsive efficiency

b. Increased lift fan efficiency

c. Seal design improvements

d. Availability of higher-strength materials.

A.4 TRADEOFF STUDIES

A.4.a Configuration

Configuration drawing studies were developed showing new arrangements for utilization of the new ship volume created above the main deck. The 02 deck was rearranged to provide an increase in crew complement from 103 to 130 men. The main deck level was faired in between the side decks, thus providing more space (unassigned), and the SSPUs were moved forward on the main deck. Increased volume on the 01 deck created by the new fairings provides space for the captain's quarters. Additional profile drawings were created to show the rearrangement and addition of weapons.

A.4.b Subsystems

A.4.b.1 Structures - 1980 3KSES

Hull material and structural arrangement tradeoff studies are shown in *Joint Surface Effect Ship Program - Structural Design Studies for Surface Effect Ship, Final Summary Report - Phase II,* Bell Aerospace Textron, Niagara Frontier Operations report 7363-950002, December, 1970.

Skin-stringer optimization analyses are in the *Technical and Operating Manual - Skin-Stringer Program,* Bell New Orleans report 7446-954001, September 1975; and *Skin-Stringer Analysis Report,* Bell New Orleans report 7446-917013, October, 1975.

Skin-stringer weight optimization study is in the *Tradeoff Study Report - Skin-Stringer Weight Reduction,* Bell New Orleans report 7446-948061, February, 1976.

The tradeoff study of structural refinements to reduce structural weight of SESs, by utilizing semi-tension field bulkhead webs instead of shear resistant webs, is in *Tradeoff Study Report - 2KSES Structural Refinements,* Bell New Orleans report 7446-948062, May, 1976.

The tradeoff study of various composite materials for local reinforcement of structural elements is reported in *Analysis of Composite Laminate Reinforcement of Structural Components,* Bell New Orleans report 7446-950003, January, 1975.

The tradeoff study of structural refinements to reduce structural weight of SESs by machine and chem-milling of material from skin-stringer panels designed by pressure loads is in *Tradeoff Study Report - 2KSES Structural Refinements,* Bell New Orleans report 7446-948062, May, 1976.

A.4.b.2 Waterjet Propulsion System

A turbine engine was used with a specific fuel consumption of 0.36. (Since a diesel engine and support structure would be much heavier than that of a turbine engine, while the sfc is approximately the same, a turbine engine is assumed for this study.)

A variable-area waterjet inlet is employed because of the high inlet drag penalty for the fixed inlet geometry, which has to have a large inlet lip leading edge radius.

A propulsor nozzle (vena contracta) area of 1.5 ft^2 was assumed to provide the required range, while maintaining reasonable propulsion system size and weight constraints,

A.4.b.3 Lift and Ride Control System

A.4.b.3.1 VFCF Concept

The selection of the ALRC variable-geometry concept for providing flow modulation is documented in Bell New Orleans report 7446-948052.

A recent study established an improved fan volute shape that will significantly reduce cost and weight without compromising fan performance. The fan casing design for the 1990 LSES utilizes a two-dimensional circular arc geometry based on existing and proven fan design criteria. This casing geometry is used by the major industrial fan suppliers, and has a demonstrated total efficiency of over 90 percent for backward-curved airfoil impellers. The housing has a cone-shaped outer skin for structural integrity. This type of structure can also be used for a fixed-geometry lift fan with no degradation to fan performance. Its simplified internal structure does not require a radial diffuser or diffuser support structure, a center support ring, or tabular internal support as in the 1980 craft. This casing system reflects a minimum requirement for tooling and manufacturing difficulties, yet presents a durable exterior insensitive to local damage. Based on the 1980 ship fan, this design produces a substantial weight reduction even when using the variable-flow impellers.

A.4.b.3.2 RCS Design

A multiparameter tradeoff study was conducted to establish the selected RCS configuration, and is documented in Bell New Orleans report 7446-948053.

Additional studies have shown that an active pitch control system could reduce vertical accelerations at the bow and stern stations of the LSES, thereby improving the ride characteristics. Such a control system was modeled in the 3DOF SES simulation, and a parametric study was conducted. The results show that ride improvements at the bridge can be realized through an active pitch control system. Vertical accelerations are reduced by 12 percent in sea state 5 and by 20 percent in sea state 6. Furthermore, the response requirements of such a system are shown to be reasonable and well within the state of the art.

A.4.b.3.3 Seal Systems

A complete and systematic analysis was followed to produce the initial bow and stern seal designs. These studies are reported in Bell New Orleans reports 7446-917006 and 7446-917025.

In addition to the referenced tradeoffs, subsequent studies were performed which showed the feasibility of reducing the stern-seal-to-cushion-pressure ratio to unity, and which allowed for a significant reduction in bow seal weight to be made.

The LSES baseline stern seal configuration represents a substantial development of the original SES-100B version, which in itself has provided excellent service, Considerable effort was expended on the LSES seal during the Phase I program, which entailed both analytical studies and model test development work. As a result, the final design is comprehensive. It is difficult to foresee further improvements within the 1990 time frame, without an extensive full-scale test program.

However, one area of possible development does exist in the manner in which the stern seal is inflated. The baseline LSES seal is pressurized via two stern seal fans to a pressure ratio of 1.25, which is essentially similar to the SES-100B system. This approach was taken since it was proven at 1/3-scale, and was considered to provide positive inflation during wave-pumping conditions. Recent studies have shown that it is theoretically feasible to develop a seal configuration that is stable at cushion pressure, or a pressure ratio of 1:1. With this low-pressure requirement, there is no longer any need for the long duct and fan arrangement to inflate the stern seal, since a short feed duct from the cushion will suffice.

Studies of math models and two-dimensional rigs have indicated that stern seal configuations can be developed which will even accept the negative pressure ratios of approximately 1:0.9 which may occur in the dynamic or wave pumping conditions.

Seal designs anticipated for the 1990 SES are expected to utilize Kevlar in place of nylon as the seal bag material. Preliminary tradeoff examinations have indicated that the high strength-to-weight ratio Kevlar material will enable the weight of the bow and stern bags to be reduced substantially. The cloth weight will be reduced 50 percent and, as a result, the elastomeric coating will be reduced correspondingly. Application of Kevlar to the bow bag and upper two lobes of the stern seal will reduce the gross weight of each seal by approximately 15 percent. This in turn has a favorable impact on cost, which is expected to be reduced by approximately 8.5 percent even though the Kevlar cost is higher. Bow fingers and the lower stern lobe will still be manufactured from nylon, due to their severe flagellation environment.

A.4.b.4 Electrical System

The tradeoff studies conducted for the electrical system are presented in the following reports:

a. Tradeoff Study Report, *2KSES Electrical System,* Bell New Orleans Report 7446-948050, January 24, 1976.

b. Tradeoff Study Report, *Power Distribution System,* Report No. 7446-948059, April 14, 1976.

A.4.b.5 Command and Surveillance (C&S)

The tradeoff studies conducted for C&S are presented in the following reports:

a. Tradeoff Study Report, *Collision Avoidance System,* Bell New Orleans Report 7446-948056, February 6, 1976.

b. Summary Report, *Ship Integrated Control System,* Bell New Orleans Report 7446-950041, June 15, 1976.

A.4.b.6 Auxiliaries

A.4.b.6.1 Piping Material Selection

Glass-reinforced plastic (GRP) and titanium alloy have been selected for distributive system piping materials. GRP was selected for use primarily in water and drain systems, as on the 1980 SES, to minimize weight and cost. Titanium was selected for those piping applications where superior fire resistance is required. Stainless steel was selected for the 1980 3000-ton SES for these same applications. Using an allowable cost factor of $35/pound for each pound of weight saved, titanium is very cost-effective compared with stainless steel, even at today's prices. It is expected that titanium and steel prices will become even closer as titanium usage grows. The complexities of forming and joining titanium make it impractical for shipyard-type usage at the present, but improvements in these technology areas by 1990 should make titanium a leading piping system material candidate for weight-critical ships.

A.4.b.6.2 Hydraulic System

The hydraulic system for the 1990 ship is assumed to be a 4000 psig system, which will naturally evolve from the present-day 3000 psig system. This evolution, which has already started in late aircraft designs, will result in smaller and lighter hydraulic systems. Components will be smaller, owing to the fact that working areas of-pistons, valves, etc, can be reduced with the higher working pressures, and pipe sizes can be reduced since pressure drop is less critical. Part thicknesses will be increased to accommodate the higher working pressure, but a net weight reduction of approximately 15 percent is gained by size reduction of parts.

A.4.b.6.3 Desalinization Unit Selection

Development work is in progress that will lead to an all fiberglass, reverse osmosis desalinization unit. This will result in a 2500 gallon/day unit weighing approximately 1200 pounds wet. Adding a 1500-pound prefilter to these units, a weight savings of 4500 pounds can be realized over the present, vapor-compression units. In addition, the power required by the R.O. units is 5 kw, as opposed to the 25 kw of the vapor-compression unit.

A.4.b.6.3 Gatex Waste Disposal System (Used on 1980 and 1990 ships)

Tradeoff studies that led to the selection of the Gatex system for waste disposal are documented in Bell New Orleans report 7446-927552, *Waste Disposal* Design Decision Paper, dated August 21, 1975.

A.4.b.7 Outfit and Furnishings

The insulation system for the 1980 and 1990 ships is similar with the 1990 ship having denser insulation to provide protection for 30 minutes instead of 15 minutes in the lower risk areas of the ship. Tradeoff studies that led to the insulation system selected are found in the following reports: (1) Summary Report, *Fire Protection System (F-1)*, Bell New Orleans report 7446-950038, July, 1976; (2) Summary Report, *Noise Reduction (N-1)*, Bell New Orleans report 7446-950046 and addenda, May 1976; (3) LSES Baseline Description Report, Bell New Orleans report 7588-RE-000004, July 19, 1976; and (4) Best and Final Offer Design Proposal, Bell New Orleans report 7588-L-800004, October 12, 1976.

A.4.b.8 Armament

The increase in the number of missiles required for the ANVCE necessitated minor revisions in the sidefairing superstructure. All missiles, including the Harpoon missiles, were placed in a vertical firing mode and located in the aft portion of the sidefairing. To accommodate the missiles and not infringe on the helicopter landing requirements, it was necessary to relocate and move the propulsion engine inlets slightly forward. The location of the missiles provides easy replacement from dockside. Their placement also precludes any ingestion of hot firing gases in any of the propulsion on lift engine intake systems.

A.4.c Parametric Performance Analysis

A.4.c.1 Introduction

In support of the definition of the far-term SES design, parametric ship performance studies were conducted to define the point design configuration. These studies were limited in scope, to be consistent with an expressed desire of the ANVCE SES Office to minimize changes from the 1980 SES design previously submitted (reference 1). Results of SES parametric performance studies, which had been conducted in recent years at Bell New Orleans (references 2, 3, and 4) provided guidance as to the parameters and ranges that should be explored to maximize ship effectiveness.

Presented herein are assumptions and results of studies defining the waterjet-propelled SES point design. Similar studies were also conducted for the propeller-driven ship; these are presented in appendix C.

A.4.c.2 Assumptions and Constraints

A.4.c.2.1 General

Consideration of the requirements of the far-term SES TLR (reference 5), and the stated objective of minimizing changes from the 1980 point design, led to the use of the same cushion area and length-to-beam ratio (L/B) as the 1980 ship (Bell's proposed LSES) for the 1990 SES. The TLR requires passage through the Panama Canal, which effectively fixes the cushion beam at the LSES value of 91 feet. (Previous studies have shown little benefit to waterjet-propelled ships by selecting a narrower cushion beam.) Thus, an increase in cushion area would require a direct increase in cushion L/B. Design studies show that the 1990 ANVCE mission-related equipment can be carried by an SES having the same hull dimensions as the present LSES. Increasing cushion area above this value was not necessary, and would be expected to adversely affect top speed and range because of the attendant increase in L/B and reduction in cushion density. It was expected, therefore, that ship effectiveness could not be improved by increasing the cushion area, so the present LSES value was retained.

The remaining ship parameters that could be varied in the parametric study are design gross weight, waterjet propulsor size, and installed power. The gross weight is restricted to the region of 2500 to 3500 metric 'tons, by directive (calculations were also done for 3750 metric tons). Because of the far-term nature of the study, it was believed appropriate to conduct parametric studies using rubberized engines and waterjet propulsors, without restricting the assumed sizes to presently available machinery. The engines and propulsors used on the point design do, however, represent components that can realistically be expected to be available by 1990 without any unusual developmental effort.

The parametric'studies were conducted by varying ship gross weight and waterjet size over appropriate ranges, and by computing ship installed power and ship range at each point. Propulsion system power installed was based on meeting the TLR performance specifications, which consisted of a hump thrust margin of 25 percent over drag in calm water and a maximum continuous speed of 70 knots in 4.6-foot (1.4 m) significant waves against a lo-knot headwind, both at an ambient temperature of 80°F. The hump requirement was assumed to apply at both primary and secondary hump speeds, A check was also made to ensure that the installed power was adequate for the selected optimum cruise speed at full-load displacement. Cruise speed in these studies was optimized to given maximum ship range.

A.4.c.2.2 Ship Drag

Ship drag is computed using the existing drag math model. This math model has been adequately described in references 6 and 7, and details of the methods used will not be reported here. Minor modifications have been made to the drag math model for the purpose of this study. These consist of a slight modification to the rough-water seal drag component to provide better agreement with model test data in the region of primary hump, and the application of improvement factors to various drag components to represent technology improvements that can be expected by the 1990 time period.

Rudder drag is eliminated in the 1990 math model. This can be achieved through the use of swing rudders, which are normally retracted during cruise and deployed only for turns.

Aerodynamic drag is computed using the same frontal area as the LSES, but with the drag coefficient reduced to 0.25 on frontal area, compared with 0.32 presently estimated for the LSES. This improvement can be expected partly as a result of improved topside shaping, an example of which is improved shaping of the foredeck area to blend into the amidships deck structures. A considerable aerodynamic drag reduction can be expected to result from use of a spoiler at the aft end of the main deck to strengthen the base vortex behind the ship and thus reduce base drag. This arrangement was shown to be effective during wind-tunnel tests of a model of the SES-100B.

The seal system drag, as predicted by the math model, is reduced by 14 percent for the 1990 studies. This can be achieved in 1990 by improved contouring of the seals to the water surface, particularly at the stern seal, and by the use of lighter, more compliant seal materials, Observations of model tests, and theoretical predictions, have indicated the existence of a transverse variation of water surface elevation within the cushion of an SEV. It is expected that a drag savings will result if the stern seal is shaped to conform to this contour at a selected cruise speed, Math-model predicted sidehull drag is reduced by 15 percent. Although the selected sidehull overall dimensions (length and thickness) used in this study, which were derived from the LSES configuration, have been shown to provide the optimum tradeoff between performance and stability requirements, further reductions in drag through shaping refinements are believed possible by 1990. The improvements will primarily consist of refinements to shaping to reduce wetted area, such as increased use of separation strips and steps.

The improvements to seal and sidehull drag are assumed to be applicable only in sea state 3 and below, In these conditions, the existing math model (without improvement factors) has demonstrated good agreement with results of l/30-scale model tests, as well as with larger-scale model and full-scale SES-100B data. In higher sea states, the math model predicts lower drags than indicated by the l/30-scale data, although results of SES-100B tests in these conditions also verify the math model values, Reasons for this discrepancy are believed to be related to the inability to correctly scale seal material properties on a l/30-scale model, as discussed in detail in reference 7. It is logical to expect that drag improvements could be achieved in high sea states as well as in low waves by 1990. However, because of the discrepancy between l/30-scale model data and the present math model in high waves, no sidehull or seal drag improvements are assumed in these conditions for 1990. This approach is believed to be slightly conservative.

The criticality of secondary hump in the design of water propulsion systems makes it necessary to consider this region even in a parametric study. Review of available weight data on waterjet propulsors indicated that inducer size was an important factor in determining propulsor weight (see section A.4.1.2.6). Inducer size is also a key parameter in determining thrust at low ship speeds, which is generally limited by the ability of the propulsor to absorb power without incurring cavitation damage. Drag at secondary hump has not heretofore been predicted analytically, since model test results for partial-cushion operation have been used for secondary hump drag. It was believed sufficiently accurate for this study to express secondary hump drag as a factor of primary hump drag, with the factor being determined empirically from LSES model test results (same L/B as the 1990 SES). The quantity (total secondary hump drag on partial cushion) divided by (total primary hump drag on full cushion) in calm water was found to be approximately 0.7, although it varied slightly with cushion density, $W_G/S_c^{1.5}$. Secondary hump speed on partial cushion was found to be somewhat higher than predicted by wavemaking theory. Therefore, the theoretical speed, multiplied by an empirically determined factor, was used in predicting secondary hump speed. The speed thus predicted for the 1990 SES is 19 knots, The effect of RCS operation on drag and performance has been treated in the same manner as that used for the LSES proposal. As in the proposal, it is assumed that in sea states 3 and 4, only the variable flow cushion fans (VFCFs) are activated, while in sea states 5 and 6 both VFCFs and cushion vent doors (CVDs) are used. The 6DOF simulation studies were used to establish an incremented Δdrag in sea states 5 and 6 due to RCS operation. This increment was then added to the drag values obtained as described above to give a final prediction of total drag with the RCS operating . For sea states below 5, it was assumed that there was no effect of RCS on drag.

In addition, for performance prediction it was assumed that the effect of RCS operation would be to increase lift system fuel flow by 25 percent for sea states 3 and 4, and 17 percent for sea states 5 and 6. The rationale for this was described in the LSES proposal.

A.4.c.2.3 Propulsion System Performance

Propulsion system performance was computed using existing methods, with small improvements assumed in some component efficiencies in anticipation of technology developments by 1990. Propulsive performance at any ship speed and power level can be determined by combining and solving, in the appropriate form, the equations

$$BHP_p = \frac{4Q_w \Delta P_p}{550\, \eta_{pump} \cdot \eta_{mp}}$$

$$T_{net} = 4\rho_w Q_w (V_J - V_o) - D_{INL}$$

$$Q_w = A_J V_J$$

where

BHP_p = Propulsion engine power required per ship

η_{pump} = Efficiency of waterjet propulsor = 0.91

η_{mp} = Mechanical efficiency of propulsion transmission system = 0.99

T_{net} = Net thrust per ship

Q_w = Volumetric flow rate per propulsor

ΔP_p = Propulsor developed pressure
= $0.5\rho_w[(XK_3 + 1)V_J^2 - \eta_{INL} V_o^2 + 2gh_{NZL}]$

XK_3 = Nozzle loss factor = 0.01

η_{INL} = Inlet recovery factor = $f(V_o)$

h_{NZL} = Height of nozzle above free-water surface
= 4 ft at secondary hump (partial cushion) = 16.5 ft on full cushion

ρ_w = Mass density of water = 1.99 slugs/ft^3

V_o = Ship forward speed

V_j = Jet exit velocity

A_J = Effective vena contracta area of the jet

D_{INL} = Inlet drag (for ship) $= 2C_{D_i} A_{INL} 0.5 \rho_w V_o^2$

A_{INL} = Area of inlet (per side) = $2Q_w/(IVR V_o)$

IVR = Inlet velocity ratio = 0.675.

At low ship speeds, for example at secondary hump, the power that can be applied to the propulsor is generally limited to less than installed power if cavitation damage is to be avoided. It is necessary to select the diameter of the inducer section of the propulsor to ensure adequate secondary hump thrust. Inducer diameter (in inches) is given by the following expression:

$$d_i = \sqrt{\frac{A_J \rho_w V_o + \sqrt{A_J \rho_w \left[A_J \rho_w V_o^2 + 4(T_{NET} + D_{INL})\right]}}{2\rho_w \sqrt{\frac{NPSH\,2g}{\tau}}\,\mathrm{KIT}}}$$

where NPSH = net positive suction head at inducer centerline at secondary hump; τ, the inlet energy ratio, is determined from the expression $\tau = (NPSH 2g)/C_m^2)$; and Cm = maximum inducer flow velocity.

The constant K is related to the geometry of the inducer by

$$K = \frac{1 - (d_h/d_i)^2}{4(144)}$$

where d_h/d_i = inducer hub to tip diameter ratio = 0.35.

Power required at secondary hump can then be solved using the equations previously presented.

The value of propulsor efficiency used, 0.91, is better than currently used for the LSES, 0.886, but is considered obtainable by 1990. The inlet pressure recovery factor, η_{INL}, is assumed to be 0.90 up to 60 knots, 0.88 at 70 knots, and decreasing at speeds above 70 knots. This is also higher than used in LSES ship performance predictions, although the higher values are supported by test data presently available. The net effect of the propulsor improvements is an improvement in net propulsive efficiency,

$$\eta_{pn} = \frac{T_{net} V_o}{550\, BHP_p\, \eta_{mp}}$$

from about 0.50 for the present LSES to 0.56 for the 1990 ship at 70 knots.

A.4.c.2.4 Lift System Performance

Lift system installed power was based on a consideration of the power required for optimum cruise speed at maximum gross weight, and the power required at maximum weight to satisfy the average wave-pumping flow in sea state 6. The larger of the two was assumed to be the installed power, and was used to size the lift engines.

At cruise, the lift power was determined by leakage flow requirements. Equivalent air gap (EAG) is defined by

$$EAG = \frac{Q_{lift}}{\sqrt{\frac{2P_c}{\rho_{air}}}\, D_c \ell_{seal}}$$

where

Q_{lift} = Total lift system volumetric flow

P_c = Cushion pressure

ρ_{air} = Mass density of air

D_c = Cushion-to-atmosphere discharge coefficient

ℓ_{seal} = Peripheral length of flexible seal = 268 ft.

EAG was assumed equal to 0.442 foot for a ship with a cushion beam of 91 feet. This value was based on scaling (on the basis of cushion beam) the EAG found to give optimum performance (ie, minimum total power) at cruise speeds, during IR&D tests of a towing-tank model conducted during 1976. The IR&D test model, designated B-29, was an ACV model on which the cushion flow could he varied without significantly affecting seal geometry. The results of the B-29 tests also confirmed the nominal EAG selected for the LSES. The EAG used for 1990 is assumed to be slightly better than required for present technology, due to improvements in the sidehull/seal interfaces.

The wave-pumping flow required for sea state 6 operation, which generally exceeded the leakage related flow, was determined using the expression

$$Q_{wp} = \frac{2}{\pi} h_w B_c (V_0 + V_{wave})$$

where

h_w = Average wave height

B_c = Cushion beam

V_{wave} = Wave celerity [speed).

A ship speed of 50 knots was used in this calculation.

A simplified method of computing lift power was used in the parametric math model. This avoids consideration of details such as fan diameters, but has been found to yield results of sufficient accuracy for parametric studies.

Lift power was computed using

$$BHP = \frac{P_c Q_c + P_s Q_s}{550 \eta_f \eta_{mf}}$$

where

Q_c = Flow direct to cushion = $0.64Q_{lift}$

P_s = Seal static pressure = $1.1P_c$

Q_s = Flow direct to seals = $0.36Q_{lift}$

η_f = Installed fan static efficiency at operating point = 0.75

η_{mf} = Fan system mechanical efficiency = 0.99.

The fan static efficiency, which includes inlet and discharge losses and which is lower than the peak fan efficiency, is an improvement over present technology that can be achieved through application of current IR&D results. The present LSES static fan efficiencies are approximately 0.67 for seal fans and 0.70 for cushion fans. The use of a lower-pressure seal will require changing seal size and/or method of attachment to maintain tuck-under characteristics. This is now being studied in connection with the ANVCE ACV efforts at Bell New Orleans and at Vosper Thornycraft in the United Kingdom.

A.4.c.2.5 Prime Mover Performance

The specific fuel consumption (sfc) data used for these studies was taken directly from Working Paper WP-11 (reference 8) for a 1980 engine, as directed in revision A. Four propulsion and two lift engines were assumed, with sizes determined by power requirements. The sfc's thus used were slightly lower than currently estimated with the Pratt and Whitney FT-9, but were slightly above estimates for an advanced version of the General Electric LM5000 with maximum continuous and maximum intermittent power ratings of 50,000 and 60,000 hp, respectively. Thus, the sfc data used is believed to be slightly conservative for 1990.

The maximum intermittent ratings of the engines were assumed to be 15-percent greater than maximum continuous power. Intermittent power is assumed for hump speed, and maximum continuous for top speed (and as limiting power during range computations).

A.4.c.2.6 System Weights

A series of equations was developed that would predict the various weight components of a 1990 SES, based on ship dimensions, installed power, etc. These equations were based on previously available methods and data, modified as necessary for the 1990 SES. The weight groups considered, and the equations used, are as follows:

a. Structure

$$W_{STR} = 0.2699(W_G \ell_s B_s)^{0.6} + 170,240$$

where

W_G = Design gross weight (lb)

ℓ_s = Ship hull length = $\ell_c + 0.3593B_c$ (ft)

ℓ_c = Effective cushion length = S_c/B_c (ft)

S_c = Cushion area (ft^2)

B_s = Ship hull beam = $B_c + 2B_{SH}$

B_{SH} = **Sidehull** beam (per hull) = 7.5 ft.

The constant represents the weight of hangar, mission-related equipment foundations, and armor, which are associated with the mission and therefore do not vary with ship parameters. This equation (except for the constant term) is equivalent to that used in references 2 and 3, converted to a form related to structural rather than cushion dimensions.

b. Propulsion, The weight of installed engines is expressed as

$$W_{PENG} = 1.58\, BHP_p$$

where BHP_p = total installed propulsion power at MCP. This term includes an engine uninstalled weight of 0.42 lb/hp as given in WP-011 for a 1980 engine.

Waterjet gearbox weight (total per ship) is given by

$$W_{GB} = 4(24) \left(\frac{BHPI_p}{4\, RPMP_{max}} \cdot \frac{(GR + 1)^3}{GR} \right)^{0.95}$$

where

$BHPI_p$ = Total installed propulsion power at MIP

$RPMP_{max}$ = Maximum propulsion engine rpm = 4000

GR = Gear ratio = $\frac{RPMP_{max} \pi d_1}{144,000}$.

This is based on a planetary gearbox, which is lighter than the offset-type gearbox presently used on the LSES.

The wet weight of the propulsors is calculated from

$$W_{PUMP} = 4(0.752)d_i^2 \left(\frac{BHPI_p}{4}\right)^{0.25} .$$

The weight of inlet ducting, inlet module, and associated mechanisms, is

$$W_{DUCT} = 10,150(0.068\ Q-7)$$

where Q = volumetric flow rate per propulsor at MIP and hump.

The latter two expressions are based on LSES weights.

Total propulsion system weight (for the ship) is then

$$W_{PSYS} = W_{PENG} + W_{PGB} + W_{PUMP} + W_{DUCT} .$$

c. Electrical System. The weight of the electrical system is assumed to be constant at 90,317 pounds. This is somewhat lighter than the present LSES system weight. Although the number of crew members and amount of combat equipment are increased for the 1990 ship, the heating, ventilating, and air-conditioning system requirements are actually estimated to be lower. This is a result of the additional insulation required for the increased fire protection specified by the ANVCE project relative to that used for the 1980 ship.

d. Seals. Seal system weight is calculated using equations previously presented in references 2 and 3. The total seal weight is broken down into the following components :

(1) Bow Bag

$$\ddot{W}_{BOWB} = 4.007 \times 10^{-4} B_s \left(\frac{WG}{S_c} h_{CUSH}\right)^2 \left[2(a_s - \ell_{SH}) - B_s + \frac{\pi B_s}{2}\right]$$

(2) Bow fingers

$$W_{BOWF} = 4.406h_{CUSH}\left[2(\ell_s \cdot \ell_{SH}) \cdot B_s + \frac{\pi R_s}{2}\right]$$

(3) Bow attachments

$$W_{BOWAT} = 79.5\left[2(\ell_s - \ell_{SH}) \cdot Bs + \frac{\pi B_s}{2}\right]$$

(4) Stern bag

$$"_{STRNB} = 0.0383B_c(W_G/S_c)h_{CUSH}$$

(5) Stern fingers or lower lobe

$$"_{STRNF} = 4.125B_c h_{CUSH}$$

(6) Stern attachments

$$"_{STNAT} = 63.3(2h_{CUSH} + B_c)$$

where

h_{CUSH} = Cushion depth = 18 ft forward, 14 ft aft

ℓ_{SH} = length of sidehull along keel.

Total seal system weight is

$$"_{SEAL} = 0.8(W_{BOWB} + W_{BOWF} + W_{BOWAT} + "_{STRNB} + "_{STRNF} + W_{STNAT}) \cdot$$

The 0.8 factor accounts for expected improvements in seal system weights by 1990. These include use of a vertical-lobe bag concept at the bow, and use of lighter weight, more compliant finger materials,

e. Lift System Machinery. The weight of the lift system machinery is

$$'LIFT = 3.7\,BHP_L$$

where BHP_L = total installed lift horsepower at MCP.

This weight allowance includes the basic engine weight per horsepower of 0.42 lb/hp specified in WP-011 for 1980 marine gas turbines. It also includes the weight of the ride control system, seal-to-cushion bypass ducts, and seal vent doors. Some improvement from present LSES weight is assumed in this area.

f. Miscellaneous Auxiliaries. This component, which includes all of the auxiliary weight (group 5) other than seals and lift system, is computed by

$$WAUXMI = 0.09h_{CUSH} 9_s B_s + 0.92\ell_s B_s + 0.0066W_G + 132,455 ,$$

The constant includes items associated with the mission, as given in the TLR. The ship-related items are based on LSES weights, with some improvement.

g. Furnishings. Outfit and furnishings weight (group 6) is computed using

$$W_{FURN} = 0.246\ell_s B_s + 0.44h_{CUSH}\ell_s B_s + 158,382 .$$

As with miscellaneous auxiliaries, the constant term includes those weights associated with the mission, and the variable terms are based on the LSES with some improvements .

h. Other. The sum of other mission-related ship equipment and load was assumed to be 837,766 pounds. This includes the command and surveillance system [group 4), armament (group 73, and constant load. The latter includes such items as crew and effects, spare lubricating oil, helicopter fuel (8 tons), ammunition, missiles, and torpedoes. This weight item was determined by meeting TLR mission requirements.

The above items are calculated in pounds, and do not include margin. Margin for these studies was 15 percent of light ship weight, per ANVCE directive. This applies to weight groups 1 through 7. Available fuel for lift, propulsion, and auxiliaries was computed assuming a 2-percent allowance far residuals. The ship service power units (SSPUs) were assumed to require 1122 lb/hr of fuel during average cruise conditions,

A.4.c.3 Parametric Study Results

Figure A.4.c-1 presents installed propulsion power, on a maximum continuous basis, for a far-term SES with waterjet propulsion systems, as a function of ship gross weight and nozzle area. Propulsion power is total for the ship, quoted at the engine shafts, while nozzle area is for each of four propulsors. Nozzle area represents the equivalent area of the vena contracta at the propulsor discharge, assuming uniform flow and atmospheric pressure. (In reality, physical vena contracta area will differ slightly from the values shown, because of deviations from uniform axial flow,) The equivalent value for the present LSES propulsor is 1.09 ft^2. It is assumed that intermittent power is 15-percent greater than the maximum continuous power (per WP-011, revision A).

Installed propulsion power is based on a consideration of the following requirements:

a. 1.25 thrust-to-drag ratio at secondary hump, calm water

b. 1.25 thrust-to-drag ratio at primary hump, calm water

c. 70 knots in sea state 3 ($h_{SIG} = 4.6$ ft, 1.4 m), lo-knot headwind

d. Optimum cruise speed in sea state 3, lo-knot headwind.

All cases were evaluated at design gross weight. The installed power is selected as the greatest of these requirements, Maximum intermittent power (MIP) is assumed for hump, and maximum continuous (MCP) for top and cruise speeds. In no case considered was the secondary hump power the greatest. Secondary hump thrust did determine the size of the inducer-section of the propulsor, as discussed in section A.4.c.2.3. Figure A.4.c-1 indicates the boundary line between the 70-knot maximum speed and the 25-percent primary hump thrust margin power criteria regions. Except for the lighter ships with large nozzles, the ships were generally sized for primary hump. The cruise power requirement never fixed installed power, since the increase in engine weight associated with installing more power more than offset the improvement in range by cruising faster,

Also shown on figure A.4.c-1 is a point indicating the selected sizing (in terms of gross weight and nozzle area) of the point design ship considered elsewhere in the report. The power selected for the point design was actually fractionally greater than indicated on the figure, being rounded off to 160,000 hp.

Installed propulsion power increases with gross weight, particularly for the ships sized for primary hump, as expected. Increased nozzle area reduces propulsion power dramatically in cases where the power plants are sized for hump. At hump speed, propulsive efficiency increases with nozzle area for realistic propulsor sizes. for a given power, increasing nozzle area increases flow rate and reduces propulsor developed head, leading to better propulsive efficiency at low speeds.

However, an increased flow rate also leads to increased inlet drag, which offsets the improvement in propulsive efficiency at higher speds. Thus, on ships sized for the ?O-knot top-speed requirement, nozzle area has relatively little effect on installed power.

Figure A.4.c-2 shows the variation of installed lift power (on the basis of MCP **rating at** the engine shafts) with design weight and cushion beam. Although cushion beam was not varied with waterjst propulsion, various cushion beams were run with propellers, and the curve is included in this section for convenience. Installed lift power is based on the greater of the cruise lift power (related to cushion leakage or FAG) and lift power required for sea state 6 operation (related to wave pumping). In all cases, the latter dominated. Installed lift power increased linearly with gross weight. Although wave-pumping flow is not related to cushion pressure, cushion pressure appears in the calculation of power. Installed lift power also increased with beam, which is expected from the wave-pumping equation (see section A.4.c.2.4). For weights of 3SO0 metric tons and less, installed lift power was less than 50,000 hp. This is considered to be a convenient lift power plant size, since this power can be provided by two engines in the 25,000 hp range, such as uprated LM2500 gas turbines.

Figure A.4.c-3 shows total installed power, equal to the sum of propulsion and lift power, as a function of gross weight and nozzle area (per propulsor) for the waterjet-propelled SES. Since wave-pumping. power, which determined installed lift power, was computed at a fixed speed (50 knots) in sea state 6, installed lift power is independent of nozzle area. Thus, these curves have a similar shape to those in figure A.4.c-1. This figure shows the amount of installed power that would be needed if an integrated lift and propulsion system were used, The sizing for the point design ship is also indicated on **the** figure, As noted before, the design total installed power is slightly greater than indicated on the figure.

Figure A.4.c-4 shows the diameter of the inducer section of the waterjet propulsor selected for each ship, as a function of gross weight and propulsor exit nozzle area. The inducer is sized in the math model to give a thrust margin of 25 percent over drag at secondary hump in calm water, using the method previously presented. Inducer size increases with ship weight, because of the increase in secondary hump drag. This increase is fairly small, however. Inducer size also increases with nozzle area. This is because propulsor flow rate increases with nozzle area, requiring a larger inducer diameter to maintain the same maximum flow velocity through the inducer. Power required at secondary hump at a given gross weight decreases with increasing nozzle area, however, because of improved propulsive efficiency. The inducer is the largest diameter section on a waterjet propulsor; therefore, the diameter of the inducer (with allowance for casing) gives an indication of the overall diameter of the pump. Since the propulsors are located in the centerbody of the SES in the ship arrangement shown for the 1980 and 1990 point designs, physical accommodation of an increased inducer diameter should provide no installation problems. However, the increased size of the inlet and ducting needed with the higher flow rate propulsor design must be considered in selecting nozzle area, as these must be accommodated in the sidehull. The sizing of the point design ship is also indicated on this figure.

Figure A.4.c-5 was prepared to show quantitatively the effect of waterjet nozzle area on propulsive efficiency at various speeds. Propulsive efficiency (including transmission efficiency) is plotted against ship forward speed for various values of thrust per nozzle divided by nozzle area. This term is analogous to disc loading on a ducted air propulsor (thrust divided by duct exit area). With the assumptions of constant pump efficiency, and constant inlet drag coefficient and free-stream pressure recovery for a given ship speed, propulsive efficiency can be essentially reduced to a function of speed and nozzle thrust loading. At lower speeds, propulsive efficiency increases with increasing nozzle area. A crossover occurs at around 80 to 110 knots, where propulsive efficiency becomes relatively insensitive to nozzle area. At speeds above this (although of only academic interest here), smaller nozzles provide higher propulsive efficiency.

The range in sea state 3 (significant wave height of 4.6 ft or 1.4 m), in head seas against a lo-knot headwind for waterjet ships, is plotted in figure A.4.c-6 versus gross weight and nozzle area. The improvement in range with gross weight is primarily a result of the improvement of fuel fraction with increasing weight. This arises from the fact that payload and many other weight items are either constant or not very sensitive to ship weight, and also because structural fraction decreases with increasing cushion density. The effect of nozzle area on range differs considerably from its effect on installed propulsion power. As previously noted, installed power was generally decreased by increasing nozzle area. This is offset, however, by the fact that the weight of the propulsor increases with nozzle area, due to increases in propulsor, inlet, duct, and onboard water weights. Thus, the optimum nozzle area for ship range is much smaller than the largest studied. For ship weights of 3000 to 3500 metric tons, a nozzle area of 1.5 ft^2 gives close *to* the optimum range. It is interesting to note that, on the 3000-ton ship, installed propulsion power did not decrease significantly for nozzle areas greater than 2 ft^2. Ship range in this case decreased rapidly with increasing nozzle area, because the increased propulsor weight was not offset to any extent by a reduction in installed power.

Range in figure A.4.c-6 is computed using a rearrangement of the formula given in the TLR for computing fuel load required to achieve the specified range. The formula used is

$$R_{TLR} = \text{'cruise}\,(1 \frac{W_{FUEL}}{+\ TP)\ (BHPR_p SFC_p + BHPR_L SFC_L + \dot{w}_{FSSPU})}$$

where

V_{cruise} = Optimum cruise speed for maximum range (knots)

W_{FUEL} = Total onboard fuel (less helicopter fuel)

TP = Allowance for fuel residuals = 0.02 for V-bottom tanks

$BHPR_p$ = Required total propulsion power (at engine shafts)

SFC_p = Propulsion engine specific fuel consumption

$BHPRL$ = Required total lift power (at engine shafts)

$SFCL$ = Lift engine specific fuel consumption

$\dot{w}_{FSSPU}$ = SSPU consumption rate = 1122 lb/hr.

$BHPR_p$, SFC_p, BHPRL, and SFCL are evaluated at the half-fuel point. Figure A.4.c-6 shows that the minimum range required by the TLR (ie, 3500 nmi) can be achieved by a ship of 3500 metric tons or less, depending on nozzle area.

The boundary line indication criterion used for the selection of installed power is also shown on figure A.4.c-6. This is seen to have little effect on the shape of the curves. Also indicated is the sizing of the point design ship. The actual installed power being greater than that given by this study, as noted earlier, the range on figure A.4.c-6 corresponding to the point design sizing also differs slightly from that quoted for the point design in section 2.2.3.

Figure A.4.c-7 shows the maximum speeds attainable by the parametric series of ships in sea state 3 conditions. A top speed of at least 70 knots is required by the TLR. In the cases of the 3000-ton ships with nozzle areas of 2 to 3 ft^2, installed power was based on the top-speed requirement, so their top speeds are exactly 70 knots. In other instances, the top speeds exceed the TLR requirement. The sizing of the point design ship is also indicated on this figure. Again, the corresponding maximum speed differs slightly from that shown for the point design in section 2.2.1, because of the slightly higher installed propulsive power.

It was clear from the parametric study results that a ship weight of approximately 3500 tons would be required to meet the TLR range requirement. A nozzle area of 1.5 to 2 ft^2 would give optimum range for a given gross weight, and thus minimum gross weight to achieve the required range. However, a larger nozzle would give a lower installed power. Since ship cost is related to both gross weight and installed power, a tradeoff is needed to find the optimum combination of the two parameters. To visualize the situation more clearly, a line of ships having the required range was superimposed on the propulsion power carpet of figure A.4.c-1. A nozzle area of less than 1.5 ft^2 required a large increase in power and some increase in weight to maintain range. However, a nozzle area greater than 2 ft^2 would give essentially no reduction in power, and would also increase gross weight. A larger nozzle area was considered to be a higher risk, since, as nozzle area increases, propulsive efficiency becomes more sensitive to changes in inlet drag and inlet pressure recovery. A more conservative approach was to select a nozzle on the small side. Therefore, a propulsor with a 1.5 ft^2 nozzle was selected for the point design.

The power plants selected for the waterjet propulsion point design were four engines having a power of 40,000 hp MCP for propulsion, and two 25,000 hp MCP engines for lift. The propulsion engines could be either an uprated version of the Pratt and Whitney FT-9 or the initial version of the General Electric LM5000. Both engines are expected to be available by 1990. The lift engines could be an uprated General Electric LM2500. Because these would provide somewhat more than the exact power required in the parametric studies to achieve a 3500 nmi range with 1.5-foot nozzles, fuel weight would be reduced relative to the values used in the parametric program because of increased machinery weight. Additional computer runs were therefore made with the installed power fixed at the preceding values. It was found that a ship with a weight of 3450 metric tons would exceed the minimum range slightly, so this was selected as the point design.

It is worth noting that, while the present results assume a reasonable amount of improvement in technology by 1990 compared with present technology, no breakthroughs or fundamental advancements in the state of the art are necessary, The maximum static seal pressure considered for a 3500-metric-ton ship is under 400 lb/ft^2; 500 lb/ft^2 is considered to be a current upper limit on static delievered fan pressure. The configurations considered in this study have characteristics that are also within the present state of the art on seals. MO limit on transmissionpower can be foreseen which would influence the results shown here for waterjet-propelled ships, since each waterjet propulsor is connected to one engine through a planetary grearbox and straight shaft in the machinery arrangement assumed for these studies. Of course, normal development would be required to produce gearboxes capable of handling higher power levels than those gearboxes presently available.

Detailed performance of the selected point design is presented in section 2.2 of the basic report.

A.4.c.4 References

1. ANVCE Design Summary Report (Near Term) (Bell New Orleans Report 7588-950047, November 19, 1976).

2. Summary Report, *Operational Utility Study (U)* (Bell New Orleans Report 7446-950008, December 10, 1975).

3. State-of-the-Art Summary, *SES Technology Assessment* (Bell New Orleans Report 7446-950043, June 1, 1976).

4. Final Report, *LSES Prototype Investigation (U)* (Bell New Orleans Report 7588-RS-000006, July 19, 1976).

5. *Top Level Requirements (TLR)* for *a 3000-Ton Surface Effect Ship (SES3)*, ANVCE Point Design (September 30, 1976).

6. Performance Report, *Drag,* Speed, and *Range* (Bell New Orleans Report 7446-950012, March 1976).

7. LSES Extension Tasks, *Interim Summary Report, Task III.A.1 (Bell New* Orleans Report 7588-950045, November 1, 1976).

8. *Standard* Power *Plant Characteristics* for *Advanced Naval Vehicles in the 1980-2000 Time* Frame (ANVCE Working Paper 011, August 31, 1976, and revision A, November 15, 1976).

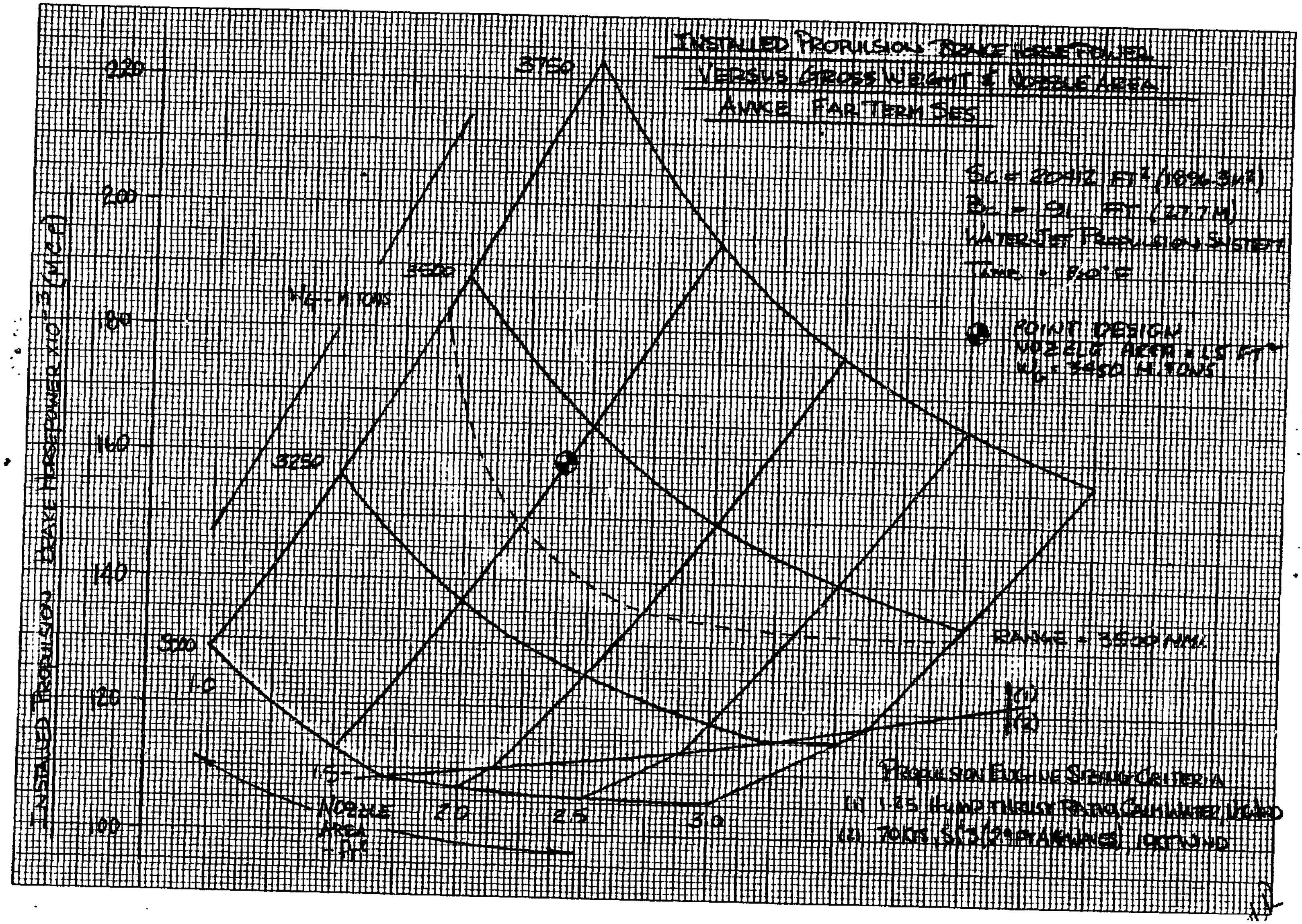

Figure A.4.c-1 INSTALLED PROPULSION BRAKE HORSEPOWER VERSUS GROSS WEIGHT AND NOZZLE AREA

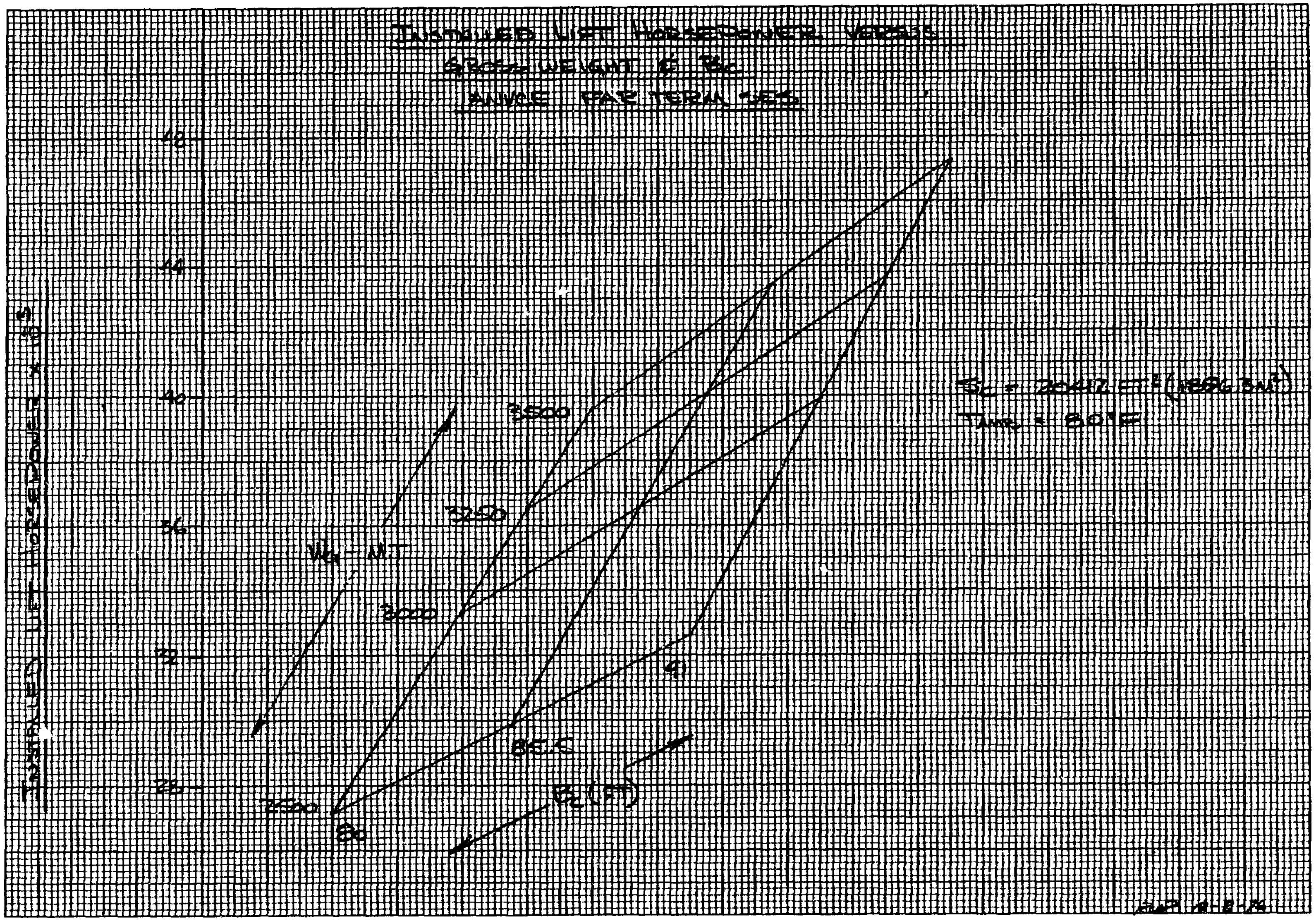

Figure A.4.c-2 INSTALLED LIFT HORSEPOWER VERSUS GROSS WEIGHT AND B_c

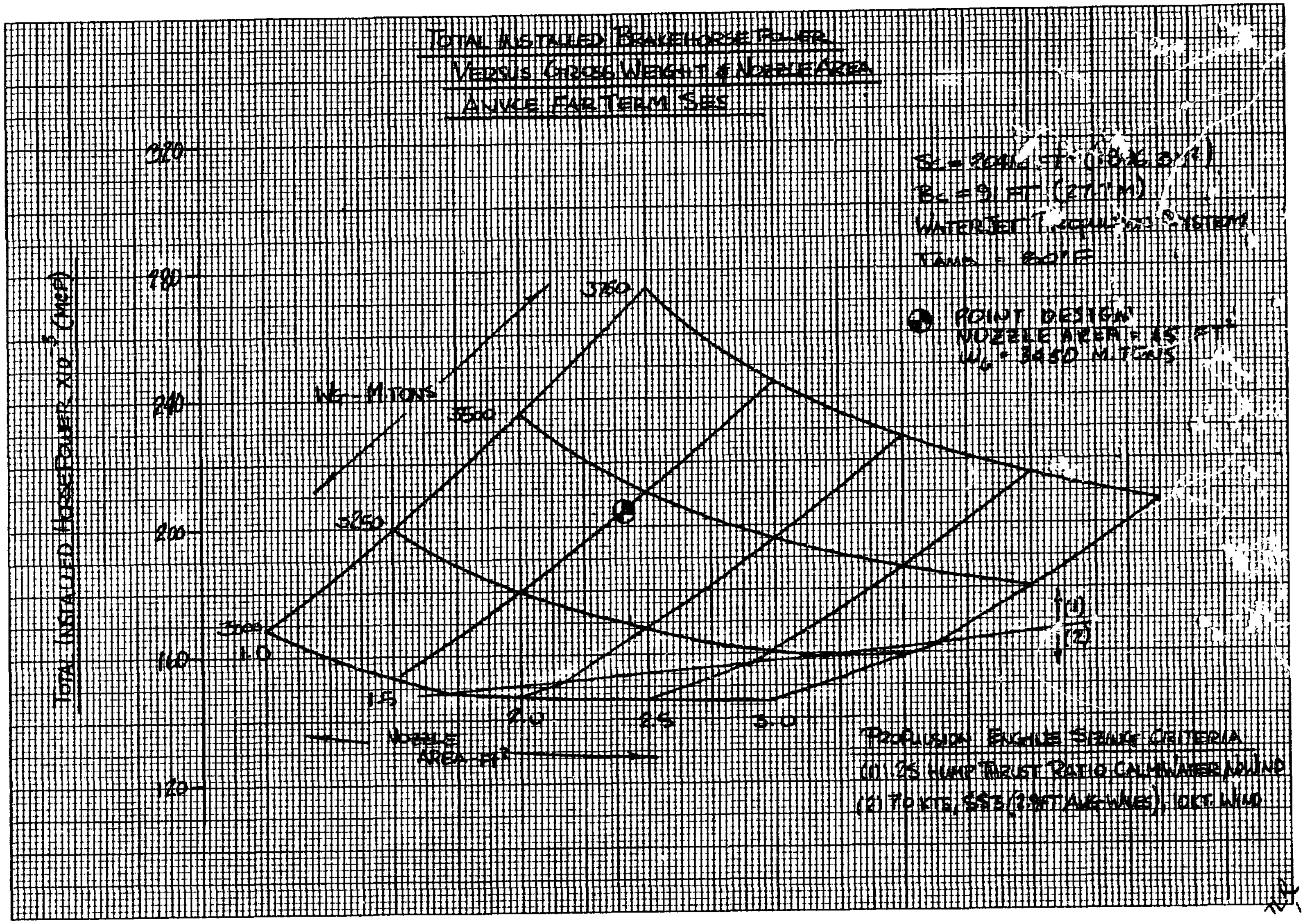

Figure A.4.c-3 TOTAL INSTALLED BRAKE HORSEPOWER VERSUS GROSS WEIGHT AND NOZZLE AREA

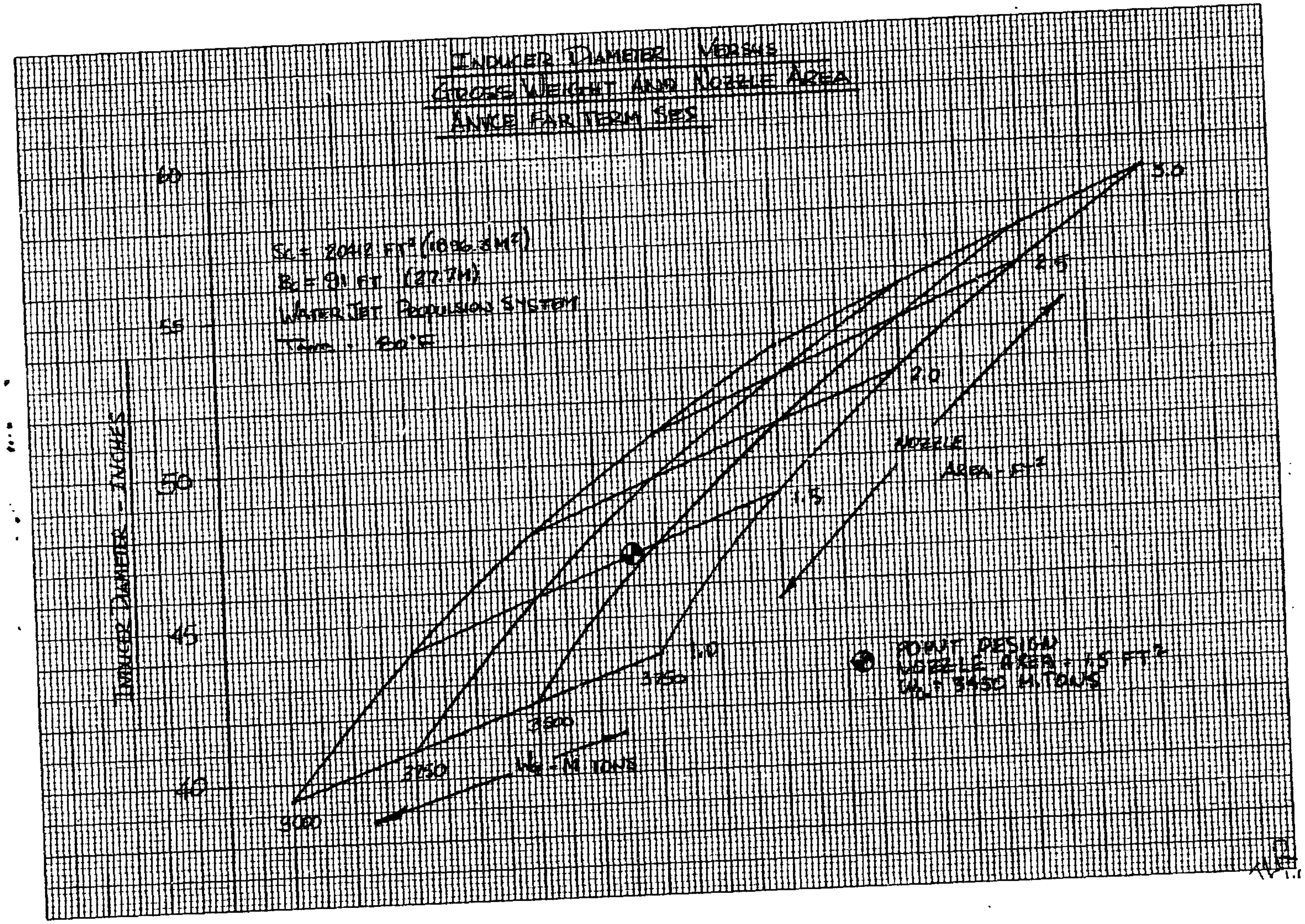

Figure A.4.c-4 INDUCER DIAMETER VERSUS GROSS WEIGHT AND NOZZLE AREA

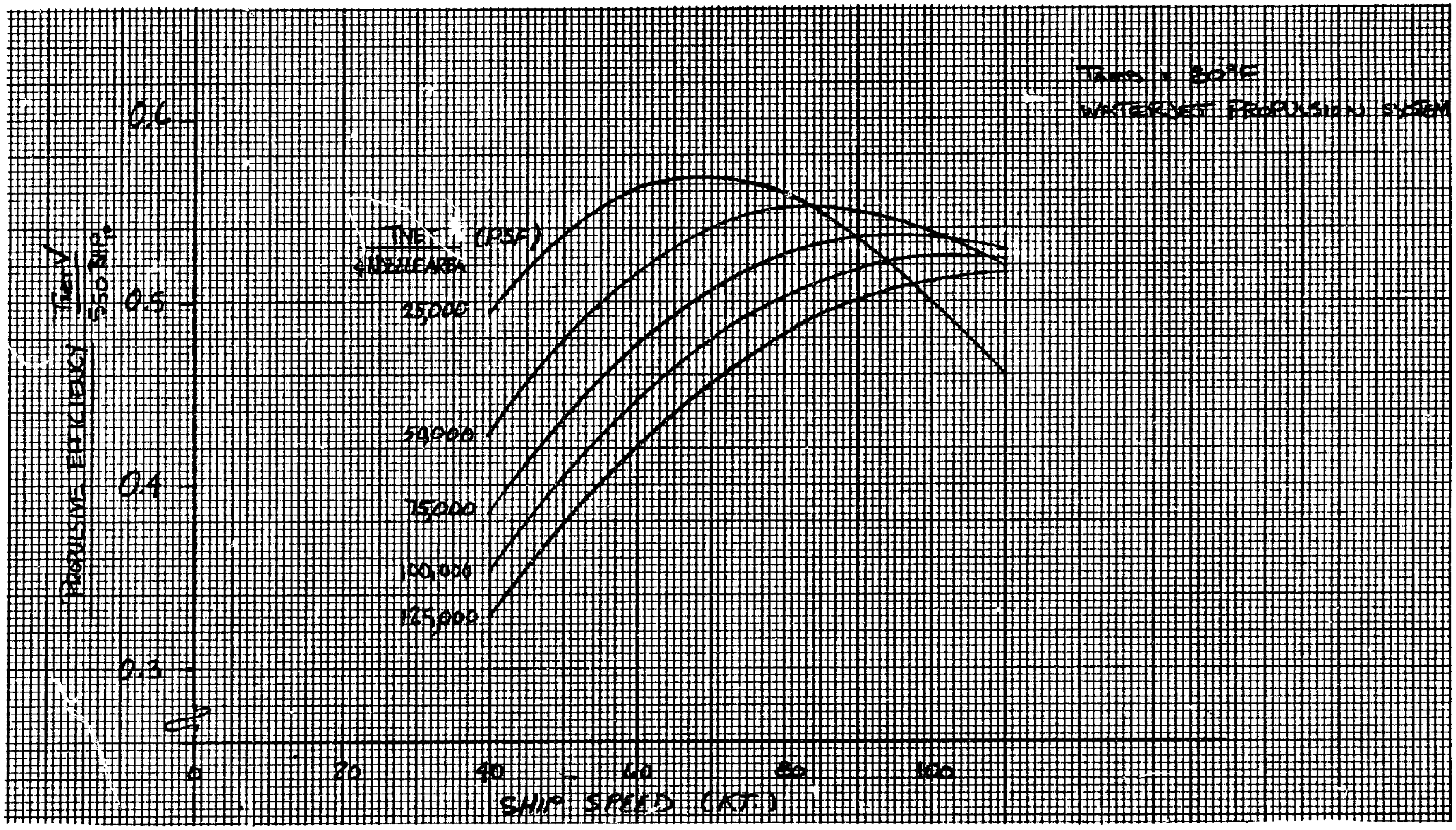

Figure A.4.c-5 PROPULSIVE EFFICIENCY VERSUS SPEED FOR VARIOUS THRUST/NOZZLE AREAS

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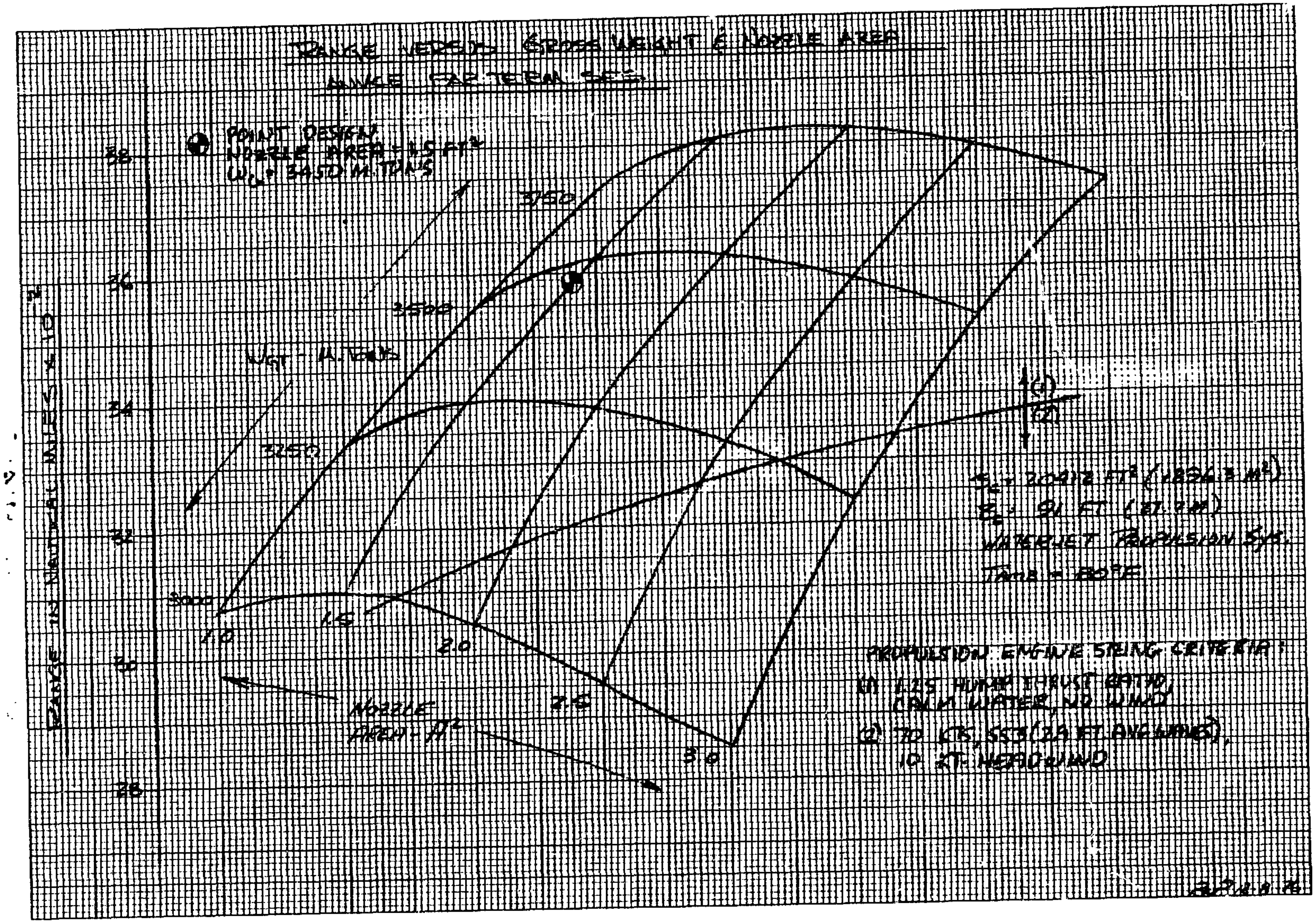

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Figure A.4.c-6 RANGE VERSUS GROSS WEIGHT AND N AREA

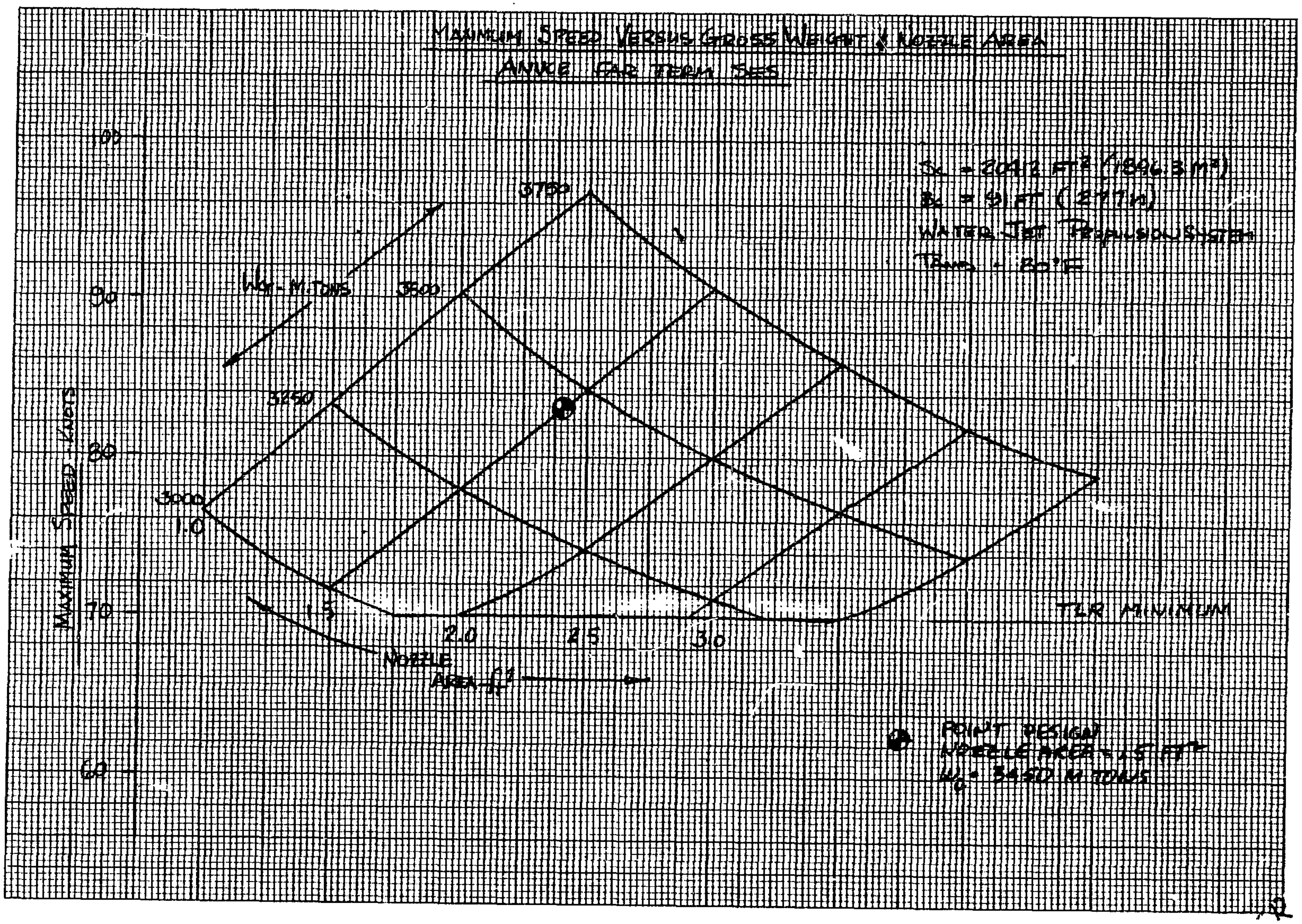

Figure A.4.c-7 MAXIMUM SPEED VERSUS GROSS WEIGHT AND NOZZLE AREA

APPENDIX B

BOOKLET OF DRAWINGS

(Submitted under separate cover)

C.l VEHICLE GENERAL DESCRIPTION

C.1.1 Principal Characteristics

~~(C)~~ Unless otherwise specified, the figures quoted below are for the ship at its full-load displacement of 345G metric tons:

Max Continuous Speed, SS Calm	106.6 kt (197.4 km/hr)
Max Continuous Speed, SS 3	95.2 kt (176.3 km/hr)
Max Continuous Speed, SS 6	71.3 kt (132.0 km/hr)
Hump Margin, SS 0, MIP	63.0 percent
Average Speed for Max Range, SS Calm	88.4 kt (163.7 km/hr)
Average Speed for Max Range, SS 3	78.9 kt (146.1 km/hr)
Range, SS Calm	4726 nmi (8753 km)
Range, SS 3	4149 nmi (7684 km)
Endurance, SS Calm	53.5 hr
Endurance, SS 3	52.6 hr
Time to accelerate to V_{MAX}, SS Calm, MIP	180 sec
Time to decelerate from V_{MAX}, SS Calm, Reverse thrust at MIP	73 sec
Stopping distance from V_{MAX}, SS Calm, Reverse thrust at MIP	4900 ft (1494 m)

(U) For all performance data quoted in this report, the following significant wave heights and wind conditions have been assumed:

a. SS 3 - $h_{1/3}$ = 4.6 ft (1.40 m), 10-kt wind

b. SS 4 - $h_{1/3}$ = 6.7 ft (2.10 m), 16-kt wind

c. SS 5 - $h_{1/3}$ = 10 ft (3.05 m), 26-kt wind

d. SS 6 - $h_{1/3}$ = 15 ft (4.57 m), 38-kt wind.

C.1.2 General Arrangement Drawing

The general arrangement drawing for the propeller ship is shown on Bell drawing AD-76-48 in appendix B.

(U) waterjet ship, thrust is assumed to be derived from four propulsion engines operating at both maximum continuous power (MCP) and maximum intermittent power (MIP) (40,000 and 46,000 hp, respectively). The intersections of the thrust and drag curves establish maximum operating speeds for the chosen conditions.

(U) Nominal lift flow has been used for all performance calculations. 2KSES and LSES test data indicates that increased lift flow can give some reduction in high-speed drag, and therefore higher maximum continuous speed; but this has not been considered here.

(U) For low-speed operation (in the vicinity of secondary hump and below), it has been assumed that the ship operates in the partial-cushion mode as described earlier for the 2KSES and LSES. For these it was determined that reduced air flow to bow and stern seals led to increased sidehull immersion, reduced cushion pressure, and as a result reduced drag through secondary hump. The high immersion in this condition, in conjunction with the partial propeller shroud, restricts ventilation of the propeller and greatly enhances low-speed thrust.

~~(C)~~ Comparison of figures C.2.1-1 with 2.2.1-1 in the basic report shows that the thrust provided by the propellers is higher than that from the waterjet propulsors at all speeds, significantly so around primary hump speed, (For ease of comparison, the same scales have been used in the two figures; as a result, propeller thrust is off the scale in the region around hump speed. Maximum thrust is obtained at about 40 knots: 7.79 × 10^5 lb with MIP and 6.77 × 10^5 lb with MCP.) As a result, maximum speeds are also higher for the propeller than for the waterjet ship as shown in the following table.

Sea State	Maximum Continuous Speed (kt)	
	Waterjet Ship	Water-Propeller Ship
0	97.3	106.6
3	83.8	95.2
4	73.3	87.3
5	64.4	80.9
6	33.9	71.3

(U) The largest speed increment is obtained in sea state 6, where greater thrust allows the ship to be operated continuously at speeds above primary hump.

Additionally, the greater thrust provides a larger hump margin in all sea states; ie, in sea state 3 the margin is > 60 percent, compared to 25 percent for the **waterjet** ship.

Another advantage of propeller propulsion is that the thrust curves intersect the drag curves at steeper angles, This makes the top speed of the propeller ship less sensitive to small changes in thrust or drag, such as caused by hull fouling, failure to achieve optimum trim, etc. The propeller ship is thus more flexible from an operational standpoint.

Curves showing drag breakdown are not included here for the propeller ship, since they are identical to those for the **waterjet** ship presented in figure 2.2.1-2 of the basic document,

The shape of the complete thrust curve can be seen in figure **C.2.1-2,** which presents the thrust **and** drag data of figure **C.2.1-1** for $T_{amb} = 80^{\circ}F$, **nondimensionalited** by dividing them by ship **weight.** Figure **C.2.1-3** shows similar data relating to an ambient temperature of $59^{\circ}F$ (corresponding figures for the **waterjet** ship are figures 2.2.1-4 and **2.2.1-5** of the basic document).

The overall propulsive efficiency (OPC) of the ship is presented in figure **C.2.1-4** as a function of speed. Comparison with the OPC of the **waterjet** system shows the superior efficiency of the propeller system at speeds above hump. This is reflected in figure **C.2.1-5,** which shows the total power requirements broken down to lift and propulsion components. Comparison with figure 2.2.1-3 shows that the required brake horsepower for **waterjet propulstion** is some 30,000 to 40,000 hp greater for all speeds above primary hump. As with the **waterjet** data, thrust and OPC data presented for the propeller ship include a deduction for **all** drag effects associated with the propulsion system. Thus, the drag of the fairings required to protect the propellers and provide control of propeller submergence is deducted from thrust,

The greater propulsive efficiency is also reflected in figure **C.2.1-6,** which shows transport efficiency as a function of speed and sea state (compare with figure 2.2.1-7 of the basic document).

Maximum continuous speed/sea state envelopes are presented in figure **C.2.1-7** for comparison with figure 2.2.1-8 for the **waterjet** ship. Curves are shown for both hullborne and cushionborne operation. Cushionborne performance is shown for operation in head seas with no head wind **and RCS** inoperative, and for operation in head seas with head winds appropriate to the sea states with RCS both on and off. (**Nominal** lift flow is assumed with RCS off.)

Comparison with the data for the **waterjet** ship shows that a higher maximum speed is achievable by the propeller ship in all conditions. Additionally, unlike the **waterjet** ship, the maximum speed of the **propeller** ship does not drop off to **subhump** values in the high sea states **with** head wind.

The ride quality limit lines are the same as those for the **waterjet** ship. These again indicate that, **for** sea states greater than 6 and speeds less than about 57 knots, the design may be ride-limited.

A comparison with the corresponding data for the **waterjet** ship (figure 2.2.2-4) is presented in the table below. Initial speed for the maneuver is assumed to be maximum continuous speed for the particular configuration.

	Speed (kt)	0	20	40	60	80	97.3
Time to speed (sec)	**Waterjet**	60	29.2	20.3	12.4	5.2	-
	Propeller	75	41	31	24	15	5.5
Distance to speed **(ft)**	**Waterjet**	3037	2660	2240	1600	820	-
	Propeller	4900	4460	3980	3380	2340	930

Available reverse thrust for the propeller ship is markedly lower than that from the **waterjet** propulsors at high ship speeds, and this is reflected in the results shown in the table. Below about 60 knots, the reverse thrust from the propellers exceeds that from the waterjets, and thus the propeller ship eventually recovers some of its initial disadvantage in stopping. In both cases, the stopping characteristics are quoted assuming the ship remains on full cushion (except at low speeds). In practice, the stopping characteristics can be reduced considerably **for either** configuration by reducing lift power and thus increasing drag.

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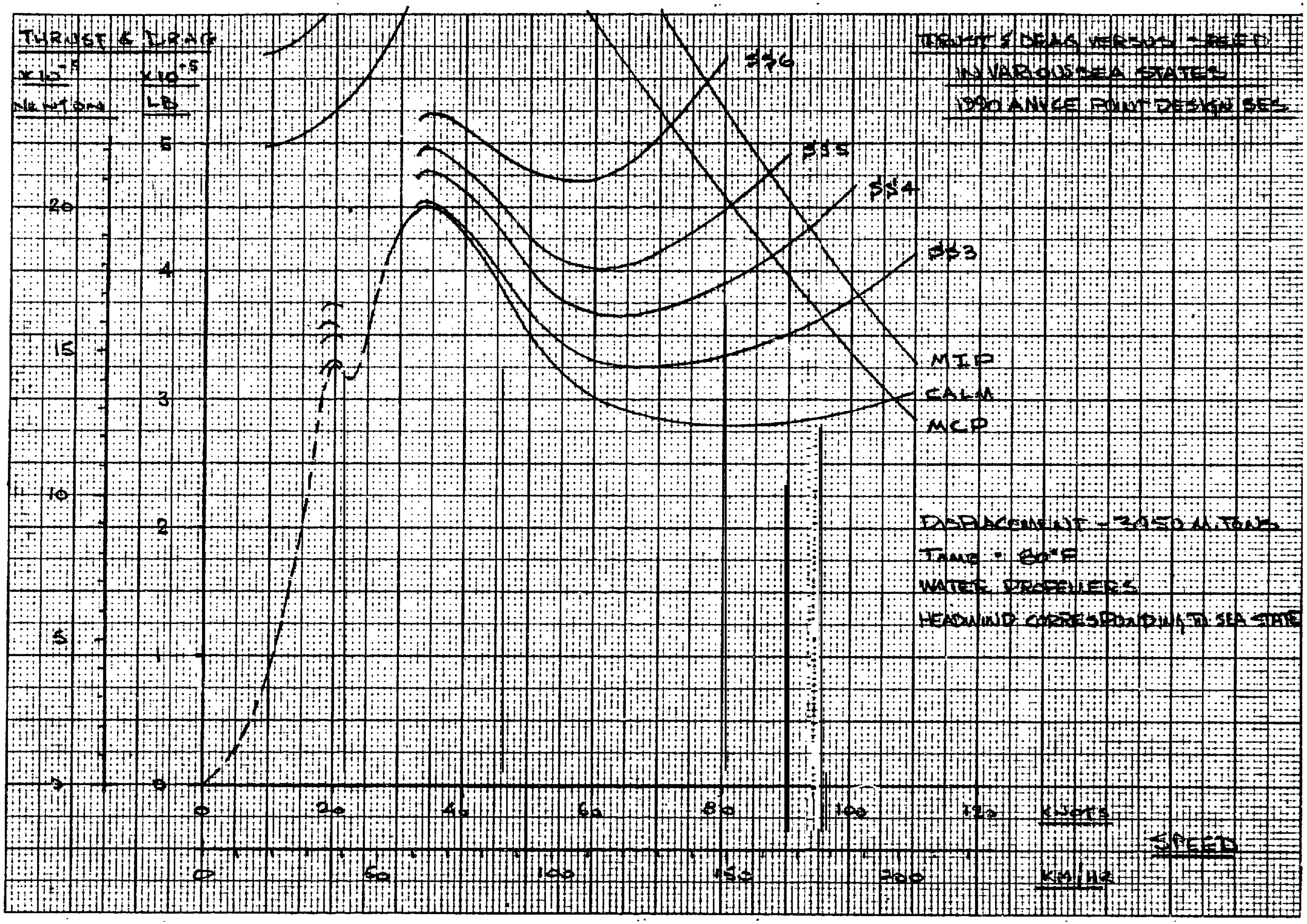

Figure C.2.1-1 THRUST AND DRAG VERSUS SPEED IN VARIOUS SEA STATES

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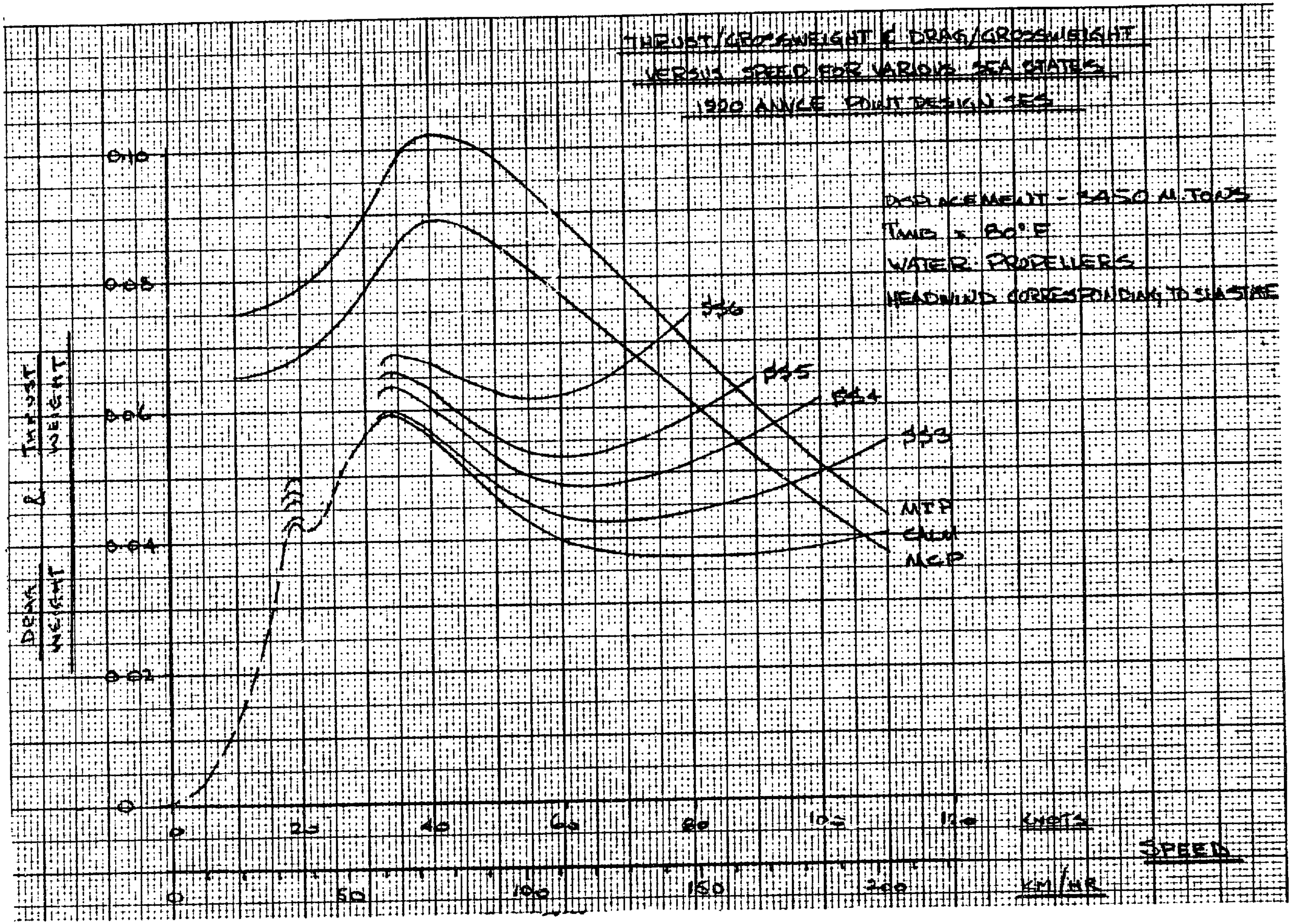

Figure C.2.1-2 THRUST/GROSS WEIGHT AND DRAG/GROSS WEIGHT VERSUS SPEED FOR VARIOUS SEA STATES

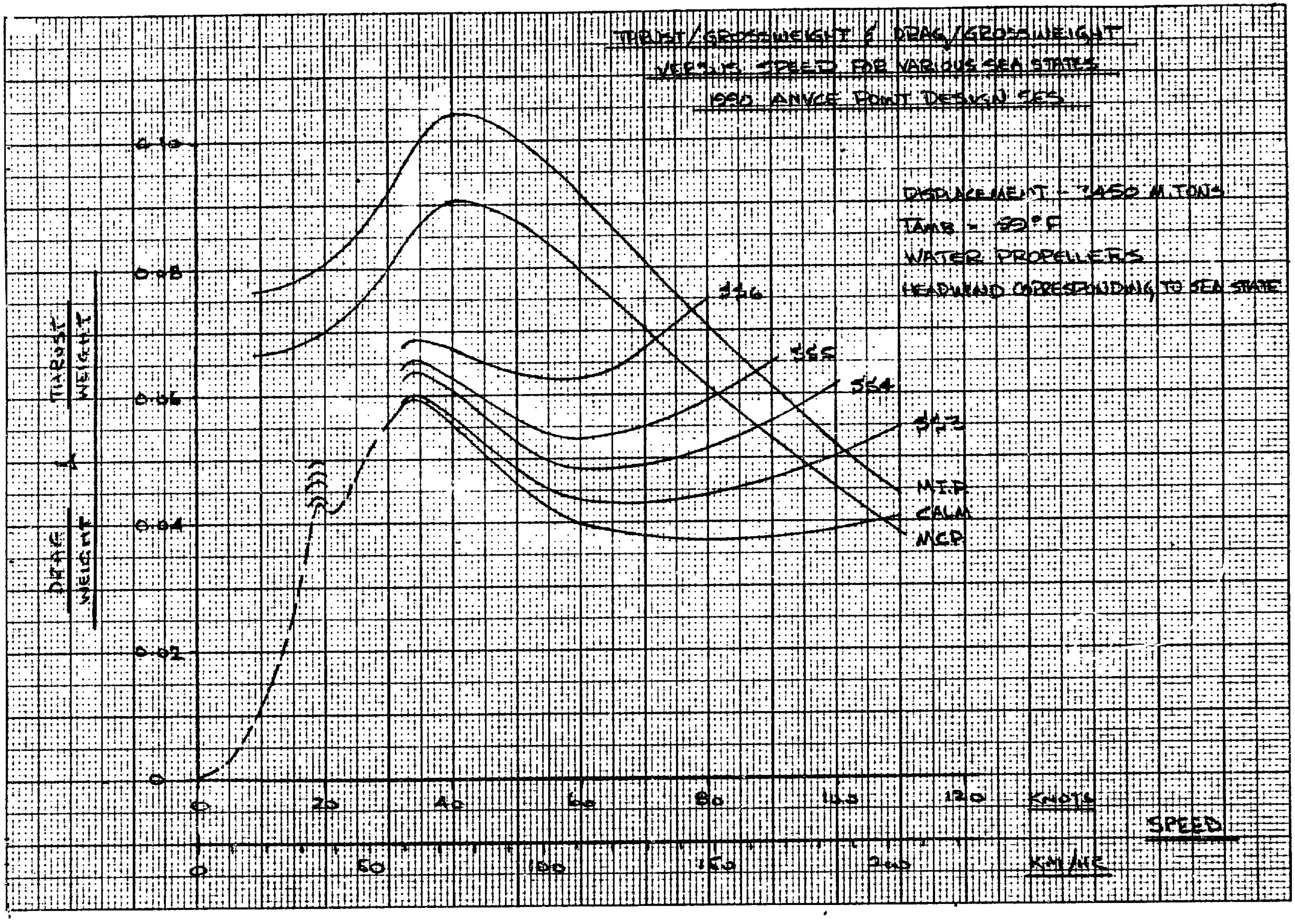

Figure C.2.1-3 THRUST/GROSS WEIGHT AND DRAG/GROSS WEIGHT VERSUS SPEED FOR VARIOUS SEA STATES

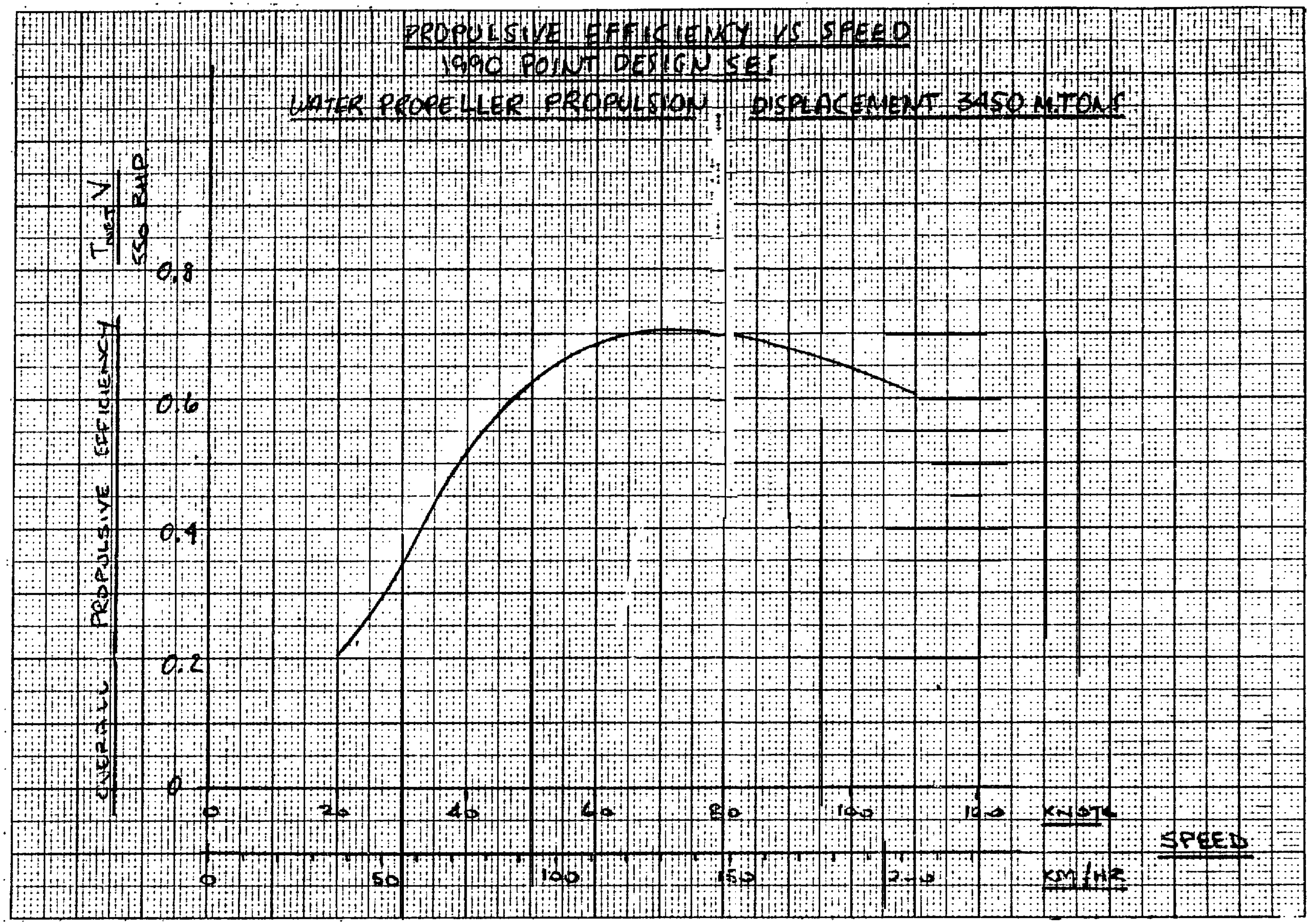

Figure C.2.1-4 PROPULSIVE EFFICIENCY VERSUS SPEED

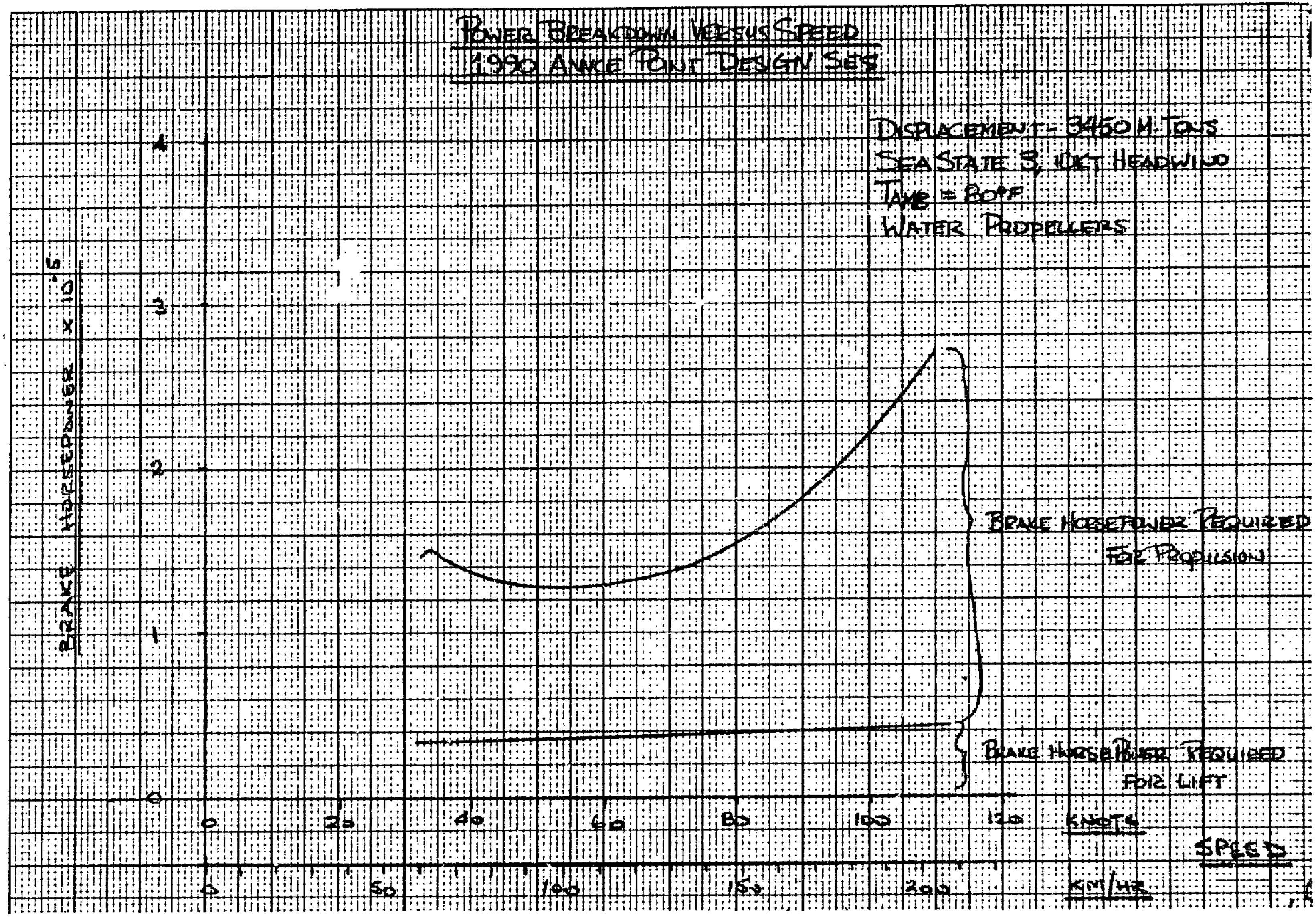

Figure C.2.1-5 POWER BREAKDOWN VERSUS SPEED

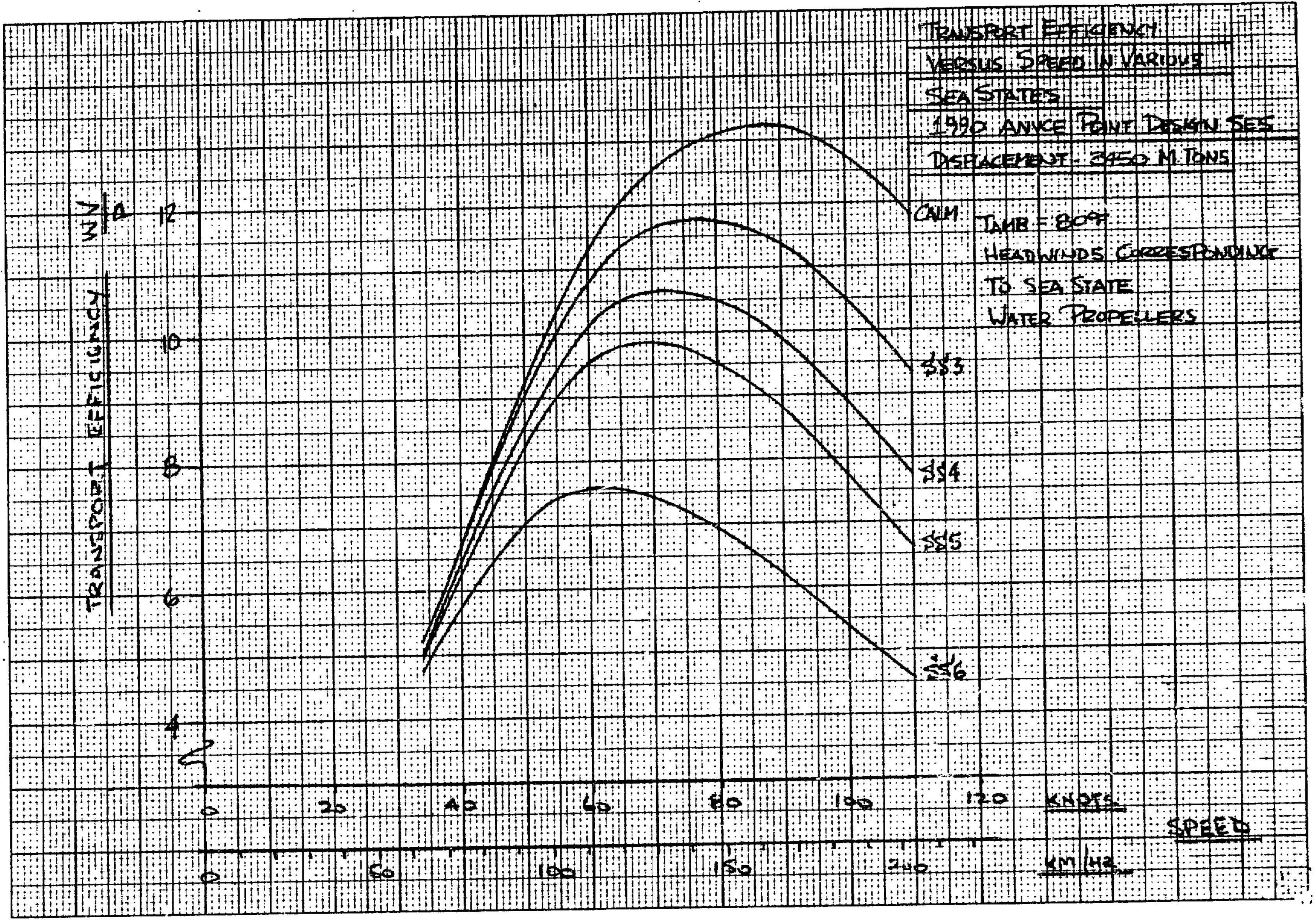

Figure C.2.1-6 TRANSPORT EFFICIENCY VERSUS SPEED IN VARIOUS SEA STATES

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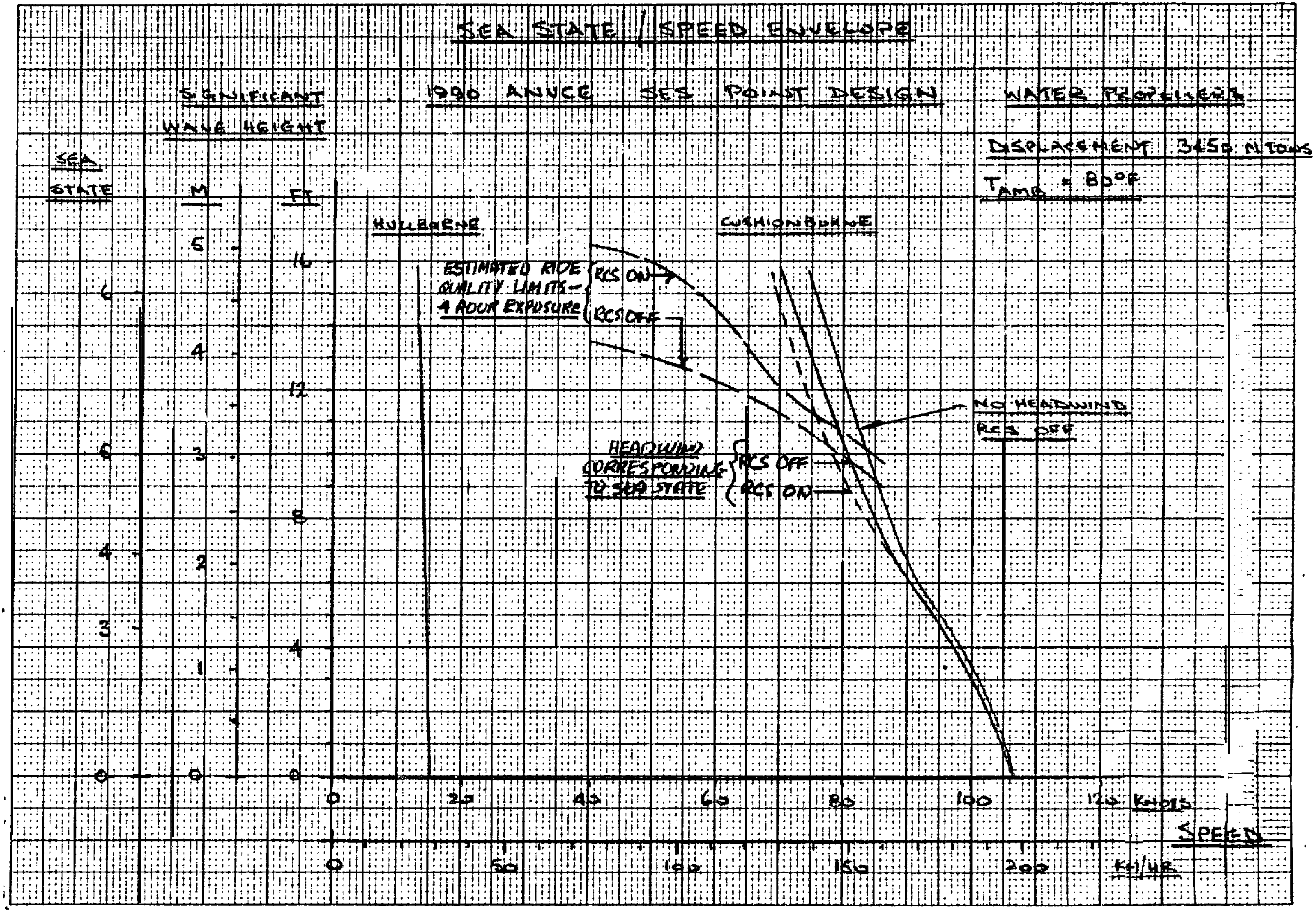

Figure C.2.1-7 SEA STATE/SPEED ENVELOPE

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C.2.2 Maneuvering

The propeller-driven LSES will have a swing rudder located in each sidehull, well forward of the propeller. Although the rudder is forward of the station of the waterjet configuration, it has been increased in size from 30 to 44 ft^2 to compensate for the reduced moment arm. The larger rudder, having the same section characteristics, will provide above-hump speed maneuvering capability very similar to that presented for the waterjet configuration, shown in section 2.2.2 of the basic report. Below-hump maneuvering capability is controlled by differential propeller thrust and/or swing rudder, Differential thrust may be obtained by varying propeller blade angle, rpm, or area (inlet ramps).

C.2.2.1 Acceleration and Deceleration

Figure C.2.2-1 shows the predicted acceleration characteristics for the water-propeller-powered ship, at FLD in calm water. Thrust available from maximum intermittent power is assumed for propulsion, and nominal power is assumed for lift except at low speeds where partial-cushion operation is in effect.

A comparison with the corresponding data for the waterjet ship (figure 2.2.2-3) is presented in the following table.

	Speed (kt)	40	60	80	97.3*	106.6**
Time to speed (sec)	Waterjet	104	157	211	299	-
	Propeller	45	66	92	132	180
Distance to speed (ft)	Waterjet	3,900	8,300	14,800	18,400	-
	Propeller	2,700	3,400	6,500	12,700	21,000

*V_{MAX} for waterjet ship **V_{MAX} for propeller ship at maximum continuous power

The marked improvement in acceleration performance of the propeller ship resulting from the increase in available thrust is immediately apparent.

Figure C.2.2-2 presents the deceleration characteristics of the water-propeller-driven ship, at FLD in calm water. Reverse thrust is assumed to be equal to the forward thrust attainable at MIP down to a speed of 40 knots. From 20 knots to zero, reverse thrust is assumed to be 25 percent of the forward thrust available. Between 20 and 40 knots, a transition is assumed. At the highest speeds, a propeller drag equivalent in magnitude to forward thrust can be achieved by rotating the propeller blades to flat pitch. Reverse pitch can be gradually applied as the ship slows down.

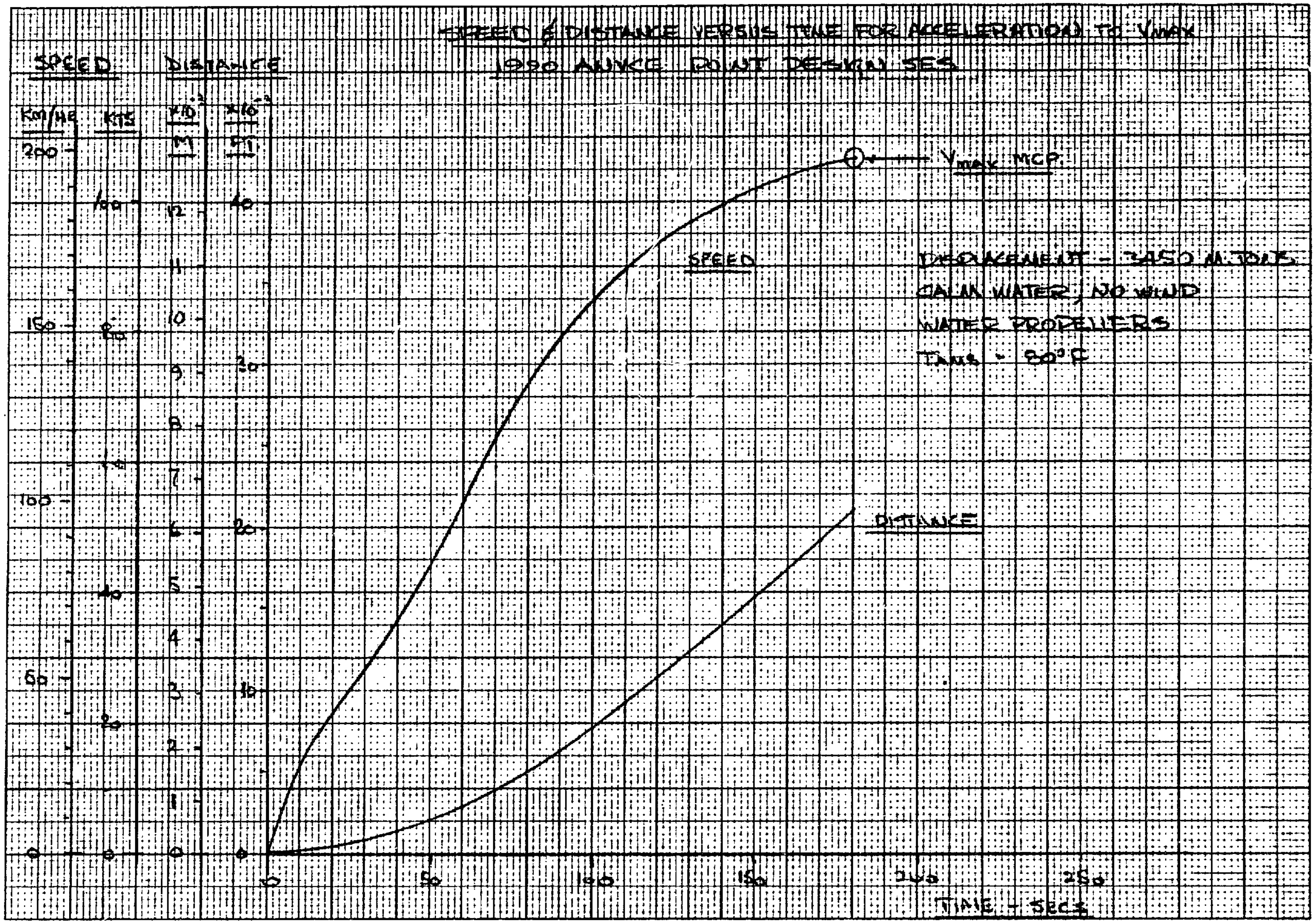


Figure C.2.2-1 SPEED AND DISTANCE VERSUS TIME FOR ACCELERATION TO V_{MAX}

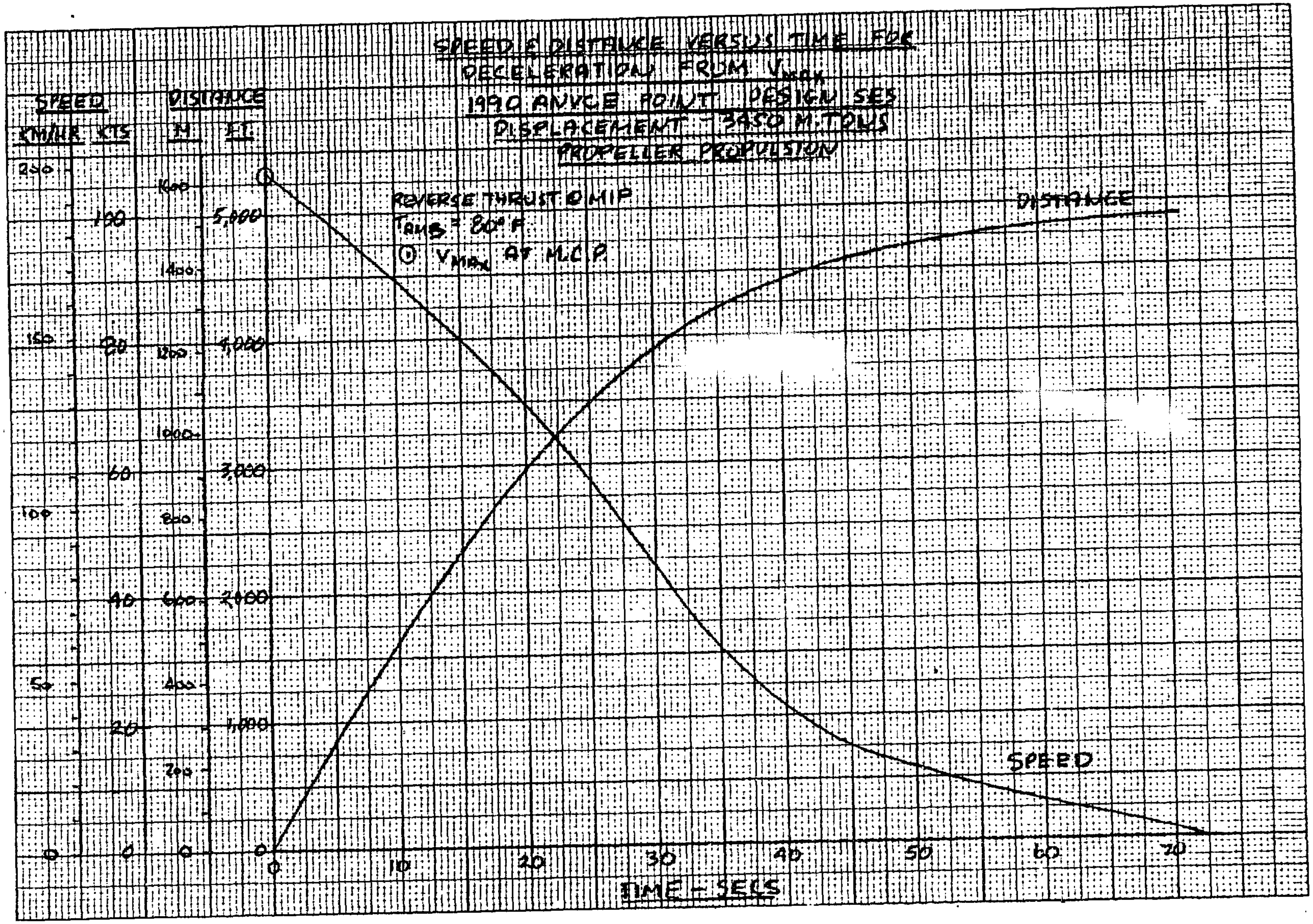


Figure C.2.2-2 SPEED AND DISTANCE VERSUS TIME FOR DECELERATION FROM V_{MAX}

C.2.3 Range and Payload

(U) Specific range (ie, distance traveled per ton of fuel used) is presented in figure C.2.3-1 as a function of speed and sea state. These values are averaged over a long-range cruise, with the ship starting at full-load displacement. As before, broken lines indicate where the required constant speed cannot be achieved until fuel burnoff reduces ship displacement to a value less than FLD.

(U) Comparison with figure 2.2.3-l for the waterjet ship shows the propeller ship to have a higher specific range in all sea states (-14 percent in calm, increasing to -25 percent in sea state 4). The speed at which maximum specific range occurs also is generally a few knots higher for the propeller ship.

(U) Range and endurance at constant speeds are presented in figures C.2.3-2 and C.2.3-3, respectively (compare to figures 2.2.3-2 and 2.2.3-4 for waterjet propulsion) . Maximum range is seen to be higher for the propeller ship in all sea states (by -14 percent in calm water, increasing to -27 percent in sea state 6). The constant speed for maximum range is approximately the same for the two ships; however, it is noted that, with waterjet propulsion, in the highest sea states this speed cannot be achieved until the displacement has been reduced by fuel burnoff. Maximum endurance presents a similar picture, with propeller propulsion giving greater endurance in all sea states. At speeds that give maximum range, the endurance of the propeller-driven ship is also greater by 15 to 20 percent. Figure C.2.3-3 also shows endurance at low speeds using minimum lift power, as discussed for the waterjet ship in section 2.2.3.

~~(C)~~ As with the waterjet ship, maximum range is not achieved by operating at a constant speed. Figure C.2.3-4 shows, for the propeller ship, maximum obtainable range as a function of sea state, the velocity during cruise being allowed to vary as necessary to optimize the range.

	Sea State	Calm	3	4	5	6
Maximum Range (nmi)	Waterjets	4120	3570	3175	2878	2157
	Propellers	4726	4149	3762	3486	2731
Endurance corresponding to max range (hr)	Waterjets	46.2	44.8	43.7	42.3	37.6
	Propellers	53.5	52.6	51.3	49.3	43.1

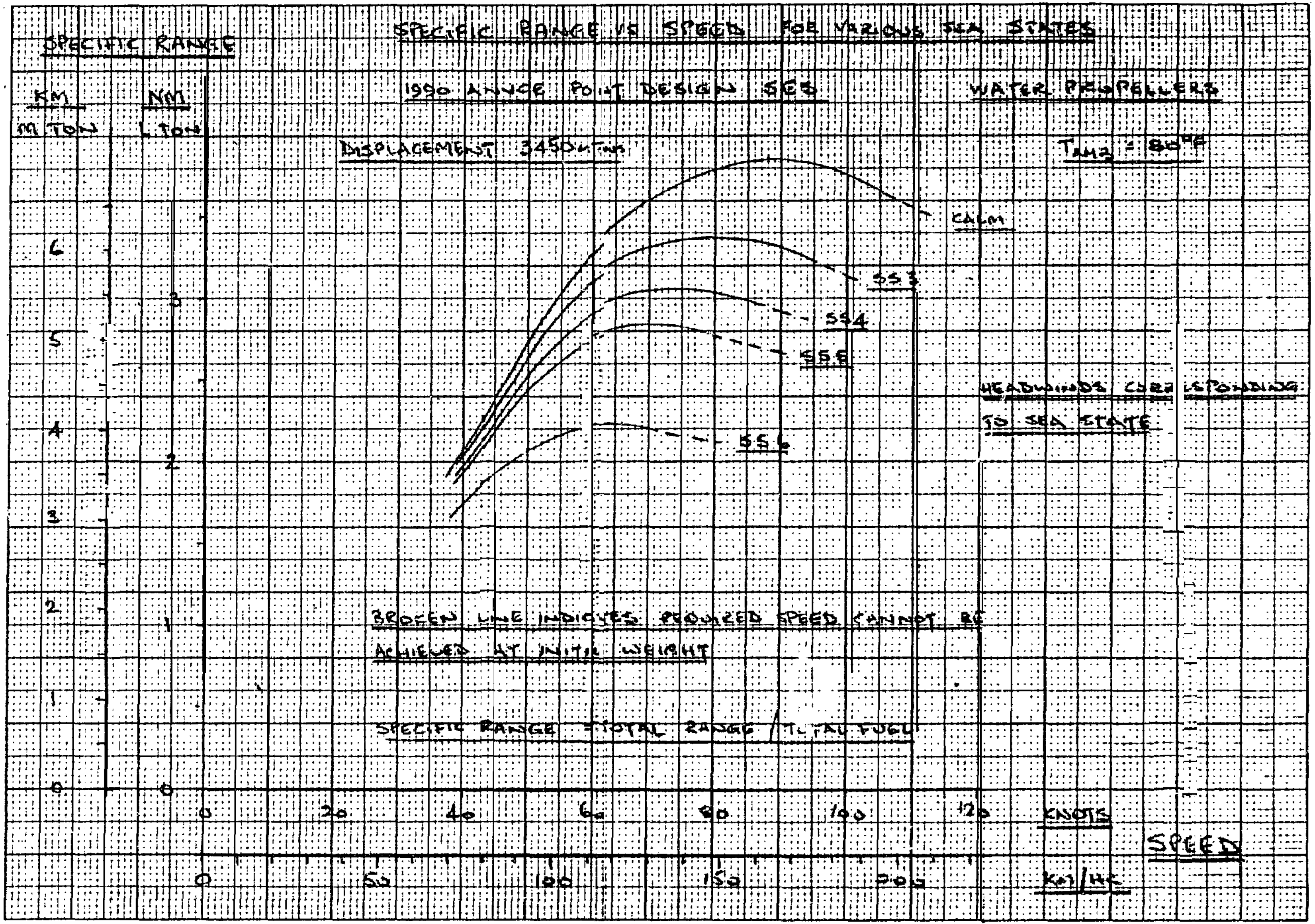
(U) The three curves presented show range with no head wind and RCS inoperative; and range with head winds appropriate to the various sea states and with RCS on and off. In all cases, head-seas are assumed.

(U) The previous table summarizes the data for head seas and wind with RCS off, and compares them with corresponding data from figure 2.2.3-3 for the waterjet ship.

(U) At sea state 3 and optimum cruising speed, the propeller ship range is 16 percent higher than the corresponding waterjet ship range.

(U) Figure C.2.3-5 shows range as a function of military payload, at an initial weight in all cases of 3450 metric tons, operating in sea state 3. Conditions are identical to those of figure 2.2.3-5 for the waterjet-propelled ship, thus allowing direct comparison. This shows that, for the same payloads, the propeller ship has greater range in all sea states. The increment increases from about 14 percent in calm to about 25 percent in sea state 6,

[redacted] All of the foregoing range calculations assume a weight margin of 15 percent of light ship weight, as specified by the ANVCE Program Office. Corresponding ranges in sea state 3 with reduced light ship margins are 4488 nmi with a 10-percent margin, and 4835 nmi with a S-percent margin. In each case, a 2-percent tail-pipe allowance has been made for the unburnable fuel associated with the additional fuel made possible by the-reduction in weight margin.



BROKEN LINE INDICATES REQUIRED SPEED CANNOT BE ACHIEVED AT INITIAL WEIGHT

SPECIFIC RANGE = TOTAL RANGE / TOTAL FUEL

Figure C.2.3-1 SPECIFIC RANGE VERSUS SPEED FOR VARIOUS SEA STATES

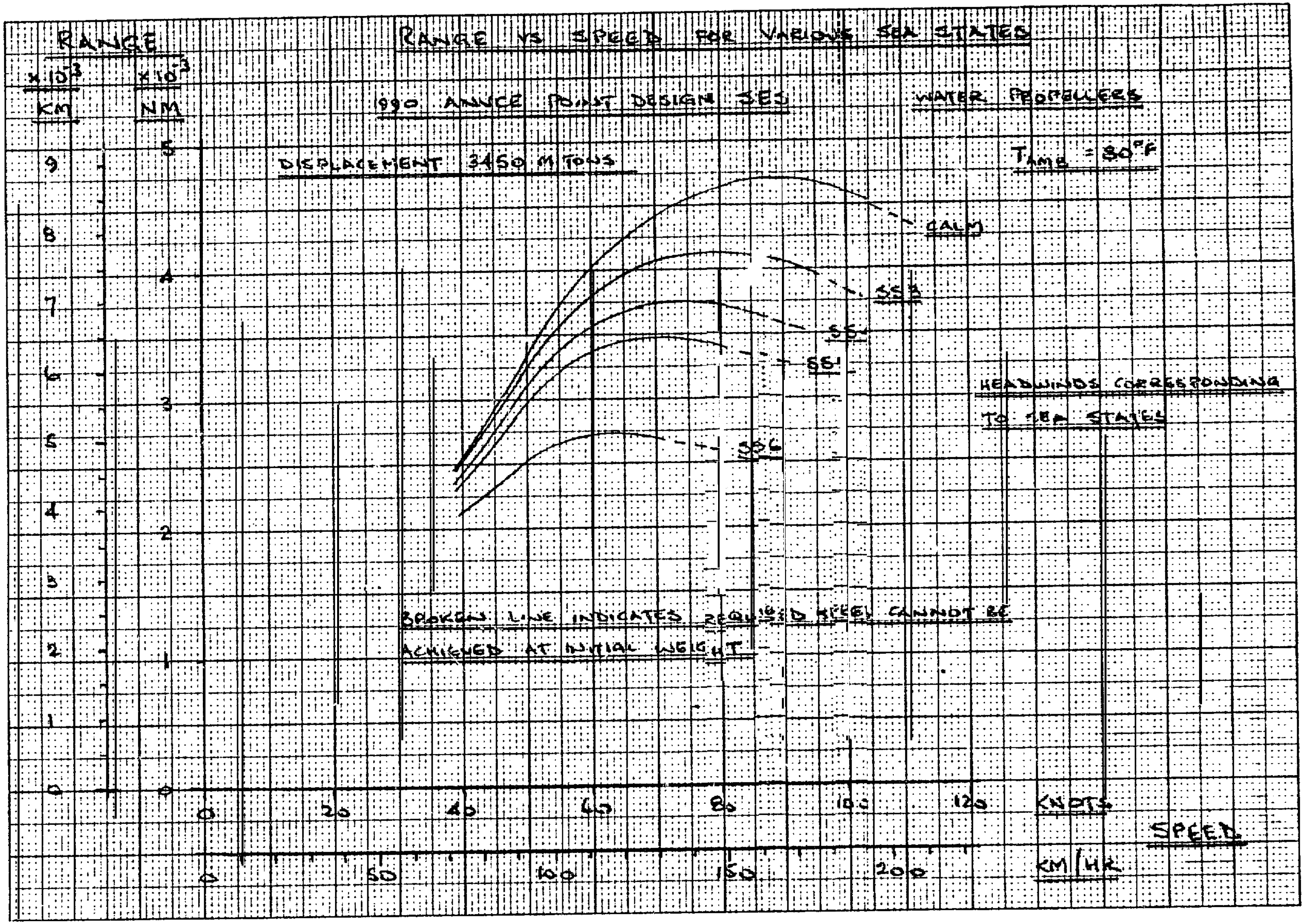


Figure C.2.3-2 RANGE VERSUS SPEED FOR VARIOUS SEA STATES

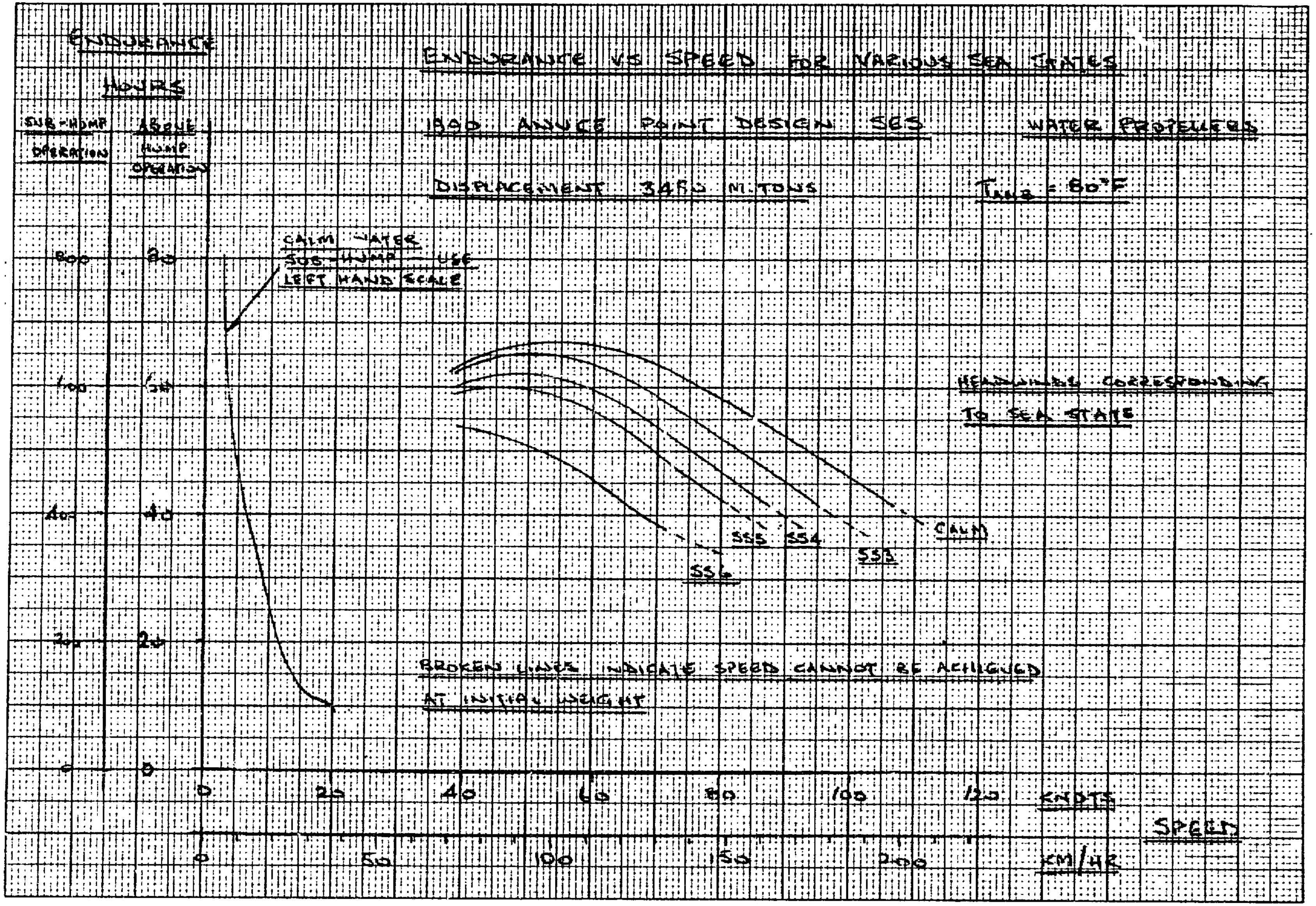


Figure C.2.3-3 ENDURANCE VERSUS SPEED FOR VARIOUS SEA STATES

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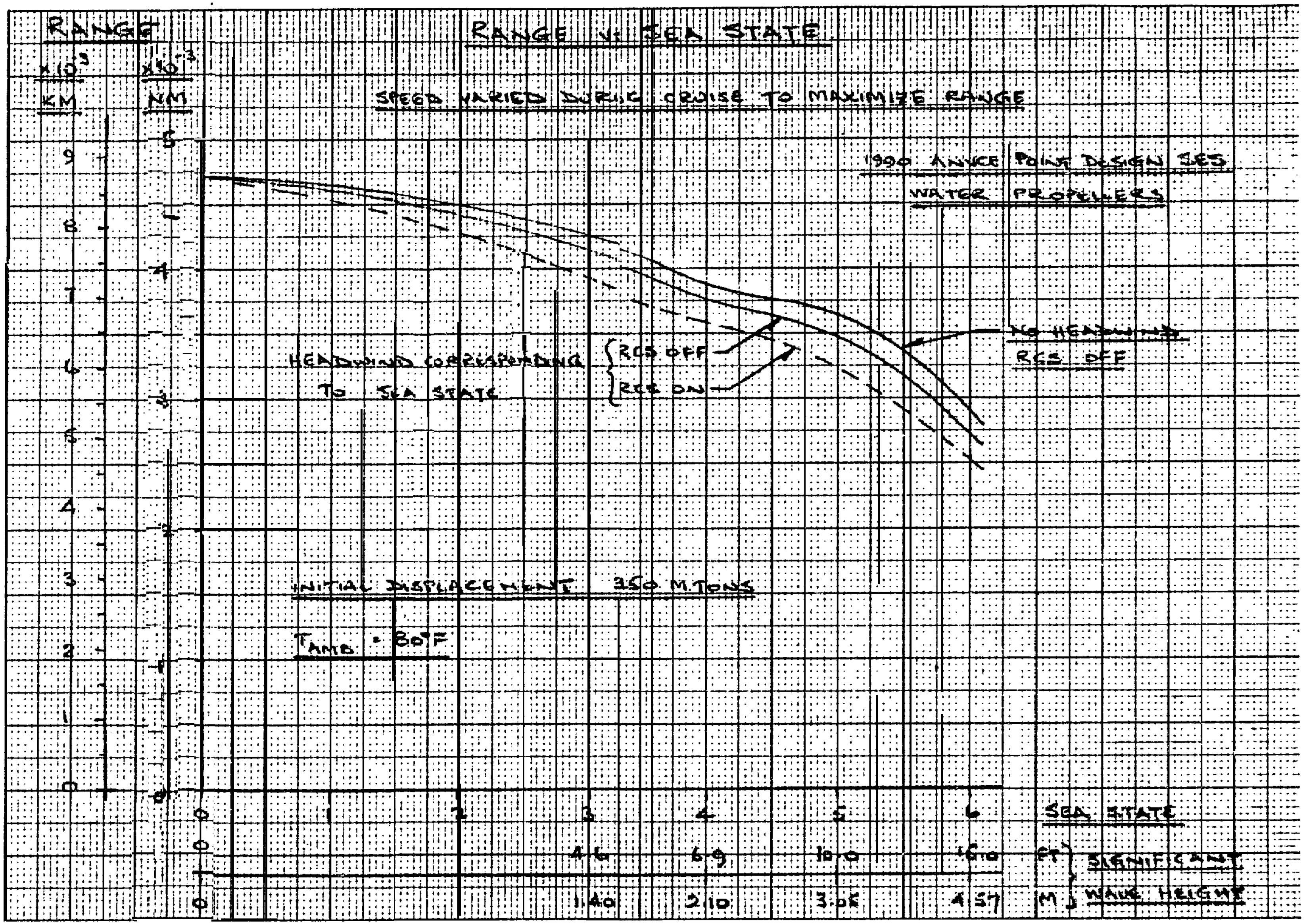

Figure C.2.3-4 RANGE VERSUS SEA STATE, SPEED VARIED DURING CRUISE TO MAXIMUM RANGE

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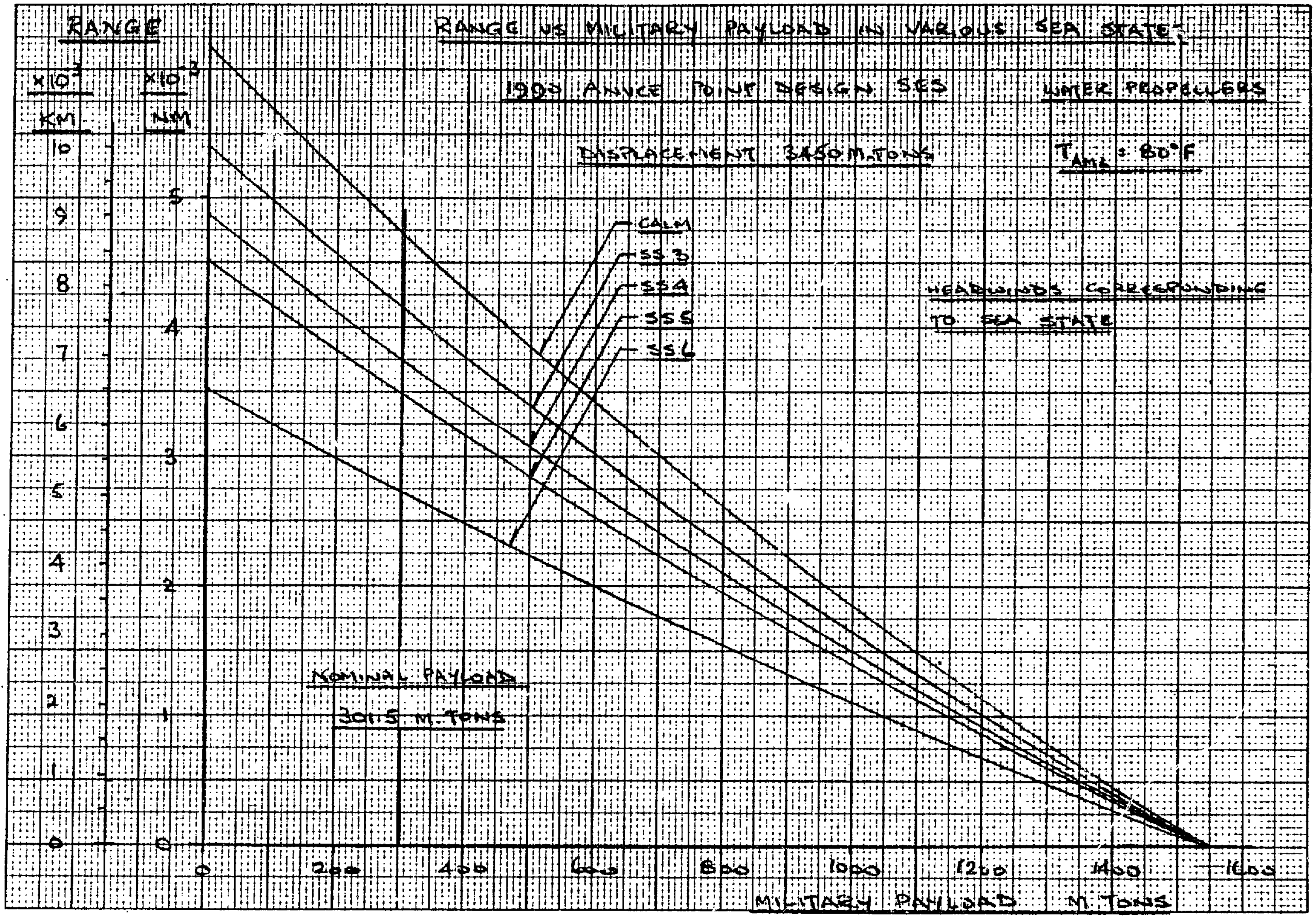

Figure C.2.3-5 RANGE VERSUS MILITARY PAYLOAD IN VARIOUS SEA STATES

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C.2.4 Weight and Volume

C.2.4.1 Weight Summary

Table C.2.4-I presents the summary weight estimates for the 1990 SES design configuration equipped with LM5000 propulsion engines and two 9.5-foot supercavitating propellers versus four waterjet propulsors. The ship design criteria is the same as presented in the basic report. The areas affected by the change to propellers are primarily in the propulsion group, margin, and available mission fuel.

The gearbox and propeller weights were estimated by a combination of empirical and analytical methods.

C.2.4.2 Volume

FUNCTION	INTERNAL VOLUME FT^3	M^3
Main Propulsion (including main machinery box, uptakes, shafting)	84,992	2,407.0
Lift System	99,786	2,825.9
Personnel (including living, messing, and all personnel support and storage)	80,447	2,278.3
Auxiliary and Electrical (machinery spaces other than main propulsion and lift outside main machinery box)	56,881	1,610.8
Payload (internal volume only)	135,042	3,824.4
Other (including passageways, maintenance spaces, and all other spaces not included in above)	374,045	10,592.9
TOTAL ENCLOSED VOLUME	831,193	23,539.3

TABLE C.2.4-I

WEIGHT SUMMARY

SWBS	SHORT TONS	METRIC TONS
Group 100, Structural System	1006.82	913.37
Group 200, Propulsion System	252.97	229.49
Group 300, Electrical System	47.48	43.07
Group 400, Command & Surveillance	79.01	71.68
Group 500, Auxiliary System	252.50	229.06
567, Lift System	128.71	116.76
Group 600, Outfit & Furnishings	145.35	131.86
Group 700, Armament	112.18	101.77
Design & Builderfs Margin	284.45	255.05
Empty Height (Light Ship)	2,180.76	1,978.35
Loads	1,622.22	1,471.65
Crew	18.06	16.39
Provisions	25.38	23.02
Stores	6.56	5.95
Freshwater	18.95	17.19
Ordnance - Main Vehicle	93.25	84.59
Secondary Vehicle	18.65	16.92
Secondary Vehicle (LAMPS & RPV)	26.50	24.04
Fuel, Including Mission, SSPU, **Helo,** 4 Residuals	1,414.87	1,283.55
Full-Load Weight	3,802.98	3,450.00

C.2.5 Stability

The propeller-driven SES stability characteristics are basically the same as those described in paragraph 2.2.5 of the basic document for the waterjet-driven SES,

C.3 SUBSYSTEMS

C.3.1 Propulsion

The propulsion subsystem consists of the gas turbine engines, the combustion air inlets and exhausts, the transmissions, and the propeller system. A brief description of each of the propulsion subsystem elements is contained herein.

C.3.1.1 Summary Description

C.3.1.1.1 General Description

The four propulsion power plants are gas turbines with a nominal 40,000 MCP and 46,000 MIP rating. Each of the two engines drives a single propeller on each side of the ship through a planetary reduction gearbox. The general layout is similar to the Bell-proposed LSES configuration, but with the incorporation of anticipated advances in technology which will result in an increase in overall propulsion subsystem operating efficiency. Specific propulsion characteristics for the various subsystem elements are given in paragraph 2.3.2.2 of the basic report.

C.3.1.1.2 Propulsion Engine Inlet System

The propulsion engine installation features an integrated inlet and exhaust system. Salt-spray removal from the inlet air is maximized by incorporating a charged droplet scrubber (CDS) demister in series with Farr Aquavanes. Improvements in filter demister state of the art allow for increased flow velocity through-both the Fair Aquavanes and CDS demister, The higher air flow velocities create significant weight savings because of more compact ducting and smaller demister units. Associated with increased air flow rates are increased pressure losses. However, by utilizing forward-facing inlets, the ram recovery will contribute to negating the higher pressure losses in the ducts. At high ship speeds, the forward-facing inlets will generate overall positive pressure at the engine face, thereby increasing installed engine performance,

The inlet contains a forward-facing entry into Farr Aquavanes. The Aquavanes turn the flow downward 90 degrees, where the flow is then diffused before entering the CDS demister. Downstream of the CDS, the flow is turned aft by a set of cascade turning vanes, and then flows into the engine, A long, smooth entry duct to the engine cancels flow turbulence and, along with the single-entry inlet system, provides for distortion-free inlet flow to the front face of the engine compressor. Blow-in doors are provided in the inlet diffuser, downstream of the Farr Aquavanes, to allow for proper air flow in the event of icing blockage of the Aquavanes. The following table shows air flow velocities for the three conditions described.

AIR FLOW VELOCITIES
(ft/sec)

(Propulsion Engine Air Flow
Plus Compartment Cooling Air
-W_a = 334 lb/sec)

V_{Farr} = 104 ft/sec

V_{CDS} = 45 ft/sec

$V_{Engine\ Duct}$ = 70 ft/sec

C.3.1.1.3 Propulsion Engine Exhaust System

The propulsion engines are moved aft to minimize shaft length between the power turbine and transmission, and also to minimize the engine exhaust duct length. The exhaust gases are ductsd out of the stern of the ship. Exhaust ducts straight out the stern provide for a minimum pressure loss installation, Also, exhaust plumes out the stern eliminate interferences with helicopter operations. By the time the exhaust plume has expanded to within the helicopter approach path, it has diffused to low velocity and temperature.

C.3.1.1.4 Propellers/Transmission

C.3.1.1.4.1 Propellers

The propellers are of a controlled submergence and blade pitch supercavitating design mounted on a 15-degree inclined shaft. The blades are raked 15 degrees.. This design is based on experimental model results of the NSRDC 4281 propeller design, which shows excellent efficiency. The installation design provides SO-percent submergence for top efficiency of 72 percent at high speeds, and full submergence with partial tip shrouding for hump speeds, with the flow-control door open. For transition from hump to high speed, or for rough seas, the door position is controllable,

Further details of propeller characteristics are given in a later subsection.

C.3.1.1.4.2 Transmission System

The transmission system combines the output of the two side-by-side engines to drive a single bull gear, The engines and gear are inclined to drive the 15-degree inclined shaft to the propeller. All reduction is accomplished at the engine end where the three gearboxes per side are at the end of the system that is high in the ship for accessibility.

The gear train consists of a right-angle spiral bevel gear pair which transmits the power of the inboard engine to a second bevel gear set behind the bull gear. The output from this second bevel set drives through its pinion into the bull gear. The outboard engine drives another pinion which engages the bull gear, The 14-inch diameter pinions and 64-inch diameter bull gear are helical gears about 9 inches wide. The gearbox is 14 inches wide and incorporates accessory power takeoffs for the lube system and the hydraulic system for propeller pitch control. The bevel gearboxes use air-mist cooling to enable the 60,000 hp intermittent power rating of the transmission to match the engine,

C.3.1.2 Propulsion Characteristics

C.3.1.2.1 Engine Characteristics

The 40,000 hp maximum continuous rating and 46,000 hp maximum intermittent rating of the engine are achieved within current parameters of engine air flow and turbine inlet temperature. The physical configuration of the engine is identical to current engines.

ENGINE CHARACTERISTICS

Maximum Continuous Power (MCP)	40,000 hp
SFC at MCP	0.36 lb/hp-hr
Maximum Intermittent Power	46,000 hp
Turbine Inlet Temperature (max)	2,250°F
Air flow	278 lb/sec
Compression Ratio	32:1
Weight	18,900 lb
Length	300 inches
Diameter	
Inlet	50 inches
Exhaust	80 inches
Number of Compressor Stages	19
Number of Turbine Stages	6
Combustor Type	Annular

C.3.1.2.2 Propeller Characteristics

The principal characteristics of the inclined propeller are given in the table below. A preliminary study of the propeller in SES-1008 size has been made and reported under task IV.B.l of LSES extension contract.

PROPELLER CHARACTERISTICS

Shaft Inclination	15°
Blade Rake	15°
Number of Blades	8
Pitch	Variable
Area Ratio	0.50
Hub Diameter	0.4D
Design Pitch/Diameter	1.6
Blade Section	Supercavitating
Immersion	
Low speed*	100%
High speed	50%
Diameter	12.1 feet
Installation drag at 70 knots	16,200 lb

*Shrouding and flow control are provided by installation in sidehull to control immersion.

During the 2KSES acquisition phase, an extensive review and analysis of propeller performance and propeller design was made which led to the design and selection of a propeller for an alternate to the waterjet propulsion system. The basis for this propeller design was founded on a conservative interpretation of model tests and SES-100B full-scale performance. The design review was based on all available supercavitating propeller performance data, but used essentially a scaled-up SES-100B propeller. A further selection of an advanced propeller design was also made that would have required model test and development substantiation by a program of model test and design which was too time-consuming at that time.

The current ANVCE propeller approach utilizes data developed from subsequent inclined propeller testing by NSRDC (also Hydronautics), and further assumes that a new model test program will be conducted for the 1990 SES or ACV. The ANVCE propeller performance also benefits from further analysis of SES-100B propeller performance recently conducted and from a much cleaner propeller installation that has been designed for the 1990 SES. Part of the improved thrust and efficiency predicted for the 1990 propellers, at both low and high ship speeds, is due to the absence of fins and rudders and the cleaner propeller flow passage that is possible because of the removal of the main reduction gear from immediately ahead of the propeller.

C.3.1.3 General Arrangement

A general arrangement of the propulsion subsystem is shown in figure 2.3.2-1, which indicates the main components and their relative locations,

C.3.1.4 Key Features

Key features of the propulsion subsystem gas turbine engine intake are shown in Bell drawing AD-76-39.

C.3.1.5 Weight Percentage Breakdown - Propulsion System

SWBS		PERCENTAGE
230	Propulsion Units	19.0
240	Transmission and Propeller Systems	45.4
250	Propulsion Support System	26.3
260	Propulsion Support System (Fuel and Lube Oil)	3.2
290	Special-Purpose Systems	0.7
	Shock Mounting	5.4
	Total	100

C.3.1.6 Propeller Application Trade Studies

Preliminary design studies of machinery arrangements were conducted in order to establish the most suitable propeller configuration for application to the 1990 3KSES. Of prime concern were considerations of simplicity and the involvement of minimum risk. During the course of design investigations, two innovative approaches were disclosed: the use of variable-flow ducts in lieu of ramps, and the use of a swing rudder.

Four preliminary designs were prepared that appeared to be satisfactory. These are shown in figures C.3.1-1 through C.3.1-4.

Concept 4 was favored primarily on a qualitative basis. To minimize gearbox requirements and simplify the shafting, all configurations utilized a E-degree inclined propeller. A brief discussion of the concepts studied is presented in the following paragraphs.

Concept 1 (figure C.3.1-1) maintained the identical engine location as that of waterjet-propelled craft. A 40,000 hp rated offset helical gearbox transferred the power from the inboard engine to a common drop box combining the power from the outboard engine to an 80,000 hp rated shaft. The power from this shaft was transmitted through a Vee reduction gearbox to the propeller shaft. It was felt that the weight of the offset and drop boxes might be excessive. A possible problem exists in the Vee reduction gearbox, since it is not a true bevel gearbox, but rather a specially developed spur or helical to take an angle other than parallel. Some development would be required because of the unique loading of the gear teeth,

Concept 2 (figure C.3.1-2), developed concurrently with concept 1, was investigated with four bevel gearboxes (40,000 hp each) in lieu of the offset and drop boxes for weight saving reas'ons. However, the problems associated with the Vee gearbox were disadvantages of both of these concepts.

In concept 3 (figure C.3.1-3), four spiral bevel gearboxes (40,000 hp each) were used to transmit the power to the propeller shaft with the speed reduction obtained through a planetary gearbox (80,000 hp). As in the case of the previous concepts, the risks involved in the development of the planetary gearbox were believed to be significant.

In view of the results to this point, concept 4 (figure C.3.1-4) was initiated by altering the engine installation to align with the propeller shaft. Contact with the engine manufacturer revealed this could be possible; however, the lube oil system would require a review to ensure proper oil scavenging. A conventional offset gearbox was used to combine the horsepower output of the engines and permit a direct drive to the propeller. For the sake of weight reduction, two bevel gearboxes (40,000 hp each) were used to transfer the power of the inboard engine. Should this prove to be undesirabie, a conventional offset gearbox can be substituted at a weight increment.

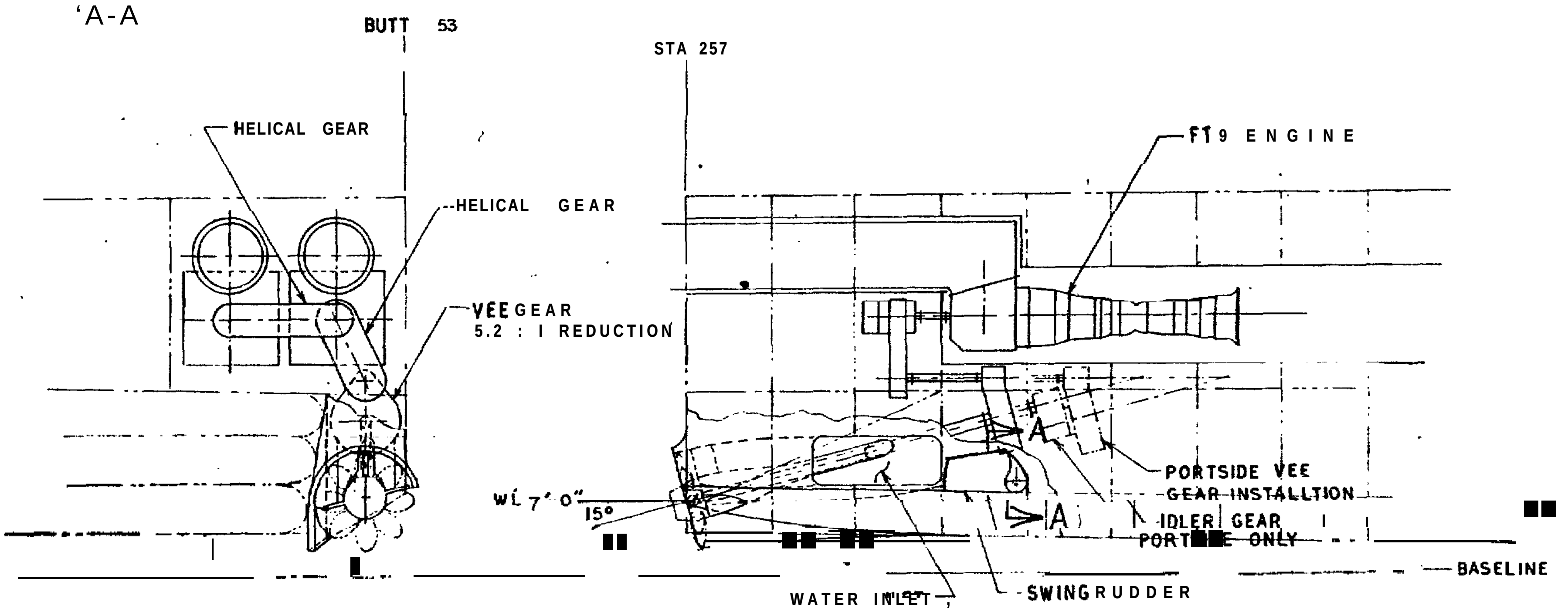

Figure C.3.1-1 CASE 1 - INCLINED PROPELLER WITH HELICAL AND 15° VEE GEAR AND HIGH-LEVEL WATER INTAKE

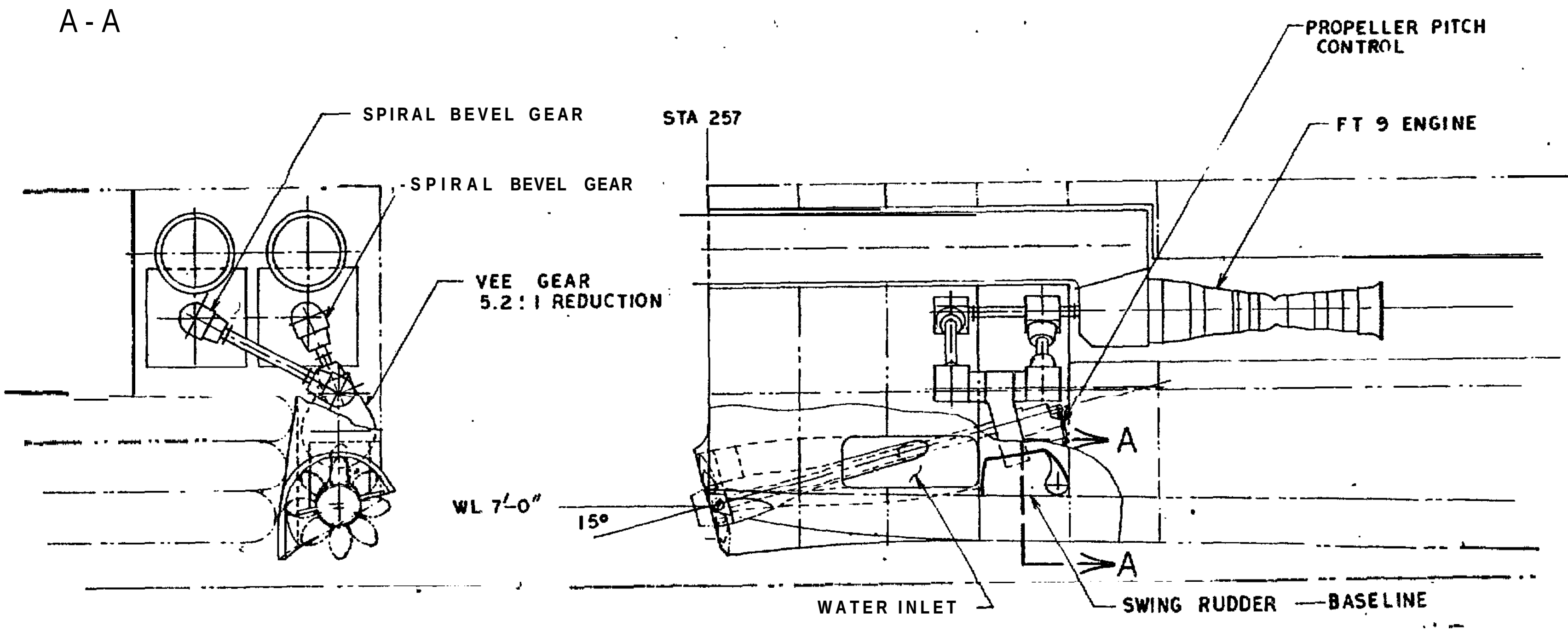

Figure C.3.1-2 CASE 2 - INCLINED PROPELLER WITH SPIRAL BEVEL GEAR AND VEE REDUCTION GEAR, HIGH-LEVEL WATER INTAKE

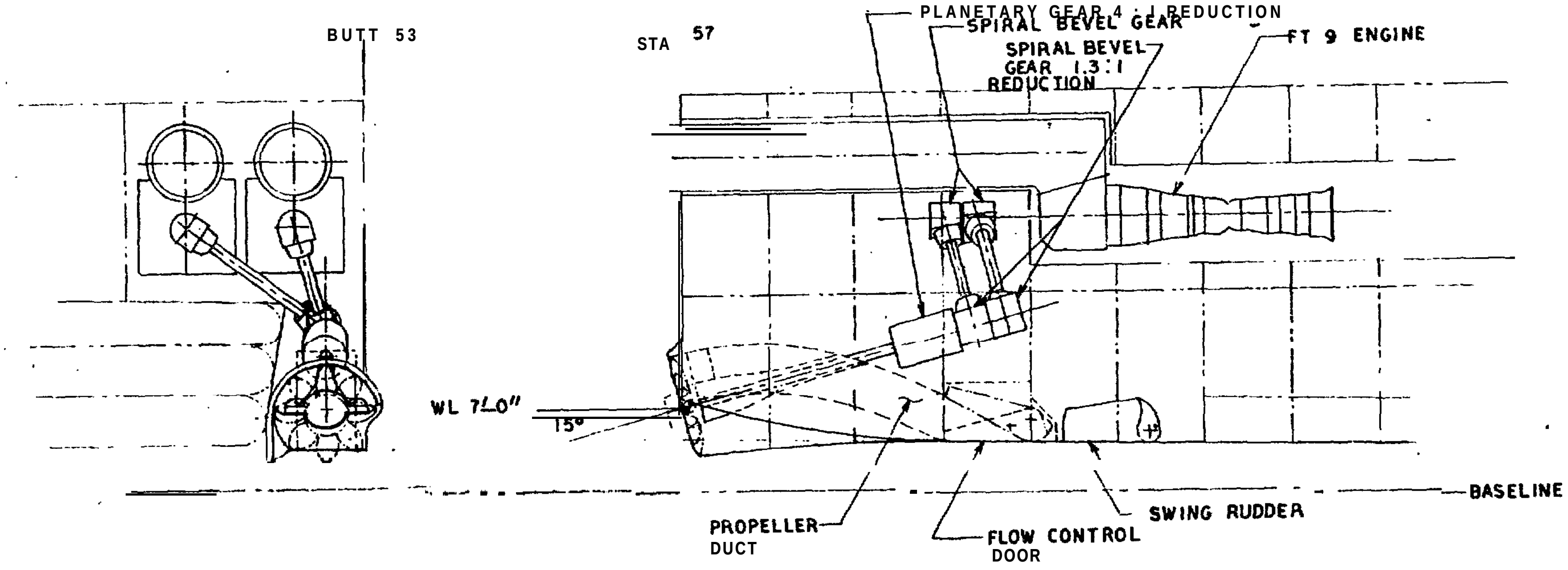

Figure C.3.1-3 CASE 3 - INCLINED PROPELLER WITH SPIRAL BEVEL GEAR AND PLANETARY GEARS, LOW-LEVEL WATER INTAKE

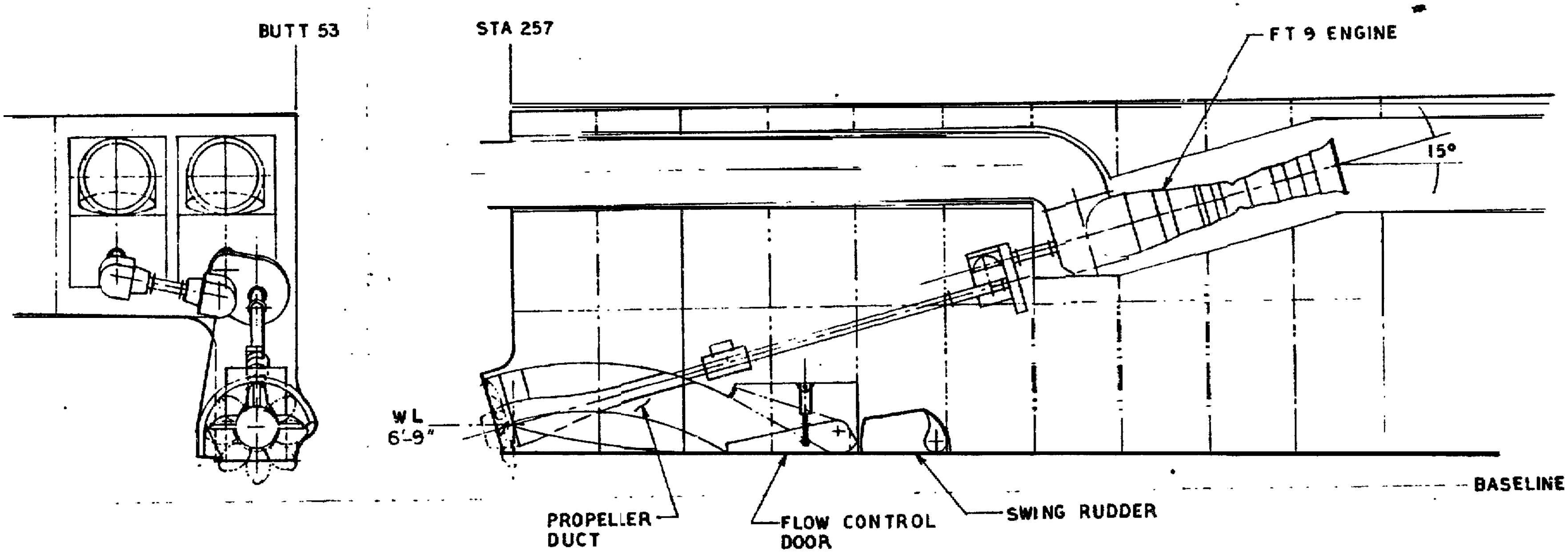

Figure C.3.1-4 CASE 4 - INCLINED PROPELLER WITH INCLINED ENGINE AND LOW-LEVEL INTAKE DUCT

C.3.2 Seals

The seal system for the propeller-driven craft is essentially the same as for the waterjet-driven craft. The bow seal is identical. The stern seal is the same except for its planform at the seal ends, In the propeller-driven version, there are no water-pump fairings that protrude into the seal space. Therefore, the seal remains essentially a constant width and does not require tailoring around such obstructions.

C.3.3 Other Systems

In addition to the very significant change in the propulsion system, a number of other subsystems are impacted by the propeller drive, though in a relatively minor way. These include shaping of the aft sidehull structure to enclose the propeller and provide a duct for the propeller that is used to increase propeller immersion during slow-speed operation. The seawater system will require another seawater pump to supply the maximum flow rate during an underway fire, (In the waterjet ship, the maximum flow rate during an underway fire was supplied by the waterjets.) Also, the seawater pumps will require an underway water inlet scoop.

Changes are also required in the lubrication, hydraulic, and electrical systems, A lubrication system is required for the propeller drive gearboxes. Hydraulic and electrical systems are required to vary propeller pitch and to move the flow control door. All of these functions are equivalent to similar functions on the waterjet ship, however, so the subsystems are different but equivalent.

C.4 AIRBORNE NOISE SIGNATURE

The description and discussion of expected airborne noise levels in paragraph 2.4.1.5.2 of the basic document apply equally well to the propeller-driven ship. Some differences in ship configuration will have localized effects on noise levels, but the overall source levels will be about the same. The angled gearboxes will probably be somewhat noisier than the offset gearboxes; however, this increase will be partially compensated for by the absence of waterjet noise. In either case, the gear noise will be overshadowed by other propulsion system noise, which will remain approximately the same for the waterjet or propeller configuration,

C, 5 RISK ASSESSMENT

The risks associated with the development of the 1990 SES propeller propulsion system are comparable to those associated with the development of the propulsion subsystem for the current LSES.

The 46,000 hp MIP engine prototypes exist today in the Pratt & Whitney Aircraft FT9A-2 and the General Electric LM5000. The LM5000 gas generator will be delivered for industrial applications in mid-1978, and the FT9A-2 will be marine qualified in 1978. Both engines are capable of the required power, and the technology improvement needed for better fuel consumption is already established by the aircraft versions or current development programs. Therefore, a low risk is associated with the engines.

Inclined propeller characteristics have been established by model tests conducted since the initial SES-100B propeller development program. The installation feature of shrouding has been model tested behind an SES sidehull, and a propeller flow control scheme similar to the design herein has been proven on the 100-ton SES-100B test craft. A moderate level of risk is associated with the propeller development for the inclined configuration. The semi-submerged, supercavitating controllable pitch propeller has been demonstrated on the SES-100B.

Development of a propeller transmission capable of combining two 46,000 hp outputs also represents a moderate technical risk due to the higher cooling loads of the bevel gear teeth.

The intake and exhaust systems are based on technology to be developed during the LSES program, and therefore represent a low technical risk. Higher filtration system efficiencies and higher flow velocities are projected for the 1990 SES. The selection of a ram-type inlet is based on improved filtration ‘efficiency and a better definition of spray environment to be obtained from the LSES program.

ANNEX I - PARAMETRIC PERFORMANCE ANALYSIS

C.I.1 Introduction

Parametric ship performance studies were conducted in support of the selection of the optimum propeller-driven SES to fulfill the 1990 ANVCE mission, The assumptions and methods used in the propeller SES studies were similar to those used in the waterjet studies discussed in appendix A. In this section, the particular assumptions used with propeller propulsion, and the results generated, will be presented.

The scope of the 1990 SES study did not permit the design of two completely different ships, one optimized for waterjet propulsion and the other for propellers, The propeller ship point design was therefore selected as a ship having the same basic hull lines, gross weight, and installed power as the selected waterjet ship, with detailed configuration changes as necessary to accommodate the propellers. The propeller ship thus has substantially better performance than the waterjet ship, in terms of speed, range, and hump margin. The parametric data presented in this section shows the alternate options available in meeting the TLR with propeller propulsion.

C.I.2 Assumptions and Constraints

C.I.2.1 General

In the propeller ship parametric studies, variations in ship cushion beam (at constant cushion area) were studied. Reasons for this were two-fold, First, previous studies have suggested possible advantages to increasing the length-to-beam ratio (L/B) for propeller-driven SES, because propeller efficiency increases rapidly with speed in the hump region and increasing L/B increases hump speed. Second, a propeller-driven ship would not fit through the Panama Canal with a cushion beam of 91 feet, unless the propeller and fairing are arranged such that the protrusion from the sidehull is entirely on the inboard side. This is considered to be a less desirable arrangement, because of possible interaction with the stern seal, and an arrangement with a major portion or all of the protrusion on the outboard side is preferred,

The cushion beams selected for this study were 91 feet (as for the waterjet ship), 85.5 feet, and 80'feet. The restriction on overall ship beam for Panama Canal transit is 106 feet, If the propellers are arranged so that the protrusion from the sidehull occurs on the outboard side, the allowable cushion beam would be about 80 feet. An 85.5-foot cushion beam represents an intermediate approach, where the propeller fairing protrudes both inboard and out-. board, This arrangement is shown on the propeller ship point design.

Cushion area for the propeller-driven 1990 SES was fixed at the value used for the waterjet ship, 20,412 ft^2 (1896 m^2). Again, it was expected that a larger ship would not be optimum, and a smaller ship would be unrealistic from the standpoint of space requirements, Cushion L/B thus varied with beam according to the relationship

$$\ell_c/B_c = S_c/B_c^2.$$

A range of gross weights, from 2500 to 3500 metric tons, was studied with propeller propulsion,

An additional variable that was introduced for the propeller ship studies was design top speed in sea state 3 (significant wave height of 1.4 m or 4.6 feet with lo-knot headwind). The TLR specifies a minimum top speed in this condition of 70 knots; accordingly, all ships were designed to meet or exceed this value, The waterjet ships studied (see appendix A) generally had installed propulsion power that was based on the hump condition, These ships generally had a top speed that was higher than 70 knots, To provide a fair performance comparison with the waterjet ships, propeller ship design top speed was varied over the range of 70 to 90 knots.

As with waterjet propulsion, the propeller propulsion systems were sized to meet) in addition to the top-speed requirement, the TLR required hump margin of 1.25 in calm water. The latter was checked at primary and secondary hump at full load, The power required to cruise at the optimum cruise speed at full load was also checked.

C. 1.2.2 Ship Drag

The drag assumed for the basic ship was identical to that used for waterjet ships. The drag of the propeller fairing, which was estimated using Bell's conventional method for a base-ventilated section, was deducted from gross propeller thrust (see section C.I.2.3).

C.I.2.3 Propulsion System Performance

Because of the use of a waterjet propulsion system on the 2KSES and LSES programs, the capability to rapidly select and compute the performance of a propeller propulsion system has not been developed at Bell New Orleans to such an extent as has been done for waterjets. In this study, a simplified approach was taken with respect to propulsion system analysis for the propeller ship. The method used, which had been found in the past to give a good approximation of a more detailed analysis, was to obtain net propulsive efficiency as a function of ship speed only from the curve shown in figure C.I-1. The net efficiency curve used includes an allowance for propeller fairing drag, but does not include transmission efficiency, which is assumed to be 0.98.

The values of propulsive efficiency used are believed attainable by the 1990 time period, The peak value, 0.72 at 70 knots, is somewhat better than has been demonstrated to date on the SES-100B, although it is fully justified on the basis of model test data, Model test data on an inclined propeller indicates a peak efficiency of 0.77 at cruise speed; this is degraded to 0.72 to allow for fairing drag and installation effects. A number of factors contribute to the improvement of the propeller installation on the 1990 SES relative to the SES-100B, which will allow the model predicted efficiencies to be achieved, The removal of all fixed appendages on the 1990 ship is expected to improve propeller inflow quality considerably. Removal of the fins has already been noted to improve propeller efficiency on the SES-100B. Removal of the rudders, which are closer to the propeller and are not canted inboard, can be expected to be even more effective. The 1990 SES propeller is shielded from the cushion by a fence on the inboard side, which will reduce cushion effects that are believed to adversely affect propeller performance on the SES-100B. The propeller tunnel arrangement shown on the 1990 SES will provide cleaner flow to the propeller at lower speeds than can be achieved on the SES-100B with the flow ramps in a raised position, Finally, model tests indicate that a higher propulsive efficiency can be attained with an inclined shaft propeller,

Achievement of the assumed propulsive efficiency envelope at all speeds will require the control of propeller submergence. This is achieved primarily by the use of a propeller inflow tunnel, which can be shut at high speeds to give an effective propeller submergence of 50 percent. When the tunnel is opened, propeller submergence of 100 percent can be achieved. At very high speeds, it may be necessary to further reduce propeller wetting through the use of trim tabs, At very low speeds (near secondary hump), the ship will be operated in a partial-cushion mode, with the sidehulls deeply immersed. This, in conjunction with a partial propeller shroud, will restrict propeller ventilation and provide a much improved thrust capability.

C.I.2.4 Lift System Performance

The methods used to compute the performance of lift systems on propeller ships were identical to those used for waterjets. The propeller studies differed from the waterjet studies in that cushion beam was varied. EAG to cushion beam ratio has been used as a convenient nondimensional parameter in roughly comparing the lift flow requirements of craft differing widely in size (as in comparing models and full-scale craft), However, for small variations in cushion beam with cushion depth kept constant (as considered here), it is not believed that EAG would vary. EAG for cruise was thus kept constant at the value estimated for the 91-foot cushion beam ship, 0.442 foot. However, installed lift power still varied with cushion beam, because it was based on cushion wave-pumping flow, which is proportional to cushion beam,

C. I. 2.5 Prime Mover Performance

This was identical in all respects to that used for waterjet propulsion.

C.I.2.6 System Weights

The only weight component affected by use of propellers is the propulsion system weight. The weight of the propulsion engines is, as for a waterjet system,

$$W_{PENG} = 1.58\ BHP_{P}$$

where

BHP_{p} = total installed propulsion power, MCP.

The weight of the remainder of a propeller propulsion system is calculated from

$$W_{PROP} = 1.235\ BHPI_{p}$$

where

$BHPI_{p}$ = total installed propulsion power, MIP.

This weight is for an inclined shaft, variable submergence, supercavitating propeller system, including gearboxes, shafts, couplings, lubrication system, propellers, and inflow ducts. The coefficient is based on weight analysis of an approximately 3000-ton SES driven by inclined shaft propellers.

The total weight of the propulsion system is, therefore,

$$W_{PSYS} = W_{PENG} + \text{‘PROP} .$$

C.I.3 Propeller Ship Parametric Results and Selection of Point Design

Figure C.I-2 shows installed propulsion power (on the basis of maximum continuous power rating) for the propeller-driven 1990 SES as a function of design gross weight WG and cushion beam B_c. As for waterjet propulsion, the installed power for propeller propulsion is selected to meet the most stringent of the following criteria:

a. Thrust-to-drag ratio of 1.25 at secondary hump in calm water

b. Thrust-to-drag ratio of 1.25 at primary hump in calm water

(U) c. Specified top speed in sea state 3 ($h_{1/3}$ = 4.6 feet, 1.4 m) with lo-knot headwind

(U) d. Optimum range cruising speed in sea state 3, lo-knot headwind.

~~(C)~~ All of the above were evaluated at design gross weight. The design top speed used in figure C.I-2 was 70 knots, as specified in the TLR. Maximum intermittent power (MIP) was assumed for hump transit, while MCP was used for top and cruising speed calculations.

~~(C)~~ Figure C.I-2 shows that, for all weights, the deciding criterion in the determination of installed power depends on cushion beam. At low values of cushion beam (high L/B ratios), the deciding criterion is the 70-knot design speed; at large beam values, it is the 25-percent thrust margin at primary hump. With increased weight, the thrust margin criterion becomes increasingly dominant. Where hump margin determines the installed power, required power increases with increasing beam because of the increase in hump wave drag with decreasing L/B ratio. Where top speed is the deciding factor, the opposite is true (though the effect is much less pronounced) because of the reduction in wave and sidehull drags with decreasing L/B.

(U) The boundary line between the power determining criteria is indicated on the figure, as is the selected point design weight and beam. The latter, in this and later figures, only indicates selected ship size. In the point design, actual installed power is greater than the minimum requirement indicated here, to be consistent with the power installed on the waterjet point design ship.

~~(C)~~ A broken line on the figure indicates ship dimensions, weights, and power requirements to meet a 3500 nmi range requirement.

(U) In no case studied did secondary hump determine installed power. In this condition, the chief concern is selection of the propeller diameter to provide adequate thrust (propeller blade angle has little effect on performance at low advance ratios), and restriction of propeller ventilation to allow the absorption of adequate power to produce the required thrust. The latter can be accomplished through the use of deep sidehull submergence (as on partial cushion) and a partial shroud to restrict the ventilation path to the surface. In these cases, the power required to exceed secondary hump drag by 25 percent was less than the installed propulsion power at MIP rating.

(U) Comparison of figure C.I-2 with figure A.4.c-1 of appendix A shows that the propeller-driven ships require far less power than the waterjet ships with realistic nozzle sizes at comparable gross weights. This is a result of the greater propulsive efficiency of a supercavitating propeller. At cruise, the propeller efficiency is 0.72, compared with 0.55 to 0.57 for a waterjet, both assuming some technology improvements by 1990. At hump, the advantage of propellers is less apparent, and the assumed propeller efficiency of about 0.42 can be matched by a waterjet system with a high-flow, low-headrise propulsor, but only at a considerable expense in onboard space and weight.

~~(C)~~ Figure C.I-3 shows the top speeds in sea state 3 that result from levels of installed propulsion power as indicated in figure C.I-2. Once again, it is seen that, in the majority of cases, the 70-knot top speed selected the installed power. For the ships whose propulsion power was sized for hump, top speed exceeds 70 knots, but in no case is it greater than about 83 knots. The speeds achieved by the propeller ships are roughly comparable to those achieved by waterjet ships at the same weight with realistic propulsor sizes, but again with a much lower installed power than with waterjets.

~~(C)~~The effect of varying required top speed on installed propulsion power, with cushion beam fixed at 91 feet, is shown in figure C.I-4. The horizontal lines on the carpet in this figure indicate areas where propulsion power is determined by hump transit, as shown in the two preceding figures. Actual top speed in these instances is fixed, being a function of gross weight and ship geometry (fixed) . As the required top speed is raised above the top speed determined by hump power, installed propulsion power increases rather rapidly. As propeller ships require less power than waterjet ships to achieve the same speed, this figure allows speeds for the two types of propulsion systems to be compared on the basis of the same power. Thus, a 3500-ton propeller ship with 150,000 propulsion horsepower (MCP) will achieve a speed of about 92 knots, while a waterjet ship at 3500 tons with the same propulsion power and 2-ft nozzles will achieve only 80 knots.

(U) Installed lift power for the propeller SES is determined, as for the waterjet SES, by the wave-pumping flow requirements in sea state 6. The lift power installed has already been shown in figure A.4.c-2 of appendix A. As seen there, lift power increases with both cushion beam and gross weight.

(U) Total installed power for the propeller SES, also quoted on the basis of MCP, is shown in figure C.I-5 as a function of gross weight and beam for a minimum design speed of 70 knots, and in figure C.I-6 against gross weight and design top speed for a constant beam of 91 feet. The carpet in figure C.I-5 is similar in shape to figure C.I-2; however, the increase in lift power with beam more than offsets the reduction in propulsion power at 2500 tons, so that total power increases slowly with beam in this case, In other cases, total power increases more rapidly with beam because of combined propulsion and lift power effects. It should be noted that the design speed axis on the total power versus weight and design speed in figure C.I-6 has been reversed from the propulsion power carpet in figure C.I-4. The shapes of the two carpet plots are otherwise similar.

~~(C)~~ Range for propeller ships as a function of design gross weight and cushion beam is shown in figure C.I-7 for a design maximum speed of 70 knots. The increase in range with decreasing cushion beam (ie, increasing L/B) can be explained by the decrease in installed power. As we have seen, lift power decreases with cushion beam at all weights, and propulsion power decreases with cushion beam for cases where hump requirements determine installed power. Lower installed power means not only lighter ship empty weight, but also that the engines can

(U) operate at a more favorable specific fuel consumption for the same amount of cruise power. These effects are offset to some extent by the increase in cruise propulsion power with increasing L/B, due to higher drag, The increase in range with decreasing beam is more pronounced at the heavier weights, where hump thrust determines installed power.

(U) The variation of propeller ship range with gross weight and design maximum speed is shown in figure C. I-8. Here, the increasing range with decreasing design speed clearly results from the decrease in installed power. The boundary line indicating change in power selection criterion is again shown on this figure. To the left of this line, range remains constant, indicating the region where the installed power, and thus top speed, are determined by the hump margin requirements.

~~(C)~~In figures C.I-7 and -8, it is clear that range with propeller propulsion greatly exceeds that available with waterjet propulsion at a comparable weight, even if the most favorable nozzle area is selected with waterjets. Waterjet ship ranges are shown in figure A.4.c-6 of appendix A. Typically, at 3000 tons the best waterjet ship range is about 3100 nmi, while a propeller ship could achieve a range of-about 3950 to 4150 nmi, depending on cushion beam. This represents an improvement in range of 27 to 34 percent with propellers.

(U) There are several reasons for the improvement in range with propeller propulsion. As noted earlier, installed propulsion power required is much lower with propellers, thus reducing engine and associated installation weight. The weight of a propeller propulsion system, on the basis of a given installed power, is about the same or slightly lower than a waterjet system (depending on propulsor design flow rate). As propellers are substantially more efficient at cruise speeds than waterjets, propeller cruise power is reduced,

(U) Because of the superiority of the propeller SES over the waterjet SES in nearly all performance aspects, there are a large number of options available for comparing the two types of propulsion systems on SES. One method is to consider the lowest cost ship having the optimum combination of low weight and power, which will satisfy all TLR performance requirements, In appendix A, we have already seen that such a ship with waterjet propulsion would have a gross weight of just over 3350 tons and an installed propulsion power of 150,000 hp, with propulsors having 1.5 ft^2 nozzles. Top speed of this ship would be 81 knots, which exceeds the TLR, but which is a result of the high hump power requirements. A propeller ship which just met the TLR range with a 91-foot cushion beam would have a gross weight of 2750 tons and an installed propulsion power of 81,000 hp. Since the installed power in this case is based on hump, the top speed (about 72.5 knots) would slightly exceed the TLR requirement. As shown in figure C. I-2, the installed power could be reduced and the top speed reduced to the 70-knot requirement, by narrowing the cushion beam somewhat. A cushion beam of 85.5 feet is consistent with an overall beam of 106 feet, which would allow passage through the Panama Canal as required in the TLR, with the propeller fairings protruding both on the inboard and outboard sides of the sidehulls as shown for the point design. With this beam, installed propulsion power would be 78,400 hp, and the ship displacement would be 2720 tons. This ship would exactly meet TLR speed and range requirements. Thus, a propeller ship to just meet the TLR performance specifications would be less costly to build than the equivalent waterjet ship, having much lower weight and installed power, The development cost of the propeller propulsion system would probably be higher, but this could be spread over a production run of ships,

There are other methods that could be used to compare waterjet and propeller SES, including ships having the same speed and range, equal weight with power to just meet the TLR in each case, and equal weight and power. The latter method has been chosen for the waterjet and propeller 1990 SES point designs, This will emphasize the superior performance features of the propeller-driven ship; in terms of speed, range, and hump margin, while foregoing the cost benefit the propeller ship might otherwise have. The propeller SES point design has thus been selected as having the same design displacement and power plants as the waterjet SES point design; its design characteristics are summarized in section C.1.1.

The cushion beam of the propeller SES is 91 feet, as for the waterjet ship. With the propeller arrangement and size shown, this configuration cannot transit the Panama Canal, unless the 106-foot overall beam restriction can be relaxed, The scope of this study did not permit the entire redesign of a separate ship optimized for propellers and meeting all TLR requirements. The point design chosen is optimized for waterjets, and meets all TLR specifications with that propulsion system installed, It has been shown in this section of the appendix, however, that ship performance, in terms of range and required power, can be improved by reducing cushion beam somewhat.

As with the waterjet-propelled parametric ships considered in appendix A, presently foreseen limits in the state of the art are not expected to impact the parametric results shown in this section. In the inclined shaft propeller transmission system arrangement assumed, each right-angle gearbox carries no more than the power of one engine. The full delivered power to the propeller is carried only by the offset reduction gearbox, which also serves to combine the power of the two engines on each side of the ship. It is presently believed that right-angle bevel gearboxes can be developed to transmit up to 40,000 hp on a maximum continuous basis. This is equivalent to a total installed propulsion power of 160,000 hp MCP. It will be noted in figures C.I-2 and C.I-4 that all parametric propeller ships considered had less than this level of installed propulsion power. The propeller ship point design selected had this installed power level in order to provide a consistent comparison with the waterjet point design, The propeller point design thus represents the expected limit in present state of the art for mechanical transmissions, Normal transmission development would be required to produce the gearboxes for this ship.

The performance of the propeller-driven 1990 SES point design is discussed in detail in section C.2 of this appendix. As can be seen there, the propeller ship performance well exceeds the TLR performance specifications in all respects.

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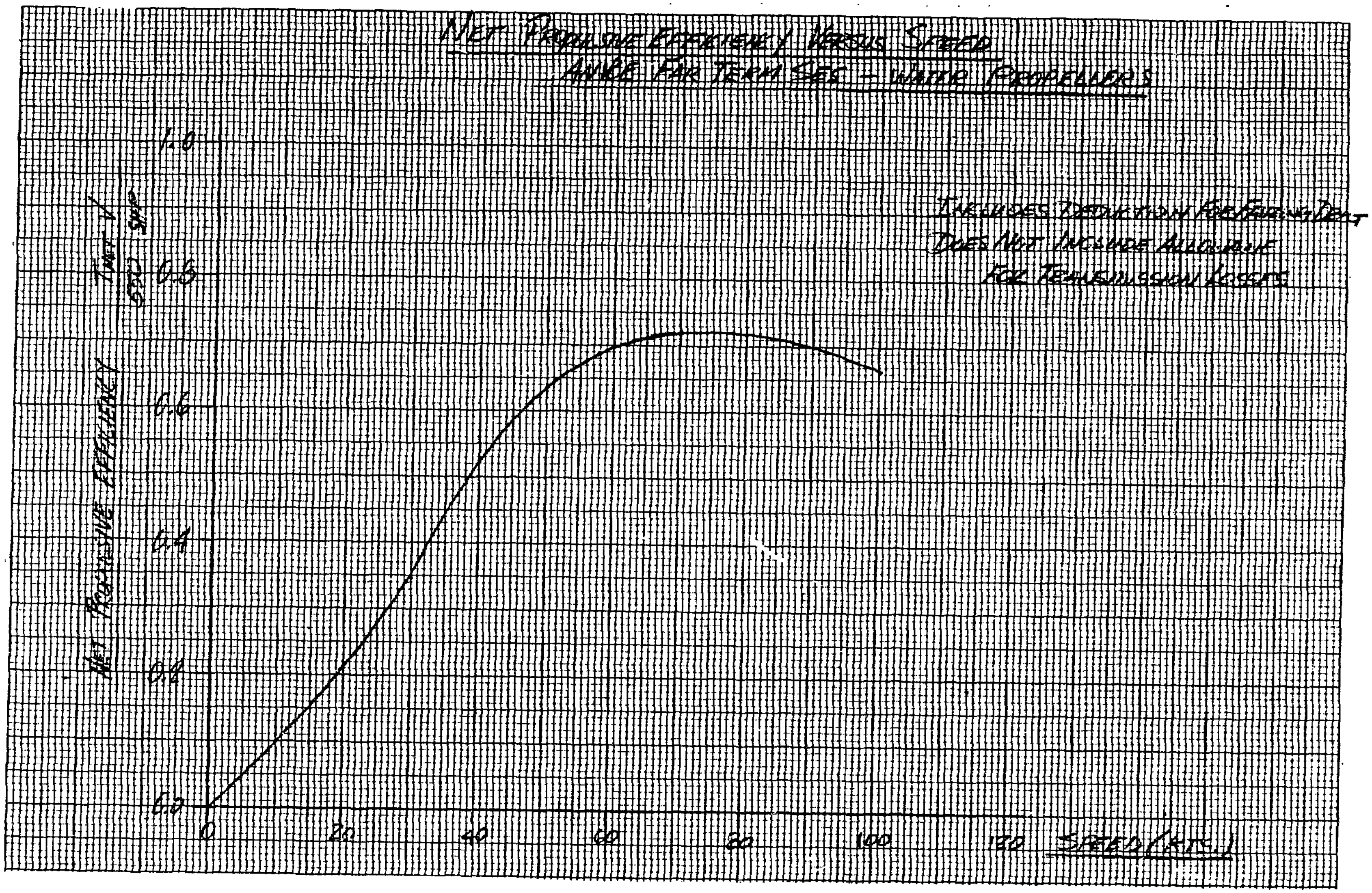

Figure C.I-1 NET PROPULSIVE EFFICIENCY VERSUS SPEED

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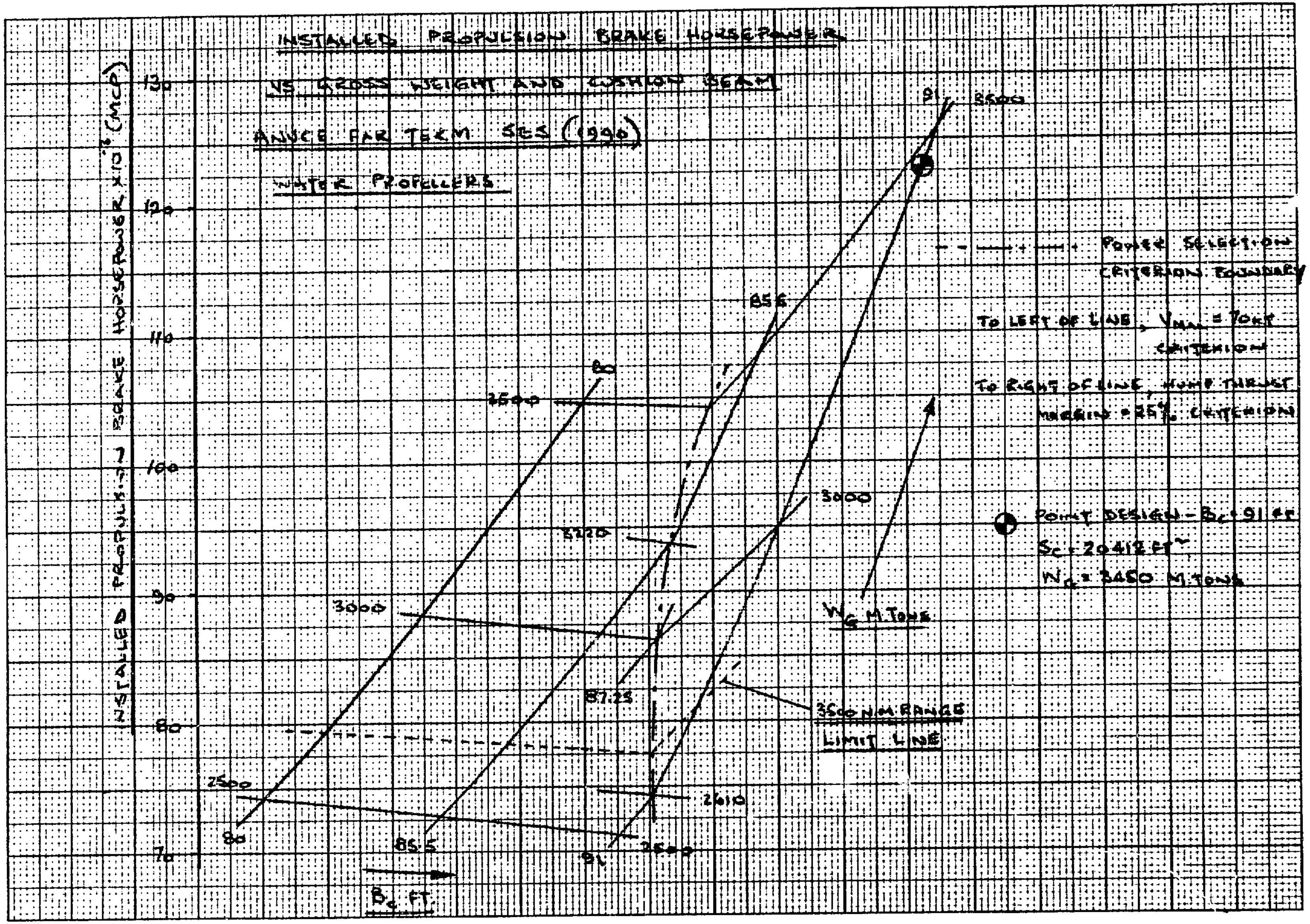

Figure C.I-2 INSTALLED PROPULSION BRAKE HORSEPOWER VERSUS GROSS WEIGHT AND CUSHION BEAM

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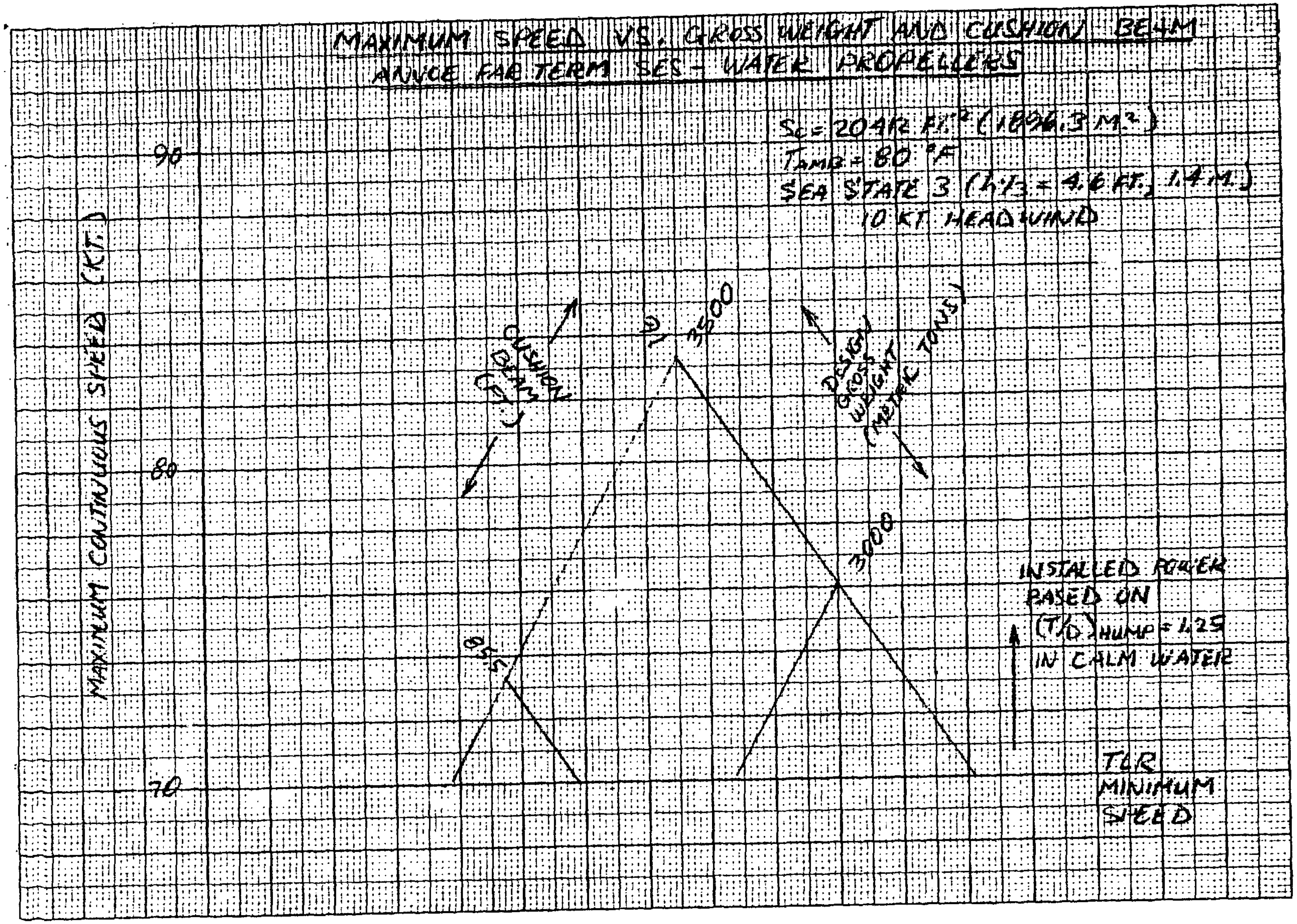

Figure C.I-3 MAXIMUM SPEED VERSUS GROSS WEIGHT AND CUSHION BEAM

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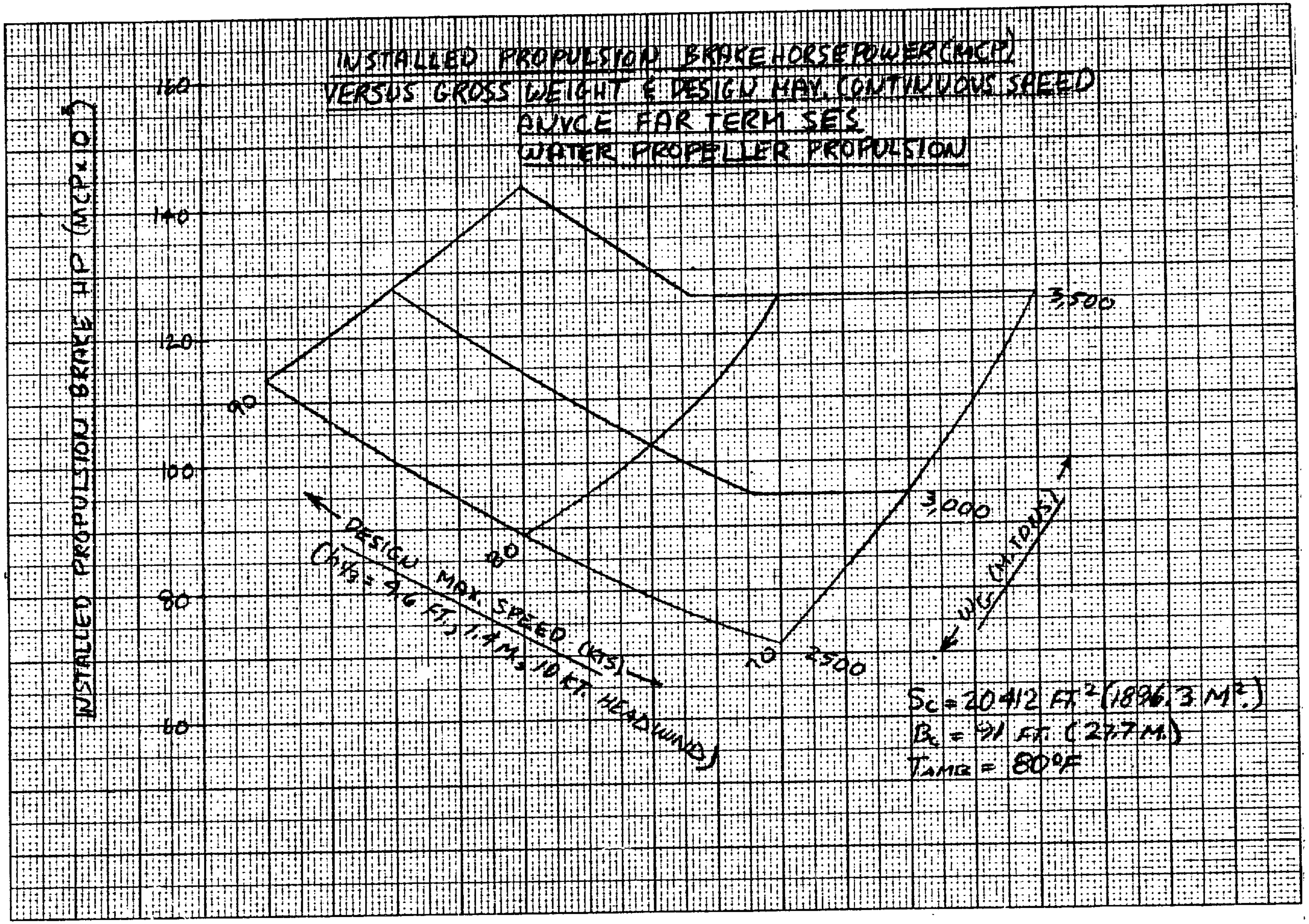

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Figure C.I-4 INSTALLED PROPULSION BRAKE HORSEPOWER (MCP) VERSUS GROSS WEIGHT AND DESIGN MAXIMUM CONTINUOUS SPEED

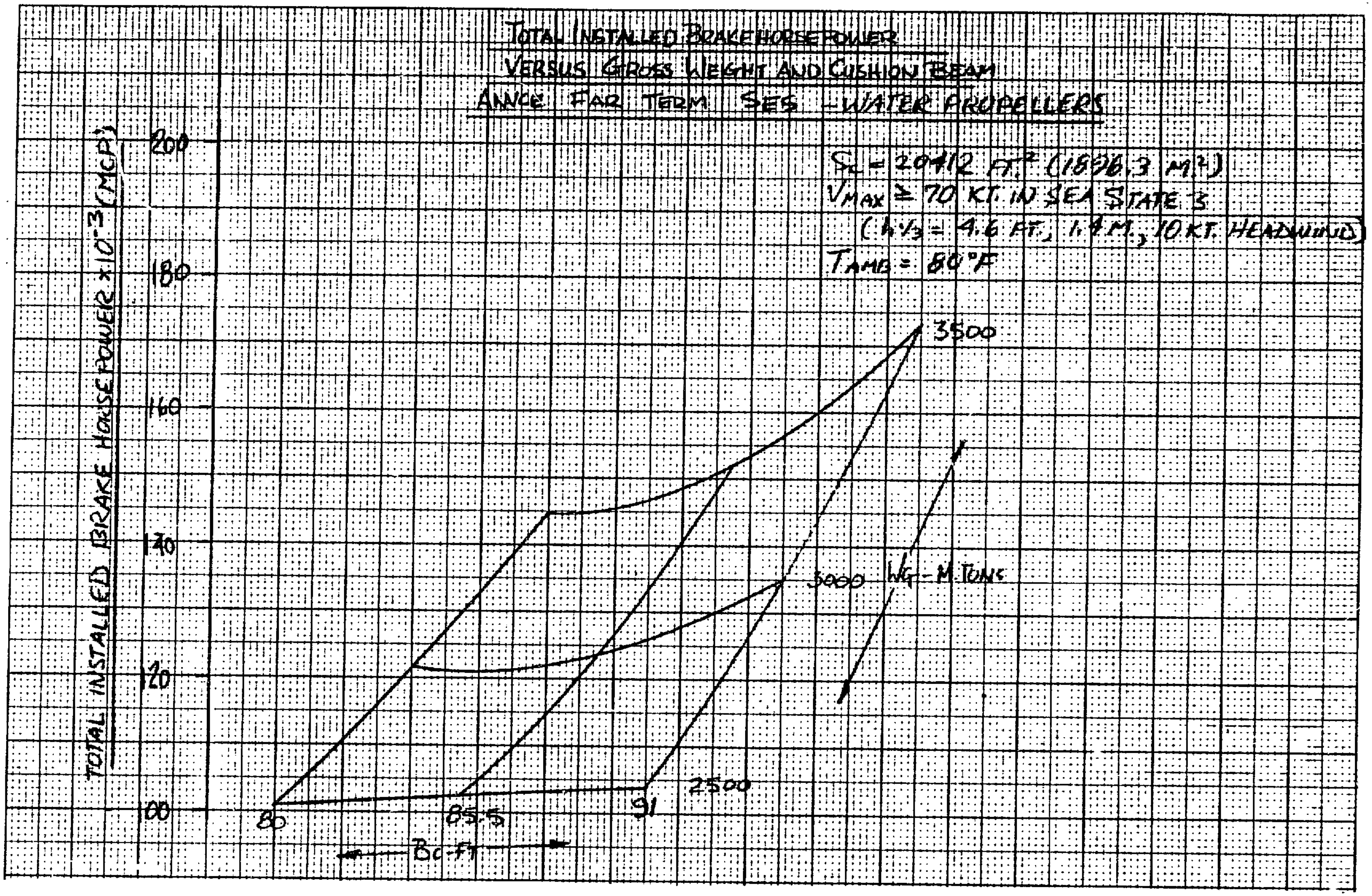

Figure C.I-5 TOTAL INSTALLED BRAKE HORSEPOWER VERSUS GROSS WEIGHT AND CUSHION BEAM

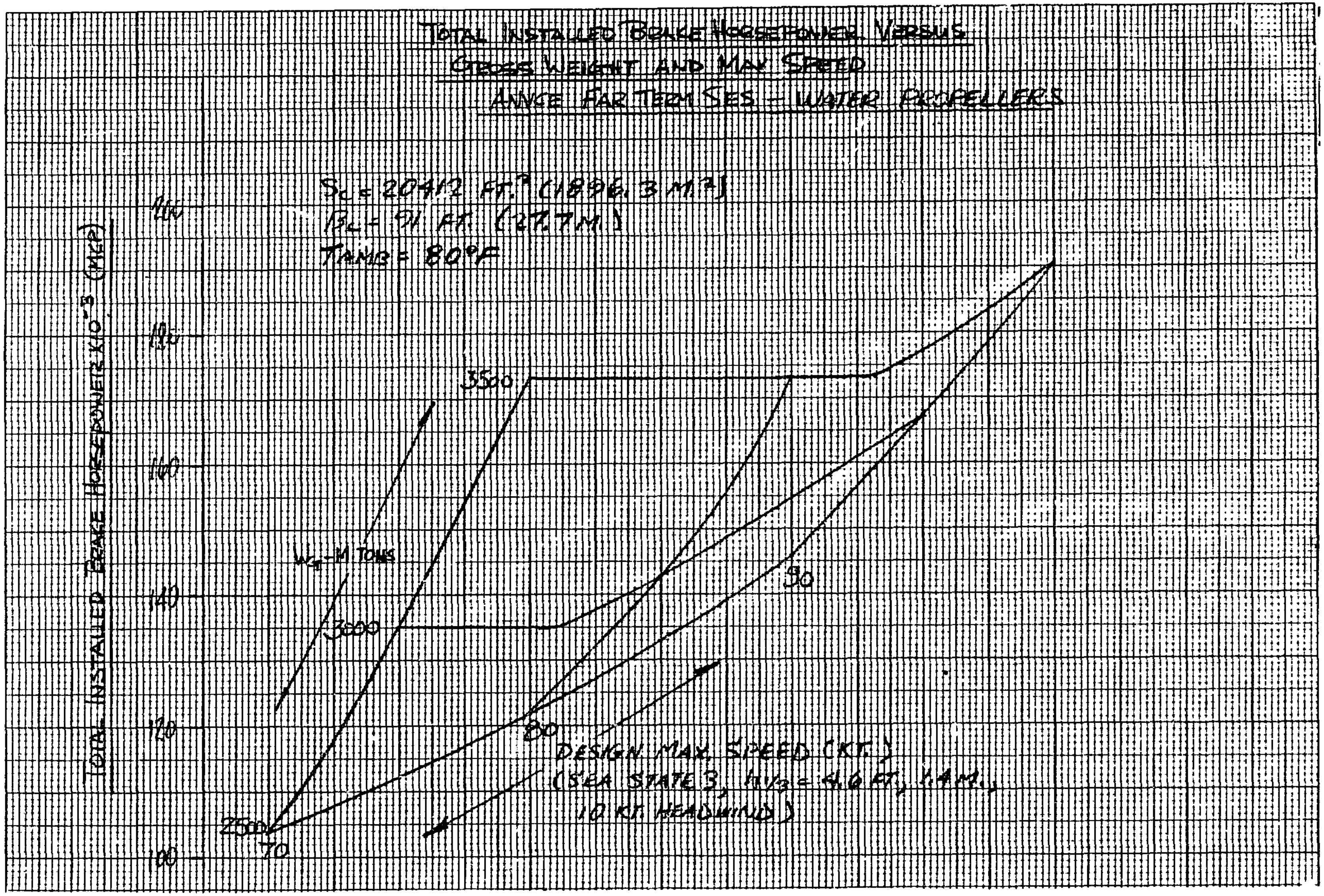

Figure C.I-6 TOTAL INSTALLED BRAKE HORSEPOWER VERSUS GROSS WEIGHT AND MAXIMUM SPEED

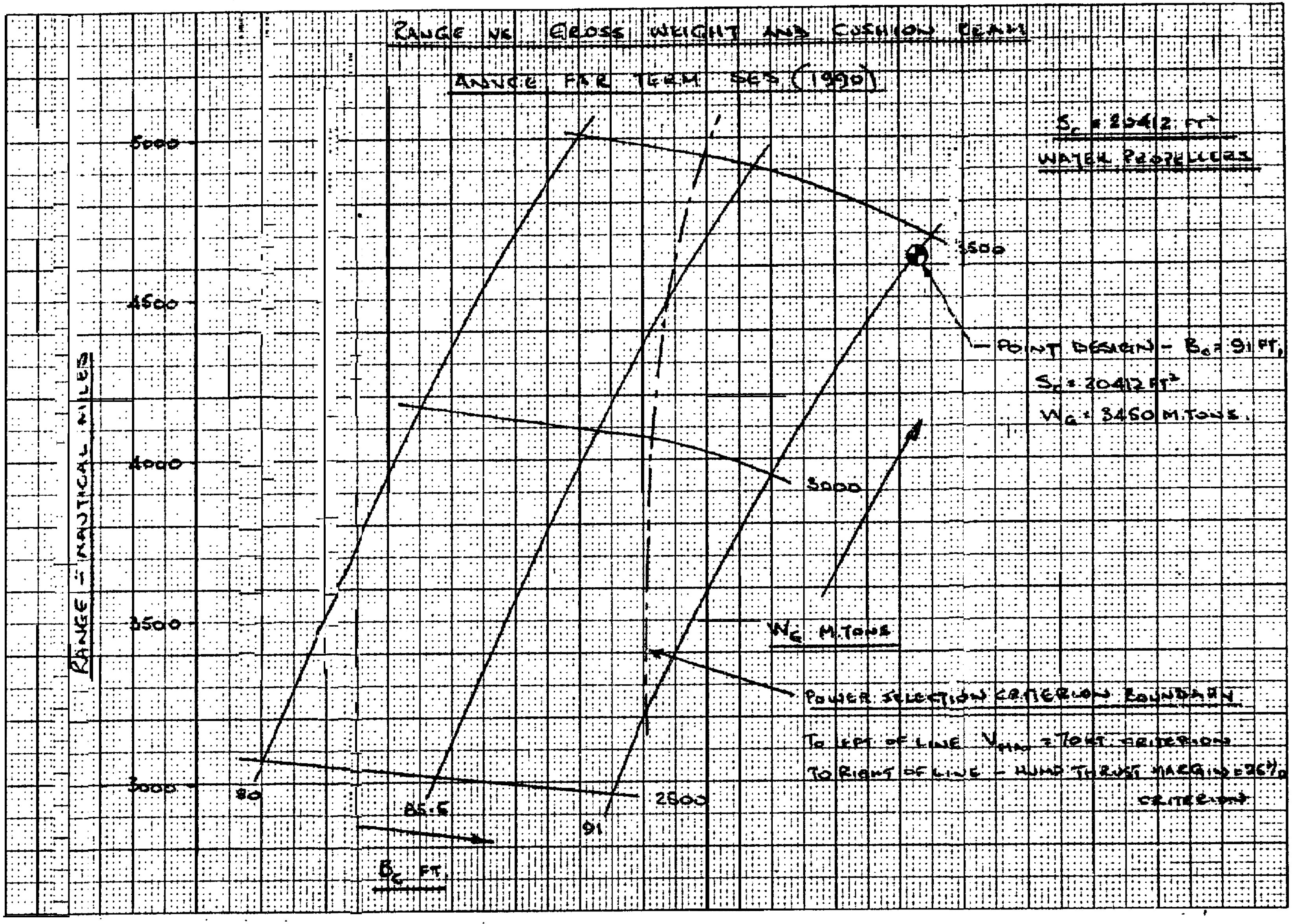

Figure C.I-7 RANGE VERSUS GROSS WEIGHT AND CUSHION BEAM

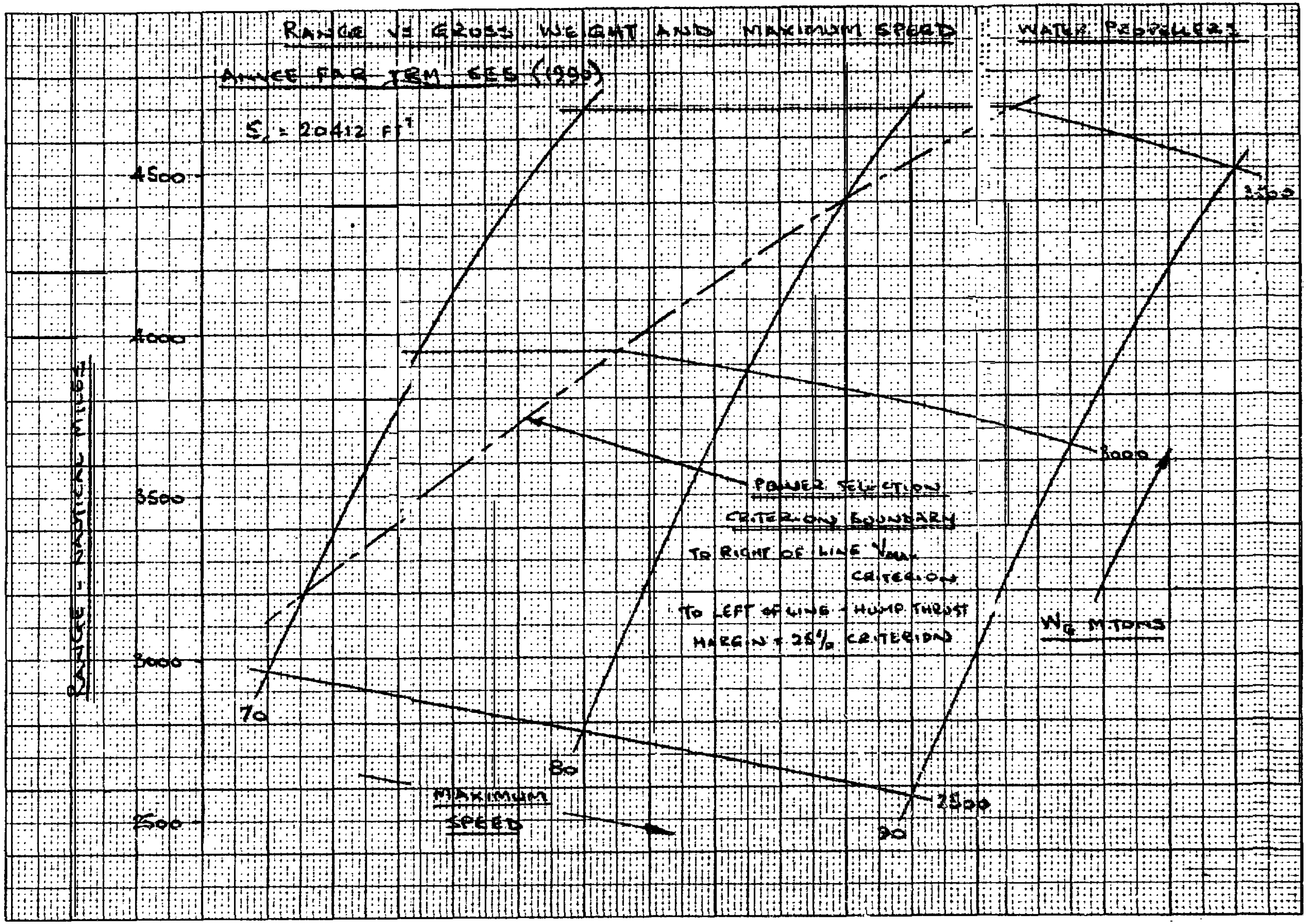

Figure C.I-8 RANGE VERSUS GROSS WEIGHT AND DESIGN MAXIMUM SPEED