SURFACE SHIP CONTINUING CONCEPT FORMULATION (CONFORM) FY 86 FEASIBILITY DESIGN STUDY

FINAL REPORT

NATO SES ASW CORVETTE

VOLUME II-- APPENDICES

SHIP DESIGN AND ENGINEERING DIRECTORATE

NAVAL SEA SYSTEMS COMMAND

WASHINGTON, D.C. 20362

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MAY 1986

NAVSEA Technical Note No. 041-501-TN-0025

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APPENDIX B

PROPELLER DESIGN

B.1 VENTILATED PROPELLER

The ventilated propellers studied are controllable pitch partially submerged types. Performance data for the propellers is given in Section 16.

The propeller blades are made from forgings machined all over to achieve accurate profiles and sections. Candidate blade materials are stainless steel, nicket based superalloy and nickel-aluminum bronze.

Each blade is replaceable externally via a bolted joint with no other disturbance of the propeller or pitch change mechanism required. The propeller blades can be changed while the ship is afloat. The blade section is a wedge with an annex section as shown in Figure B.1. This blade shape and section is similar to that used successfully on the SES-100B.

The propellers derived from this study have diameters of 3 and 4 meters and a hub to tip ratio of 0.4. The hub is an approximately cylindrical body made from corrosion resistant material which contains the pitch change mechanism. Attached to the after-end of the hub is a fairing. The propeller is mounted behind the sidehull so that 25 or 50 percent of its disc area is masked by the sidehull transom. From the propeller, the drive shaft is installed at an inclined angle up and forward. Immediately adjacent to the propeller hub is the thrust bearing module.

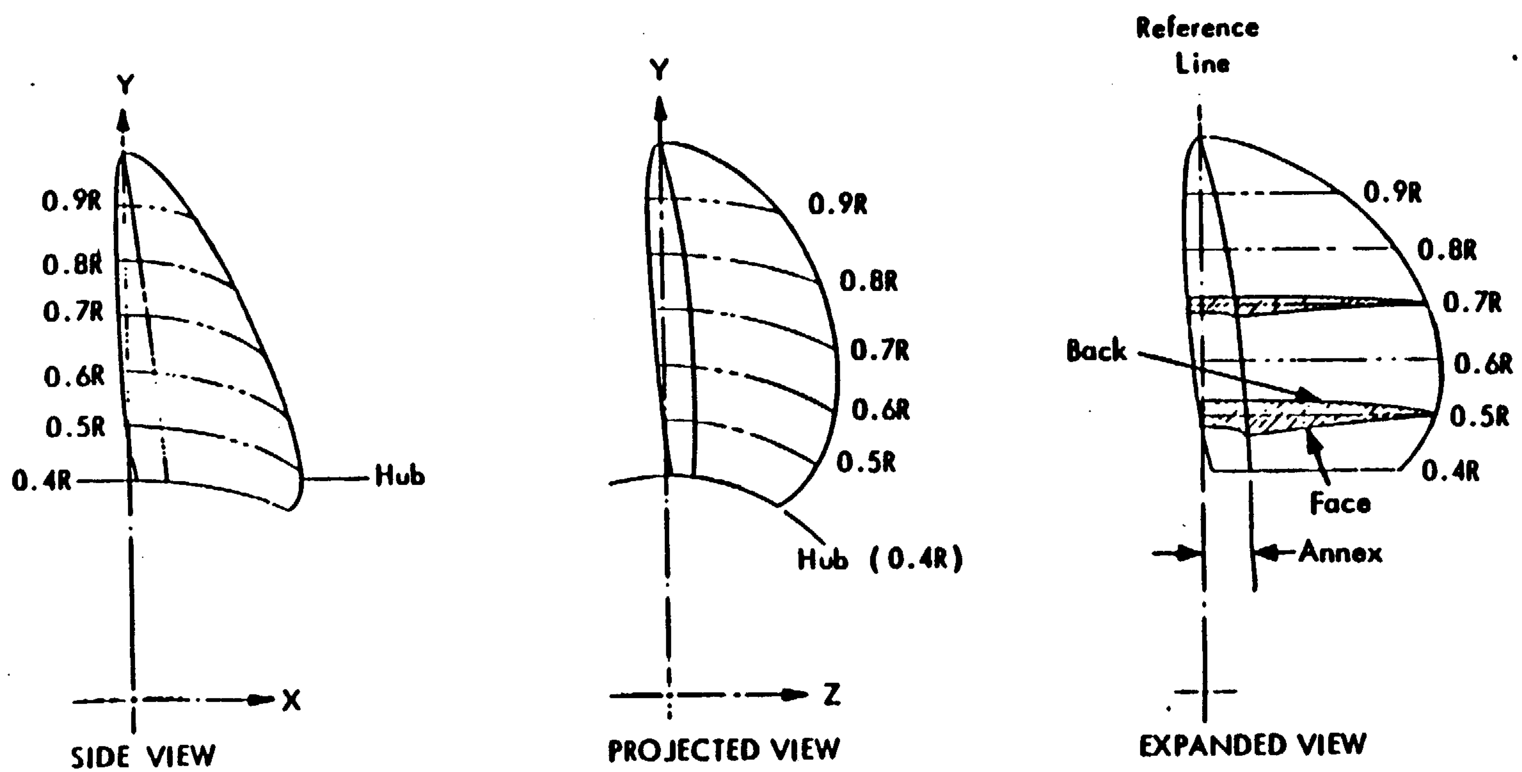


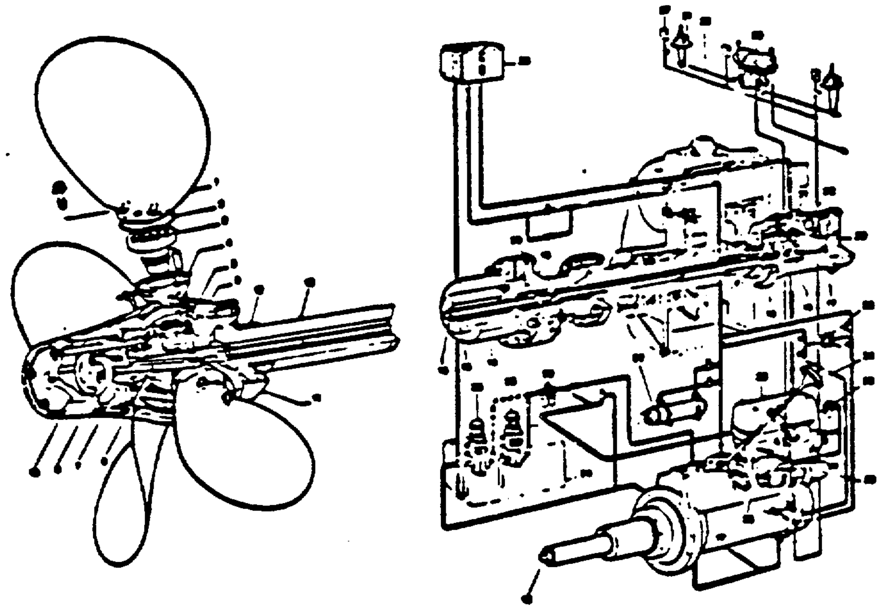
Figure B.1. Ventilated Propeller Shapes and Sections

B.2 PITCH CHANGE MECHANISM AND CONTROLS

Many modern commercial and naval ships use controllable pitch propellers to achieve operating economy and to suit the special requirements of the particular ship. Pitch change mechanisms and their controls have been fully developed as a consequence.

The Tacoma Boat/Escher Wyss type of pitch change mechanism and control is shown in Figure B.2 is briefly described as follows.

Each propeller blade is bolted to a trunnion which carries a crank arm. Each crank arm is linked to a servomotor piston. Hydraulic oil is fed to the piston via a double oil tube from an oil distribution unit mounted within the hull either on the end of the propeller shafting or around the propeller shaft. The double oil tubes are nested inside the propeller shaft. A control valve and feedback system is integral to the oil distribution unit. In response to a pitch change signal, the control valve directs pressurized oil to the servomotor piston. As the piston moves, and causes the propeller blades to rotate on their trunnions, a feedback signal is transmitted back mechanically to the control valve (via the double oil tube) so that when the input signal and propeller blade pitch agree, the control valve spool is centered and no further blade movement occurs. Pressurized oil is supplied from a tank having main and standby electric pumps. The tank is connected to a head oil tank so that when the system is unpressurized there is sufficient head in the propeller pitch change mechanism and hub to prevent ingress of the surrounding water. This mechanism plus the command transmitter, pitch



I. Propeller
1 Propeller blade
2 Blade seal
3 Double supported blade trunnion
4 Adjusting crank
5 Trunnion nut
6 Link
7 Cross head with double supported adjusting rod
8 Servomotor piston
9 Propeller hub
10 Servomotor cylinder

II. Propeller Shaft
11 Protecting hood for propeller shaft flange
12 Bushing of sterntube seal
13 Propeller shaft
14 Coupling flange
15 Double oil tube

III. Oil Distribution Unit
16 Oil distribution shaft
17 Oil distribution box housing
18 Intermediate shaft
19 Control housing
20 Feedback system
21 Control valve
22 Pilot valve

IV. Hydraulic Control System
23 Main and standby control oil pump with electric motor
24 Suction tank (yard's supply)
25 Head oil tank
26 Oil filter
27 Oil cooler
28 Hand pump for mechanical locking device
29 Mechanical locking device,

V. Remote Control and Pitch Indication
30 Command transmitter
31 Slave unit
32 Mechanical connection (yard's supply)
33 Pitch setter
34 Handwheel for local emergency control
35 Mechanical pitch indication
36 Actual pitch transmitter
37 Pitch indicator

Figure B.2. Typical Pitch Change Mechanism and Controls indicator, and normal hydraulic system components comprise a reliable and simple pitch change mechanism and controls. Provisions are made to allow emergency local control in the event of hydraulic failure.

B.3 THRUST BEARING

For the ventilated propeller installation, the sidehull construction in the area of the stern and transom permits placement of the thrust bearing assembly entirely within the sidehull and much closer to the propeller hub than in conventional displacement craft. The proximity of the stern bearing to the thrust bearing permits mounting both bearings in a common housing, with both bearings being lubricated and cooled by circulating oil. This assembly is called the Thrust Bearing Module. See Figure B.3.

Loads are generated by the ventilated propeller in the lateral and vertical directions, as well as in the axial direction. In addition, there is a bending moment generated by the eccentric thrust of the partially immersed propeller, and the weight load of the propeller itself.

By designing the stern bearing and the thrust bearing into a common housing, the two bearings are made to react the lateral loads, the thrust loads, and the bending moments generated by the propeller, while minimizing the risks due to wear and misalignment normally associated with water-lubricated stern bearings.

The design speed of the propellers makes possible the use of a high capacity, tapered-roller thrust bearing to absorb both the forward and

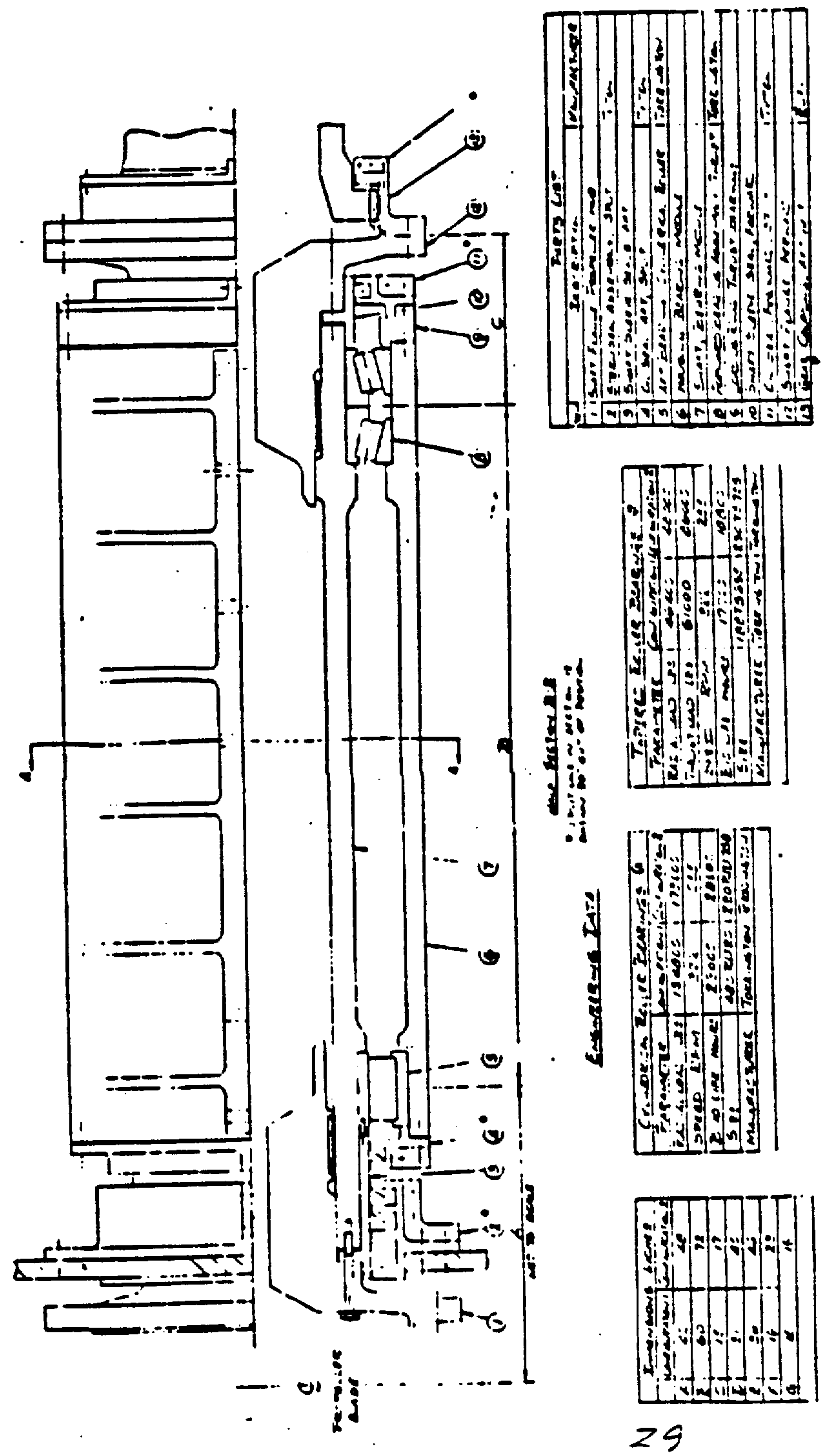


Figure B.3. Thrust Bearing Module

reverse thrust of the propeller, and a high-capacity cylindrical roller bearing to react the loads and moments due to the combined effects of propeller weight, vertical thrust, lateral thrust, and offset axial thrust.

The radial bearing is located aft, closest to the propeller, to minimize the propeller shaft bending moment. The thrust bearing is located at the forward end of the housing to react the axial thrust of the propeller and the lower radial loads that occur at this location in the drive line.

The propeller hub is flanged-bolted directly to the aft flange of the thrust bearing module. The aft half of the gear coupling that connects the propeller to the gearbox is flanged-bolted to the forward end of the bearing module.

The thrust bearing module is foot-mounted in the horizontal plane that contains the shaft centerline, to minimize the load on the hold-down bolts from the axial thrust of the propeller. Since both bearings that support the propeller are oil lubricated, rolling contact assemblies, progressive wear and resulting misalignment that occur in water-lubricated stern bearings are eliminated. This feature is of particular importance when considering the complex loading into the bearings and hull structure that occur with ventilated propellers, and the compounded adverse effects that wear in the stern bearing would produce.

This module incorporated one cylindrical roller bearing that accommodates only radial loads, and a pair of tapered roller bearings in a 'TDI' mounting, to accommodate axial thrust in either direction while providing for slight angular misalignments resulting from shaft deflections. All bearings are lubricated by circulating oil that is filtered and cooled by the system that serves the propeller gearbox. Lube oil to the bearings is supplied by a number of jets evenly spaced around one side of each bearing annulus. The oil to the thrust bearings is fed by separate jets on each side of the assembly, from where is flows through the bearings to the space between the outer races, then to the groove and a gravity drain to a sump; the oil is pumped from this sump to the sump in the gearbox.

Horizontally split oil seals are installed at each end of the module. All parts in each seal assembly may be inspected and replaced without disturbing the bearings or removing the module from its mounting.

Bearings are secured and clamped by hardened steel rings that are shimmed to the proper axial fitup at assembly.

The bearing housing is made from a steel weldment that is stress relieved prior to final machining. The housing is bolted to the ship's structure at two flanges that extend radially outward from the housing, with the bolting surface lying in the horizontal plane that contains the shaft centerline. This construction minimizes eccentric loading of the module housing as well as of the ship's structure under the action of the propeller thrust.

All exposed parts of the bearing module are treated and coated to resist corrosion.

B.4 DRIVE SHAFTS AND COUPLINGS

In order to reduce weight, forged tubular drive shafts are used to transmit torque from the gearboxes to the propeller. Shaft weights are reduced to about 50 percent of the weight of a solid shaft operating at the same design stress. In the case of the propeller shafting, the central hold is used to route the hydraulic oil feed tubes for the controllable pitch propeller from the control unit, located on the forward side of the gearbox, to the propeller hub outboard of the thrust bearing module.

All shafts are machined from through-hardened alloy steel, and are designed for combined stresses in bending and torsion that do not exceed 10,000 psi at the maximum load conditions. Exposed sections of shafting are coated to resist corrosion.

Torque through the thrust bearing module is transmitted by means of flanges splined, piloted, and bolted to the shaft ends. All splines are registered by means of a long pilot on each side of the spline. In the thrust bearing module the replaceable seal sleeves are clamped by the bolting interface for the spline to minimize the number of loose pieces; the seal sleeves serve also as the clamping rings for the inner races of the radial and thrust bearings.

The size of the drive shafting in each configuration was determined by the bore size of the thrust bearing required to react the propeller thrust load. An additional factor was the need for a hollow shaft in which to install the piping and control transfer mechanism for the controllable pitch propeller.

The weight of the drive shafting was determined by the outside diameter and the design stress level. The shafting for these applications is designed primarily to transmit the torque from the gearbox to the thrust bearing module, with a very minimum of bending. The radial loads and bending moments due to the ventilated propeller are reacted by the bearings in the thrust bearing module (thrust block) at the transom. The shaft bore size was determined on the basis of the allowable torsional shear stress, which was set at a maximum value of 6000 psi at maximum engine torque.

The shaft sizes for both propulsion plant configurations, as determined from these considerations, are tabulated in Figure B.3.

SHAFT COUPLINGS

Because of the low propeller speeds in both configurations, the large propeller shaft torques are beyond the range of most commercially available flexible couplings. Flexible couplings are considered necessary to accommodate misalignments, thermal differential expansion between the steel machinery and the aluminum sidehulls, and distortions in the sidehulls due to conditions that include off-cushion and on-cushion operation under wide ranges of loading in various sea states. A preliminary survey of available couplings indicated that the propeller torques for both propulsion plant configurations exceed the capacities of commercially available disc and diaphragm couplings. Available grease-lubricated gear couplings manufactured by Zurn (Reference 6) were found to have torque capacities adequate not only for the present torque loads, but for torque loads well in excess of present requirements. In the torque ranges in which disc couplings are available, the weights of the disc and gear couplings are comparable. Therefore, it is expected that no weight penalties will develop when gear couplings are applied to the subject drive lines. From the layouts made in the course of developing the concepts for the thrust bearing modules, the proportions of the gear couplings are consistent with those of the shafting and the thrust bearing modules.

B.5 WATERJET PERFORMANCE

Conceptual waterjet installations were reviewed to provide comparative inputs to the propeller selection process. Figure B.4 shows that, in general, waterjet propulsors have a lower efficiency than propellers. This reflects directly on range and speed performance. The conclusion is confirmed by comparison of the ALRC PHM waterjet pumps and ventilated propellers shown in Table B.1.

For low speeds, i.e., about 18 knots, the thrust/efficiency values for waterjet propulsion were calculated using two PJ-24 pumps powered by SACM195V20RVR diesel engines. This is in accordance with current practice for waterjet propelled ships whereby a separate cruise or low speed propulsion mode is furnished by a separate system. Examples of these cruise systems include the PHM hydrofoil, the "American Enterprise" crew boat and "HMS Speedy", a hydrofoil patrol ship very similar to the

"Jetfoil" hydrofoil ferry. For the NASW SES the cruise waterjet diesel would drive the lift fans in the cushion-borne mode when propulsion is by the maint LM2500 engines.

The values of thrust given in Table B.1 show that for the NASW SES, two waterjets would give approximately 5 knots less off-cushion top speed when compared to two propellers and approximately 10 knots less on-cushion top speed. These differences do not take into account the weight differences of the two installations which are judged to be in favor of the propeller ship propulsion machinery largely because of the entrained water in the inlet ducting and waterjet pump. This weight would affect, primarily, range since less fuel could be carried.

In view of these results, waterjets are eliminated early in the study phase.

B.6 FULLY SUBMERGED PROPELLER

A brief study of a fully submerged trans-cavitating propeller was sized to verify its suitability as a backup to the baseline partially submerged ventilated propellers. The performance appears to be acceptable and could be implemented if required.

SUBMERGED PROPELLER PERFORMANCE

Submerged propellers were selected using cavitation tunnel data. This data contains the effect of blade area ratio, pitch angle and cavitation

Table B.1. Comparison of Waterjets and Propellers (1500LT)

	Ship Speed Knots	Engine Power SHP [3]	Two Waterjets Thrust Lb	Two Waterjets Efficiency	Two Propellers Thrust Lb	Two Propellers Efficiency
	15	3700	46,000	.29	72,134	.46
(1)	18	3700	42,000	.31	72,127	.56
	22	3700	38,000	.35	67,159	.63
	30	22,500	153,776	.33	207,749	.44
(2)	40	22,500	141,920	.41	206,791	.58
	50	22,500	130,847	.48	189,788	.67

(1) Off-Cushion

(2) On-Cushion

(3) Rated engine power - 2 engines per ship

index of the water velocity approaching the propeller. An advantage of the submerged propeller is good performance both at speeds of at least 50 knots and at low speeds. Characteristics of the chosen design are:

Number of Blades	3
Blade Area Ratio	0.48
Hub/Tip Diameter Ratio	0.3
Thrust/Disc Area	Less than 1000 psf
Appendage Hull	0.91
Diameter	11.6 ft
RPM	214
N PROP	.72
N GB	.97
N BRGS	.98

The efficiency losses associated with each propeller type installation and the uncertainties associated with each installation differ. For the ventilated propeller there is little drag associated with its installation. A small fairing before the propeller boss and a rudder forward of the propeller are used on each sidehull, for the submerged propeller there is judged to more drag associated with its installation. A summary of rudder and appendage drag aspects follow.

RUDDER DRAG

Ventilated Propeller	Submerged Propeller
o Larger area rudder not in propeller jet.	o Smaller rudder in propeller jet.

o Propeller jet swirl not reduced by rudder ahead of propeller disc.	o Propeller jet swirl reduced by rudder; can increase propeller efficiency.
o No propulsion benefit from rudder. Effect of rudder flow into propeller requires evaluation but estimated small.	o Possible efficiency benefit requires evaluation but estimated small.

OTHER APPENDAGE DRAG

o Propeller hub drag is assumed included in Navy performance data.	o Propeller hub drag included in Newton and Radar data.
o No struts, bossings, shaft fairings.	o Drag associated with struts, bossings and shaft fairing.
o Drag of hub/thrust bearing module fairing ahead of the propeller not included in performance. o No appendage drag used in ventilated propeller performance. Requires evaluation.	o Appendage drag of 9 percent included in submerged propeller performance predictions based on planning craft data. Requires further evaluation for SES craft.

Both propeller types have been successfully demonstrated at high ship speeds. The ventilated propeller is fitted to the SES-100B. The submerged propeller type has been fitted to 50 knot craft and has performed well. At this time adequate performance for the NASW is indicated using either propeller type based on available data.

B.7 WEIGHTS

Weight estimates for the lift and propulsion equipment have been made based on manufacturer's data for standard off-the-shelf machinery, responses to requests for quotation where special equipment was involved and on designs and calculations based on the installation layouts. All components and subsystems have been sized in accordance with the performance requirements. The total weight of the equipment for the lift and propulsion systems is 238 long tons. Descriptions of the items in each SWBS 3-digit group follow.

DIESEL ENGINES (SWBS 233)

Four engines in two sizes are used for the propulsion and lift fan drives; these are the SACM 195V12RVR's and two are SACM 195V20RVR's. The engine weights, including their respective standard accessories packages are from catalog information.

TURBINES

An LM2500 gas turbine engine in production by the General Electric Company is installed in each sidehull. The exhaust collectors are included as part of the engine weights. The weights of the lube oil systems external to the engine are included in SWBS item number 262.

GEARING

There are six gearboxes in the lift and propulsion system; four are modified versions of standard parallel-shaft increase and are used in the lift system drives; the other two are special combination designs of parallel-shaft and planetary gearing and are used in the propulsion system. Weight estimates for the lift fan gearboxes are based on catalog data; the weights of the gearboxes for the propeller driven are based on preliminary design layouts developed by the Cincinnati Gear Company. The lube system weights for all gearing are included in SWBS item number 262.

CLUTCHES AND COUPLINGS (SWBS 242)

The weight of equipment in this category comprises those components installed or mounted remotely from the engines and gearboxes. Included in this group are the flexible couplings between the propeller gearboxes and the propeller assemblies, and the overrunning clutches installed between the gas turbines and the propeller gearboxes.

SHAFTING AND SEALS (SWBS 243)

The weights in this category include only the shafting and seals that are separate from equipment such as the engines, gearboxes, fans, etc., and involve primarily the lift fan and propeller shafting and the stern seals.

BEARINGS (SWBS 244)

Included are the special bearing assemblies designed to support the propellers and the aft ends of the turbine engine shafts. The weights of all other bearings are included in the weights of the equipment in which they are installed.

PROPELLERS AND CONTROLS (SWBS 245)

The weights tabulated comprise those of the controllable pitch propellers and the associated hydraulic actuators and controls, including piping and valves. The weights of the propeller shafting and thrust bearings are listed under SWBS 243 and 244, respectively.

LIFT FANS (SWBS 248)

Six lift fans are installed, two forward and two in each sidehull. All fans are the same size and capacity. The fan weights include inter-connecting shafting, couplings, and the ductwork required for installation.

COMBUSTION AIR SYSTEM (SWBS 251)

This equipment comprises two sets of demisters and filters, one set per sidehull, to condition the combustion air for the gas turbines. Included are the weights of the acoustic treatment and the anti-ice equipment for the duct walls.

Propulsion Control (SWBS 252)

The propulsion control equipment comprises the controls and monitoring equipment for the gas trubines and the diesel engines, but does not include the controls for the controllable gas propellers, which are included in SWBS item number 245.

Uptakes (SWBS 259)

The weights of the uptakes include the weights of the exhaust ducting for the gas trubines and for the diesel engines.

Lube Oil Systems (SWBS 262)

The lube oil systems comprise the main pumps, auxiliary pumps, heat exchangers, filters, valves, and piping for the gas turbines and the lift fan and propulsion reduction gears. The lube systems for the diesel engines are included as part of the engine accessories packages in SWBS item number 233.

Operating Fluids (SWBS 298)

The weights of the operating fluids include the lube oil and cooling water for the turbines, diesel engines, and the lift fan and propulsion gearboxes.

B.8:TECHNICAL RISK

The following subsections are a discussion of the technical risk for the prime movers, the propulsors, and the reduction gearing.

B.8.1 PRIME MOVERS

The ancillary system for the prime movers are all within the state of the art. The air inlet system, a combination of ducting, demisters with by-pass provisions, anti-ice systems and noise suppression measures have all been applied to modern ships in commercial and Navy service with excellent results. The inlet system for the SES is a completed design which was fully model tested for performance during the 3KSES Program. All gas turbine and diesel powered craft and ships have similar air inlet systems. Similarly, exhaust/uptake systems, usually comprised of gas turbine and diesel connections, ducting, sound suppression material/items and weather closures, are well known, within the state of the art and show good service.

DIESEL ENGINES -- The MTU 16V538TB82 and alternative engines are representative of modern, reliable, high specific power, high speed diesels being used in increasing numbers for all applications world-wide. These engines are fully developed rugged units with superior economy at part and full load and are considered low risk.

GAS TURBINES -- The GE LM2500 gas turbine is a fully developed free turbine unit currently in Navy inventory. Service experience includes the DD 963, the FFG 7, the PHM and ships of foreign Navies. There is low risk associated with its selection.

REDUCTION GEAR — The reduction gear design is a low risk conservative, state-of-the-art design furnished by the Cincinnati Gear Company. The design has not been compromised by small size, weight or low cost approaches which would reflect on reliability. Premium grade steels and conservative stress levels combined with a rigid casing, generous bearing areas, high capacity lube supply and fully factored loadings give confidence in the design. The reduction gear designs which are proposed do not require developmental activity or unusual manufacturing techniques.

Comparable in-service reduction gears designed and manufactured by the Cincinnati Gear Company include the parallel offset reduction gearbox for the Boeing Jetfoil and the combined drop/epicyclic gearbox for the American Enterprise craft.

B.8.2 PROPULSORS

Of the propulsors evaluated, the submerged (conventional) propeller for high speed craft, is considered to be the lowest risk. Many have been, and are currently being used, for high speed naval craft such as the PC and PCG. Vendors are therefore experienced in the manufacture of these propellers and much is known about propeller blade performance. The high speed ventilated propeller blade does not enjoy the benefit of previous service experience except in the SES-100B test craft and many smaller racing craft. It follows that manufacturing expereince for the ventilated propeller is lacking.

Pitch change mechanisms and controls have minimal technical and producibility risk when associated with submerged and ventilated propellers. These systems are now employed extensively on commercial and naval ships. The same mechanisms and controls associated with ventilated propellers also have low risk because of the extensive experience with these mechanisms on large tankers and are carriers that routinely operate partially submerged in a ventilated condition while transiting in ballast.

B.9 COMPONENT AND SYSTEM RELIABILITY

The selection process for the equipments for the propulsion machinery configurations used reliability as one of the driving parameters. The high reliability of the chosen equipments with the diesel engines used for lift power for off-cushion operations assures a very reliable ship. Redundancy for off-cushion is provided with the gas turbines, however, they will be operating inefficiently on the low end of their power curve. This case then, would be for emergency operation only.

The MTU diesels and the LM2500 gas turbine have been proven reliable. The LM2500 is currently in Navy inventory. The diesels are in commercial/industrial and European naval use. The combination of engines chosen for the arrangements offers an efficient reliable match.

The propulsion transmission trains feature Cincinnati Gear Company gearbox designs. These designs utilize conservatively loaded gears and journal bearings which result in gearboxes that are durable and reliable. A typical combat mission profile was used as a basis for reliability evaluation (Reference: Medium Displacement Combatant Surface effect Ship Technical Report, April 1981). This profile does not have any operational conditions that would affect the inherently high reliability of the proposed gearboxes, which feature conservatively designed helical hears mounted in journal bearings. The SSS overrunning clutches and the air clutches that are used to engage/disengage the diesels are mounted on the outside of the gearbox. These clutches are reliable and commonly used in marine and industrial applications. The demisters and exhaust system in all configurations are of straightforward design and are not considered to be reliability-critical. These power trains will be very reliable in any of the configurations presented.

The Tacoma Boat/Escher Wyss propeller design includes the pitch controls, instruments, sensors, the hydraulic system which contains pumps, hydraulic controls, oil collers, filters, valves and fittings, the propeller and the pitch change mechanism.

Since the ship thrust and the ship maneuvering capability are dependent on this system, high reliability of these parts are mandatory. The Tacoma Boat/Escher Wyss propeller and associated equipment, has proven capabilities on previous designs. The highest probability of failure occurs in the elements of the hydraulic system. For this reason redundancy in pump and controls is provided. Additional redundancy is provided in the manual control. In the event of a complete breakdown of the hydraulic system, the propeller can be mechanically locked in an ahead position by means of the linkage between the propeller blades and the double oil tube.

B.10 MAINTAINABILITY ASSESSMENT

The maintenance philosophy for the SES is minimum preventive maintenance while operational. Corrective maintenance onboard ship will be limited to removal and replacement of mission-essential equipment. This philosophy dictates a total maintenance concept that demands high reliability parts with most maintenance performed while the ship is in port.

Removal and replacement of major items is discussed in 4.3.2.1. The following maintainability criteria were applied in developing the concepts described in this report.

a. No secondary equipment removals required for access.
b. Adequate access doors for all equipment with sliding or hinged covers.
c. No structural cutouts for equipment access.
d. Adequate access around all equipments for inspections, checks, adjustments and corrective in-place maintenance.
e. Cathodic protection for dissimilar metal joints.
f. Standardization of fasteners/parts/materials.
g. Quick disconnect latches, cables, lines, etc.
h. Minimizing special tools and test equipment.

All the heavy components such as gear boxes, engines, etc., will have lifting lugs. Maintenance rails are provided on special removal paths through combustion air inlet or the fan air inlet for major equipment.

The Escher Wyss propeller is a highly maintainable design. The mechanical pitch change mechanisms in the propeller hub is designed for the life of the ship and requires no maintenance. The hydraulic activation system which requires some maintenance is installed in the shafting within the ship. Accessibility is provided for all scheduled and unscheduled maintenance required in the mechnism itself. Access from the engine room around the equipment is satisfactory for the various installations.

Escher Wyss has estimated a 6.9 hour MTTR for the hydraulics and controls. Ready access for these systems on the machinery arrangements presented assure that the baseline MTTR will hold at 6.9 hours.

All similar parts, including repair parts, are interchangeable without additional machining or selective assembling. Daily maintenance is minimal involving oil level and oil filter checks.

B.11 PRODUCIBILITY

All components and assemblies for the Propulsion System Configuration have a solid manufacturing base relative to state-of-the-art practices, tooling and machines.

The gas turbine and diesel engines are in series production.

The reduction gear designs as selected by RMI and Cincinnati Gear do not present producibility problems beyond learning curve development during manufacturing and test of the first reduction gear set.

Propeller size and materials for fully submerged propellers do not pose producibility problems since much larger conventional propellers in similar materials have been manufactured and are in service both in commercial and naval ships. For the ventilated propeller, there may be a need for manufacturing development since the blades will be made of harder and tougher alloys to resist the generally higher steady state and alternating stress levels used for ventilated propellers. It is held, however, that overall, the task of producing either a conventional submerged propeller or a ventilated propeller is about the same providing some manufacturing development is performed on the ventilated propeller.

The other aspects of the propeller, the CP mechanism and controls, present no producibility problems, being state of the art and familiar to vendors.

The thrust bearing module and shafting are custom designed. They present no producibility problems. The bearings and couplings are catalogue items and seals are similar to items in service.

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APPENDIX C

STRUCTURAL DESIGN

C.1 RATIONALE FOR USING RELIABILITY BASED METHODS

This appendix summarizes the rationale and methods used to estimate structural weight and provide structural design criteria for structural design when reliability based load and design methods are used.

The order of presentation is as follows: section C.1 provides the rationale for using reliability based methods, especially for vehicles for which a large experience base does not exist; section C.2 presents the method for developing loads and shows how it can be applied; section C.3 discusses design and fabrication.

It has been found from experiments that the cause of the greatest load acting on a ship's structure is different for different ship types. For a monohull, the longitudinal bending moment arising from differences between weight and buoyancy loads (W-B load) is dominant; for a SWATH, the transverse bending moment due to forces acting on the sidehulls is largest or dominant; while for SES's the off-cushion longitudinal load due to head sea slamming in survival sea states is dominant.

A reliability based method of selecting design loads was selected for the SES as a large historical data base does not yet exist. This method makes possible the extrapolation of experimental and service data, as well as analytical results. The reliability approach allows the direct use of results obtained from consideration of first principles in the various disciplines associated with ship design, and shows the effects of the variables of interest upon structural weight and reliability.

In summary, the use of reliability based methods for design allows technology independent evaluation criteria to be established for comparing ship types or variants within a given ship type and gives the engineer or project manager a method for evaluating the effect of proposed reliability level changes upon the mission effectiveness and the cost of the design.

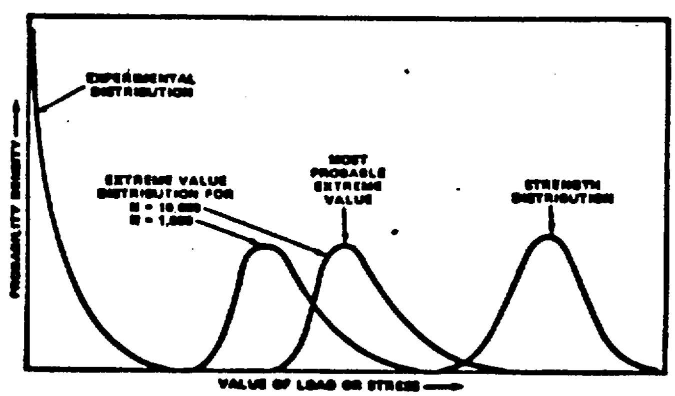
C.2 USE OF RELIABILITY METHOD IN PREDICTING STRUCTURAL WEIGHTS

Structural weight is a function of the operational profile (the table of the lifetime hours spent in each sea state and speed for each operating mode), the required reliability, the simultaneously acting loads, the materials used, and the design stress analysis methods employed.

In order to make clearer the origin of uncertainties in load and strength estimation, please refer to Figure C.1. Figure C.1 shows four probability density (not probability) curves. The curve on the left shows an experimental or parent probability distribution. The two curves in the middle show the probability density of the largest load plotted against load magnitude for two different experimental sample sizes. The right-hand curve shows the probability density of the strength (resistance) of the structure plotted against applied load magnitude.

The distribution curves shown in figure C.1 may be thought of as arising in the following manner. First, a largest load distribution curve. Suppose that a large number j of experimental runs to measure loads are made in a random seaway, each run of which has a number of wave

Figure C.1



Probability Density Distributions.

encounters resulting in n pitch cycles for the run. For each pitch cycle we record the maximum value of the load during that pitch cycle. Each run has a certain largest measured value among the loads thus recorded. If we count the number of largest values from all runs which lie between load L and L + L and divide by the toal number J of largest values we obtain an estimate of the probability density at L + L/2 which may then be plotted. If we continue in this fashion we will trace out the shape of the probability density curve of the largest load values. This probability density curve is called the extreme value distribution curve for the sample size J, and its exact shape depends also upon the statistical distribution (the experimental or parent distribution) which describes the physical process which gives the experimental load samples. Note that the shape of the load probability density curve is skewed to the right.

Second, the strength distribution curve. If we build a large number of ships having the same nominal dimensions, general arrangements, and scantlings, and then load them to failure, there will be a range of failure loads since there are strength variations due to variations in the strength of the plates and shapes, in the shape thicknesses, in the straightness of plates and shapes, in the weld strength, in the quality of fit up (alignment), in the principal dimensions and location of decks and stiffeners on decks, in the residual welding stresses, and in the amount of stress relieving. If we follow the same procedure of counting the number of occurrences in a load zone and dividing by the total number of occurrences and plotting resulting values we will approximate the shape of the strength or resistance probability density curve.

Note that most probability density curves have a peak. The magnitude of the load corresponding to the peak of the extreme load probability density load is called the most probable extreme load, and corresponds to the most often occurring, or most likely extreme or largest value measured during a test of many samples. The magnitude of the load corresponding to the peak of the strength curve is called the most probable strength.

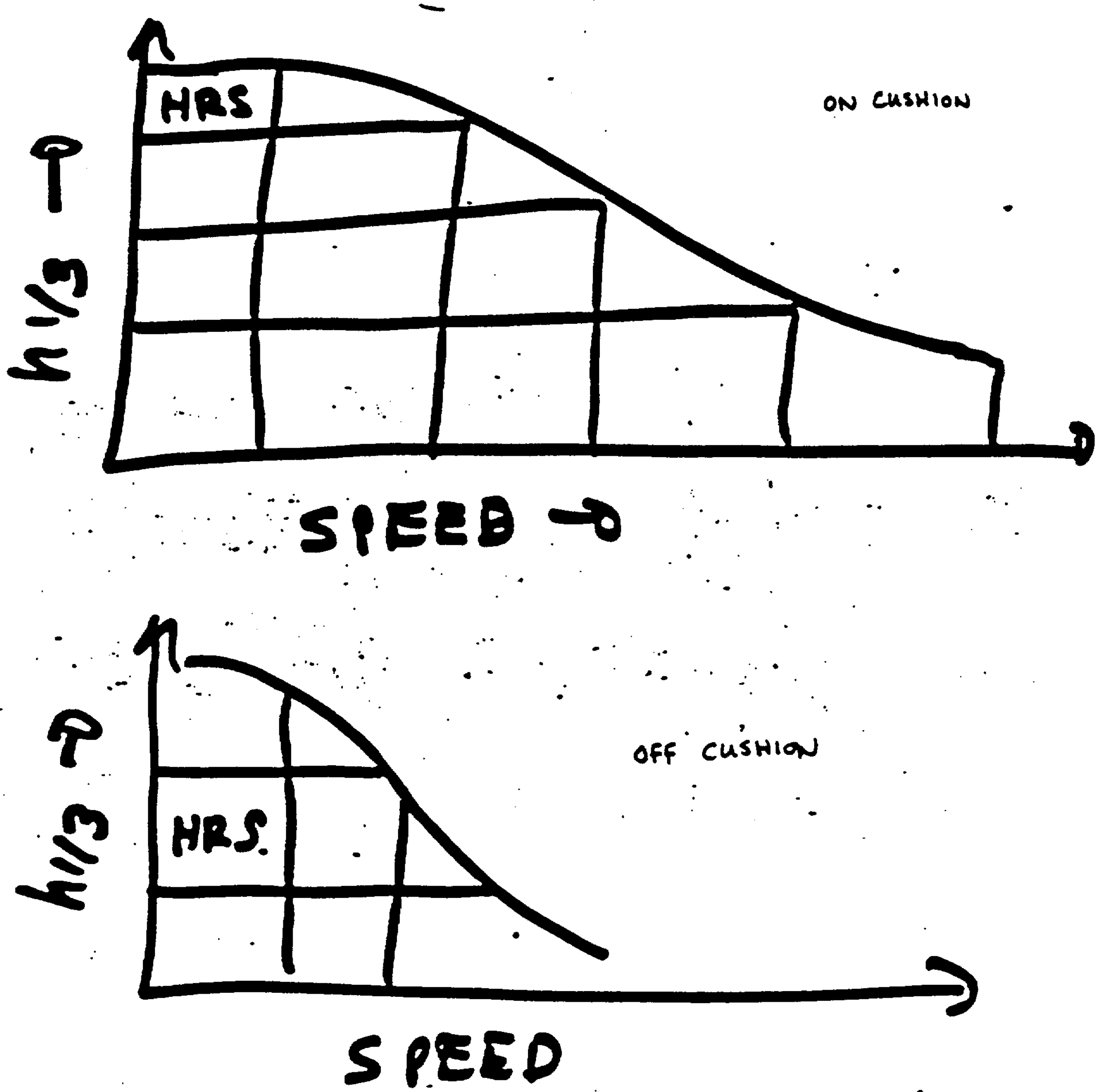
The shape and magnitude of the largest or extreme load curve can be found by applying extreme value theory, Ref. C-1, to the results of experimental tests. The exact shape and magnitude of the structural strength (resistance) curve is unknown, but ongoing work is aiding in the delineation of this curve. In the meantime, two assumptions are made: first, that the shape of the curve is Gaussian, and secondly, that the overall strength of the ship is taken to be that corresponding to the yield strength of the material in tension (not the ultimate strength), or the buckling strength of local structure as computed using Navy standard design practice, where the yield or buckling strength is taken to be that corresponding to using the as welded minimum mechanical properties. There are three elements of conservatism in using this approach (1) 99 percent of the welded joints are stronger than minimum mechanical properties, (2) the difference in strength between yield and ultimate strength is ignored, and (3) the post buckling strength of the structure, which may range from 1.3 to 2.0 times the yield buckling strength, is ignored.

C.2 LOAD ESTIMATION

Load estimation consists of using the operational profile, which specifies the lifetime hours spent in each sea state and speed combination, both hullborne and cushionborne, and then (1) finding the distribution of loads corresponding to each sea state-speed combination as a function of exposure time, and (2) finding a fixed load for design such that the risk of exceeding such fixed load over all operational profile combinations corresponds to the required reliability. Risk is here defined to be equal to (1.0 - reliability). Figure C.2 is an example of an operational profile where the number of lifetime hours is given for each sea state-speed combination. The upper number in each cell is the lifetime hours, the lower number is the number of head sea encounters in thousands.

Experimental results show that there are two physical processes contributing to SES loads in a seaway consisting of random waves. One is due to the difference between the weight and the buoyancy along the ship at any instant of time. The second is due to slamming, usually in the bow region, due to ship motion induced by the waves. Slamming is usually dominant for determining hullborne SES loads since it is often two to six times the W-B load. The frequency and severity of slamming is a function of speed, wave height, and wet deck clearance above the off cushion calm water line.

FIGURE C.2 OPERATIONAL PROFILE



There are two steps in using the load information: (1) find the statistical distribution (called the parent distribution) which best describes the data collected in a run, and (2) estimate the extreme value corresponding to this distribution, the exposure time, and the specified reliability.

PARENT DISTRIBUTION

The method of using the load magnitude information to estimate the parent distribution parameter values from experimental data is as follows: record the largest magnitude found in an interval of time long enough such that the occurrence of one event does not influence the magnitude of a subsequent event, i.e., each event is independent of other events. Order these events by magnitude from smallest to largest. Estimate the values of the parameters of the statistical distribution which best fits the data. A statistical distribution which fits both the W-B forces and the slam forces is the Weibull distribution with probability given by

$$P = 1.0 - e - ((\quad (v - Vo)^{c}) \qquad (1)$$

P = probability that the value of the variable is V or less

= scale factor

V = variable such as load or response

Vo = truncation value (value below which the probability is always zero)

c = exponent

c = 2 specifies a Rayleigh distribution which characterizes the W-B

distribution while c = 1 specifies an exponential distribution which characterizes a slam distribution. The Weibull distribution has also been found appropriate as in describing commercial ship loads, Ref. C-2.

The probability density for the parent (experimental) distribution is given by

$$p = \frac{\partial P}{\partial x} = c * ((\lambda(v-v_0))^{(c-1)} / * e^{-((\lambda(v-v_0))^c)} \quad (2)$$

Note that if we define x = (V-Vo) and substitute we obtain.

$$P = 1.0 - e^{-(x^c)} \quad (1a)$$

and

$$P = c * (x^{(c-1)}) * e^{-(x^c)} \quad (2a)$$

EXTREME VALUES

The extreme value distribution probability density equation if

$$f = n * (P^{(n-1)}) * P \quad (3)$$

Where

f = extreme (largest) value probability density distribution

n = sample size

P = parent probability distribution

P = parent probability density distribution

The extreme value distribution is a function of the parent distribution and the exposure time where n is the number of encounters or events expected during a given exposure time.

The above expression may be directly integrated to give the probability F associated with qan extreme value

$$F = P^{n} \qquad (4)$$

Which for the Weibull distribution as a parent distribution results in

$$F = (1 - @ - (x^{c}))^{n} \qquad (5)$$

To find the load corresponding to a specified probability od exceedance when the parent distribution and sample size are known solve eq (5) for x to obtain

$$x = \left(\ln \left(\frac{1.0}{(1.0 - F^{1/n}} \right) \right)^{(1.0/c)} \qquad (6)$$

Table C.1 lists magnitudes of x for various values of F, n, and c. f is the ratio to the area below the value of x to the total area (the probability), n is the sample size, and c is the slope of the Weibull distribution.

TABLE C.1 - VALUE OF EXCEEDANCE LOAD FOR THE WEIBULL DISTRIBUTION

PROB F	PROB OF EXCEEDANCE	NUMBER OF EVENTS, N	NON DIMENSIONAL VALUE OF LOAD C = 1.0	C = 2.0
0.3679	0.6321	10**3	6.908	2.628
		10**4	9.210	3.035
		10**5	11.51	3.393
		10**6	13.82	3.717
0.999	10-3	10**3	13.82	3.717
		10**4	16.12	4.015
		10**5	18.42	4.292
		10**6	23.03	4.799
0.9999	10-4	10**3	16.12	4.015
		10**4	18.42	4.292
		10**5	20.72	4.552
		10**6	23.03	4.799
0.999	10-5	10**3	18.42	4.292
		10**4	20.72	4.552
		10**5	23.03	4.799
		10**6	25.33	5.033
0.999	10-6	10**3	20.72	4.552
		10**4	23.03	4.799
		10**5	25.33	5.033
		10**6	27.63	5.257

The most probably extreme value (the value at the peak of the extreme value probability density curve) occurs, for the sample sizes shown, at F = 0.368. This means that if 1,000 vessels were sent into the same sea state for the same amount of time at the same speed, heading, and initial load conditions, 632 of them would experience a load greater than the most probable (most often occurring) load. It will be noticed that the most probable load increases with the number of encounters (the exposure time).

In order to arrive at a load to be used for design in a given operating condition, the most probable load is increased by a factor corresponding to the risk (probability) of exceedance which is specified. Such a factor is the ratio for the (exceedance load/most probable load). These ratios, obtained from Table C.1 are given in Table C.2.

TABLE C.2 - RATIO OF EXCEEDANCE LOAD TO MOST PROBABLE EXTREME LOAD

PROB F	PROB OF EXCEEDANCE	NUMBER OF EVENTS, N	RATIO OF EXCEEDANCE TO MOST PROBABLE c = 1.0	c = 2.0
0.3679	0.6321	10**3	1.00	1.00
		10**4	1.00	1.00
		10**5	1.00	1.00
		10**6	1.00	1.00
0.999	10-3	10**3	2.00	1.41
		10**4	1.75	1.32
		10**5	1.60	1.27
		10**6	1.50	1.23
0.9999	10-4	10**3	2.33	1.53
		10**4	2.00	1.41
		10**5	1.80	1.34
		10**6	1.67	1.29
0.99999	10-5	10**3	2.67	1.63
		10**4	2.25	1.50
		10**5	2.00	1.41
		10**6	1.83	1.35
0.999999	10-6	10**3	3.00	1.73
		10**4	2.50	1.58
		10**5	2.20	1.48
		10**6	2.00	1.41

It will be noted that for a given probability of exceedance the ratio decreases with increasing sample size so that the greater the operational exposure in a cell, the smaller the factor required to cover a given probability of exceedance. It should also be noted that the larger the value of c, the smaller the factor required to cover a given probability of exceedance. Larger values of c correspond to non slam loadings, and so current practice from a structural loads point of view is to have a high wetdeck clearance hullborne, and to operate on cushion so as to minimize slamming frequency and slamming magnitude.

EXTREME VALUE FOR DESIGN

The extreme value used for design is the one for which the risk of exceedance, over the operational profile, meets the specified risk of exceedance. For each cell in the operational profile there is a given risk of exceedance of a specified load. The risk of exceedance for the entire operational profile is the statistical sum of exceedance for all the cells. In order to proceed we need to a) find the risk of exceedance in a given cell, and then b) sum in a probability sense the risk for all the cells.

a) Exceedance in a specific cell. Suppose the vessel has a certain strength. Determine the probability of not exceeding this strength for the operating conditions and duration specified for a particular cell in the operational profile. For example, the first line of Table C.3 shows the probability of not exceeding the strength for operating condition cell one. Denote this reliability = (1 - 3.62* 10-4) = 0.999638 by F1.

b) Overall reliability and risk. Having found the reliabilities for each operating cell, find the overall reliability by using

Rn = Fi (7)

where

Rn = reliability for n cells

Fi = reliability for the ith cell

The risk is (1-Rn). Table C.3 shows typical results. it will be noted that the high sea state conditions, and the higher speeds in a given sea state, provide most of the risk. For most operating profiles, most of the risk is associated with the boundary cells which are called the operational envelope. Further, for most hull horn borne operating envelopes the high sea state operating conditions (survival conditions) provides most of the risk.

TABLE C.3 - RELIABILITY FOR HEADSEA HULLBORNE OPERATIONAL ENVELOPE OP1

CELL	ENCOUNTERS, THOUSANDS	WEIBULL SLOPE = C	MOST PROBABLE LOAD	SES STRENGTH	PROBABILITY OF EXCEEDING STRENGTH (RISK)
H3,V1	20	1.0	10	18	3.62 * 10-4
H2,V1	90	1.4	6	18	7.76 * 10-19
H2,V2	90	1.2	9	18	3.74 * 10-7
H3,V1	240	1.7	2	18	10-100
H3,V2	250	1.5	4	18	7.41 * 10-47
H3,V3	220	1.3	8	18	1.03 * 10-10

Overall reliability = 0.999638, Overall risk = 3.62 * 10-4

If the operating profile is changed, the risk can again be estimated. Table C.4 shows two such changes, one where the operating time in a high sea state cell (OE2) is changed by a factor of 2, and one where a lower sea state cell (OE3) is changed by a factor of 10.

TABLE C.4 - EFFECT ON RISK OF INCREASING NUMBER OF ENCOUNTERS

	ENVELOPE OE1		ENVELOPE OE2		ENVELOPE OE3	
CELL	ENCOUNTERS THOUSAND	RISK	ENCOUNTERS THOUSAND	RISK	ENCOUNTERS THOUSAND	RISK
H3,V1	20	3.62*10-4	40	7.25*10-4	20	3.62*10-4
H2,V2	90	3.74*10-7	90	3.74*10-7	900	3.74*10-6
H1,V3	220	1.03*10-10	220	1.03*10-10	220	1.03*10-10
Overall Encounters	330		350		1140	
Risk		3.62*10-4		7.25*10-4		3.66*10-4

The probability distribution for each cell stays the same because the sea state and speed are still the same. The change in reliability occurs because of the change in the duration or time spent in a particular operating condition. Note that in both cases the risk increases (the longer one is at sea, the greater the risk). If we compare the risk for the two changed operating conditions OE2 and OE3, we see that the risk for OE2 is greater than the risk for OE3 even though the change in the number of encounters for OE2 is much less than that for OE3. This example shows that the overall risk is primarily a function of the severity of the operating conditions in a cell, and that the overall risk must be obtained by summing the risk for each cell rather than by summing the number of encounters. Put another way, the vessel runs a higher risk by doubling the number of hours spent in a survival sea state than by increasing by a factor of 10 the number of operating hours in a less severe sea state.

CUMULATIVE FATIGUE LOADING

In order to determine whether fatigue is controlling the stress level corresponding to a given load must be estimated.

The cumulative fatigue loading may be estimated by application of a cumulative damage rule such as Miners rule:

$$\frac{ni}{Ni} = K \qquad (8)$$

ni = actual number of cycles at level i

NI = number of cycles at level i to cause failure (usually obtained from S-N curves for the material)

K = constant of summation, approximately 1/3 to 1/4 for 3 to 4 ship fatigue lifetimes

In order to apply Miner's rule, we need to know the number of loading cycles for each loading intensity. This information is known since we have the experimentally estimated probability density loading curves which were earlier used to estimate the extreme values. As before, we estimate the cumulative fatigue damage for each cell, and then sum the cumulative fatigue damage for all cells to find the overall fatigue damage. The stress which is used for computation is the nominal stress times the stress consultation factor applicable at a particular location. If the fatigue stress found for the lifetime number of loading cycles is greater than the cumulative damage stress, then the strength of the vessel is adequate. Due to uncertainties in the order of applied loads, the vessel is usually required to show a fatigue life which is 3 to 4 times greater than the estimated lifetime of the vessel.

An example of such a calculation for an operating cell is shown in Table C.5. In order to compute the ratio of (actual loading cycles)/(fatigue life) an experimentally determined S-N curve for the material involved is used. For each cell the lifetime probability density curve (not the extreme value probability density curve) is used to establish the relation between a load level and the number of times such a load occurs.

TABLE C.5 - FATIGUE LIFT CONTRIBUTIONS OF AN OPERATIONAL CELL

STRESS LEVEL (INCLUDING STRESS CONCENTRATION)	NUMBER OF CYCLES TO FAILURE	ACTUAL LIFETIME CYCLES	RATIO
70	5X10**3	1	0.000200
50	3X10**4	7	0.000233
30	10**6	41	0.000041
10	10**8	223	0.000002
Sum for the cell			

After finding the cumulative fatigue damage contribution of each cell, the overall fatigue damage estimate is found by summing the various cell contributions. The contribution of each cell is not proportional to the extreme load in each cell, but also depends upon the number of events and the Weibull slope c for a cell. Finally, the value of K should be less than 1/3 or 1/4.

If the value of K is too large then fatigue loading is controlling on the section rather than the once in a lifetime load and the scantlings will have to be increased until the value of K is satisfactory.

C.3 STRUCTURAL DESIGN

Structural Design Criteria

The structural criteria specifies the load magnitudes and their combinations, the factors of safety, and sometimes the material properties and analysis methods of guides to be used.

Combined load sets are the sets of loads which occur simultaneously on a structural element. Each set specifies the overall or global loads, such as bending and vessel motion loads such as acceleration, and local area loads such as fluid or point loads. Material properties, rather than material allowables are specified. This is consistent with using lifetime loads estimated from actual data.

In order to specify the combined factor of safety to be used in the case of combined loads interaction equations have to be developed or modified. Two points should be addressed. First, select the theory which describes the criteria for the onset of damage to the material, and secondly, determine how reliability based loads should be combined with deterministically obtained loads. One possible equation for estimating a combined factor of safety for tensile loads acting in the same direction is

$$ESC = \frac{1.0}{\dfrac{1.0}{\dfrac{SY / FSG}{SG}} + \dfrac{1.0}{\dfrac{SY / FSL}{SL}}}$$

where

ESC = combined factor of safety (should be 1.0)

FSG = factor of safety for global or reliability based loads, usually equal to 1.0 since the risk is already included in the magnitude of the load causing the stress SG

FSL = factor of safety for deterministically obtained load

SY = yield stress of material

SG = stress due to global or reliability based load

SL = stress due to deterministically obtained load

Combined factor of safety equations should be specified for other combined loading cases including compressive loads, out of plane loads, and loads acting in different directions in plane.

MATERIALS

Materials used to date for hulls are high strength marine service aluminum alloys of the 5000 series. Craft include the SES-100A, the SES-100B, and the SES 200. Both 5086 and 5456 alloys have been used. As SES sizes grow larger, the use of high strength steels becomes attractive, especially those having yield strengths of 80 ksi and above such as HSLA, HY80, and HY100. The choice of which material to use from a weight viewpoint is determined by comparing the weight of an aluminum structure plus any needed fire insulation sheathing against the weight of a steel structure. For special applications such as minesweeping, the use of plastic composites such as GRP is often worth considering.

Minimum guaranteed (in the case of metals usually the as welded) properties are normally specified.

STRUCTURAL DESIGN

Since as SES is supported cushionborne by an air cushion whose pressure is supplied by lift fans and whose resistance is in part caused by the cushion pressure, attention to minimum weight design pays off.

Once the structural criteria specifying the combined loads and factors of safety is available, the remainder of the design can be carried out by current design techniques including the use of structural optimization programs such as described in Hughes Ref. C-3 often using, in the case of Navy designs, current design practice as analysis guides.

The resulting structure is usually a longitudinally framed plate and grillage structure. Closely spaced longitudinal stiffeners usually result in a minimum weight design. Additionally, large amounts of permanent set are often tolerated in the wet deck area since the deck is usually close to the neutral axis and so contributes little to longitudinal strength.

Information as to the shape of structural details to minimize fatigue failure and to estimate the effect to misalignment may be found, for example, in Ref. C-3.

STRUCTURAL FABRICATION NOTES FOR DESIGN

SES's have the advantage that most of the vessel is composed of flat panels forming relatively boxlike assemblies. Since the sidehulls are narrow compared to ships of normal form, they may be shaped using flat plate elements joined together rather than being made up of curved elements. The relatively large amount of flat plate work makes the use of automatic welding machines quite attractive and minimizes the fabrication cost.

REFERENCES

Ref C-1 Gumbel, Statistics of Extremes

Ref C-2 Munse, W., et al., "Fatigue Characteristics of Fabricated Ship Details for Design," Illinois University at Urbana, Department of Civil Engineering, SSC-318, (Aug 1982)

Ref C-3 Hughes, Owen F., "Ship Structural Design - A Rationally Based, Computer Aided, Optimization Approach," Wiley-Interscience, (1983)

APPENDIX D

COMPARISON OF FRG AND US SCANTLING DIMENSIONS

D.1 ALU-ALLOY

Figure D.1 shows the midship section with elements corresponding to the text below.

The MTG-sizing is provided for smaller plate-thickness regarding the deck element No. 7, 10 and 11 as well as smaller profiles of longitudinal stiffenings regarding elements 5 to 14.

Concerning the cross-stiffenings, the MTG-version provides for a floor plate - regarding elements 1 to 4 - instead of T-profiles which are stated in the US-version. Both results are nearly equal in weight.

Within the MTG-version even more weights result from element 12. The MTG-version shows this as "continuous longitudinal wall at ___". In the US-version, this element consists of pillars.

The strength-calculation showed the necessity of this longitudinal wall. An additional weight is caused by the thicker plate used with the lower part of element 13.

Different longitudinal frame spacings were selected:

US Version: 13 inch (330 mm)

German Version: 11.8 inch (300 mm)

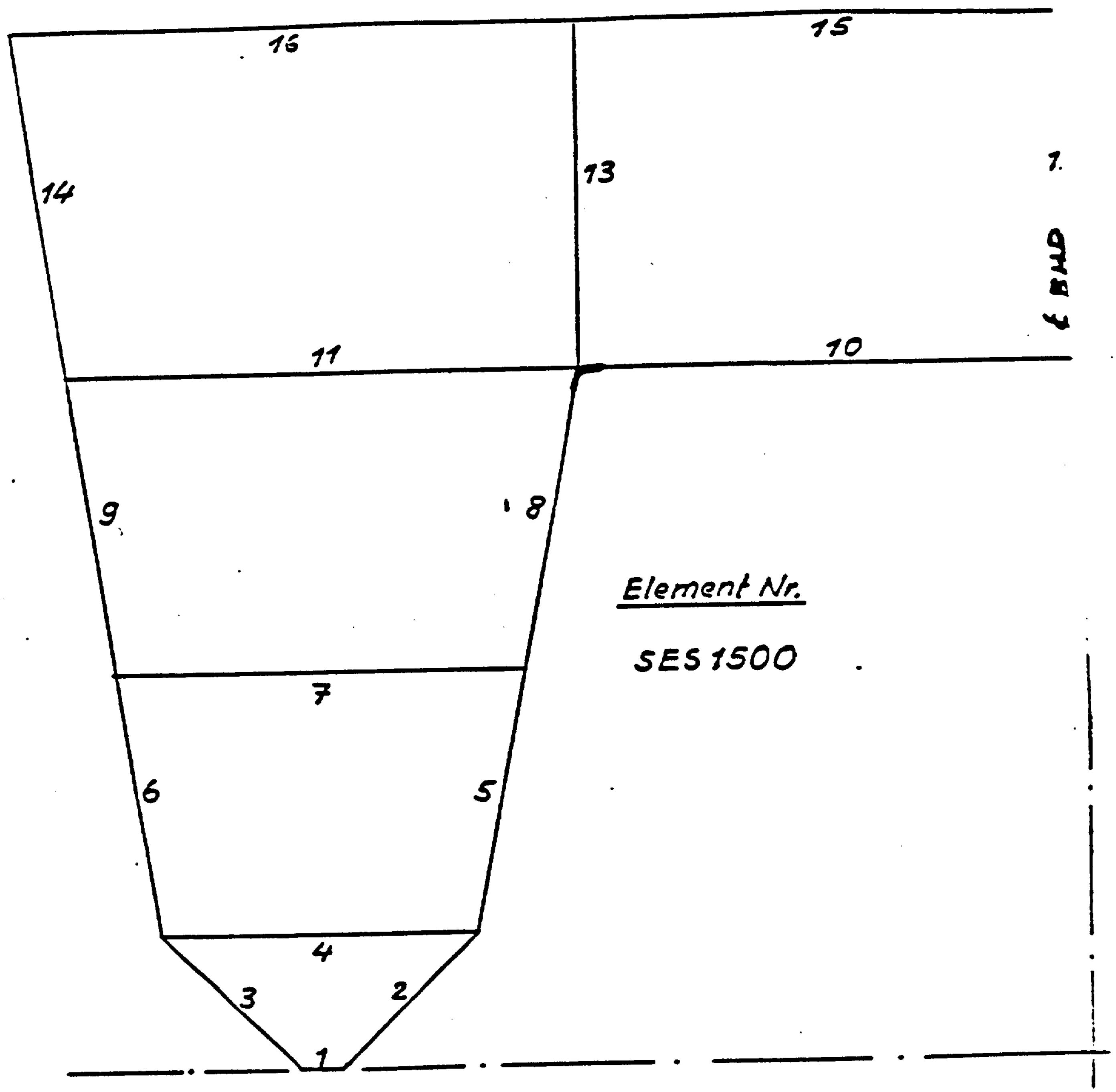


Figure D.1. ELEMENT MODEL

Similarly Web frame spacing were different:

US Version: Bulk-head spacing in drawing is 60 feet divided by 17 = 35.294 inches = 896 mm frame-spacing.

MTG Version: 50 feet = 600 inches = 15.24 m: 15 parts @ 40 inch (1016 mm) frame-spacing.

The comparison of the distance of the longitudinal stiffeners shows, that the MTG-version is provided for more "longitudinal frames" however less "web frames", which means for example: Half a wet-deck-width of 14 ft (4.267 m) contains 14 "longitudinal frames" in the MTG-version and 13 "longitudinal frames" in the US-version.

The MTG-version shows for each compartment (600" = 15.24 m) 14 "web frames" whereas the US-version plans 16 "web frames".

Steel:

The MTG-version shows smaller plate-thickness in deck-elements 7 and 11 and principally for all elements the smallest longitudinal frames as shown in the US-profile-list (T-Profile 3x2x0, 125/0, 188 weight 3.75 kg/m).

In the US-version the smallest profiles are T 4x2x0, 188/0, 133 with a weight of 6.728 kg/m."

That means, the MTG-version contains a reduced weight for "longitudinals frames" in comparison to the US-version. (The reduction of weight is 2,978 kg/m).

Regarding elements 1 to 4 the MTG-version contains as cross-stiffening a "floor plate" which is neutral in weight in comparison to the US-version. Additional weights are given in the MTG-version with higher plate-thicknesses within the upper and lower hull elements 1,2,3,14,15, and 16. Element 1 has been chosen extremely thicker because it is meant to be the keel-plate. The thickness for the other elements depends on the strength calculation.

Table D.1 presents the full structural data for the design described above.

Table D.1

Element Nr.		AL 5456 Blechdicke inch	AL 5456 Langsspauf-/balken T-Profil (inch)	AL 5456 Rabmenspauf/-balken T-Profil (inch)	Stahl HSLA-80 Blechdicke (inch)	Stahl HSLA-80 Langsspauf/-balken T-Profil (inch)	Stahl HSLA-80 Rakmenspauf/-balken (T-Profil (inch)
1	D US	0,938 0,938	ohuc ● 6x3x0,250/0,438	Bodenwrange 0,250 ● 6x3x0,250/0,375	0,563 ● 0,250	ohuc ● 4x2x0,188/0,313	Bodenwrange 0,188 ● 3x2x0,125/0,188
2	D US	0,813 0,813	6x3x0,250/0,438 6x3x0,250/0,438	Bodenwrange 0,250 ● 6x3x0,250/0,375	0,250 ● 0,188	3x2x0,125/0,188 ● 4x2x0,188/0,313	Bodenwrange 0,188 ● 3x3x0,188/0,313
3	D US	0,813 0,813	6x3x0,250/0,438 6x3x0,250/0,438	Bodenwrange 0,250 ● 6x3x0,250/0,375	0,250 ● 0,188	3x2x0,125/0,188 ● 4x2x0,188/0,313	Bodenwrange 0,188 ● 4x2x0,188/0,313
4	D US	0,375 0,375	4x3x0,188/0,313 ● 4x2x0,188/0,313	Bodenwrange 0,250 ● 8x5x0,250/0,438	0,188 ● 0,188	3x2x0,125/0,188 ● 4x2x0,188/0,313	Bodenwrange 0,188 ● 6x4x0,188/0,313
5	D US	0,375 0,375	3x2x0,125/0,188 ● 4x2x0,188/0,373	6x3x0,250/0,375 6x3x0,250/0,375	0,188 0,188	3x2x0,125/0,188 ● 4x2x0,188/0,313	5x2x0,188/0,313 ● 4x3x0,125/0,188
6	D US	0,563 0,563	3x2x0,125/0,188 ● 4x2x0,188/0,313	6x3x0,250/0,375 6x3x0,250/0,375	0,188 0,188	3x2x0,125/0,188 ● 4x2x0,188/0,313	5x2x0,188/0,313 ● 4x2x0,188/0,313
7	D US	0,188 ● 0,375	3x2x0,125/0,188 ● 4x2x0,188/0,313	6x3x0,250/0,375 6x3x0,250/0,375	0,125 ● 0,188	3x2x0,125/0,188 ● 4x2x0,188/0,313	5x2x0,188/0,313 ● 3x3x0,125/0,188
8	D US	0,375 0,375	3x2x0,125/0,188 ● 4x2x0,188/0,313	8x5x0,250/0,438 ● 6x3x0,250/0,375	0,188 0,188	3x2x0,125/0,188 ● 4x2x0,188/0,313	6x3x0,250/0,375 ● 5x2x0,188/0,313
9	D US	0,375 0,375	3x2x0,125/0,188 ● 4x2x0,188/0,313	6x3x0,250/0,375 6x3x0,250/0,375	0,188 0,188	3x2x0,125/0,188 ● 4x2x0,188/0,373	5x2x0,188/0,313 ● 3x2x0,188/0,313
		Thickness	Longitudinal Frame	Web Frame	Thickness	Longitudinal Frame	Web Frame

D = MTG Dimension
US = Amerikaulsck Dimension
(US dimensions)

● = Abweichung Zwiscken Du-US Dimensioner
= Nicht baubar in Verbludung mit Langsspauf

(difference between D and US)
(not possible in connection with longit. frame)

Table D.1 (Cont.)

Element Nr.		AL 5456			Stahl HSLA-80		
		Blechdicke inch	Langsspauf-/balken T-Profil (inch)	Rahmenspauf/-balken T-Profil (inch)	Blechdicke (inch)	Langsspauf/-balken T-Profil (inch)	Rakmenspauf/-balken (T-Profil (inch)
10	D US	0,250 ● 0,375	3x2x0,188/0,313 ● 4x2x0,188/0,313	72x5x0,375/0,656 72x5x0,375/0,656	0,188 0,188	3x2x0,125/0,188 ● 4x2x0,188/0,313	10x5x0,375/0,438 ● 8x5x0,250/0,375
11	D US	0,188 ● 0,250	3x2x0,125/0,188 ● 4x2x0,188/0,313	6x3x0,250/0,375 6x3x0,250/0,375	0,125 ● 0,188	3x2x0,125/0,188 ● 4x2x0,188/0,313	5x2x0,188/0,313 ● 4x2x0,188/0,313
12	D[1/] US[2/]	U 0,250 O 0,281 ● 0,250	3x2x0,125/0,188 ● 3x2x0,125/0,188 ● 72x5x0,375/0,656	8x7x0,250/0,438 8x7x0,250/0,438 8x7x0,250/0,438	U 0,188 O 0,234 ● 0,188	3x2x0,125/0,188 ● 3x2x0,125/0,188 ● 5x4x0,188/0,250	5x2x0,188/0,313 ● 5x2x0,188/0,313 ● 3x2x0,125/0,188
13	D US	U 0,281 ● O 0,375 U 0,250 O 0,375	3x2x0,125/0,188 ● 3x2x0,125/0,188 ● 4x2x0,188/0,313 4x2x0,188/0,313	6x3x0,250/0,375 6x3x0,250/0,375 6x3x0,250/0,375 6x3x0,250/0,375	U 0,188 O 0,234 ● 0,188 0,188	3x2x0,125/0,188 ● 3x2x0,125/0,188 ● 4x2x0,188/0,313 4x2x0,188/0,313	5x2x0,188/0,313 ● 5x2x0,188/0,313 ● 3x2x0,125/0,188 3x2x0,125/0,188
14	D US	0,375 0,375	3x2x0,125/0,188 ● 4x2x0,188/0,313	6x3x0,250/0,375 6x3x0,250/0,375	0,188/0234● 0,188	3x2x0,125/0,188 ● 4x2x0,188/0,313	5x2x0,188/0,313 ● 4x2x0,188/0,313
15	D US	0,375 0,375	4x2x0,188/0,313 4x2x0,188/0,313	6x3x0,250/0,375 6x3x0,250/0,375	0,234 ● 0,188	3x2x0,125/0,188 ● 4x2x0,188/0,313	5x2x0,188/0,313 ● 5x4x0,188/0,250
16	D US	0,375 0,375	4x2x0,188/0,313 4x2x0,188/0,313	7x3x0,250/0,438 7x3x0,250/0,438	0,234 ● 0,188	3x2x0,125/0,188 ● 4x2x0,188/0,313	5x2x0,188/0,313 ● 5x4x0,188/0,250
		Thickness	Longitudinal Frame	Web Frame	Thickness	Longitudinal Frame	Web Frame

[1/] Langswandauf HS
[2/] 67 Stutzen (pillars)

(longitude bulkhead)

U = untere Halfte (lower part)
O = obere Halfte (upper part)
D = MTG Dimension
US = Amerikauisck Dimension
(US dimensions)

● = Abweichung Zwischen Du-US Dimensioner
= Micht baubar in Verbiudung mit Langsspauf

(difference between D and US)
(not possible in connection with longit. frame)

APPENDIX E

AUXILIARY SYSTEMS DETAILED CHARACTERISTICS

The systems discussed in Appendix *E* were not developed specifically for the NASW SES. They were developed and proposed for other SES designs, principally for the U.S. 3KSES. They are presented as general background only.

APPENDIX E.1

CRITICALITY ANALYSIS FOR AUXILIARY SYSTEMS

The definitions used for this analysis are as follows:

(1)	Technology Critical (rating of 5)	- A system or element which is critical for the mission but has not been previously engineered for SES applications.
(2)	Mission Critical (rating of 4)	- A basic system or element which is required to allow the craft to be operational.
(3)	Capability Critical (rating of 3)	- A system or element which is required to demonstrate capability relative to "test drivers", e.g., helicopter operations, etc.
(4)	Design Critical (rating of 2)	- A system or element which has previous SES engineering but required modifications to suit optimum craft configuration.
(5)	Non-critical (rating of 1)	- Existing technology satisfactory.

Ratings were assigned to these five definitions and all auxiliary systems evaluated as shown in Table E.1-1. The matrix was then used to develop the system priority listing shown in Table E.1-2.

A set of guidelines for each critical auxiliary subsystem was prepared to encompass: approval hierarchy, operational, performance, and design requirements. Standard commercial, U.S. Coast Guard, and U.S. Navy design criteria were used to determine system requirements and derive concepts. The major selection criteria for an applicable design were cost, weight, safety and technical risk.

Table E.1-1

AUXILIARY SYSTEMS CRITICALITY MATRIX		TECHNICAL	MISSION	CAPABILITY	DESIGN	NON-CRITICAL	CRITICALITY
SWBS	RATING	5	4	3	2	1	
506	Overflows, Air Escapes and Sounding Tubes				X	1	
510	CLIMATE CONTROL						
511	Compartment Heating System					X	1
512	Ventilation System		X		X		6
513	Machinery Space Ventilation System		X	X	X		9
514	Air Conditioning System		X	X	X		9
516	Refrigeration System					X	1
520	SEA WATER SYSTEMS						
521	Firemain and Flushing (Sea Water) System	X	X	X	X		14
522	Sprinkler System		X		X		6
524	Auxiliary Sea Water System		X		X		6
526	Scuppers and Deck Drains					X	1
528	Plumbing Drainage					X	1
529	Drainage and Ballasting System			X	X		5
530	FRESH WATER SYSTEMS						
531	Distilling Plant					X	1
532	Cooling Water				X		2
533	Potable Water					X	1
534	Aux. Steam and Drains Within Machinery Box (Machinery Drains)					X	1
536	Auxiliary Fresh Water Cooling				X		2
540	FUELS AND LUBRICANTS, HANDLING AND STORAGE						
541	Ship Fuel and Fuel Compensating System		X	X	X		9
542	Aviation and General Purpose Fuels		X	X	X		9
545	Tank Heating (Diesel Heating)					X	1
549	Special Fuel and Lubricants, Handling & Stowage				X		2

AUXILIARY SYSTEMS CRITICALITY MATRIX	TECHNICAL	MISSION	CAPABILITY	DESIGN	NON-CRITICAL	CRITICALITY
SWBS RATING	5	4	3	2	1	
550 AIR, GAS, AND MISC. FLUID SYSTEMS						
551 Compressed Air Systems		X		X		6
552 Compressed Gases					X	1
553 O_2 N_2 System					X	1
555 Fire Extinguishing Systems		X	X	X		9
556 Hydraulic Fluid System				X		2
560 SHIP CONTROL SYSTEMS						
561 Steering and Diving Control Systems	X	X	X	X		14
562 Rudder	X	X	X	X		14
565 Trim and Heel (Roll Stabilization)			X	X		5
570 UNDERWAY REPLENISHMENT SYSTEMS						
571 Replenishment-At-Sea			X	X		5
572 Ship Stores and Personnel and Equipment Handling					X	1
573 Cargo Handling			X	X	X	6
574 Vertical Replenishment Systems			X	X		5
580 MECHANICAL HANDLING SYSTEM						
581 Anchor Handling and Stowage Systems		X	X	X		9
582 Mooring and Towing Systems		X	X	X		9
583 Boat Handling and Stowage Systems			X	X		5
584 Mech. Operated Door, Gate, Ramp, Turntable Sys.			X	X		5
586 Aircraft Recovery Support Systems	X		X	X		10
588 Aircraft Handling, Servicing and Stowage			X	X		5
590 SPECIAL PURPOSE SYSTEMS						
593 Environmental Pollution Control Systems		X	X	X		9
598 Auxiliary Systems Operating Fluids					X	1

Table E.1-2. Modified Auxiliary Systems Priority Listing

SWBS	System	Priority
506	Overflows, Air Escapes and Sounding Tubes	1
511	Compartment Heating System	1
516	Refrigeration System	1
526	Scuppers and Deck Drains	1
528	Plumbing Drainage	1
531	Distilling Plant	1
533	Potable Water	1
534	Machinery Drains	1
545	Diesel Tank Heating	1
552	Compressed Gases	1
553	O_2/N_2 System	1
572	Ship Stores and Personnel and Equipment Handling	1
598	Auxiliary Systems Operating Fluids	1
532	Cooling Water	2
536	Auxiliary Fresh Water Cooling	2
549	Special Fuels and Lubricants, Handling & Storage	2
556	Hydraulic Fluid System	2
528	Plumbing Drainage	5
565	Trim and Heel (Roll Stabilization)	5
571	Replenishment-At-Sea	5
574	Vertical Replenishment Systems	5
583	Boat Handling and Stowage Systems	5
584	Mechanically Operated Door	5
588	Aircraft Handling, Servicing and Stowage	5
512	Ventilation System	6
522	Sprinkler System	6
524	Auxiliary Seawater System	6
551	Compressed Air System	6
573	Cargo Handling	6
513	Machinery Space Ventilation System	9
514	Air Conditioning System	9
541	Ship Fuel System	9
542	Aviation and General Purpose Fuels	9
555	Fire Extinguishing Systems	9
581	Anchor Handling and Stowage Systems	9
582	Mooring and Towing Systems	9
593	Environmental Pollution Control Systems	9
586	Aircraft Recovery Support Systems*	10
521	Firemain and Flushing (Seawater) System*	14
562	Steering Control System*	14
562	Rudder*	14

*These are the four systems that are considered critical, all others are essential.

APPENDIX E.2

DRAINAGE SYSTEMS

SYSTEM REQUIREMENTS

The ship drainage system consists of plumbing drains, scupper and deck drains, oily waste collection, and main and secondary drainage. The design requirements of the system are outlined in General Specifications for Ships of the U.S. Navy, Sections 528, 529 and 534. Specifically, the following requirements were identified for the Drainage System of the 3KSES design:

a. Segregation of soil and sanitary waste drains.

b. Plumbing drains for all plumbing fixtures.

c. Independent drainage for sanitary drains from commissary spaces and medical spaces.

d. Air gaps in drain lines from refrigerators, hot food tables and similar equipment.

e. Plumbing drains penetrating watertight transverse bulkheads have a full port ball or plug valve operable at the valve and from the damage control deck.

f. Space deck and weather deck drains provided to prevent accumulation of water on weather and hangar decks, decks of sanitary and commissary spaces and decks in other spaces where water may accumulate.

g. Independent drains for the hangar, magazines, and R.A.S. stations.

h. Main drainage to have the capability of evacuating water from propulsion engine rooms, combustion air intakes, and auxiliary pump rooms at a rate of not less than 500 gpm under emergency conditions. Seawater pump bilge injection will provide a boosted dewatering capacity to the propulsion engine rooms.

i. Secondary drainage via drain pumps provided from drain wells in lift engine rooms, auxiliary machinery rooms, electrical generator rooms, and the propulsion engine rooms.

j. Secondary drainage eductors provided for drainage of lift fan rooms, and of the combustion air intakes. Drainage requirement per lift fan is up to 33 gpm average continuous and to 116 gpm intermittent.

k. Damage flooding in compartments not served by the main drainage eductors will be handled by submersible pumps.

l. Main drainage control shall be both locally and at the damage control auxiliaries and electrical console (DCAEC).

m. The secondary (waste water) drainage system and the oily waste collection system are segregated.

n. A waste oil system which collects oils at discrete points from lift and propulsion engines, gas turbine generators, expended lube oils, oil seepage from engine gearboxes and waste oils from the aviation and general workshop. (Oily water separator drainage is part of the Pollution Control System.)

CANDIDATE CONCEPTS AND TRADEOFFS — Two candidate concepts for the plumbing drainage system were examined; the conventional seawater gravity flow and a system which utilizes fresh water flushing and vacuum collection.

Conventionally, soil and waste drains have relied solely on gravity as the driving force. Associated with this approach have been restrictions with regard to piping slopes (1/2 inch per foot minimum) and to the use of piping sizes compatible with standard gravity operated fixtures. In particular, water for flushing of water closets has usually been seawater with the resulting soil waste generation rate of 30 gallons per capita per day (GPCD). When the ship is within the prohibited discharge zone this places unnecessary loading on sewage treatment units and/or on the collection, holding and transfer tanks (CHT). Water closets are presently available which substantially reduce the quantity of soil wastes resulting from each flush. Table E.2-1 lists some of these units and the methods employed to obtain the controlled flush volumes. The quantity of water utilized by the various units (1/4 to 1/2 gallons per flush) is a reduction of approximately 90% over conventional gravity systems which require 4 to 5 gallons per flush of the non-vacuum operated systems, the GATX water closet utilizes the least quantity of waste water per capita day, but its weight (80 lbs. with necessary valves) does not represent any saving over the standard shipboard unit. The GATX unit is not vacuum operated and macerator/transfer pump(s) are used in the installation to propel the waste slurry along the piping. The Jered water closet/controlled urinal system with the resulting combined waste rate of 1.92 gallons per capita day is vacuum operated. The water closet weight is 33 lbs. complete with the necessary control and discharge valves. This is a weight reduction of 42 pounds per unit over a standard unit, for a total saving of 588 pounds for the SES, which is equipped with 14 water closets.

Vacuum collection system for soil drains, in addition to requiring conventional gravity drain piping and fittings, includes vacuum pump(s), vacuum collection tank(s), vacuum interface valves, and electrical

Table E.2-1. Reduced Volume Flush Data

	FLUSHING WATER QUANTITY, GALLONS/FLUSH	FLUSHING TIME, SECONDS	VOLUME OF SEWAGE AND WATER PER FLUSH, GALLONS	AIR USAGE PER FLUSH, SCF	ESTIMATED USAGE/MAN/DAY	FLUSHING WATER, GPCD*	SOIL WASTES, GPCD*	MANUFACTURER	REMARKS
Urinal	1/8		.22	.2	4	.5	.88	Jered	Vacuum System
Water Closet	1/2	8 to 12	.52	1 Ft^3 @ 60 psi	4	2	2.1	Microphor LF-210 LF-310	Compressed Air System
	3/8	7	.39	3 to 4.5	4	1.5	1.6	Envirovac	Vacuum System
	1/4	6	.26	1.5	4	1	1.1	Jered	Vacuum System
	3/8	10	.39	-	4	1.5	1.6	GATX	Wastes are transferred by a pump.

* Gallons per capita per day.

instrumentation and control. The vacuum interface valves are located in the drainage lines close to the urinals and control the application of vacuum and atmospheric air to the transported liquid waste. A brief weight comparison between the ship and seawater gravity drains and with the vacuum collection concept is given in Table E.2-2. The equipment weight penalty incurred by the vacuum concept is approximately .23 long tons. This weight penalty is soon absorbed when compared to the weight of liquid collected and retained when the ship is operating within prohibited discharge zones. Using an overall daily soil accumulation rate of 30 GPCD for a conventional seawater system and 1.92 GPCD for the vacuum system, the weight saving in stored liquid is illustrated in Figure E.2-1. After a twelve hour period in a non-discharge zone, a 6.3 long ton differential would exist in favor of the vacuum system. This differential increases to 9.5 long tons after 18 hours, which is the designed holding time capacity of the vacuum collection tank system.

For the ship's one day CHT holding capacity, the weight differential would be approximately 12.8 long tons. In addition to the weight savings, the following advantages of the vacuum system can be listed:

- Piping runs need not be sloped, thereby facilitating installation by standardization in the length of pipe hangers.
- Higher flush differential pressure allows the use of smaller pipe and valve sizes.
- Line leakage is from the compartment(s) into the drain lines, thereby reducing the risk of fluid contamination.
- The number of piping vent lines is greatly reduced: venting of the collection holding and transfer tank providing this function for the complete system.

Table E.2-2. Plumbing Drainage Equipment Weight Comparison

STANDARD SYSTEM		VACUUM SYSTEM	
COMPONENT	LBS	COMPONENT	LBS
- - -		Vacuum pumps, complete with motor, tanks, valves	2 @ 425 = 850 (See Appendix B)
- - -		Vacuum collection tanks, (135 gal. each with 10 gal. low level liquid)	2(175+10x8.34) = 517 (See Appendix B)
- - -		Vacuum interface valves	8 @ 10 = 80
Standard vitreous china fixtures	14 @ 75 = 1050	Lightweight fixtures complete with valves (1)	14 @ 33 = 462
Differential weight penalty for larger piping sizes due to sloping requirement	Est. @ 200	- - -	
Vent piping differential weight including hangers, etc.	Est. @ 150	- - -	
Total Weight	1400	Total Weight	1909

(1) Based on Jered, Inc. Model AVT 300

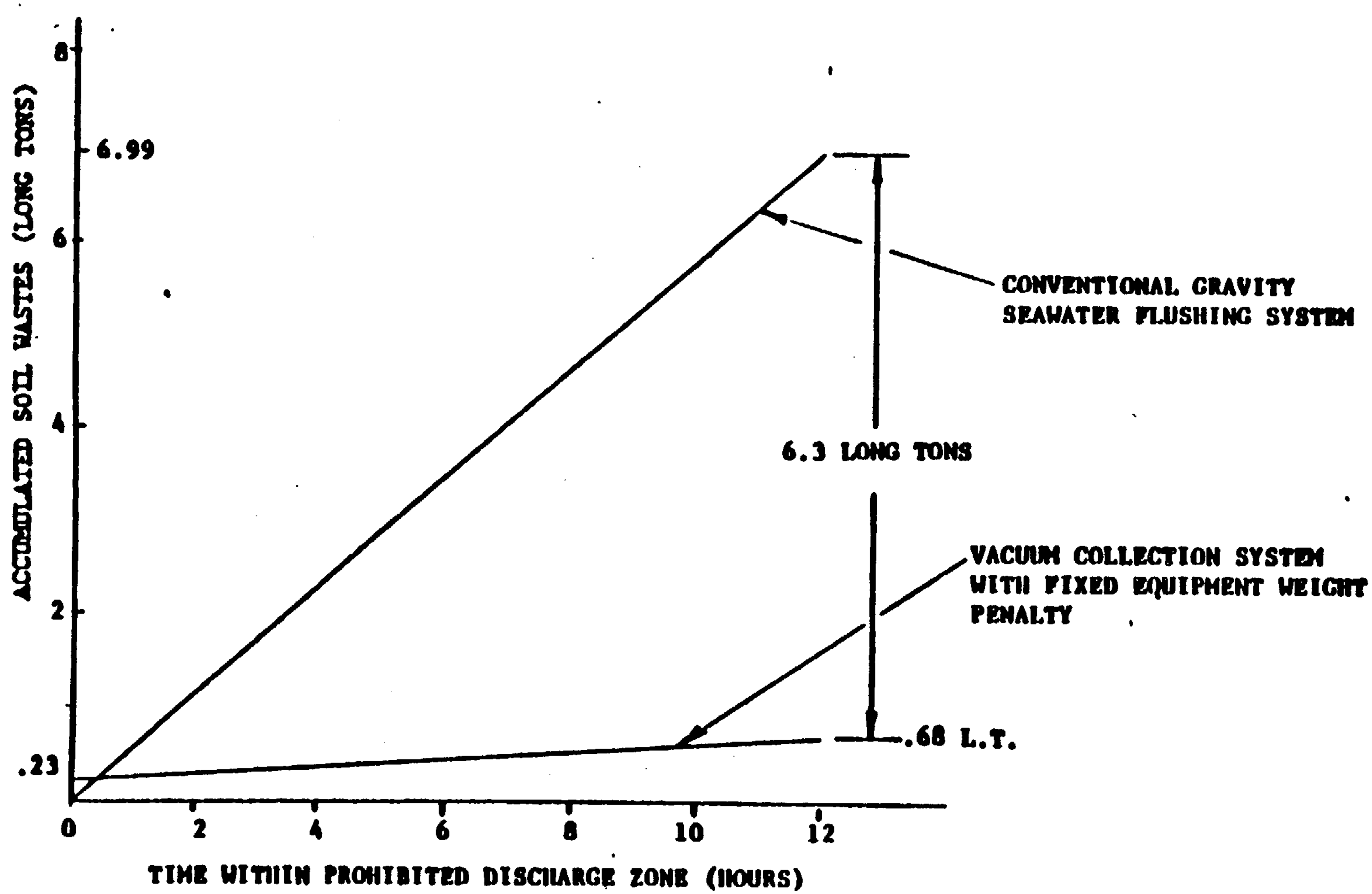


Figure E.2-1. Soil Wastes Accumulation Rates

Sewage treatment equipment was investigated in an attempt to further reduce the collection and holding tank capacity. However, it was concluded that the weight penalty of approximately 1500 pounds and increased electrical load of approximately 25 kw precluded such installation.

DRAINAGE SYSTEM DESCRIPTION AND CHARACTERISTICS

PLUMBING DRAINAGE

Plumbing drains are separated into two distinct systems; soil drains and sanitary drains (ss Figure E.2-2).

SOIL DRAINAGE

The soil drain system transports wastes of human origin emanating from the water closets and urinals, both being supplied with sea water for flushing. The soil drainage system is divided into two subsystems, a forward and an aft. Drains from the urinals and water closets of the forward system are combined in a header below the second deck and are collected into a 1850 gallon collection tank. Similarly, drains from the urinals and water closets of the aft system are collected by a 1850 gallon tank.

SANITARY DRAINAGE

Drains from lavatories, sink, showers, laundry machines, commissary equipment (including the garbage grinder) and deck drains from the galley

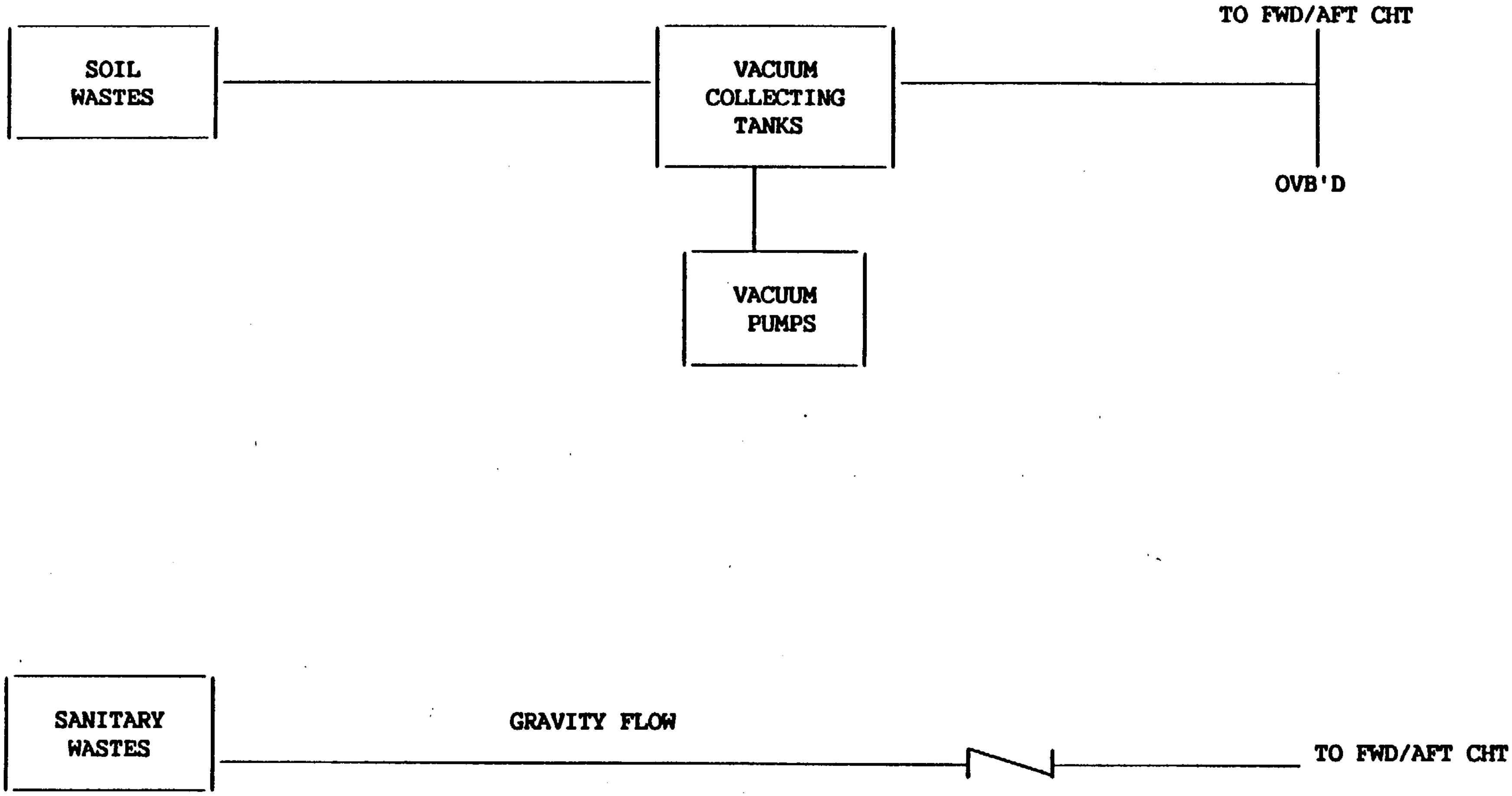


Figure E.2-2. Plumbing Drainage

and the scullery are transported by the sanitary waste drainage system. This gravity system consists of two sub-systems, one forward and one aft.

Waste drains from the vegetable peeler, dishwasher, refrigerators, steam tables, kettles, ice machines, commissary sideboards and dressers are discharged through an air gap to the drain system.

The drain piping, made of GRP material, is pitched a minimum of 0.23 inch per foot.
Drains from the medical treatment room are led independently to the forward CHT.

Piping penetrating watertight transverse bulkheads utilize motor driven full ported ball valves. These can be operated manually, or can be controlled electrically at the DCAEC.

SCUPPER AND DECK DRAINS

These drains are grouped as much as possible between watertight subdivision transverse bulkheads and led overboard via scupper valves. Valves below the damage control deck are of the gag-type and can be remotely operated from the second deck via reach rods. Piping material is aluminum. Overboard discharges are fitted with hose connections to permit attachment of portable submersible pump discharges. Drain piping from the helicopter hangar is independently led directly overboard and is trunked for fire protection. The piping material for these drains is CRES.

OILY WASTE COLLECTION

The oily waste collection system is shown in Figure E.2-3. Waste oil from propulsion, lift, gas turbine engines and diesel generators is collected by gravity. This piping leads to four 5 gallon tanks, or directly to the main waste oil drain tank located below the auxiliary machinery Rooms, and electrical generator Rooms. Associated with each local tank is a level control and pump to transfer the oil to the main waste oil drain tank.

MAIN AND SECONDARY DRAINAGE

The location of the eductors, their size, function, seawater requirements and drainage characteristics of the main and secondary drainage are summarized in Table E.2-3. Each element of this system is briefly discussed in the following paragraphs.

MAIN DRAINAGE

The main drainage system comprising eight eductors, has the capability of evacuating water from each of the main machinery spaces, combustion air intake Rooms, the port and starboard propulsion engine air plenum chambers, and auxiliary pump rooms, at a rate of not less than 500 GPM.

Four of the eight eductors provide a two flow rate drainage capability. During the lower operating rate, the ship seawater pumps are taking suction from the sea. Each eductor serving a propeller room is located (in elevation) such that a suction lift of five feet of water or less

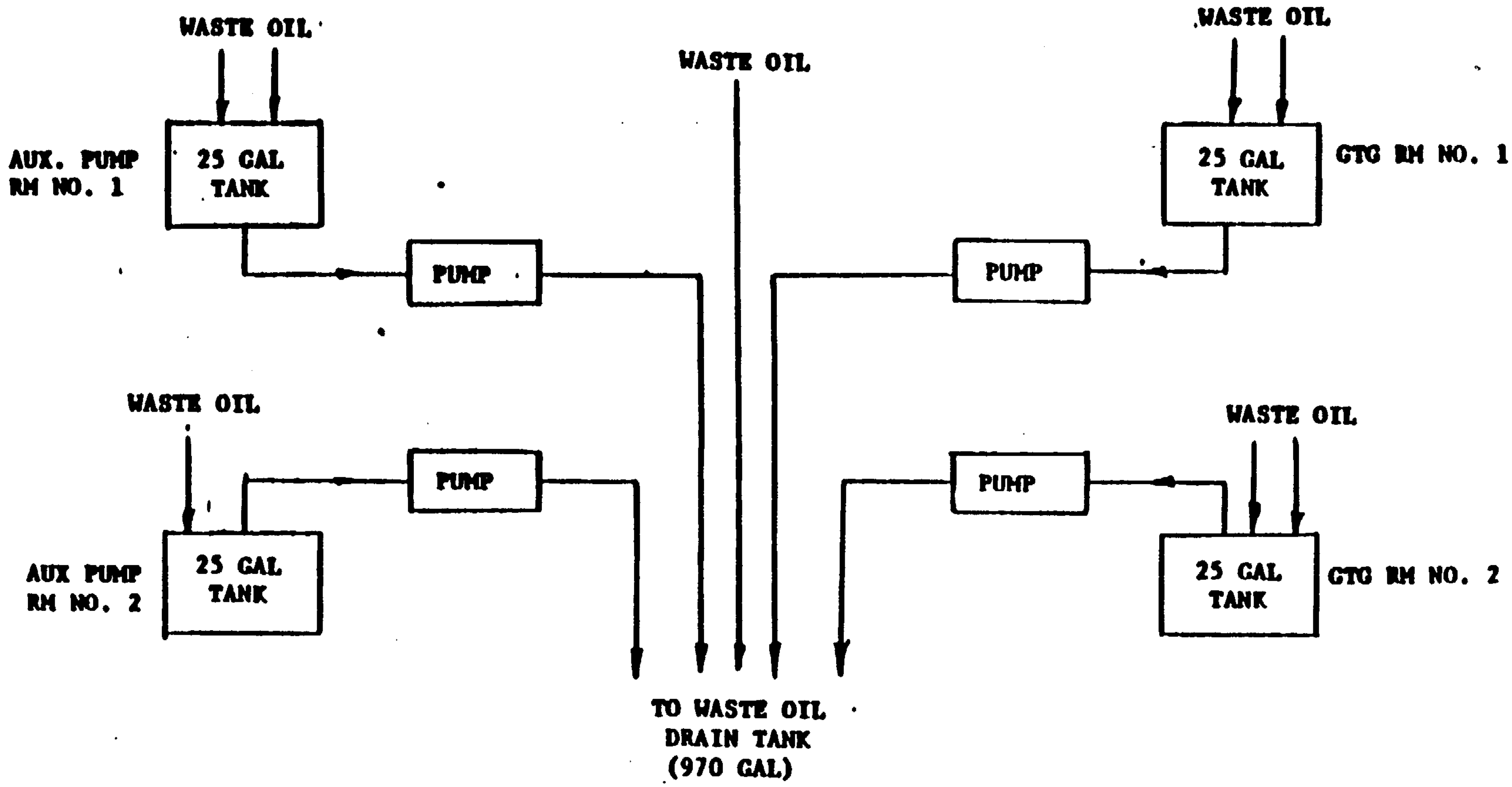


Figure E.2-3. Waste Oil Drainage

Table E.2-3. Main and Secondary Drainage Eductors

LOCATION	FUNCTION	SIZE (INCH)(2)	DRAINAGE FLOW RATE RELATED INLET LIFT, DISCHARGE HEAD (FT. H_2O)	SEAWATER SUPPLY FLOW & PRESSURE REQUIRED GPM	PSIG
Transducer/Fuel Rm No. 1 6-56-1-Q	Main drainage of Pump Room No. 1 and starboard sidewall aft segment	6 x 6 x 4	500 gpm @ 15' Lift with up to 20' Head (1)	340	100
Transducer/Fuel Rm No. 1 6-56-2-Q	Main drainage of Pump Room No. 2 and port sidewall aft segment	6 x 6 x 4	500 gpm @ 15' Lift with up to 20' Head (1)	340	100
Transducer/Fuel Rm No. 1 6-56-2-Q	Main drainage of Propulsion Engine Rms 1 & 2, Aux Pump Rm No. 1, and port propulsion engine plenum chamber	6 x 6 x 4	500 gpm @ 15' Lift with up to 20' Head (1)	340	100
Combustion Air Intake No. 1 3-38-1-Q	Main drainage of Combustion Air Intake No. 1	6 x 6 x 4	500 gpm @ 15' Lift with up to 20' Head (1)	340	100
Combustion Air Intake No. 2 3-38-1-Q	Main drainage of Combustion Air Intake No. 2	6 x 6 x 4	500 gpm @ 15' Lift with up to 20' Head	340	100
Combustion Air Intake No. 1 3-38-2-Q	Secondary drainage of Combustion Air Intake No. 2	2 x 2 x 1 1/4	40 gpm @ 15' Lift with up to 20' Head	28	100
Combustion Air Intake No. 2 3-38-2-Q	Secondary drainage of Combustion Air Intake No. 2	2 x 2 x 1 1/4	40 gpm @ 15' Life with up to 20' Head	28	100
Lift Fan Rm No. 1 4-8-1-Q	Secondary drainage of Lift Fan Rm No. 1 & 3	3 x 3 x 2	116 gpm @ 12' Lift with up to 20' Head	75	100
Lift Fan Rm No. 2 4-8-2-Q	Secondary drainage of Lift Fan Rm No. 2 & 4	3 x 3 x 2	116 gpm @ 12' Lift with up to 20' Head	175	100
Lift Fan Rm No. 1 4-8-1-Q	Secondary drainage of Lift Fan Rm No. 1 & 3	4 x 4 x 3	235 gpm @ 15' Lift with up to 20' Head	175	100
Lift Fan Rm No. 2 4-8-2-Q	Secondary drainage of Lift Fan Rm No. 2 & 4	4 x 4 x 3	235 gpm @ 15' Lift with up to 20' Head	175	100
Aux Pmp Rm No. 1	Main drainage of Aux Pump Rm	4 x 4 x 3	175 gpm @ 15' Lift with up to 20' Head	—	—
Aux Pmp Rm No. 2	Main drainage of Aux Pump Rm	4 x 4 x 3	175 gpm @ 15' Lift with up to 20' Head	—	—

Notes:

1. Drainage flow rate is 620 gpm @ 5' lift with up to 25' head.
2. Sizes given refer to the size of end connections. The first and second number apply to the suction and discharge; the last number to the driving fluid connection.

exists at the eductor inlet, thereby providing a drainage rate for propeller rooms of approximately 620 GPM, with a seawater supply pressure of 10 psig.

Similarly, the eductor located in each auxiliary pump room, being at a lower level will operate at submerged inlet conditions thereby providing a drainage rate in excess of 620 GPM for the propulsion engine rooms and/or the combustion air plenum.

By directing (valving) from the compartment to be drained, into the suction of the seawater pump(s) and closing the normal suction from the sea, (boot strapping) the water evacuation rate from the compartment is increased by 340 GPM.

SECONDARY DRAINAGE

The secondary drainage system has two, 50 GPM, 3 HP (60 Hz) positive displacement pumps which permit collection of drainage into the waste water tank, pumping directly overboard, or transfer from the tank to shore facilities. These pumps are attached to a common fore and aft header. Branches from the header provide suction through motor operated valves and check valves to drain wells. The wells are alarmed and monitored via level controls and are located in the waterjet pump rooms, the propulsion engine rooms, the auxiliary machinery rooms, electrical generator rooms, and the two lift fan engine rooms. The six eductors of the secondary drainage system (independent of the pumps) are located in the lift fan rooms and in the combustion air intake (CAI).

The secondary eductor in each CAI is employed to remove small volumes of water collected in the CAI drainwell emanating from exhaust stacks and demisters of the GTG(s), from rainwater and light spray entering directly through the CAI opening, and water from washdown of propulsion and lift engine demisters. The larger, main drainage eductor located in each CAI is employed during ship operation in higher sea states when greater flow rates are incurred.

The two secondary drainage eductors located in the lift fan rooms serve to remove water entering fan rooms through the lift air openings. Level controls in the lift fan rooms control the operation of the smaller eductor when dewatering rates of up to 33 GPM per fan are required, and control the operation of the main drainage eductor, to complement the first, to achieve a dewatering rate of up to 116 GPM per fan. This higher rate is related to ship operation at maximum fan speed, under combined conditions of dense spray and heavy rain.

For all eductors, actuation power is provided from the seawater system via motor operated valves, with watertight and explosion proof actuators and capable of local (manual) or remote (DCAEC) operation. Similarly, there are motor operated valves for the eductor suction and discharge, the latter two being combined with check valves. The check valve in the eductor inlet line serves to protect against reverse flow of water into the compartment from the actuation line caused by inadvertent or accidental operation with a closed discharge valve.

All eductors have a vacuum pressure gage installed on the suction side of the eductor, and a pressure gage on the seawater supply side. A flow switch is installed on the suction side for remote indication at the DCAEC. Flow switches are also installed on the inlet side of both secondary drainage pumps.

Normal control of the drainage system is at the DCAEC, where the following functions are monitored:

a. Area flood warning (16),
b. Eductor status ON/OFF (12),
c. Drainwell(s) high level alarm (18),
d. Pump status ON/OFF (2).

All secondary drainage pumps can be operated locally as well as via the DCAEC.

Sequencing of valve operation for operation of eductors is controlled automatically, except that:

i) All six secondary drainage eductors are provided with over-ride control at the DCAEC allowing operator start/stop.

ii) All main drainage eductors are supplied with seawater system power only at the discretion and command of the DCAEC operator.

Operation of the secondary drainage eductors and/or pumps serving compartments which are also dewatered by main drainage eductors is discontinued upon activation of the respective main eductor level control units.

Operation of secondary drainage pumps and valves is automatically controlled, the demand signal coming from level control located ub draub week(s). Each has a low and a high level triggering point, in addition to its regular monitoring capability. Control is set-up to operate the pump which is nearest the drainwell being served; should the flow rate into the drainwell exceed the outflow, the second level will demand the start-up of the second pump.

Valves are normally controlled to discharge the waste water into the waste water drain tank. An over-ride control at the DCAEC allows the operator to divert the waste water directly overboard.

At dockside, the wastewater drain tank is emptied to the shore facility by either pump (pump No. 1 on standby) after the port or the starboard dockside discharge valve is manually opened.

A low level control within the tank signals the stop of the pump and closing of the tank drainage (three way ball) valve (TDV).

During the tank drainage operation, any drainwell demand will interrupt the tank drainage by closing the TDV; the wastewater from the drainwell than being directed to the shore facility.

Tank drainage mode is automatically resumed upon the removal of the demand.

To prevent pump operation under cavitating conditions, a thermostat is installed at the drainwells in the propulsion engine rooms which prevents pump start-up until the water wash temperature in the drainwell cools to at least 100°F.

APPENDIX E.3

HVAC SYSTEM DESIGN

HVAC SYSTEM DESIGN

AIR CONDITIONING SYSTEMS

Each Air Conditioning System for a 3000 ton SES design contained two, three or four independent condensing units and refrigerant circuits located in the air conditioning fan rooms. There were four HVAC Fan Rooms aboard the SES, two of which include an additional HVAC system dedicated to electronic equipment cooling. Therefore, the total number of HVAC systems was six. Each condensing unit consisted of a compressor, condenser, condensing water control valve, receiver, suction accumulator and necessary control devices. The unit is located below its associated evaporator.

Compressor sizes are approximately 2.5, 3.0, 5.0 and 7.5 tons in combination to match loads. The six systems provide the following capacities:

System No.	Cooling Load (Tons)
1	4.8
2	14.3
3	13.3
4	13.9
5	8.6*
6	10.9*

*These systems are dedicated systems for electronic equipment loads.

CAPACITY CONTROL

Each air conditioning plant can be reduced in capacity by step sequencing compressors within the plant. The logic for the step sequence will be through control devices consisting of thermostats located within the conditioned space and signal selectors, or thermostats located in the return ducts for equipment cooling.

Each control system consists of a number of zone monitors (thermostats) and a summary control to stage A/C compressor operation.

The signal selector will accept thermostat (voltage signal) output from each zone within a multizone system and select the highest voltage for transmission to the relays controlling compressor staging. The high signal will cause compressors to come on line or drop off in proportion to its voltage level.

Within the controlled zone, the local thermostat will also cause displacement of the actuator for the variable air volume terminal proportional to the thermostat output. A final function of the zone thermostat will be to control the electric resistance heater within the air distribution duct for that space. Each controlled zone will have one variable air volume terminal and generally an electric resistance heater. The variable air volume terminal functions to control the amount of conditioned air serving a zone and thereby control the cooling capacity based on load requirements. For equipment dedicated systems, the thermostat is located to sense return air temperature. A functional block diagram for HVAC control is shown in Figure E.3-1. The concept of

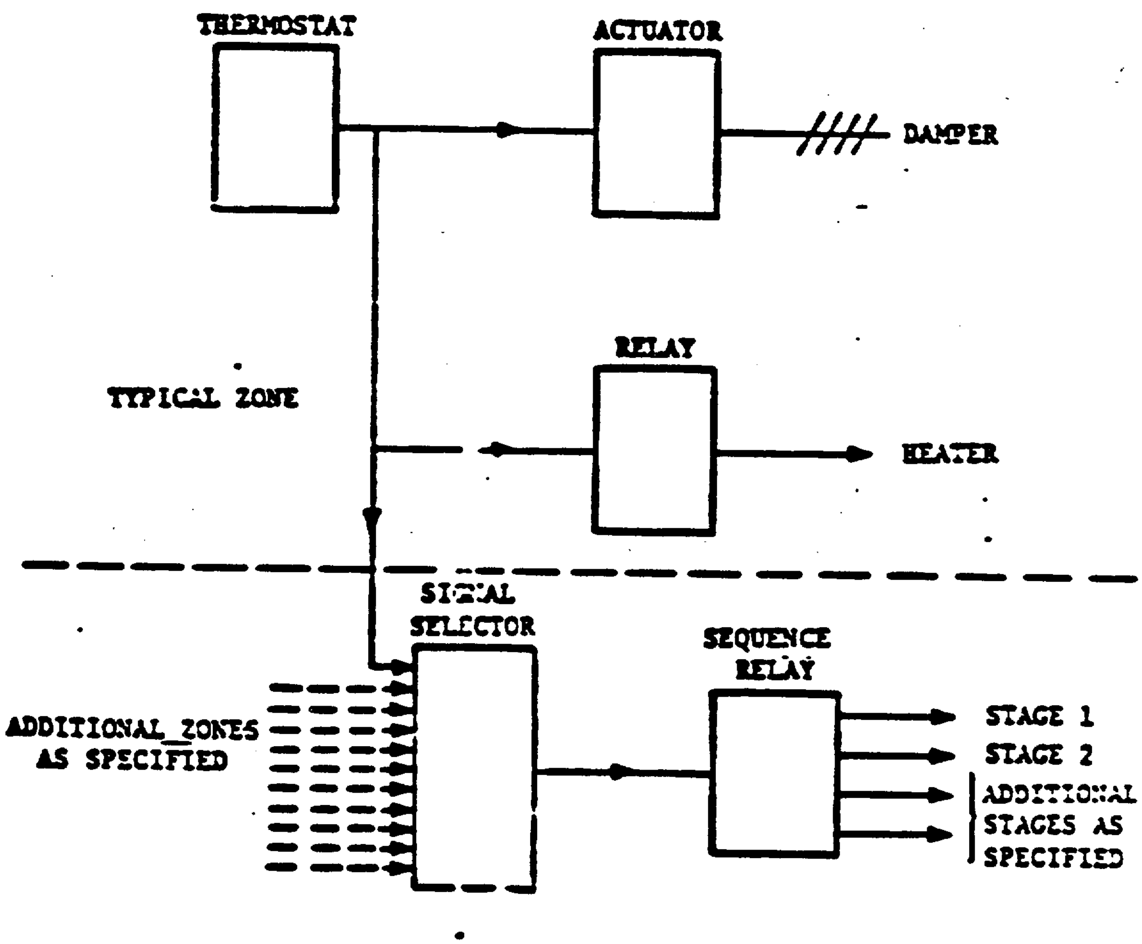


Figure E.3-1. Functional Block Diagram for HVAC Control System compressor staging with reference to zone temperature is shown in Figure E.3-2.

AIR DISTRIBUTION

A high pressure fan is located in each air conditioning plant fan room. The fan draws a mixture of replenishment and return air from the fan room and forces it through a filter and cooling coil into high velocity (2000 - 4000 feet per minute) ducting. In systems which are not equipment dedicated, variable air volume terminals in each space admit only the quantity of air necessary to cool the space to between 75°F and 80°F. The thermostatically controlled terminal has a preset maximum and minimum flow rate. Minimum flow is approximately 50% of maximum flow. Highly loaded electrical equipment spaces may be further reduced to less than 50% to reduce reheat requirements. In addition to cooling flow control, the terminal contains noise absorption materials to minimize air velocity noise. An induction feature of terminals serving occupied spaces causes secondary induction of space air through the terminal when primary air is reduced, thus maintaining nearly constant air flow through the heater and diffuser.

Return air travels back to the fan room through passages, and in some cases, is fan forced. Some of the air is expelled by exhaust fans located in water closet spaces and other designated exhaust spaces. Replenishment air from the 01 level is fed from the ventilation system to the fan rooms. The replenishment air rate is reduced in one step to 50% in the heating season to conserve electrical power.

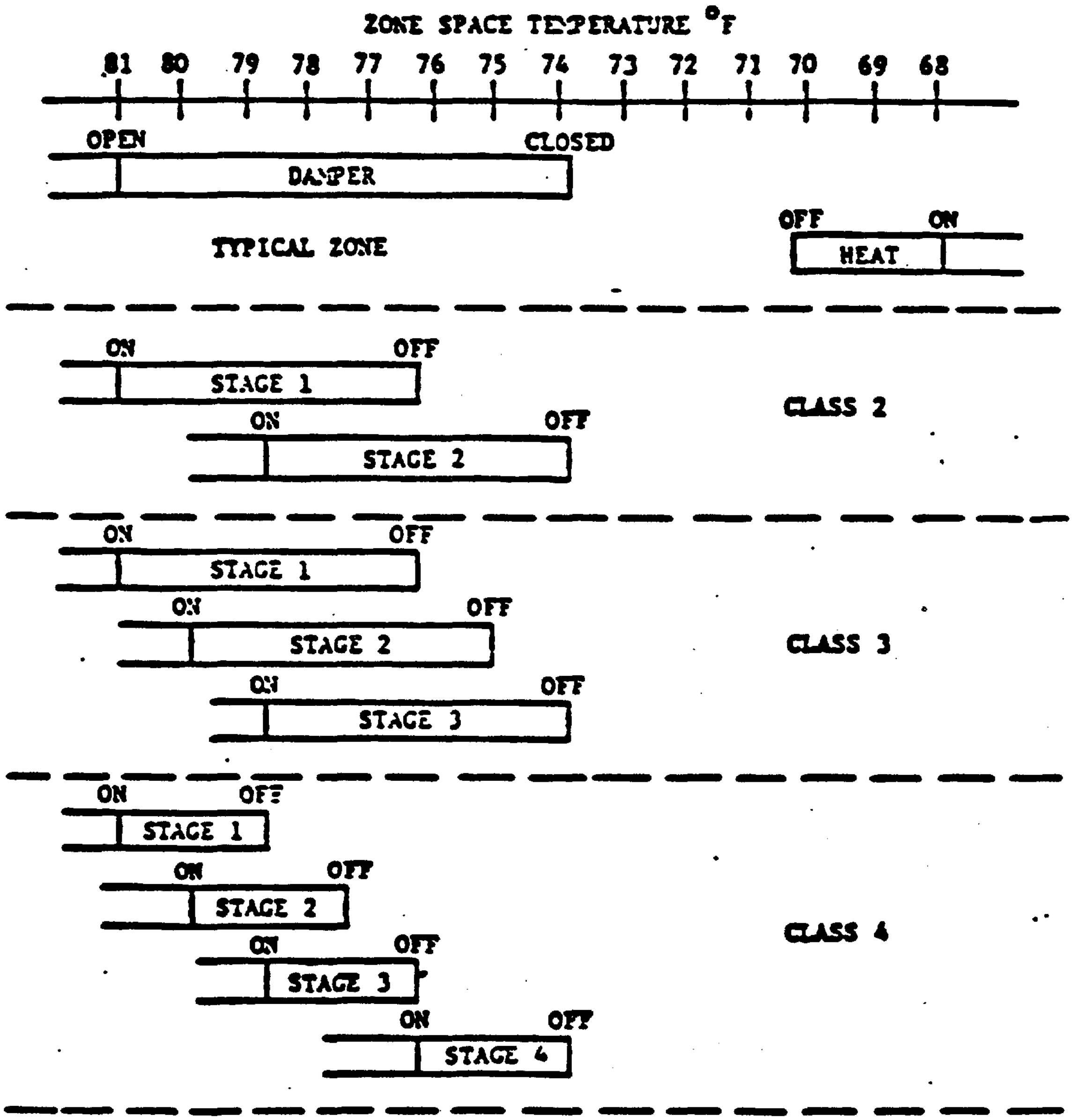


Figure E.3-2. Compressor Staging Concept

A relief or bypass damper located between the high pressure supply fan inlet and outlet dumps air directly back to the fan room or return fan as the terminals decrease air flow. This maintains relatively constant fan flow to avoid instability of the fan which could occur at less than design flow. The functional flow diagram for HVAC distribution is shown in Figure E.3-3.

HEATING AND REHEATING

Electric duct heaters are located in the supply air duct to each space or zone. In some cases, a separate space or radiant heater is used.

VENTILATION SYSTEMS

Three supply fan rooms on the 01 level deliver from the weather, via electric duct preheaters, fresh air to ventilated compartments and fan rooms of the air conditioning system.

Supply air to the medical spaces, pilot house and central control station include fumetight dampers in the ventilation supply ducts to preclude possible contamination from another space in case of casualty. Mechanical and natural supplies are used to ventilate these spaces.

The propulsion and lift engine rooms ventilation is considered part of the combustion air systems. The electrical generator rooms and auxiliary machinery rooms are provided with mechanical supply and exhaust ventilation systems.

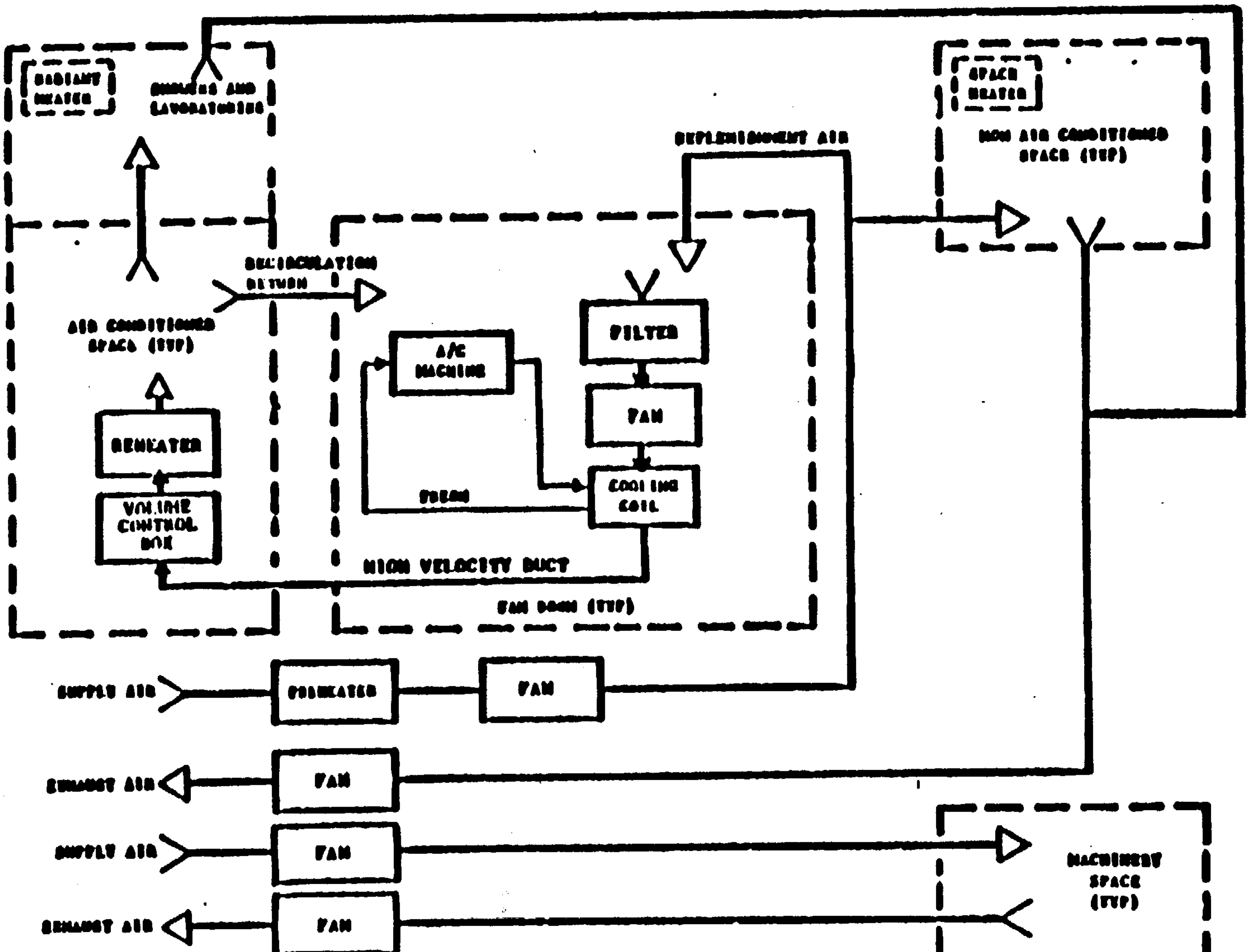


Figure E.3-3. Functional Flow Diagram - HVAC Distribution

Electric radiant heaters and mechanical exhaust to the weather are provided for all sanitary spaces.

Ventilation air flow for non-air conditioned spaces is sized to keep maximum summer compartment temperatures or rate of change in accordance with the requirement of the Design Criteria Manual. In the winter, the ventilation rate is reduced for energy conservation, by a single thermostat sensing weather ambient air.

HEATING OF VENTILATED SPACES

Spaces requiring preheated air have heaters in the air supply duct. This air is thermostatically controlled at 45°F (average). Spaces requiring warmer temperatures are provided additional duct heaters, supplemented by space heaters as necessary. These space heaters are controlled by space thermostats.

GENERATOR COOLING

While normal ventilation is supplied to generator rooms, a secondary source of air from the combustion air intake is applied directly to the generator enclosures. The secondary exhaust air becomes warmer than the primary exhaust air. Each is exhausted via separate fans. The enclosure exhaust is exhausted up the stack while the room is vented by normal exhaust.

SMOKE PROPAGATION

In the preparation of this study, the paramount hazard related to smoke propagation has been considered:

The propagation of smoke and possible failure of ventilation control aboard SES may lead to the reduction of or inability to fight the originating fire hazard. Limited visibility and the physical effect of smoke inhalation will seriously hamper or negate conventional fire fighting techniques. As such, this study has identified means of smoke and fire extinguishant containment.

The application of dampers as recommended in this study satisfies the requirements set forth in the Ship System Specification, T22000001C, Para. 3.2.2.7 in regards to a method of counteracting the effects of smoke and toxic fumes. It further fulfills the requirements of the means of such protection by planning restrictions on the ventilation system of the SES.

SAFETY RECOMMENDATIONS

1. Install dampers in ducts to machinery spaces.

2. All dampers installed serving a machinery space or a space from which machinery draws air must be provided with an interlock to insure that the damper cannot be closed until machinery in the space has ceased to operate.

3. Under current design, the SES was not provided with an automatic back-up fire extinguishing system. The incorporation of the smoke dampers specified in this study is a provision which, through the containment of smoke, or at least delay in smoke propagation, allows conventional fire-fighting techniques to be used as rapidly as personnel and equipment can be moved.

4. The build-up of residual heat in the Turbine Spaces following shut-off of the cooling fans is still being evaluated. Until the impact and amount of such residual heat is accurately determined to be structurally safe it should be remembered that the use of Halon as an extinguishing agent may be ineffective.

5. Should such be the case, an alternate, remotely actuated extinguishing system should be considered. A technique identified in Amphibious Assault Landing Craft Technology report, dated Sep 1978, recommends the use of pressurized (400 psi) water discharged as a mist. Test results indicated that a 9 ft^2 pan fire was extinguished in 4 seconds with a discharge of 2 quarts of water in a 500 cu. ft. volume space.

6. Where dampers are recommended but cannot be installed due to weight or space considerations, the space served should be provided with Halon flooding and, ideally, an additional bleed rate of Halon to compensate for loss of fire extinguishant through doors and ducts.

7. Where grills or louvered vents are placed in doors or bulkheads serving spaces for which dampers are recommended, the trills or vents should be provided with a manual closing operation that can be controlled from either side of the grill or vents.

8. Where a smoke damper requirement is satisfied by a watertight closure, the closure's mode of operation should be that recommended for a smoke damper at that location.

9. Fume-tight dampers should be manually operated and located, as far as is practicable, immediately outside the space served. Dampers should be secured open and so tagged under normal conditions.

Tradeoff studies conducted during the U.S. 2K and 3KSES programs identified some promising subsystem design options and components as follows:

ROTARY VANE COMPRESSOR

A commercial 60 Hz vane compressor is now being manufactured by the Fedders Compressor Company. The compressor is considerably lighter than the Carrier Compressor that had been tentatively selected for SES. Vane compressors are not internally vibration isolated like reciprocating compressors. The latter are not suitable in applications where external vibration or shocks are applied because excitation of the compressor motor to the limits of the internal springs ultimately results in fatigue cracking of the tubing connecting the compressor to the outside housing. Only specially modified compressors like the Carrier military compressor could be used, with a resultant high cost. The vane compressor is currently being used in mobile applications. Welco Industries of Cincinnati is currently testing 400 Hz modified vane compressors, but they are not as yet being marketed. The problem is higher rpm and life. When available, these compressors should be considered. Also, the light weight but expensive Fairchild Stratos screw compressor should be considered.

LIGHT WEIGHT DUCTING

A major consideration in the initial design of the SES was to decrease weight wherever possible.

One area where weight was saved on the HVAC system was the use of light weight, high-pressure aircraft fans rather than the much heavier Navy standard fans.

Weight-saving considerations were not fully explored for duct material specifications. The initial HVAC design used the General Specifications for Ships of the United States Navy. This general specification gives the minimum thicknesses listed in Figure E.3-4.

These material thicknesses are for use on all surface ships. However, most surface ship designs are not faced with the same weight saving considerations as SES.

Sheet for Fabricated Ductwork

	Nonwatertight		Watertight	
Diameter or longer sides (Inches)	Galvanized Steel (Inch)	Aluminum (Inch)	Galvanized Steel (Inch)	Aluminum (Inch)
Up to 6	.018	.025	.075	.106
6.5 to 12	.030	.040	.100	.140
12.5 to 18	.035	.050	.118	.160
18.5 to 30	.048	.060	.118	.160
above 30	.060	.080	.118	.160

Welded or Seamless Tubing

	Nonwatertight	Watertight
Tubing Size (Inches)	Aluminum (Inch)	Aluminum (Inch)
2 to 6	.035	.106
6.5 to 12	.050	.140

Sprially Round Duct (Nonwatertight)

Diameter (Inches)	Steel (Inch)	Aluminum (Inch)
Up to 8	.018	.025
Over 8	.030	.032

Figure E.3-4

In an effort to find an alternative to these specifications, the HVAC design section investigated other types of ductwork for applicability to SES. One promising ductwork system is produced by United Sheet Metal of Westerville, Ohio. They are specialists in spiral duct and have provided ductwork for many U.S. shipbuilders.

A new development at United Sheet Metal was of interest to the HVAC section. It involved a new process that formed a continuous raised ridge around the spiral ductwork. According to the United sales representative, the added strength of this ridge allows the use of lighter weight duct. For example, if .060 aluminum ductwork is required in a certain situation, a .050 raised ridge duct would provide the same strength at a weight savings of .183 lbs. per square foot.

Another opportunity for weight savings would be the use of spiral raised ridge flat oval ductwork in place of standard rectangular duct. Previously, marine spiral ductwork was limited to round use only. The new process at United would almost eliminate the need for rectangular duct.

It should be pointed out that spiral duct is available for straight runs only. Fittings are only available in standard weldable thicknesses.

Also, before the raised ridge duct is specified for any shipboard use, test results must be obtained to verify that a lighter weight duct could withstand the loads placed on it in high-pressure installations.

Should the strength tests prove favorable, the use of this type of ductwork would appreciably reduce the overall weight for the entire ship.

SMOKE PROPAGATION

The propagation and dispersal of smoke and noxious gases must be included during the ventilation design phase. Final recommendations included:

a) Installing smoke dampers with interlocks in ducts to machinery spaces;

b) Adding manual closing operations for louvers in doors and bulkheads.

Since smoke propagation and halon containment are a real concern, recommendations must be made prior to ventilation system design and analysis.

By breaking up these ventilation systems into smaller systems with separate fans, cross-connections can be eliminated. This will reduce the chance of smoke or halon infiltration into manner spaces during a shipboard fire.

MIL-STD-1472B offers much broader temperature and humidity ranges for its comfort zones and provides a more realistic approach to military shipboard conditions. The summer comfort zone temperature ranges from 67 to 89 degrees and humidity ranges from 10 to 90 percent. The winter comfort zone temperature ranges from 66 to 83 degrees and humidity ranges from 10 to 90 percent.

The boundaries for the MIL-STD-1472B comfort zones are based on an effective temperature (ET) scale, which shows constant physical sensation lines. These lines give the combination of temperature and humidity which provide the same comfort.

ASHRAE also has developed an effective temperature scale which varies from the MIL-STD-1472B scale. Refer to ASHRAE Fundamentals Book for further information.

TEMPERATURE REQUIREMENTS

The temperature requirements for air conditioned personnel spaces (offices, berthing, wardrooms, etc.) in summer was 80 degrees F dry bulb/55 degrees relative humidity, and in winter was 70 degrees F dry bulb/no R.H. requirement. These were the standards from which the HVAC calculations were developed. If it was possible to use more realistic requirements, the heating and cooling loads might be reduced appreciably. The lower loads would allow for smaller or less HVAC equipment with a considerable conservation of energy and wright.

HEATING SEASON

The original U.S. Navy temperature requirement for air conditioned spaces on surface ships was 65 degrees F dry bulb. That temperature was raised to 70 degrees in OPNAVINST 9330.7A, U.S. Navy Shipboard Habitability Design Standard. This standard also includes the provision that appropriate tradeoffs be conducted to derive habitability features most responsive to mission requirements.

In the case of the SES, a tradeoff study should be made to determine whether lowering the design temperature in berthing spaces to 65 degrees F dry bulb will have an effect on reducing the heating load requirements. The lower design temperature would probably be more comfortable for sleeping, since metabolism for sleeping is approximately half that of light office work.

Making a rough preliminary estimate, it was determined that lowering the design temperature of berthing spaces from 70 to 65 degrees would reduce the KW required for heating those spaces by approximately 10 percent, a considerable savings of energy. This savings would reduce the size of many heaters, thereby saving weight.

COOLING SEASON

The cooling season requirements for most air conditioning spaces (offices, berthing, etc.) on the SES is 80 degrees D.B./55 percent R.H. This design temperature condition, when plotted on the cooling season psych chart gives an effective temperature reading of 74 degrees ET, below the 75 degree ET upper boundary of the summer comfort zone.

To analyze the air conditioning systems, each system room mix temperature and relative humidity could be plotted on the psych chart to determine the effective temperature for the system. The results of this analysis are as follows:

A/C System	Room Mix Temperature	Effective Temperature
1	80.4°	72°
2	82.6°	74.5°
3	82.6°	74.7°
4	80.0°	72°
5	85.0°	76°
6	85.0°	76°

As shown above, all but two systems (numbers 5 and 6) have an effective temperature under 75 degrees and as such are within the MIL-STD-1472B summer comfort zone.

Since nine of the A/C systems have room mix temperatures under the upper boundary of the comfort zone, there is an opportunity for energy savings if the room mix temperature were allowed to increase to the upper limit.

HEAT PUMPS

The ultimate HVAC system for an SES is one which meets all of the requirements for personnel health and safety and the combat readiness of the ship at minimum weight and maximum energy efficiency.

Such a system requires a departure from traditional and Navy standards of design, equipment and materials. From preliminary studies, a water source heat pump offers promise of providing the ultimate system. The heat pump has become, in recent years, one of the outstandingly energy efficient devices for controlling an interior environment. In the commonly known heat pump, heat is removed from a space and rejected to the outside by the standard vapor cycle refrigeration system. By reversing the cycle, heat is extracted from the outside and rejected to the space. In the water source heat pump, the outside is replaced by a circulating water supply which serves as a rejection medium or the source of heat, depending on the mode of operation of the heat pump. The circulating water system is provided with means for cooling or heating as required to maintain the circulating temperature within limits which will produce efficient space heating and cooling.

Customarily, heat pumps are applied to a complex structure in small unitary machines served by a single water system. It can be seen that by this means heat can be removed from one portion of a structure and added to another part if required.

For the SES, as applied to other structure of similar complexity and compartmentation, individual heat pump units would be installed within the space being controlled and would require little or no duct work. An exception might be a series of contiguous spaces, such as berthing areas having similar environmental requirements, where one heat pump may serve several spaces with interconnecting ducts.

The advantages offered by this system is weight, efficiency and space saving are as follows:

1. The duct work required may be reduced in weight by as much as 80%, partially by reduced size and primarily by elimination.
2. The weight and complexity of electric duct heaters is eliminated entirely along with the wiring and controls.

3. Electrical load is drastically reduced for heating since heat pumps provide approximately three times the heat of resistance heaters per watt.

4. Fuel consumption for electric generation is reduced.

5. Waster heat from the exhaust of the electric generators is added to the circulating water system to provide space heating.

6. Simultaneous heating and cooling of any space is eliminated saving energy and fuel.

7. Fan rooms for HVAC are eliminated.

8. Controls become simple heating/cooling thermostats, reducing system complexity.

9. Reliability is enhanced since each heat pump is an individual system. The failure of a heat pump will only affect the area served and not affect the operation of the balances of the system.

10. Infinite zoning is possible for special temperature requirements.

The disadvantages are:

1. Additional ventilation ducting would be required since replenishment air must be piped to each heat pump. However, these are small ducts and do not add significantly to the system weight.

2. Piping would be increased by the circulating system. Such pipes are light weight fiberglass and do not require insulation.

3. A means of heat rejection and a waste heat boiler would be required adding to system weight.

4. Condensate drainage problems would be complicated by the number and dispersion of the evaporators.

Water source heat pumps have been marketed for over 20 years, and are available from a number of suppliers. However, no information is available as to their compatibility with the marine environment.

PROPULSION EXHAUST DUCTS

In the current ship configuration, the outboard propulsion exhaust ducts are located in the upper level of the 2and deck aft, both port and starboard. The extremely high temperatures in the exhaust ducts require that the pump rooms each have their own ventilation system.

The solution to this design problem is to locate the propulsion exhaust ducts outside the watertight boundary of the ship, by locating a watertight deck directly under the exhaust ducts at the 2and deck level, and providing grating above and outboard of the ducts.

The propulsion exhaust ducts would then be cooled by exposure to outside air, and would not require a separate ventilation system.

The drawback of this proposed solution is that a sizeable portion of the flight deck would be made of some type of grating, with reduced structural strength. A structural analysis would be required to determine whether additional structural members were necessary.

VORTEC COOLING SYSTEM

In reviewing the problem of backup cooling for vital equipment, the VORTEC cooling system was investigated.

The VORTEC enclosure cooling system sold by VORTEC Corporation of Cincinnati is a product which converts compressed air into two streams, one hot and one cold. The cold air is directed into the electrical enclosures, replacing the heated enclosure air which is induced and vented outside with the hot exhaust of the vortex tube. The product can be used continuously, or with a thermostat for intermittent usage.

The entire cooling system uses 25 CFM at 100 psi inlet pressure. Refrigeration is generated at the rate of 1500 BTU/Hr or 440 watts when running continuously.

As can be seen from the above figures, these products offer only a partial solution to equipment cooling. However, they might be used as a backup system in the event of A/C system failure, or as preliminary cooling for the A/C system.

As stated above, this system requires connection to the ship service air lines. Also a route must be found for the exhaust from this system to the outside.

APPENDIX E.4

FRESH WATER SYSTEMS

For the distillation plant, three options were considered:

a. An electrically heated vacuum distriller
b. A vacuum distiller which used the turbine engine exhaust waste heat,
c. A reverse osmosis process

The electronics cooling, potable and fresh water and auxiliary fresh water cooling systems adhere to standard Navy practice and no system alternatives were considers; however, some variations were considered primarily to offer a weight or water savings. As an example, Table E.4-1 outlines several showerhead options. The Low Flow Showerhead which uses 1.75 GPM was selected for the system.

The results of trade-off studies performed in the distiller area have lead to selection of a commercial, electrically heated, vacuum distillation unit. The reverse osmosis unit, even though advances have been made in membranes suitable for sea water use, was eliminated because no commercial unit specifically packaged for shipboard service was available. This process, however offers long tern potential because of modest installed weight and minimal operating power requirements. Utilization of turbine exhaust waste heat was eliminated on the basis of convenient packing of water heating coils around the GTG exhaust ducts and because of somewhat higher overall weight than the vacuum still.

Table E.4-1. Showerheads Comparison

OPTION	WATER USAGE RATE (HOT & COLD)
Standard Showerheads	2 gpm min. at 5 psig min. per GEN SPECS 5 gpm at 12 psig per commercial standards 2.5 gpm per MIL-S-955 5.3 gpm per DD 938
Low-Flow Showerheads	Approximately 1.75 gpm Installation is simple
"Minuse" System Showerheads (Minuse System, Inc. Jackson, CA)	0.5 or 0.7 gpm depending on nozzle design chosen. Electrical power required for operation. Pressure required is 35 to 125 psig. Highest cost of all.
NSRDC Handheld Unit	0.75 gpm, this system requires the user to push a button to maintain water flow.

DISTILLING PLANT

The distillation units (2) selected are of the vapor compression type (thermo-compression). The units are self-contained "package type". The units are designed for automatic operation, and is suited to remote start and monitoring.

Each unit will produce, without descaling or cleaning, an average of 2400 gallons per 24 hours of operation over a period of 10 days. The plant will produce distillate from sea water of not less than 1.32 density (32 pounds of sea water containing one point of dissolved salts) and at temperatures between 28° and 85°F. The product water will have a salinity content not exceeding 0.0325 equivalent per million of chlorides (epm) or 0.125 grains of sea salts per gallon (gpg).

The unit operates on input power sources as follows:

a. 440 V, 3-phase, 400 Hz for all pump motors, electric heaters, and compressor motors.
b. 28 V, direct current for control circuitry.
c. 110 V, 1-phase, 400 Hz for operation of the salinity indicating system.

The unit incorporates a suitable system for locally monitoring distillate purity by means of a relay meter calibrated in microhms/cm, with automatic correction to 77°F. The meter will provide adjustable set point relay contacts for local audible and visual alarms with sufficient contact rating for additional remote alarms and controls.

The distillate will be disinfected by use of two in-line (one for each distiller) proportioning brominators. Bromine concentration will be maintained at the correct level by an off-line, manually operated, recirculating brominator in the potable water storage portion of the system.

The materials of construction conform to U.S. MIL-D-16196D (Ships) Class A, for those surfaces in contact with the process fluids. In the interest of weight reduction, aluminum alloys will be used in the fabrication of the mounting skid, pipe supports and brackets. Suitable design precautions will be observed for the prevention of galvanic corrosion. Figure E.4-1 depicts the distillation plant diagrammatically.

POTABLE AND FRESH WATER SYSTEMS

The potable and fresh water service system is designed for continuous duty with suitable redundancy or duality in major equipment items. The system design is in general compliance with General Specifications, but contains some modifications designed to tailor the system to the specified needs for the SES. Hot and cold water is furnished to the ships fixtures in accordance with the GSS. The fixtures and maintenance service outlets requiring hot and cold potable water are listed in Table E.4-2.

Recirculation loops for the fore and aft portions of the system ensure that hot water is provided within 15 seconds at any outlet. An independed system provides pressurized, untreated water, at specified flows and temperatures to all of the ships turbine engines for washing.

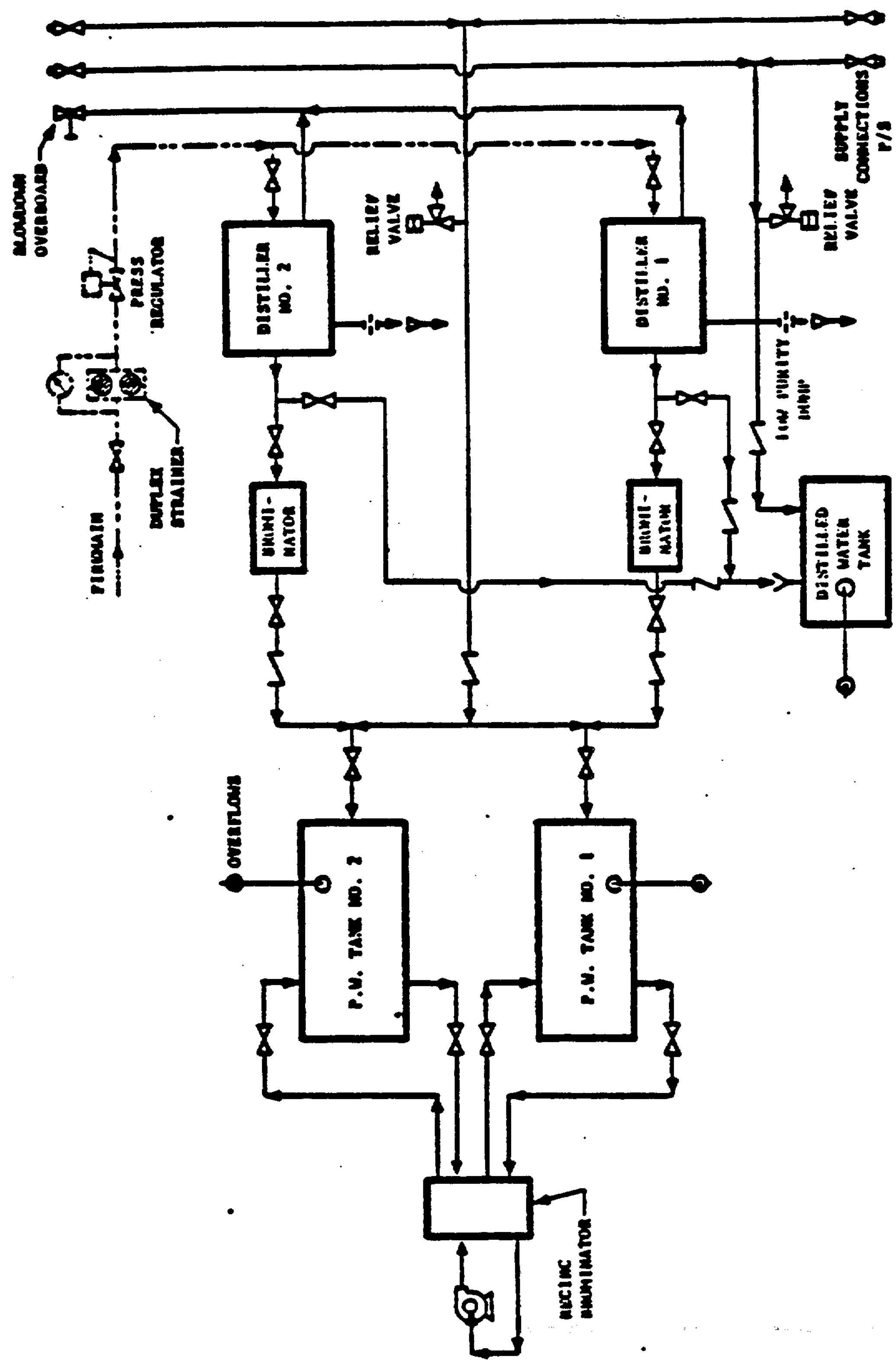


Figure E.4-1. Distilling Plant Diagram

Table E.4-2. Potable Water Service Connections

FIXTURE OR SERVICE OUTLET	QTY	INSTANTANEOUS FLOW RATE (GPM)	PRESSURE AT FIXTURE (PSI)	SUPPLY TEMP (°F)
Shower	12	1.75	10	H & C
Sink, Service	5	6	10	H & C
Sink, Scullery	1	6	10	160 & C
Lavatory	22	3	10	H & C
Veg. Peeler	1	3	10	C
Dishwasher	1	1.8	30	180
Washing Machine	2	25	40/100	H & C
Drinking Fountain	7	0.2	10	C
Ice Machine	1	3 gph	40	C
Ice Cream Dispenser	1	-	10	C
Steam Table	3	10	60	70/225
Grease Intercept Hoods	6	5.4	40/80	140/180
Water Closets	14	3.5	35	C
Urinals	8	3.5	35	C
Helo Wash Outlet	1	10	30	C
Windshield Wash Outlet	2	5	5	C
Steam Generator	1	3	20/50	H
Carbonated Beverage Dispenser	1	3	30/80	C
Coffee Urn/Maker	3	5	15/45	H
Booster Heater	1	6	30	H
Lift Fan Room Outlet	4	10	30	C
Combustion Air Room Outlet	2	10	30	C
Filter Cleaning Hood	1	7.9	40/80	140/180
Trash Compactor Room	1	5	30	C
Propulsion Room Outlet	2	10	30	C
Propulsor Room Outlet	2	10	30	C
Auxiliary Machinery Room Outlet	4	5	30	C

Provision is made for proportioning detergents into the wash water, as specified by the turbine manufacturers.

Figure E.4-2 illustrates the potable and fresh water service system.

ELECTRONIC COOLING WATER SYSTEM

The electronic cooling water system delivers 59°F fresh water to electronic units. The system is comprised of standard package type water chiller, with an electrically powered compressor and a sea water cooled condenser, distribution piping (essentially CRES), two pumps, flow balancing valves, expansion tank and pressure, temperature and flow instrumentation of both local and remote indication type. Figure E.4-3 depicts the system schematically.

AUXILIARY FRESH WATER COOLING

The system design is based on the system described in Navy Mechanical Standards Drawing No. 803-225-1137 entitled "Electronics Cooling Water System". A standby heat exchanger is not included in the system design. The system, constructed essentially of CRES, provides demineralized water at 105°F and the purity specified in MIL-STD-11399; which is a standard governing cooling water to be used in support of electronic equipment. The system is initially charged with water of this quality and is maintained at this level of purity by a demineralizer located in a bypass loop of the system. The bypass loop is sized at 5 percent of the total system flow. Figure E.4-4 depicts, schematically, the system elements.

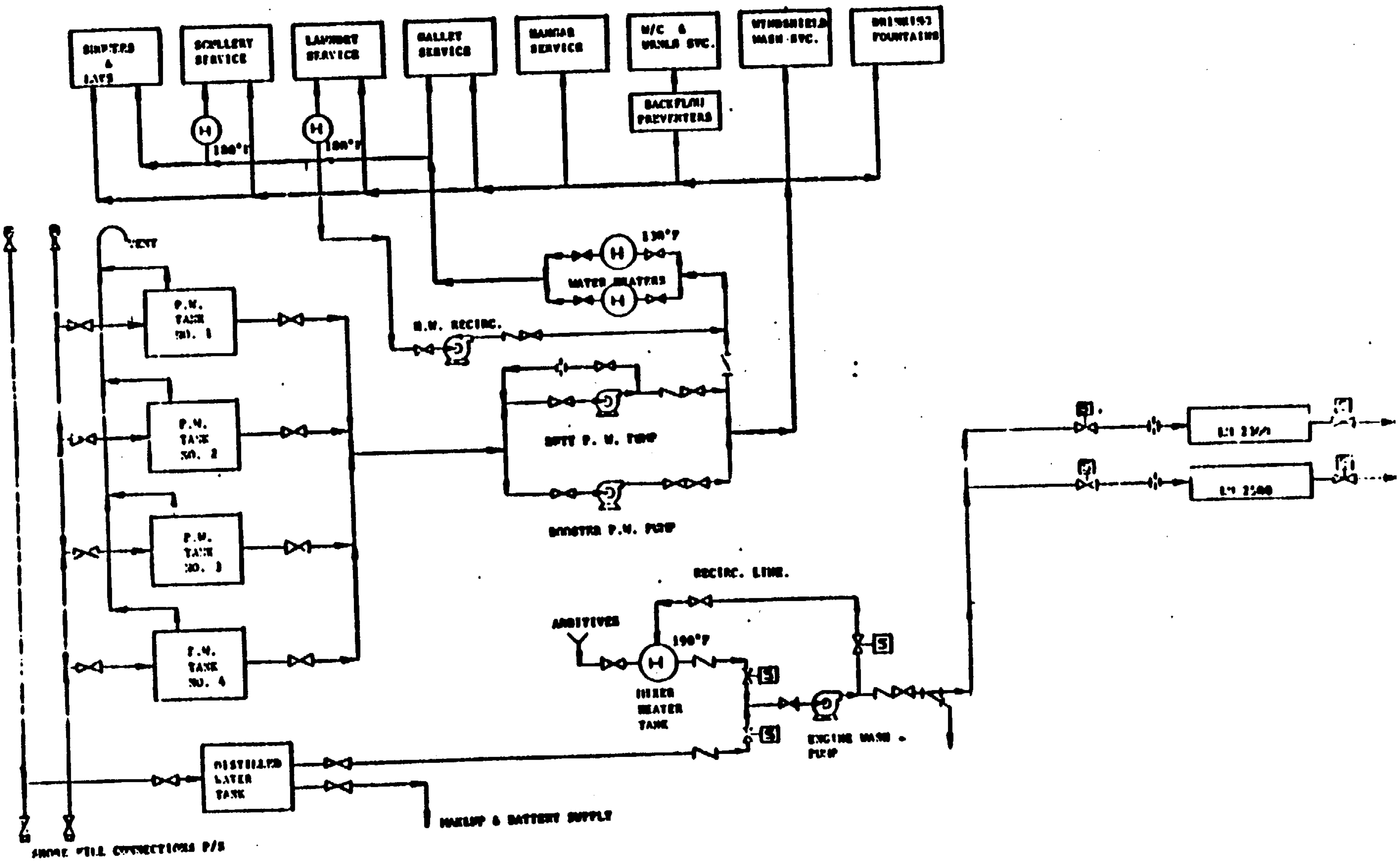


Figure E.4-2. Potable and Fresh Water Service Diagram

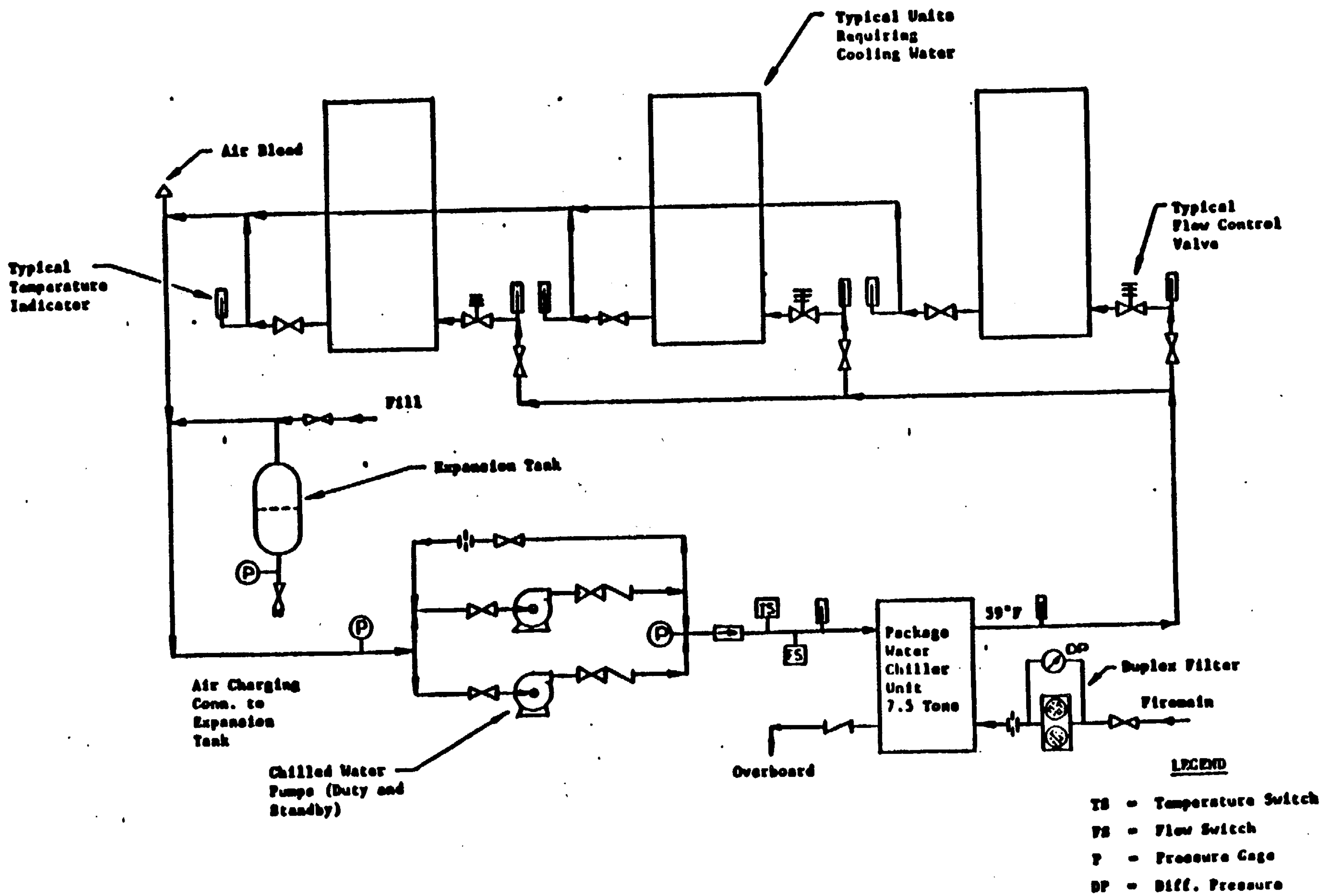


Figure E.4-3. Chilled Water Cooling System (SWBS 532)

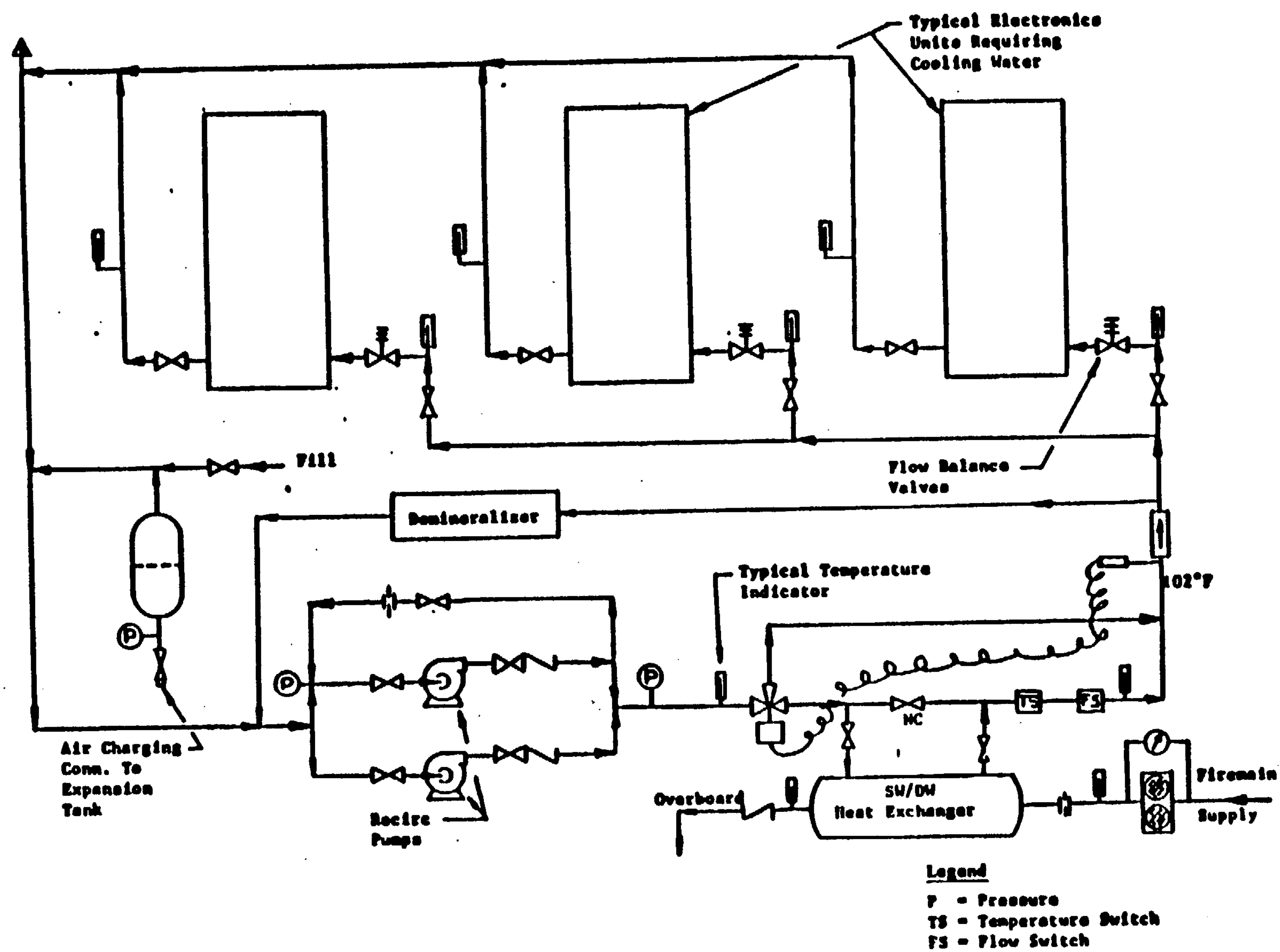


Figure E.4-4. Auxiliary Fresh Water Cooling System

APPENDIX E.5

FUEL SYSTEMS

FUEL OIL SYSTEM

The fuel oil system had three basic functions; service, transfer and trim, and stripping. The service subsystem served the fuel demands of the propulsion plant the lift system, the electric plant and also provide "clean" fuel to the helicopter service tanks.

Table 2-10 provides a summary of the Fuel Oil Service operating parameters.

Table E.5-1. SES Fuel Oil Service System Requirements

Fuel	MIL-T-5624 (Grade UP-5)
Fuel Pressure	5 to 50 psig
Fuel Temperature	15° above cloud point to 150°F
Particle Size	10 u absolute
Particle Quantity	10 mg/gal
Maximum Entrained Water Content (per volume) at 70°F	40 ppm
Maximum Flow Rate (all services)	350 gpm
Black Ship Flow Rate	12 gpm (28 VDC Motor Driven Pump)

The SES Fuel Oil Service System originated at the ship's service tank. Fuel was drawn from the fuel oil storage or fuel oil trim/storage tanks, processed through a set of duplex filter separators and transferred to the dedicated Fuel Oil Service tanks. When the fuel oil is delivered to these tanks, it is no longer available for trimming, thereby reducing air and water contamination. The fuel oil service subsystem took suction on the service tanks, and a second set of filter separators processed the fuel again before delivering it to the propulsion, lift and electrical engines. The Fuel Oil Service System is divided into port and starboard distribution systems. Each system incorporated dedicated pumping, filtering, and flow control components. By cross-connecting the starboard and port systems, complete redundancy is afforded the SES. Components included are:

- Two service tanks
- Two service manifolds
- Two prefilter-filter/separators
- Two service pumps
- Vents and overflows
- Liquid level indicators
- Damage control valving
- Flow control valves

The heart of the service system is its distribution center or fuel oil service manifolds. The manifolds are designed to integrate into one unit; a high flow (350 gpm) centrifugal aircraft pump, a low flow (12 gpm) centrifugal pump, and cartridge type isolation valves.

The high flow service pump is for normal operating conditions, the low flow pump will be used for "start-up" and black ship operation. The high flow service pump is driven by a 400 VAC - 30 - 60 Hz electric motor, the low flow pump is powered by a 28 VDC electric motor.

The concept behind manifolding the service components is to reduce weight, eliminate tubing joints, and provide a local center of control.

The filter-separators conform to MIL-F-15618 and are designed for 350 gpm, 10 u absolute particle size, and 40 ppm entrained H_2O at 70°F. The units are designed with a prefiltering stage to eliminate particulate contamination at the filtering elements thus maintaining high performance and long life.

The trim and transfer system receives the ship fuel from the refueling stations and distribute it to the fuel oil storage and fuel oil trim/storage tanks. The system incorporates 2 pumping stations or manifolds, for trim and transfer. Each has a capacity of 350 gpm at 80 psi. The transfer system supplies fuel to the service tank through a set of duplex filter separators similar to the service system. The trim system route fuel to and from the trim/storage tanks, and if required the storage tanks, to adjust the craft center of gravity as required by the operating profile.

The transfer and trim manifolds were designed with the same basic idea of the service manifold, and incorporated similar components. Redundancy was obtained by pairing the trim manifold with the transfer manifold. The distribution system was symmetrical about the centerline of the ship, thereby providing equal pressure drop and an even fueling rate during refueling operations. The transfer and trim system consisted of the following components:

Transfer System

- One fuel oil storage tank
- One transfer manifolds
- One 350 gpm, 80 psi, 440 VAC - 30 - 400 Hz centrifugal pump'
- One duplex filter/separators per MIL-F-15618
- Damage control valves
- Vents and overflows
- Liquid level indicators

Trim System

- Four trim-storage tanks
- One trim manifolds
- One 350 gpm, 80 psi, 440 VAC - 30-400 Hz, centrifugal pump
- Damage control valves

A stripping subsystem was incorporated into the overall fuel oil system to remove water contamination. Contaminated fuel oil is collected and processed to the Contaminated Fuel Tank (CFT). The contaminate is then transferred from the CFT to a dedicated contaminated fuel holding tank (CFHT), and retained here until discharge to a proper facility is available. The stripping system is independent of the fuel oil system and served all fuel oil tanks.

The stripping system consisted of:

- Two stripping manifolds
- Two centrifugal 100 gpm, 50 psi, 400 VAC - 30 - 400 Hz electric motor driven pumps

Refueling and defueling operations are performed at refueling at sea stations (RAS). The fueling replenishment at sea equipment was designed, located and installed in agreement with U.S. Navy Document NWP 38D. The requirements of fuel replenishment at sea are defined as "side by side replenishment, at a maximum of 3,000 gpm using U.S. Navy standard equipment." The requirement of 3,000 gallons per minute replenishment rate was satisfied through transfer stations (7" hose, single proble receiver) port and starboard. The receiving station included the required equipment to handle the 300 foot heavy weather rig. Dockside fueling of the craft was performed through the same fueling equipment used for underway fueling.

The design of the controls for the fuel system was based on a combination of manual and automatic control. All valves were electrically (24VDC) operated with manual redundancy and position indicators. The use of the functional manifolds allows the controls to be set to any function (alignment of the system) and powering the system to achieve predetermined tank levels.

Fuel control functions were performed manually and electrically. At each manifold, a centralized electric control station and a local control station was provided. The display was: (a) digital and warning light for the fuel level, (b) digital and warning light for the pressure indicators (selector switch), (c) warning lights for filter P, (d) functional lights for pumps, filter, filter coalescer, (e) digital indicator for fuel temperature at service tanks (selector switch), (f) digital indicator for fuel temperature at engine inlet (engine instrumentation), and (g) readout for strapped-on flow meter (selector switch).

Fuel systems design integration was represented by the central control where all the functions of the system are monitored and all the functions except the helicopter fueling functions are controlled.

Through fuel management, the proper ship center of gravity can be controlled for the best attitude and performance of the craft. The central control together with the monitoring devices and instruments make fuel management possible.

AVIATION FUEL SYSTEMS (JP-5)

The aviation fuel system (JP-5) was designed and engineered in accordance with Section 542 of the GSS. The JP-5 Aviation Fuel System from the JP-5 service tanks is an independent system in its operation and control. The tanks are filled from the SES JP-5 service tanks through the prefilter-filter/separator units of the SES fuel system service subsystem.

The JP-5 system included a manifold that integrated the fuel pumps and valves (identical to the one of the SES DFM Fuel Oil System), electric motor operated valves, a filter/separator, and a control station just below main deck level that included the hose reel for inflight refueling and connections for deck fueling, defueling and fuel recirculation. Since the pumping equipment was of the centrifugal type, the differential pressure increase during inflight refueling reduced the flow capability to 150 gpm.

MATERIALS

The Fuel Oil System on the SES has the advantage of being compatible with existing aircraft materials and components. Except for the large size components and filters, aircraft hardware was utilized to its maximum potential.

Tubing is a corrosion resistant steel of high strength per AMS 5561, commonly known as 21-6-9 CRES or ARMCO Nitronic 40. This high tensile strength alloy allowed the use of thin wall tubing that together with the reliability improved the system installation with a large margin of safety. The resistance to corrosion is compatible with CRES 3161.

A survey of the market indicated that the fuel valves as used in aircraft fuel systems were suitable and compatible with all the conditions. The only modification required was the change of the aluminum alloy butterfly disc to stainless steel to increase the pressure rating of the valves. All valves incorporated thermal relief.

APPENDIX E.6

COMPRESSED AIR AND NITROGEN SYSTEMS

STARTING AIR SYSTEM REQUIREMENTS

The system requirements for the 3KSES were established by the FT9 (propulsion engine) and LM2500 (lift engine) starters, propulsor (waterjet) priming and engine motoring (wash). Table E.6-1 summarizes these requirements.

Table E.6-1

Starting Air System Requirements

SYSTEM	DUTY	FLOW, LBS/MIN	PRESSURE, PSIA (MIN)	TEMP., °F (MAX)	AVAILABILITY
Start Air					
	Start LM2500	194	49.7	450	
	Prime Propulsor	116	59	425	Intermittent
	Wash LM2500	119	40	200	

HIGH PRESSURE COMPRESSED AIR REQUIREMENTS

MK32 torpedo tubes launch system required 1500 psig charged flasks (900 cu. in.) for torpedo launching. In addition, 250 psig for the VLS is required. This was an intermittent service.

SERVICE AIR SYSTEM REQUIREMENTS

The service air provided uninterrupted service to vital systems by the use of a priority valve. Dry air was provided for wave guide pressurization and other equipment as required. Regenerative type desicant dehydrator was used to assure air quality per MIL-D-23523 for Type II dehydrators. Outlets for non-vital services were fitted with in-line filter, regulators and gauges as required. Table E.6-2 provides a summary of service air requirements.

NITROGEN SYSTEM REQUIREMENTS

Nitrogen System provided oil-free nitrogen at 4 to 3000 psig in accordance with Federal Specification BB-N-411, Type 1, Grade A, Class I. Distribution and outlet discharge pressures of nitrogen stations satisfied those requirements of NAVAIR Bulletin 1C to accomplish certification. System demand for nitrogen is provided in Table E.6-3, Nitrogen System Requirements.

SYSTEM DESIGN

The Start Air System is shown in Figure E.6-1. The source of start air was three load compressors driven by 3 diesel generator sets. Each DGS drove one load compressor as required. The load compressors could be de-clutched when not required. One load compressor was capable of starting one propulsion engine at a time or one lift engine at a time. The propulsion engines could also be started by cross bleeding, one at a

Table E.6-2. Service Air Requirements

ITEM	USE	LOCATION	TOTAL FLOW, SCFM	PRESS, PSIG	DRY AIR YES	DRY AIR NO	FILTER REQUIRED	REMARKS
1.	Collecting & Holding Tank	Wet Deck Aft FR 57 Aft FR 2	20	5		X	No	Emergency
2.	Wave Guide Oper. (radar) SPS 49	Radar Room 1-1-0-C	5	80 to 100	Dew Pt -40°F & 80 psig		98% 8μ	Continuous
3.	Wave Guide Oper. (radar)	Radar Room 1-1-0-C	10	80 to 100	Dew Pt +60°F +20°F		* Yes	Emergency
4.	Air Driven Intensifier for Nitrogen Sys (helo serv)	Hanger Main Deck	30	100		X	Line Filter	Intermittent
5.	Shop Air, Hose Connections	12 places: Aux Mach Room 3, Gen Rooms, Armory, Lift Fan Rooms, Refrig Mach Room, Elec Maint., Aviat & Gen. Work Shop, Filter Cleaning	40-80	50-100		X	Line Filter	Intermittent
6.	Rescue Boat Lift	Main Deck Aft Frame 52	85 (2 to 3 min.)	90		X	No	Intermittent, emergency
7.	Aux.Fresh Water Cooling Sys (compression tank charging)	Aux. Mach. Room #1	No flow	50-80		X	No	Intermittent, once a day
8.	Thermostat Control	About 60 Thermostats	less than 1	20-25	X		No	Continuous
9.	Valve Operation, Distiller #1 and 2	AMR #3 and #4	10-20	100		X	No	Intermittent
10.	Chilled Water Cooling Tank Charging	AMR #2	3	80		X	No	Intermittent, once a day
11.	Windshield Wash	01 Level & Pilot House	5	80		X	No	Intermittent, once a day
12.	Buffer Air ([redacted]h)	Propulsion Engine Room	180	50		X	No	Intermittent
13.	Sea Chest (2)	Propulsion Engine Room	20-30	50		X	No	Intermittent

*Oil .8 gram/lb air; moisture saturated at 80 psig

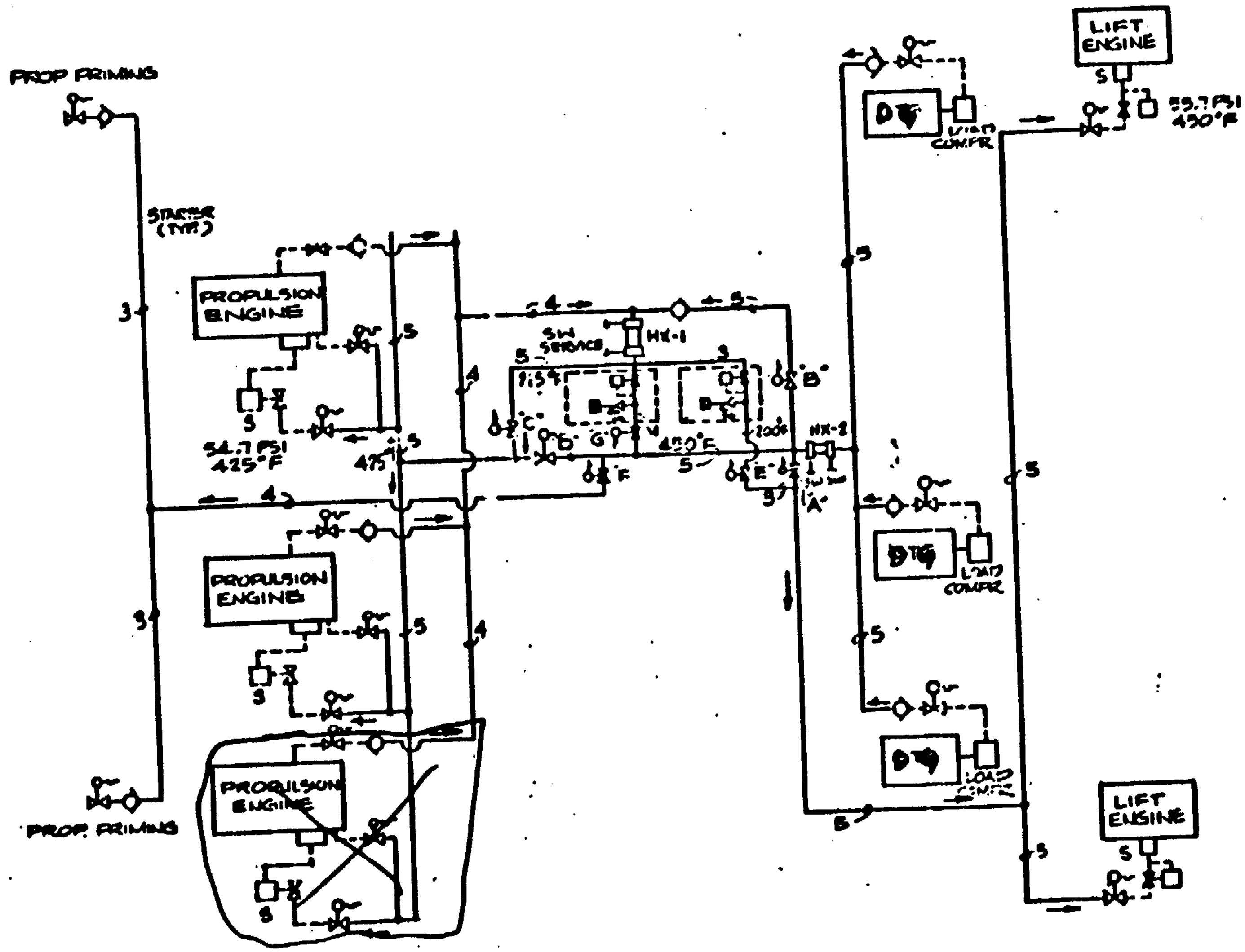


Figure E.6-1. Start Air System

Table E.6-3

Nitrogen System Requirements

*Service	Pressure, PSIG
Tires	75 - 250
Landing Gear Struts	1500
Emergency Gear Extension	3000
Rotor Blade Fold Accumulator	1500
Auxiliary Flotation Cylinders	3000
Tailwheel Centering Cylinders	425
Rotor Blade Inspection	4 - 16

* (15-50 SCIM)

time. During cross-bleed start, the propulsion turbine bleed air is to be routed via a heat exchanger and reducing valves to lower the temperature and pressure to the turbine-starter requirements in accordance with manufacturer's requirements.

The control and monitoring of the start air system is from PLCC and monitoring is also accomplished at the DCAEC Panel. In an emergency, the start air system can also be controlled at the LOP.

A detailed tradeoff study and analysis was made to evaluate the best method of starting the propulsion and lift engines. s This study was made on the basis of least weight and cost in meeting performance requirements. It was ascertained that the load compressors driven by diesel generator sets was the method to be adopted. A weight efficient SES would delete existing cross-bleed due to triple starting redundancy, thereby reducing system weight and cost.

The start air system as shown in Figure E.6-1 performs the following functions:

- Start propulsion engines, one at a time, using air from a load compressor.
- Start lift fan engines, one at a time, using air from a load compressor.
- Start propulsion engines, one at a time, using cooled and pressure reduced bleed air from an operating propulsion engine.
- Provide air for propulsor priming from a load compressor.
- Provide air for propulsor priming using cooled bleed air from an operating propulsion engine.
- Provide buffer air during propulsion engine starter motoring for engine water wash using cooled air from a load compressor.

All piping, fittings, valves (including solenoid valves), heat exchangers and components are to be of stainless steel since this system was required to withstand 104°F intermittently, which produces very high piping thermal stresses.

The lightweight stainless steel system, with thermal expansion joints and bends, meets the overall weight and displacement objective as well as performance requirements of the system.

HIGH PRESSURE COMPRESSED AIR SYSTEM

The high pressure compressed air system is a 3000 psig system with two 1500 psig branches for torpedo charging. This system is capable of charging one flask (900 cu. in.) in about 6 minutes. The system used CRES piping and deliveries clean (50 microns), dry air to the torpedo charing stations.

A multi-stage high pressure compressor feeds into a half cubic foot separator flask and then into an air dyer and purifier unit. The system is then divided into port and starboard branches (3/8" CRES piping). Each branch containing four cubic foot flask charged to 3000 psig and terminating in a torpedo charging station including an air filter, a needle valve, a pressure reducing valve and a pressure relief valve.

SHIP SERVICE AIR SYSTEM

The Ship Service Air System is in accordance with Figure E.6-2. The source of air was two air compressors each with discharging at 125 psig and 110°F (max). One air compressor is capable of servicing the whole ships service air requirements. The other air compressor is for standby. The compressors are hooked up electrically so that on low pressure in the receiver tank (110 psig), the compressor would automatically cut-in; and cut-out at 125 psig. In case of failure of one

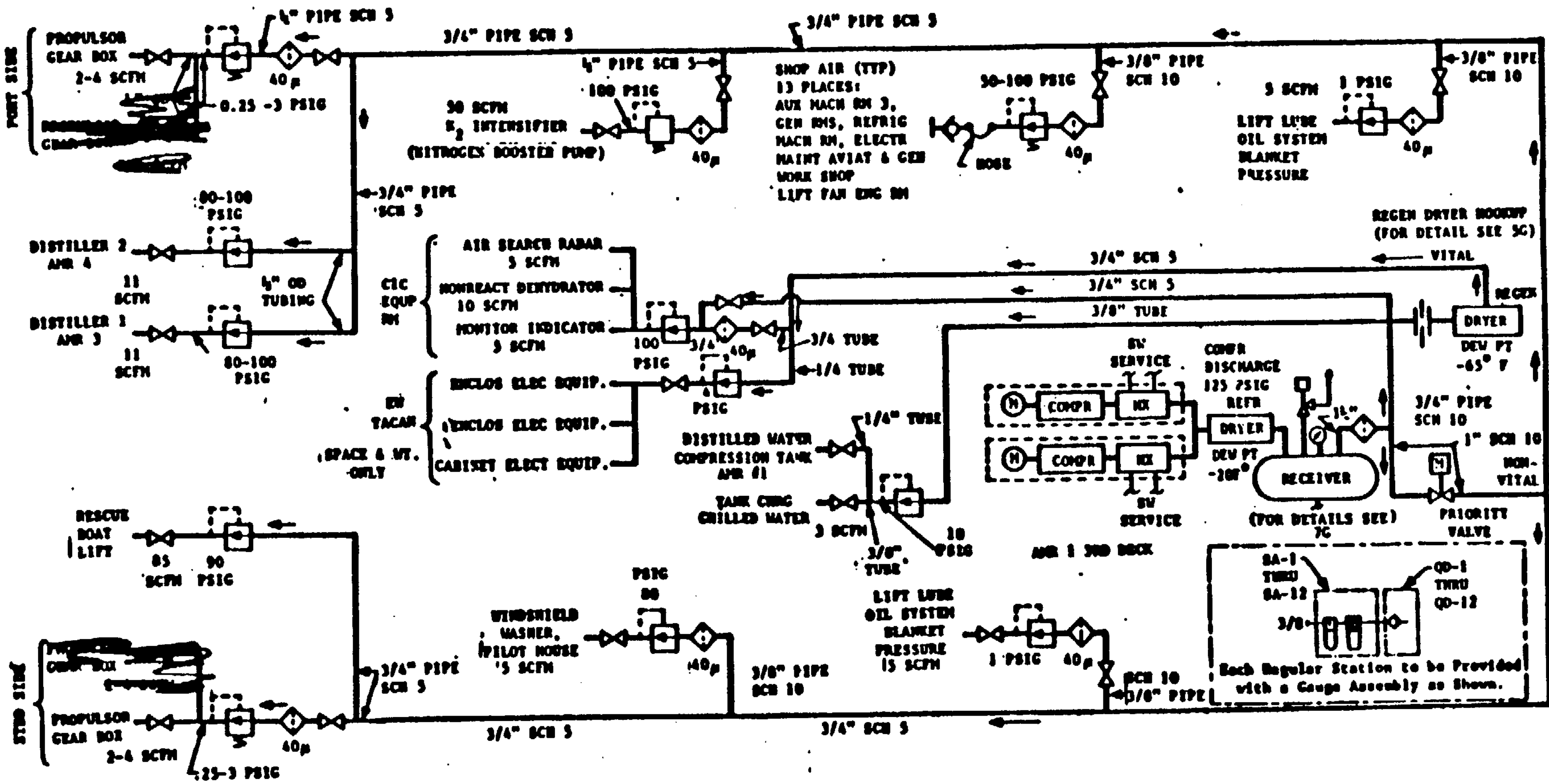


Figure E.6-2. Ship Service Air System

compressor, the other compressor would automatically cut-in. The air is filtered and dried before delivery to various service points throughout the ship. The control of these compressors would be located on the DCAEC panel as well as locally. Monitoring is also done at both locations.

The air supply was divided into two systems, vital and non-vital. The vital supply via a regenerative dryer fed wave guides and electronic equipment. The non-vital could be closed off by a motor operated priority valve.

Two independent dedicated low pressure air compressors are used on the SES to support the ship service air requirements. All piping is to be stainless steel and all fittings will be socket welded. The valves are of stainless steel and to be socket welded to a 150 psig rating. The system pressures were below 150 psig and the maximum temperature of service air was 110°F.

NITROGEN SYSTEM

This system is a dry, oil-free nitrogen system provided from two cylinders with distribution CRES piping to supply nitrogen for servicing helicopters.

Service stations are provided to service the helicopter in its normal landing position on the flight deck and also in the hangar area. Each low pressure outlet is to be regulated by an adjustable pressure reducing valve with inlet and outlet pressure gauges.

The nitrogen is to be pre-purified dry, per Type I, Class 1, Grade A, Specification BB-N-411b, and stored in cylinders per MS-39224-6 with service pressure of 2265 psi and 230 SCF capacity (cylinder volume is 2640 cu. in.). To provide nitrogen at 3000 psig, an air-driven booster was used. The booster was a 30:1 ratio and is driven by 100 psig air from the service air system.

APPENDIX E.7

FIRE EXTINGUISHING SYSTEMS

HALON 1301 SYSTEM

Areas containing flammable fluids are protected by dedicated Halon 1301 system designed in accordance with NFPA Manual 12A. Each area protected is supplied with a primary and secondary supply of halon. Concentration levels of 5.0 to 7.0 percent by volume are developed within protected spaces by a 10 second halon discharge initiated remotely by the fire detection system.

Halon (FE 1301) fixed flooding system is provided for propulsion engine rooms, waterjet pump rooms, fuel oil pump rooms, machinery rooms, electric generator rooms, lift fan engine rooms, flammable liquids storerooms, the gas turbine generator enclosure and the electronic equipment enclosures.

Halon containers are located outside the compartment served. Halon containers for gas turbine generator and electronic equipment enclosures are located local to the equipment. Operation of system is local and remote from DCAEC, manual release is accessible outside the compartment of enclosure served.

FOAM SYSTEMS

The AFFF system will supply only the aviation facility (landing platform, hangar, VERTREP and HIFR). Application rates of 0122 gal/sq ft overhead area for helicopter hangar foam/water sprinkler systems are maintained. The landing platform coverage afforded the SES is 011 gal/sq ft. of foam.

The AFFF system has one 90-1000 GPM delivery from a 2000 gallon capacity foam proportioning system utilizing a 3% "lightwater" foam concentrate capable of supplying the worst hazard with foam for a continuous operation of 10 minutes.

PORTABLE EXTINGUISHING

Portable fire extinguishers are located through the crew's living areas, work spaces and areas where small fire hazards may exist. Halon 1211 portable fire extinguishers replaced the conventional CO_2 extinguishers in their use as described by General Ship Specifications.

This represented in weight and an increase in system performance. Halon 1211 units were augmented with dry chemical (PKP) and Portable "Lightwater" AFFF units depending on the fire hazard.

APPENDIX E.8

HYDRAULIC SYSTEM

The hydraulic system has four separate subsystems located in the general ship areas where the hydraulic power is generated and where the power actuation is required.

Figure E.8-1 shows the four separate subsystems and functions performed by each subsystem.

An operating mode evaluation indicated that each of the four subsystems can obtain hydraulic power from two identical pumps driven by the engine gearboxes. Four small auxiliary electric motor-driven pumps are used when all engines are shut down for checkout and maintenance, as well as anchor and sonar retraction.

The hydraulic functions for each subsystem are as follows:

Subsystem No. 1, Starboard, Forward

Bow Seal Retraction

Lift Fan Variable Geometry Nos. 1, 3 and 5

Lift System Gearbox Holding Brake No. 1

Anchor Windlass

Sonar Retraction

Shut-off Valve Lift Fans Nos. 1 and 3

Subsystem No. 2 Port, Forward

Lift Fan Variable Geometry Nos. 2, 4 and 6

Lift System Gearbox Holding Brake No. 2

Shut-off Valves Lift Fans Nos. 2 and 4

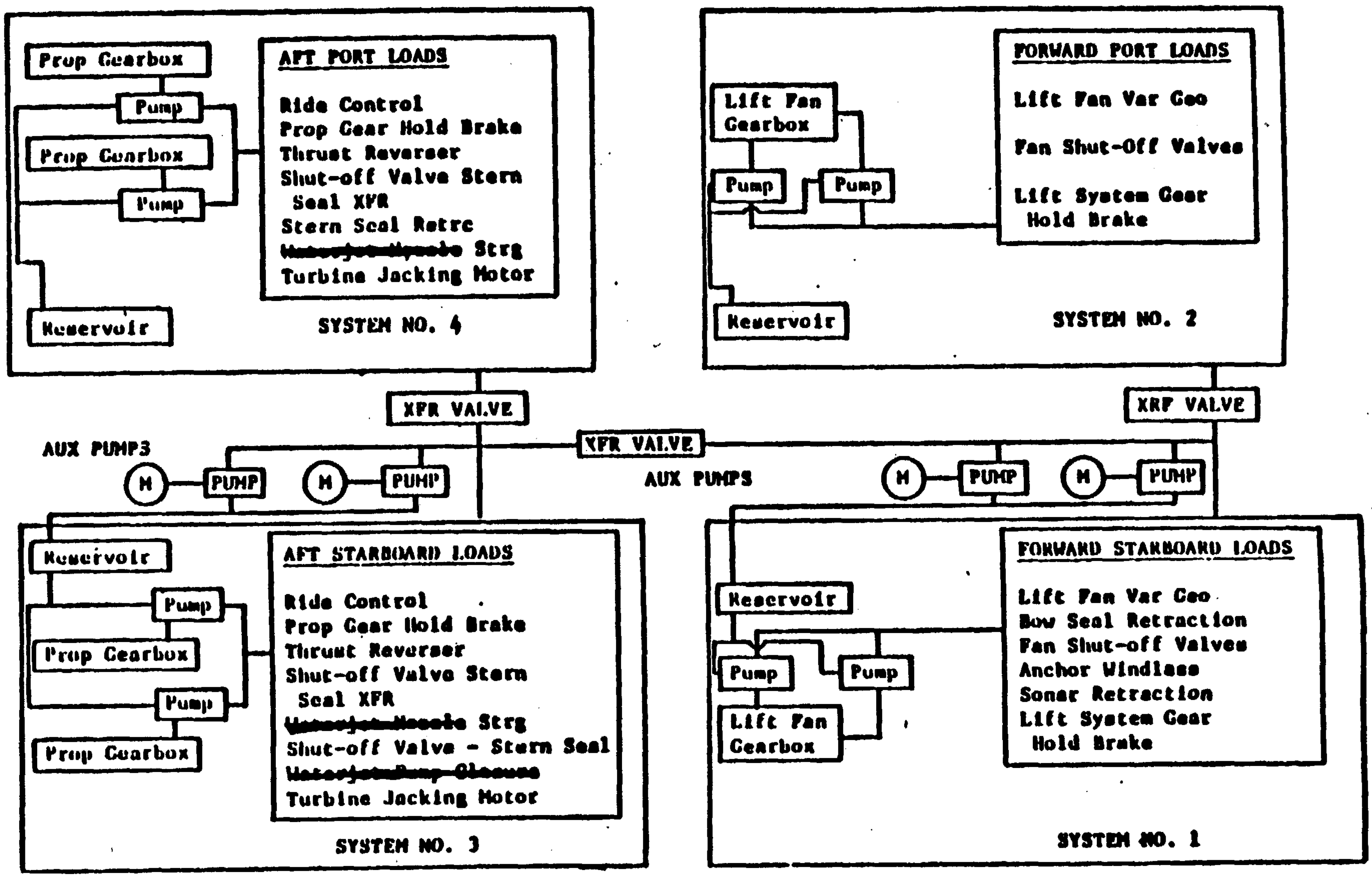


Figure E.8-1. Hydraulic System

Subsystem No. 3, Starboard, Aft

Ride Control (Vent) Valves Nos. 1 and 3

Shut-off Valve Stern Seal Transfer No. 1

Steering No. 1

Thrust Reverser No. 1

Propulsor Gearbox Holding Brake Nos. 1 and 2

Shut-off Valve Stern Seal No. 1 (Fan No. 5)

Jacking Motors Nos. 1 and 2

Subsystem No. 4, Port, Aft

Stern Seal Retraction

Ride Control (Vent) Valves Nos. 2 and 4

Shut-off Valve, Stern Seal Transfer No. 2

Shut-off Valve Stern Seal No. 2 (Fan No. 6)

Steering No. 2

Thrust Reverser No. 4

Propulsor Gearbox Holding Brakes Nos. 3 and 4

Jacking Motors Nos. 3 and 4

During operation without one of the two banks of lift fans, subsystems 1 and 2 may be interconnected by a solenoid valve operation. For emergency purposes any system can be interconnected to any other system through interconnecting solenoid valves.

Each of the four hydraulic subsystems are powered by two identical 3.0 cu. in./rev., 3000 psig, variable displacement piston pumps. The No. 1 pump of each subsystem would be set for 3100 psig at zero output flow and would have full flow at 3000 psig. The second, or No. 2 pump, would be set at 3000 psig for zero flow and would have full flow at 2900 psig. Thus, the No. 2 pump would only be pumping output flow when the system demand exceeds that of the No. 1 pump.

Four electric motor-driven pumps are used for auxiliary power subsystem checkout and other operations. These are small variable displacement pumps with a total flow capability of 40 gpm.

The four hydraulic subsystems as shown in Figure E.8-1, consist of the hydraulic power supplies, the description lines and the activated mechanical subsystems. All power supply components, actuators, motors and different types of valves (as required) are diagramatically shown in TB556001 using American National Standard (ANS) symbols.

Due to subsystem dynamic or functional requirements some of the mechanical subsystems are required to be linearly or rotary activated, some must be servo controlled, and others must be two or multi-purpose controlled.

SYSTEM REQUIREMENTS

The ship hydraulic system is required to be capable of delivering 3000 psig hydraulic power at a rate of sufficient to meet propulsion, lift, and other auxiliary system requirements. A list of hydraulic system functions is as follows:

- Thrust Reversers
- Propulsor Brakes

Bow Seal Retraction

Stern Seal Retraction

Lift Duct Valves (including Fan Shut-off Valves and Stern Seal Transfer Valves)

Ride Control Valves

Lift Fan Variable Geometry

Anchor Windlass

Sonar Retraction

Propulsor Jacking Gear

Tables E.8-1. E.8-2, and E.8-3 summarize the function flow requirements. It is desired that the system have lightweight, flexible power distribution and be capable of rapid response.

CANDIDATE CONCEPTS

These candidate concepts for major component arrangement were explored.

a. Central System — The Central System has one main pressure and return line running the length of the ship to supply the various subsystems.

This system contains five hydraulic pumps. Two of the pumps, with a displacement of 4 cu. in./rev., are lift fan gearbox driven while the remaining three pumps, with a displacement of approximately 1 cu. in./rev., are electric motor-driven. For maintenance and reliability, two complete reservoir, filtration and cooling systems are provided.

Table E.8-1. Hydraulic System Flow Requirements During Combined Subsystem Operation

SUBSYSTEM	3KSES OPERATING MODE										
					ON CUSHION LOW SPEED						
	MAX. FLOW RATE GPM	DOCK SIDE	OFF-CUSH. OPER. SEA STATE 0-5	PARTIAL CUSH. OPER. SEA STATE 6-9	LOW SEA STATE 0-3	HIGH SEA STATE 4-6	HIGH SPEED CRUISE SEA STATE 0-6	OPER. WHILE CRAFT STOPPED	EMERGENCY STOP INITIAL	EMERGENCY STOP FINAL	ANCHOR RECOVERY
Bow Seal Retraction (1)*	40	-	2.5	2.5	2.5	2.5	2.5	2.5	40	2.5	2.5
Lift Fan Variable Geometry (6)*	120	-	31.2	62	62	120	120	3	31..2	3	3
Turbine Reduction Gear Holding Brake (6)	.78	-	.52	.26	-	-	-	.78	-	.78	.52
Shut-off Valve-Lift Fan (4)**	.65	-	-	-	-	-	-	-	-	-	-
Shut-off Valve-Stern Seal (2)											
Anchor Windlass (1)	20	-	-	-	-	-	-	-	-	-	20
Sonar Operation (1)	12	-	-	-	-	-	-	12	-	-	-
Ride Control Valve (4)*	68.8	-	1.6	16.5	34	68.8	68.8	9	17.5	9	-
Shut-off Valve Stern Seal Transfer (2)	1.3	-	1.3	-	-	-	-	-	-	1.3	-
Steering Vectoring (4)*	24	2.7	24	24	24	24	24	2.7	24	2.7	24
Thrust Reverser (2)*	17.6	3	3	3	3	3	3	3	17.6	3	17.6
Stern Seal Retraction (1)	20.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	20.5	2.5	2.5
TOTAL FLOW REQUIRED (GPM)	-	25.7	38.4	79.96	128	220.8	220.8	35.48	150.8	24.8	25.12

* Servo Valve Leakage
** Valves oper. before or after fan oper.
*** Operated one at a time
**** Servo Valve Systems shut-off at dockside

Table E.8-2. Hydraulic System Pump Data

SUBSYSTEM NO.	GEARBOX DRIVE	MAXIMUM PUMP SPEED, RPM	PUMP DISPLACEMENT CU. IN./REV.	FLOW PER PUMP AT MAXIMUM PUMP SPEED GPM	NUMBER OF PUMPS PER SUBSYSTEM	TOTAL PUMP DISPLACEMENT CU. IN/REV.	TOTAL PUMP FLOW GPM
1	No. 1 Lift Reduction Gear	5600	3.0	70	2	6.0	140
2	No. 2 Lift Reduction Gear	5600	3.0	70	2	6.0	140
3	No. 1 Propulsor Reduction Gear	4800	3.0	59			
	No. 2 Propulsor Reduction Gear	4800	3.0	59	2	6.0	118
4	No. 3 Propulsor Reduction Gear	4800	3.0	59			
	No. 4 Propulsor Reduction Gear	4800	3.0	59	2	6.0	118

Table E.8-3. Auxiliary Pump Data

NUMBER OF PUMPS	ELECTRIC MOTOR DRIVE SPEED, RPM	PUMP DISPLACEMENT CU. IN/REV.	PUMP FLOW EACH PUMP, GPM	HP
4	7600	0.4	10	20

b. Modified Central System — This system includes two pumps per lift fan gearbox; otherwise, it is the same as the central system.

c. Dual System —The Dual System divides the baseline system into two separate subsystems, port and starboard. Each subsystem is powered by three main system pumps. One 4 cu. in./rev. pump is driven by the lift fan gearbox while two 3 cu. in./rev pumps are mounted on the two propulsor gearboxes (totaling six pumps for the Dual System). This system also provides two auxiliary electric motor-driven pumps of 0.42 cu. in./rev.capability each for system maintenance and for operating the waterjet pump closures prior to startup of the engines. The system also contains two reservoir-filter - cooler groups, one in each subsystem.

d. Quad System — The Quad System divides the baseline system into 4 separate hydraulic subsystems. These separate hydraulic subsystems are located in areas adjacent to pump power suppliers. The Quad System uses eight hydraulic pumps (3 cu. in./rev. each) - two pumps for each of the four subsystems. The system also provides four electric motor-driven pumps of 0.42 cu. in./rev. each; these units are used for system maintenance.

The major weight of hydraulic systems is concentrated in the piping and associated hydraulic fluid. The Central system has large pressure and return lines running the length of the ship. The Dual System contains slightly smaller pressure and return lines with two sets running the length of the ship. The Quad System has the smallest pressure and return lines. These lines are located in the area adjacent to their pump power supply.

The Central System cannot be effective during a single lift engine operation nor during a lift engine-driven failure. The modified Central System does have adequate flow capability during the aforementioned condition; total pump displacement is 19 cu. in./rev. (CIR).

The Dual System with a total of 3 major pumps and a combined displacement of 24 CIR provides the desired total flow margin and also provides functional growth capability for added ship functions.

PUMP SELECTION

A variety of hydraulic pumps are available. Some of these can operate only at low system pressure while others are capable of operating at high pressure. The selected system pressure is 3000 psi, which narrows the field to the use of piston type pumps. Piston pumps are made in either fixed or variable displacement.

The fixed displacement pump will always deliver its maximum flow rate are driven speed. If the required flow rate at some time is less than the maximum then the excess flow is bypassed through a relief valve which adds heat into the system. The pump delivery requirement for different ship operative modes indicates a flow rate range of from 2 to 64 gpm in one of the four Quad Systems. This would mean almost continuous operation of the relief valve.

Variable displacement axial piston pumps maintain a nearly constant system pressure range by varying the output flow rate to meet system demand. The displacement or output flow is pressure controlled. If there is no system demand, the pump yoke will position the piston assembly for minimum displacement to hold 3000 psi pressure. When a system demand is made, by usually opening a valve to a subsystem, the pressure starts to drop. The pump pressure control senses this pressure drop and positions displacement (and output flow) to hold the pressure. The pump will have minimum flow at 3000 psi and maximum flow at approximately 2900 psi pressure. Thus, the added heat to the system is minimized by using a variable displacement pump with its normal mechanical and volumetric efficiency losses only approximately 13% of the rated input power.

The pump type selected is the variable displacement type.

HYDRAULIC FLUID SELECTION

Many hydraulic fluids are available of different formulation and characteristics but all are essentially one of two basic types; petroleum base and synetic. The synthetic type fluids can be separated in chemically compounded and water base hydraulic fluids. Synthtic fluids are formulated from compounds which are made chemically resistant to burning by the addition of snuffer agents, usually water, to flammable compounds to form water base fluids. Water alone, or with soluble oil additives to increase lubricity and reduce ruting, is used in some industrial applications where large quantities of fluid due to its restrictive liquid range, high viscosity, low lubricity and corrosive capability.

Two types of hydraulic fluids are presently in use or being planned for future operation of surface effect ships; hydraulic fluid in accordance with MIL-H-5605 is employed in the SES 100-Ton Testcraft, and fluid per MIL-H-83282 will be used in the Amphibious Assault Landing Craft. Hydrofoil crafts such as PCH-1 and Dennison have phosphate ester based (Skydrol) hydraulic fluid in their system.

Hydraulic fluid that meets Specification MIL-H-5606 has been in use for more than 30 years and is generally accepted as the hydraulic fluid in industry. It is a petroleum-base fluid, it possesses desirable characteristics of viscosity behavior with temperature variation and good lubricity for moving components. The drawback is its low flash point.

Phosphate ester hydraulic fluid (Skydrol) was developed primarily for aircraft systems to improve the fire resistant properties over MIL-H-5606. However, this fluid is toxic and incompatible with many materials such as standard seals of Buna N and Vitou materials, painted surfaces, electric wire insulation etc.

Historically, fire resistant phosphate ester base fluid, in accordance with MIL-H-19457, has been used in some Navy ship applications. However, this fluid has the problems of toxicity, seal compatibility and few aircraft type components qualified for it. To overcome these types of problems, MIL-H-83282 fluid has recently been developed.

MIL-H-83282 fluid is a new synthesized hydrocarbon fluid that was developed to provide both improved performance and safety as compared to existing hydraulic fluids. Some of the advantages of this fluid are:

a. High operating temperatures and improved thermal characteristics which allow system operation to at least 400°F.

b. Improved fire resistance flammability characteristics, resulting in reduced hydraulic fire hazards related to petroleum-base hydraulic fluids.

c. It is non-toxic and requires no special precautions such as required by phosphate ester or similar fluids.

PIPING MATERIAL

The hydraulic lines considered here are the high pressure and return lines consisting of rigid and flexible material. Lines of rigid material will be used in general, and lines of flexible material will be used to locally connect the pumps and actuators to rigid main distribution lines.

a. (1) Rigid Tubing —CRES 304-L is the selected material for rigid tubing; it is readily available in the required tube diameters, relatively easy to bend and weld, and is appreciably less costly than tubing made from 21 Cr-6Ni-9Mn that requires the procurement of mill runs in sizes greater than 1.25 O.D Swaged and weld fittings were selected in preference to the use of flared fittings in the interest of minimizing the potential of leakage. Welding is preferred to brazing because successful brazing requires an inordinate degree of care and cleanliness, which is costly and difficult to endure under ship building conditions. In addition, brazed lines must be flushed with water many times to remove the flux, followed by drying of the system with acetone followed by alcohol. Inspection is facilitated, since welded joints can be ultrasonically inspected, whereas brazed joints are not readily inspectable.

(2) Flexible Tubing -- Wherever flexible tubing is used, it will be Teflon-lined, since rubber turing takes on a static charge and picks up and holds dirt despite best efforts to clean the internal surfaces. Rubber tubing also "sluffs off" particles which can damage servo valves. Fittings that are particularly designed not to damage the Teflon lining will be employed with this tubing.

b. Hydraulic Line Jointing -- The primary fittings will be of the swage and weld type configuration to eliminate line leakage. Where separable lines must be used, the Deutsch or Dynatube fittings or equivalent is recommended.

APPENDIX E.9

REFRIGERATION SYSTEM

The refrigeration capacity of each plant is 3/4 ton. Freon 22 has been chosen as the most practical refrigerant. The following information gives equipment description and function in detail.

COMPRESSOR

The compressor type is 60 Hz heavy duty reciprocating accessible hermetic. It is provided with suction and discharge service valves, and has a force feed lubricating system. The compressor motor is provided with thermal overload protection as a safety measure.

CONDENSER

The condenser is the shell and tube type in which water circulates through the tubes within the shell. The condenser is equipped with a seawater flow valve which is controlled by the refrigerant discharge pressure.

RECEIVER

The refrigerant receiver has the capacity to hold at least 110 percent of the normal operating refrigerant charge. The liquid outlet is covered by liquid at all times during pitch or roll conditions of the ship. The receiver has two fused quartz sight glasses equipped with float bills to determine the refrigerant level. The receiver is designed for a test pressure of 450 psig.

PRESSURE SWITCH

Pressure switches are provided in the suction and discharge lines from the compressor. The suction pressure switch is a single pole, single throw switch with automatic reset on pressure rise. It will shut down the compressor when there is a low level of refrigerant or when refrigerant flow is stopped by the liquid solenoid valves. The discharge pressure switch is a single pole double throw switch with manual reset. It will shut down the compressor and actuate an alarm circuit in the event of an overpressure condition.

FILTER-DRYER

The filter/dryer is the replaceable core type. The core material removes water, acid, and particulate matter from the refrigerant. It is installed with isolation valves,f which are used while replacing the core.

SIGHT GLASS

A refrigerant flow sight glass is provided in the liquid line to the evaporator. The sight glass incorporates a color code moisture indicator. The sight glass with moisture indicator is combined with the filter/dryer cartridge fitting.

EVAPORATOR

The evaporators are the fan forced circulation type. There are two in both the Chill and Freeze rooms. The evaporator coil is the copper tube type and is mechanically bonded to the aluminum fins. Fin spacing is compatible with sub-zero evaporating temperatures. The evaporators and fans are enclosed in an aluminum housing arranged for overhead mounting.

EXPANSION VALVE

Each evaporator is served by a thermostatic expansion valve. The valve is compatible with both the operating mode and the defrost mode. It is constructed so that all working parts may be replaced without removing the valve body from the piping system

SOLENOID VALVE

Each evaporator is controlled by a solenoid valve which is energized by the refrigerated space thermostat.

SUCTION PRESSURE REGULATOR

The chiller room evaporator suction lines are provided with suction pressure regulators. They control the evaporating temperature needed to produce the capacity required in the chiller mode without freezing of the evaporator. The regulators are internally regulated. A full line-size manual bypass valve is provided for operation in the freezer mode.

CRANKCASE PRESSURE REGULATOR

The compressor regulator which is provided in the suction line to each condensing unit. The regulator prevents the suction pressure from rising beyond a pre-determined limit during a period of pull-down, when the room temperatures are abnormally high. This control is optional depending on compressor selection.

HEAT EXCHANGER

Heat exchangers are used to fully vaporize the suction gas, or to further sub-cool the liquid refrigerant. This component is optional depending on compressor selection.

MANUAL VALVES

Manual valves are of the diaphragm globe type in full line size.

CONTROL REQUIREMENTS

The refrigeration system requires both remote and local controls systems.

REMOTE CONTROLS DESCRIPTION

The refrigeration system remote controls command the operation of the evaporators and fans for system Number 1 and system Number 2. Refrigeration system Number 1 controls one evaporator and one fan in the Freeze Room, and one evaporator and one fan in the Chill Room. Similar controls apply to refrigeration system Number 2. The off command is the only remote control required for DCAEC (in the Central Control Station) from the refrigeration system.

The refrigeration system is normally in continuous operation and would be shut down only during the defrost mode or an emergency condition. Reference G.E. Ship Control Drawing SK56137-61-20 for the refrigeration system DCAEC Control Panel layout.

The refrigeration system command controls and monitor controls will interface with Data Terminal Number 3, which will receive and transmit these signals to and from the DCAEC panel in the central control station.

REMOTE CONTROL FUNCTIONS

Remote control functions are as follows:

a. Commands

   1. Refrigeration System No. 1 - off control only
   2. Refrigeration System No. 2 - off control only

b. Monitors

   1. Freeze Room high temperature alarm
   2. Chill Room high temperature alarm
   3. Refrigeration System No. 1 status
   4. Refrigeration System No. 2 status
   5. Refrigeration System No. 1 fault alarm
   6. Refrigeration System No. 2 fault alarm

LOCAL CONTROL DESCRIPTION

The local control panel is located in the Refrigeration Machinery Room. The local operator will be able to perform all operations and controls of system Number 1 and, including start, stop, and defrost functions. THe front panel contains switches and indicators labeled according to their function. The rear of the panel contains relays, contactors, and terminal boards.

LOCAL CONTROL FUNCTIONS

The main function of the local control panel is to start up refrigeration system Number ql and Number 2, and maintain continuous operation until defrosting or maintenance is required. The local control operator may then shut down the system by either depressing the on/off switch to the off position, or depressing the defrost switch. The later action turns on the defrost heater(s) that begin the defrost sequence. After defrost or maintenance is completed, the on/off switch is depressed to the on position, and normal operation is resume.

There are two maintenance switches, one for system No. 1, one for system No. 2. These switches are used to trouble-shoot the freeze and chill systems by opening the thermostat paths and also the paths to the refrigerant valves, isolating problem areas.

The chill room has the capacity to be used as either a chill or freeze space. Therefore, a chiller/freezer select switch has been proved on the local control panel to select the desired mode for the space. The local/remote select switch is used to put the system either in local or remote control mode. If in the local mode of operation, the system cannot be turned off by the remote operator. If in the remote mode of operation, only the remote operator will shut down the system. See Refrigeration System Controls Diagram, Figure E.9-1.

The 3KSES Auxiliary Systems Specification was developed in accordance with the ship specification and implicates Section 516 of the GSS and MIL-R-16743.

The intent of Section 516 has been followed in the development of the Refrigeration system, but not strictly adhered to. In an effort to reduce weight and complexity without sacrificing performance or safety, the following requirements per Section 516 have not been incorporated in the Refrigeration system.

a. Interchanger on the liquid line with shut off valve. (Having two refrigerant plants eliminates the need for this valve).
b. Replacement charge of R-22 and lubricating oil, one per plant, (Two independent plants eliminates the need for redundant service materials).
c. NAVSHIPS Drawing No. 810-1385899 to be used for refrigeration box penetrations. (This standard penetration was determined to be too complicated and unnecessary).
d. Hot gas by-pass between compressor discharge and expansion valve. Hot gas control valve, and additional solenoid valve. (Function replaced by evaporator pressure regulator and electric defrost).

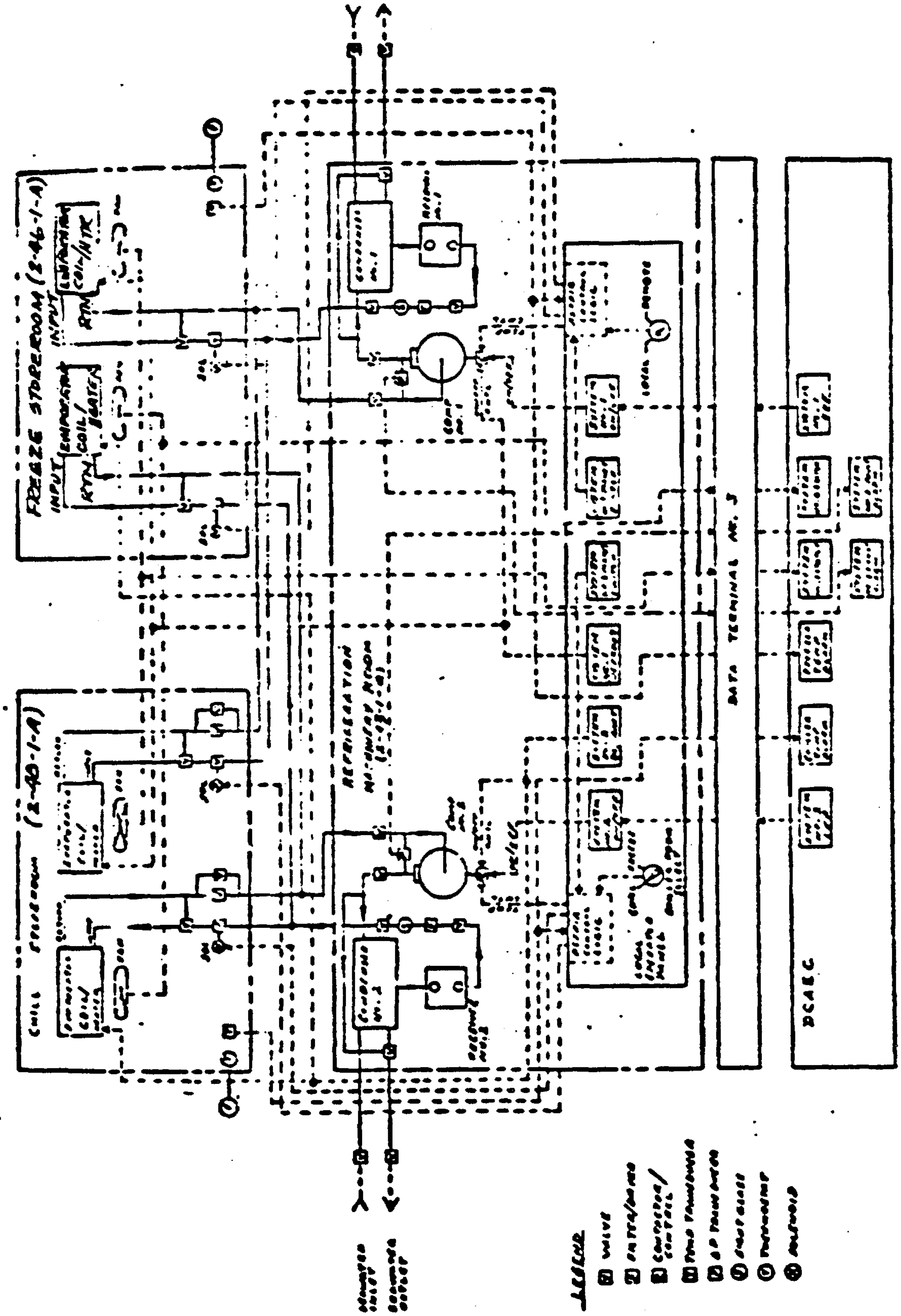


Figure E.9-1. Refrigeration System Control Diagram

e. Portable vacuum pump, hoses, and adaptor for evacuating and dehydrating refrigeration system to be stored onboard. (Impractical from a weight standpoint. See Item b.).

f. Provide separate refrigeration circuits for each refrigerated space, with valves to cut off service.. (In effect, there are separate circuits for each space because of two separate systems. Because the refrigeration system is not a standard system, the valves are not needed).

g. Distribute air by means of duct work. (Compartment size is such ducting is not required).

h. Coil defrost to be accomplished by means of hot seawater spray. (From a weight standpoint (additional piping system) and system simplification, electric defrost was determined to be a more practical defrosting method).

i. All safety control as invoked by MIL-R-16743.

The 3KSES Auxiliary System was reviewed by the Navy. They requested the following be added to the specification: "The refrigerating units shall be provided with operating and safety controls as required by MIL-R-16743". Because the refrigeration system is not the type usually installed in Naval vessels, this could not be added without redesigning the system, adding the weight and complexity of a typical system. The Navy then agreed that we would instead follow the intent of MIL-R-16743, without sacrificing safety or performance. This has been accomplished, and listed below are the operating or safety controls not relevant to the current design configuration.

a. Oil failure switch

b. Oil indicator

c. Water failure switch

d. Shut-off valve (between condenser and receiver)

e. Pressure relief valve (bypasses shut-off between condenser and receiver).

f. Hand expansion valve (bypass there expansion valve).

g. Shut-off valves (at evaporator outlet for each cooling coil).

h. Liquid line strainer (in addition to dehydrator/filter).

i. Suction line strainer (between suction shut-off and compressor).

j. Moisture indicator (in addition to sight flow indicator).

Heat load circulation for the refrigeration system have been performed in accordance with DDS 516-1, and equipment is sized and selected accordingly. There have been some tradeoffs with regard to equipment. Initially, a centrifugal type compressor was considered, but commercial availability was poor, and it was not particularly suited to the system. A 60 Hz hermetic compressor is the current selection; it is heavier, but less expensive, readily available, and suits the refrigeration application. The major tradeoff in the refrigeration system is the use of the split system, which was chosen over the standard system primarily for reliability. Each system serves the chill and freeze room. In the event of a system failure, the other system will be employed, insuring maintained compartment temperatures.

APPENDIX F

WEIGHT ESTIMATE

NAVY SWBS 3 DIGIT WEIGHT REPORT

ITEM	DESCRIPTION	WT	LCG	VCG
SUBGROUP 100	HULL STRUCTURE, GENERAL	.00	0.00	0.00
SUBGROUP 110	SHELL AND SUPPORTING STRUCTURE	.00	0.00	0.00
SUBGROUP 111	SHELL PLATING, SURF.SHIP AND SUB PRESS.H	129.45	170.64	0.00
SUBGROUP 112	SHELL PLATING, SUB NON-PRESSURE HULL	.00	0.00	0.00
SUBGROUP 113	INNER BOTTOM	19.01	170.64	0.00
SUBGROUP 114	SHELL APPENDAGES	.00	0.00	0.00
SUBGROUP 115	STANCHIONS	3.28	156.35	0.00
SUBGROUP 116	LONG.FRAMING,SURF.SHIP AND SUB PRESS.HLL	69.13	170.64	0.00
SUBGROUP 117	TRANS.FRAMING,SURF.SHIP AND SUB PRES.HLL	34.57	170.64	0.00
SUBGROUP 118	LONG.AND TRANS.SUB NON-PRESS.HULL FRAMIN	.00	0.00	0.00
SUBGROUP 119	LIFT SYSTEM FLEXIBLE SKIRTS AND SEALS	15.36	156.35	0.00
SUBGROUP 120	HULL STRUCTURAL BULKHEADS	.00	0.00	0.00
SUBGROUP 121	LONGITUDINAL STRUCTURAL BULKHEADS	29.52	156.35	0.00
SUBGROUP 122	TRANSVERSE STRUCTURAL BULKHEADS	31.00	170.64	0.00
SUBGROUP 123	TRUNKS AND ENCLOSURES	.00	0.00	0.00
SUBGROUP 124	BULKHEADS IN TORPEDO PROTECTION SYSTEM	.00	0.00	0.00
SUBGROUP 125	SUBMARINE HARD TANKS	.00	0.00	0.00
SUBGROUP 126	SUBMARINE SOFT TANKS	.00	0.00	0.00
SUBGROUP 130	HULL DECKS	.00	0.00	0.00
SUBGROUP 131	MAIN DECK	129.27	170.64	0.00
SUBGROUP 132	2ND DECK	129.27	170.64	0.00
SUBGROUP 133	3RD DECK	41.12	170.64	0.00
SUBGROUP 134	4TH DECK	.00	0.00	0.00
SUBGROUP 135	5TH DECK AND DECKS BELOW	.00	0.00	0.00
SUBGROUP 136	01 HULL DECK (FORCASTLE AND POOP DECKS)	.00	0.00	0.00
SUBGROUP 137	02 HULL DECK	.00	0.00	0.00
SUBGROUP 138	03 HULL DECK	.00	0.00	0.00
SUBGROUP 139	04 HULL DECK	.00	0.00	0.00
SUBGROUP 140	HULL PLATFORMS AND FLATS	.00	0.00	0.00
SUBGROUP 141	1ST PLATFORM	.00	0.00	0.00
SUBGROUP 142	2ND PLATFORM	.00	0.00	0.00
SUBGROUP 143	3RD PLATFORM	.00	0.00	0.00
SUBGROUP 144	4TH PLATFORM	.00	0.00	0.00
SUBGROUP 145	5TH PLATFORM	.00	0.00	0.00
SUBGROUP 149	FLATS	.00	0.00	0.00
SUBGROUP 150	DECK HOUSE STRUCTURE	31.20	170.64	0.00
SUBGROUP 151	DECK HOUSE STRUCTURE TO FIRST LEVEL	.00	0.00	0.00
SUBGROUP 152	1ST DECK HOUSE LEVEL	.00	0.00	0.00
SUBGROUP 153	2ND DECK HOUSE LEVEL	.00	0.00	0.00
SUBGROUP 154	3RD DECK HOUSE LEVEL	.00	0.00	0.00
SUBGROUP 155	4TH DECK HOUSE LEVEL	.00	0.00	0.00
SUBGROUP 156	5TH DECK HOUSE LEVEL	.00	0.00	0.00
SUBGROUP 157	6TH DECK HOUSE LEVEL	.00	0.00	0.00
SUBGROUP 158	7TH DECK HOUSE LEVEL	.00	0.00	0.00
SUBGROUP 159	8TH DECK HOUSE LEVEL AND ABOVE	.00	0.00	0.00

NAVY SWBS 3 DIGIT WEIGHT REPORT

ITEM	DESCRIPTION	WT	LCG	VCG
SUBGROUP 160	SPECIAL STRUCTURES	.00	0.00	0.00
SUBGROUP 161	STRUCT. CAST.,FORGINGS, AND EQUIV.WELDMT	6.18	170.64	0.00
SUBGROUP 162	STACKS AND MACKS (COMBINED STACK, MAST)	.00	0.00	0.00
SUBGROUP 163	SEA CHESTS	.88	170.64	0.00
SUBGROUP 164	BALLISTIC PLATING	.00	0.00	0.00
SUBGROUP 165	SONAR DOMES	.00	0.00	0.00
SUBGROUP 166	SPONSONS	.00	0.00	0.00
SUBGROUP 167	HULL STRUCTURAL CLOSURES	4.71	170.64	0.00
SUBGROUP 168	DECKHOUSE STRUCTURAL CLOSURES	.00	0.00	0.00
SUBGROUP 169	SPECIAL PURPOSE CLOSURES AND STRUCTURES	6.18	170.64	0.00
SUBGROUP 170	MASTS, KINGPOSTS, AND SERVICE PLATFORMS	8.36	156.35	0.00
SUBGROUP 171	MASTS, TOWERS, TETRAPODS	.00	0.00	0.00
SUBGROUP 172	KINGPOSTS AND SUPPORT FRAMES	.00	0.00	0.00
SUBGROUP 179	SERVICE PLATFORMS	.00	0.00	0.00
SUBGROUP 180	FOUNDATIONS	.00	0.00	0.00
SUBGROUP 181	HULL STRUCTURE FOUNDATIONS	.00	0.00	0.00
SUBGROUP 182	PROPULSION PLANT FOUNDATIONS	11.91	156.35	0.00
SUBGROUP 183	ELECTRIC PLANT FOUNDATIONS	3.21	156.35	0.00
SUBGROUP 184	COMMAND AND SURVEILLANCE FOUNDATIONS	2.68	156.35	0.00
SUBGROUP 185	AUXILIARY SYSTEMS FOUNDATIONS	5.64	156.35	0.00
SUBGROUP 186	OUTFIT AND FURNISHINGS FOUNDATIONS	1.41	156.35	0.00
SUBGROUP 187	ARMAMENT FOUNDATIONS	.91	156.35	0.00
SUBGROUP 190	SPECIAL PURPOSE SYSTEMS	13.98	170.64	0.00
SUBGROUP 191	BALLAST,FIXED OR FLUID,AND BUOYANCY UNIT	.00	0.00	0.00
SUBGROUP 197	WELDING	.00	0.00	0.00
SUBGROUP 198	FREE FLOODING LIQUIDS	.00	0.00	0.00
SUBGROUP 199	HULL REPAIR PARTS AND SPECIAL TOOLS	.00	0.00	0.00
TOTAL GRP 1	HULL STRUCTURE	728.24	169.02	0.00

NAVY SWBS 3 DIGIT WEIGHT REPORT

ITEM	DESCRIPTION	WT	LCG	VCG
SUBGROUP 200	PROPULSION PLANT, GENERAL	.00	0.00	0.00
SUBGROUP 210	ENERGY GENERATING SYSTEM (NUCLEAR)	.00	0.00	0.00
SUBGROUP 211	(RESERVED)	.00	0.00	0.00
SUBGROUP 212	NUCLEAR STEAM GENERATOR	.00	0.00	0.00
SUBGROUP 213	REACTORS	.00	0.00	0.00
SUBGROUP 214	REACTOR COOLANT SYSTEM	.00	0.00	0.00
SUBGROUP 215	REACTOR COOLANT SERVICE SYSTEM	.00	0.00	0.00
SUBGROUP 216	REACTOR PLANT AUXILIARY SYSTEMS	.00	0.00	0.00
SUBGROUP 217	NUCLEAR POWER CONTROL AND INSTRMENTATION	.00	0.00	0.00
SUBGROUP 218	RADIATION SHIELDING (PRIMARY)	.00	0.00	0.00
SUBGROUP 219	RADIATION SHIELDING (SECONDARY)	.00	0.00	0.00
SUBGROUP 220	ENERGY GENERATING SYSTEM (NON-NUCLEAR)	.00	0.00	0.00
SUBGROUP 221	PROPULSION BOILERS	.00	0.00	0.00
SUBGROUP 222	GAS GENERATORS	.00	0.00	0.00
SUBGROUP 223	MAIN PROPULSION BATTERIES	.00	0.00	0.00
SUBGROUP 224	MAIN PROPULSION FUEL CELLS	.00	0.00	0.00
SUBGROUP 230	PROPULSION UNITS	.00	0.00	0.00
SUBGROUP 231	PROPULSION STEAM TURBINES	.00	0.00	0.00
SUBGROUP 232	PROPULSION STEAM ENGINES	.00	0.00	0.00
SUBGROUP 233	PROPULSION INTERNAL COMBUSTION ENGINES	28.40	156.35	0.00
SUBGROUP 234	PROPULSION GAS TURBINES	17.60	156.35	0.00
SUBGROUP 235	ELECTRIC PROPULSION	.00	0.00	0.00
SUBGROUP 236	SELF-CONTAINED PROPULSION SYSTEMS	.00	0.00	0.00
SUBGROUP 237	AUXILIARY PROPULSION DEVICES	.00	53.49	0.00
SUBGROUP 238	SECONDARY PROPULSION (SUBMARINES)	.00	0.00	0.00
SUBGROUP 239	EMERGENCY PROPULSION (SUBMARINES)	.00	0.00	0.00
SUBGROUP 240	TRANSMISSION AND PROPULSOR SYSTEMS	.00	0.00	0.00
SUBGROUP 241	PROPULSION REDUCTION GEARS	60.00	156.35	0.00
SUBGROUP 242	PROPULSION CLUTCHES AND COUPLINGS	2.15	156.35	0.00
SUBGROUP 243	PROPULSION SHAFTING	30.00	156.35	0.00
SUBGROUP 244	PROPULSION SHAFT BEARINGS	8.68	156.35	0.00
SUBGROUP 245	PROPULSORS	26.00	156.35	0.00
SUBGROUP 246	PROPULSOR SHROUDS AND DUCTS	.00	0.00	0.00
SUBGROUP 247	WATER JET PROPULSORS	.00	0.00	0.00
SUBGROUP 248	LIFT SYSTEM FANS AND DUCTING	13.00	156.35	0.00
SUBGROUP 250	PROP. SUPPORT SYS.(EXCEPT FUEL,LUBE OIL)	.00	0.00	0.00
SUBGROUP 251	COMBUSTION AIR SYSTEM	8.00	156.35	0.00
SUBGROUP 252	PROPULSION CONTROL SYSTEM	8.16	156.35	0.00
SUBGROUP 253	MAIN STEAM PIPING SYSTEM	.00	0.00	0.00
SUBGROUP 254	CONDENSORS AND AIR EJECTORS	.00	0.00	0.00
SUBGROUP 255	FEED AND CONDENSATE SYSTEM	.00	0.00	0.00
SUBGROUP 256	CIRCULATING AND COOLING SEA WATER SYS.	3.20	156.35	0.00
SUBGROUP 258	H.P. STEAM DRAIN SYSTEM	.00	0.00	0.00
SUBGROUP 259	UPTAKES (INNER CASING)	5.00	156.35	0.00
SUBGROUP 260	PROP. SUPPORT SYS. (FUEL AND LUBE OIL)	.00	0.00	0.00

NAVY SWBS 3 DIGIT WEIGHT REPORT

ITEM	DESCRIPTION	WT	LCG	VCG
SUBGROUP 261	FUEL SERVICE SYSTEM	6.69	156.35	0.00
SUBGROUP 262	MAIN PROPULSION LUBE OIL SYSTEM	8.20	156.35	0.00
SUBGROUP 263	SHAFT LUBE OIL SYSTEM (SUBMARINES)	.00	0.00	0.00
SUBGROUP 264	LUBE OIL FILL, TRANS. AND PURIFICATION	5.76	156.35	0.00
SUBGROUP 290	SPECIAL PURPOSE SYSTEMS	.00	0.00	0.00
SUBGROUP 298	PROPULSION PLANT OPERATING FLUIDS	2.00	156.35	0.00
SUBGROUP 299	PROP. PLANT REPAIR PARTS, SPECIAL TOOLS	5.30	156.35	0.00
TOTAL GRP 2	PROPULSION PLANT	238.14	156.35	0.00

NAVY SWBS 3 DIGIT WEIGHT REPORT

ITEM	DESCRIPTION	WT	LCG	VCG
SUBGROUP 300	ELECTRIC PLANT, GENERAL	.00	0.00	0.00
SUBGROUP 310	ELECTRIC POWER GENERATION	.00	0.00	0.00
SUBGROUP 311	SHIP SERVICE POWER GENERATION	11.25	156.35	0.00
SUBGROUP 312	EMERGENCY GENERATORS	.00	0.00	0.00
SUBGROUP 313	BATTERIES AND SERVICE FACILITIES	.58	156.35	0.00
SUBGROUP 314	POWER CONVERSION EQUIPMENT	3.60	156.35	0.00
SUBGROUP 320	POWER DISTRIBUTION SYSTEMS	.00	0.00	0.00
SUBGROUP 321	SHIP SERVICE POWER CABLE	9.12	156.35	0.00
SUBGROUP 322	EMERGENCY POWER CABLE SYSTEM	.00	0.00	0.00
SUBGROUP 323	CASUALTY POWER CABLE SYSTEM	.32	156.35	0.00
SUBGROUP 324	SWITCHGEAR AND PANELS	5.25	156.35	0.00
SUBGROUP 330	LIGHTING SYSTEM	.00	0.00	0.00
SUBGROUP 331	LIGHTING DISTRIBUTION	2.42	156.35	0.00
SUBGROUP 332	LIGHTING FIXTURES	2.92	156.35	0.00
SUBGROUP 340	POWER GENERATION SUPPORT SYSTEMS	.00	0.00	0.00
SUBGROUP 341	SSTG LUBE OIL	.00	0.00	0.00
SUBGROUP 342	DIESEL SUPPORT SYSTEMS	.00	0.00	0.00
SUBGROUP 343	TURBINE SUPPORT SYSTEMS	9.15	156.35	0.00
SUBGROUP 390	SPECIAL PURPOSE SYSTEMS	.00	0.00	0.00
SUBGROUP 398	ELECTRIC PLANT OPERATING FLUIDS	3.00	156.35	0.00
SUBGROUP 399	ELEC.PLANT REPAIR PARTS, SPECIAL TOOLS	1.50	156.35	0.00
TOTAL GRP 3	ELECTRIC PLANT	49.09	156.35	0.00

NAVY SWBS 3 DIGIT WEIGHT REPORT

ITEM	DESCRIPTION	WT	LCG	VCG
SUBGROUP 400	COMMAND AND SURVEILLANCE, GENERAL	.00	0.00	0.00
SUBGROUP 410	COMMAND AND CONTROL SYSTEMS	.00	0.00	0.00
SUBGROUP 411	DATA DISPLAY GROUP	1.05	156.35	0.00
SUBGROUP 412	DATA PROCESSING GROUP	2.00	156.35	0.00
SUBGROUP 413	DIGITAL DATA SWITCHBOARDSS	.00	0.00	0.00
SUBGROUP 414	INTERFACE EQUIPMENT	.00	0.00	0.00
SUBGROUP 415	DIGITAL DATA COMMUNICATIONS	.00	0.00	0.00
SUBGROUP 417	COMMAND AND CONTROL ANALOG SWITCHBOARDS	.00	0.00	0.00
SUBGROUP 420	NAVIGATION SYSTEMS	.00	0.00	0.00
SUBGROUP 421	NON-ELECTRIC/ELECTRONIC NAVIGATION AIDS	.10	156.35	0.00
SUBGROUP 422	ELECTRICAL NAVIG. AIDS(INCL.NAVIG.LIGHT)	.18	156.35	0.00
SUBGROUP 423	ELECTRONIC NAVIGATION SYSTEMS, RADIO	.61	156.35	0.00
SUBGROUP 424	ELECTRONIC NAVIGATION SYS. ACOUSTICAL	.27	156.35	0.00
SUBGROUP 425	PERISCOPES	.00	0.00	0.00
SUBGROUP 426	ELECTRICAL NAVIGATION SYSTEMS	.30	156.35	0.00
SUBGROUP 427	INERTIAL NAVIGATION SYSTEMS	.18	156.35	0.00
SUBGROUP 428	NAVIGATION CONTROL MONITORING	.00	0.00	0.00
SUBGROUP 430	INTERIOR COMMUNICATIONS	.00	0.00	0.00
SUBGROUP 431	SWITCHBOARDS FOR I.C. SYSTEMS	.15	156.35	0.00
SUBGROUP 432	TELEPHONE SYSTEMS	.03	156.35	0.00
SUBGROUP 433	ANNOUNCING SYSTEMS	.15	156.35	0.00
SUBGROUP 434	ENTERTAINMENT AND TRAINING SYSTEMS	.51	156.35	0.00
SUBGROUP 435	VOICE TUBES AND MESSAGE PASSING SYSTEMS	.08	156.35	0.00
SUBGROUP 436	ALARM, SAFETY, AND WARNING SYSTEMS	.00	0.00	0.00
SUBGROUP 437	INDICATING, ORDER,AND METERING SYSTEMS	.00	0.00	0.00
SUBGROUP 438	INTEGRATED CONTROL SYSTEMS	.29	156.35	0.00
SUBGROUP 439	RECORDING AND TELEVISION SYSTEMS	.03	156.35	0.00
SUBGROUP 440	EXTERIOR COMMUNICATIONS	.00	0.00	0.00
SUBGROUP 441	RADIO SYSTEMS	3.93	156.35	0.00
SUBGROUP 442	UNDERWATER SYSTEMS	.55	156.35	0.00
SUBGROUP 443	VISUAL AND AUDIBLE SYSTEMS	.72	156.35	0.00
SUBGROUP 444	TELEMETRY SYSTEMS	.00	0.00	0.00
SUBGROUP 445	TTY AND FACSIMILE SYSTEMS	.18	156.35	0.00
SUBGROUP 446	SECURITY EQUIPMENT SYSTEMS	.19	156.35	0.00
SUBGROUP 450	SURVEILLANCE SYSTEMS (SURFACE)	.00	0.00	0.00
SUBGROUP 451	SURFACE SEARCH RADAR	.16	156.35	0.00
SUBGROUP 452	AIR SEARCH RADAR (2D)	.00	0.00	0.00
SUBGROUP 453	AIR SEARCH RADAR (3D)	.00	0.00	0.00
SUBGROUP 454	AIRCRAFT CONTROL APPROACH RADAR	.00	0.00	0.00
SUBGROUP 455	IDENTIFICATION SYSTEMS (IFF)	.87	156.35	0.00
SUBGROUP 456	MULTIPLE MODE RADAR	1.00	156.35	0.00
SUBGROUP 459	SPACE VEHICLE ELECTRONIC TRACKING	.00	0.00	0.00
SUBGROUP 460	SURVEILLANCE SYSTEMS (UNDERWATER)	.00	0.00	0.00
SUBGROUP 461	ACTIVE SONAR	.00	0.00	0.00
SUBGROUP 462	PASSIVE SONAR	.00	0.00	0.00

NAVY SWBS 3 DIGIT WEIGHT REPORT

ITEM	DESCRIPTION	WT	LCG	VCG
SUBGROUP 463	MULTIPLE MODE SONAR	7.96	156.35	0.00
SUBGROUP 464	CLASSIFICATION SONAR	2.65	156.35	0.00
SUBGROUP 465	BATHYTHERMOGRAPH	.00	0.00	0.00
SUBGROUP 470	COUNTERMEASURES	.00	0.00	0.00
SUBGROUP 471	ACTIVE ECM (INCL COMBO. ACTIVE/PASSIVE)	4.38	156.35	0.00
SUBGROUP 472	PASSIVE ECM	.00	0.00	0.00
SUBGROUP 473	TORPEDO DECOYS	.00	0.00	0.00
SUBGROUP 474	DECOYS (OTHER)	3.70	156.35	0.00
SUBGROUP 475	DEGAUSSING	29.69	156.35	0.00
SUBGROUP 476	MINE COUNTERMEASURES	.00	0.00	0.00
SUBGROUP 480	FIRE CONTROL SYSTEMS	.00	0.00	0.00
SUBGROUP 481	GUN FIRE CONTROL SYSTEMS	.00	0.00	0.00
SUBGROUP 482	MISSILE FIRE CONTROL SYSTEMS	.00	0.00	0.00
SUBGROUP 483	UNDERWATER FIRE CONTROL SYSTEMS	3.28	156.35	0.00
SUBGROUP 484	INTEGRATED FIRE CONTROL SYSTEMS	1.48	156.35	0.00
SUBGROUP 489	WEAPON SYSTEM SWITCHBOARDS	.00	0.00	0.00
SUBGROUP 490	SPECIAL PURPOSE SYSTEMS	.00	0.00	0.00
SUBGROUP 491	ELEC. TEST, CKOUT, AND MONITORING EQUIP.	.00	0.00	0.00
SUBGROUP 492	FLIGHT CONTROL AND INSTRMT LANDING SYS.	.00	0.00	0.00
SUBGROUP 493	NON COMBAT DATA PROCESSING SYSTEMS	.00	0.00	0.00
SUBGROUP 494	METEOROLOGICAL SYSTEMS	.00	0.00	0.00
SUBGROUP 495	SPECIAL PURPOSE INTELLIGENCE SYSTEMS	.00	0.00	0.00
SUBGROUP 498	COMMAND AND SURVEILLANCE OPERATING FLUID	.00	0.00	0.00
SUBGROUP 499	COMMAND, SURV. REPAIR PARTS, SPEC. TOOLS	.10	156.35	0.00
TOTAL GRP 4	COMMAND AND SURVEIL.	66.78	156.35	0.00

NAVY SWBS 3 DIGIT WEIGHT REPORT

ITEM	DESCRIPTION	WT	LCG	VCG
SUBGROUP 500	AUXILIARY SYSTEMS, GENERAL	.00	0.00	0.00
SUBGROUP 510	CLIMATE CONTROL	.00	0.00	0.00
SUBGROUP 511	COMPARTMENT HEATING SYSTEM	.65	156.35	0.00
SUBGROUP 512	VENTILATION SYSTEM	3.27	156.35	0.00
SUBGROUP 513	MACHINERY SPACE VENTILATION SYSTEM	2.61	156.35	0.00
SUBGROUP 514	AIR CONDITIONING SYSTEM	15.89	156.35	0.00
SUBGROUP 515	AIR REVITALIZATION SYSTEMS(SUBMARINES)	.00	0.00	0.00
SUBGROUP 516	REFRIGERATION SYSTEM	.90	156.35	0.00
SUBGROUP 517	AUXILIARY BOILERS AND OTHER HEAT SOURCES	.00	0.00	0.00
SUBGROUP 520	SEA WATER SYSTEMS	.00	0.00	0.00
SUBGROUP 521	FIREMAN AND FLUSHING (SEA WATER) SYSTEM	2.29	156.35	0.00
SUBGROUP 522	SPRINKLER SYSTEM	.13	156.35	0.00
SUBGROUP 523	WASHDOWN SYSTEM	.00	0.00	0.00
SUBGROUP 524	AUXILIARY SEA WATER SYSTEM	.65	156.35	0.00
SUBGROUP 526	SCUPPERS AND DECK DRAINS	.25	156.35	0.00
SUBGROUP 527	FIREMAN ACTUATED SERVICES - OTHER	.00	0.00	0.00
SUBGROUP 528	PLUMBING DRAINAGE	4.58	156.35	0.00
SUBGROUP 529	DRAINAGE AND BALLASTING SYSTEM	1.47	156.35	0.00
SUBGROUP 530	FRESH WATER SYSTEMS	.00	0.00	0.00
SUBGROUP 531	DISTILLING PLANT	5.88	156.35	0.00
SUBGROUP 532	COOLING WATER	2.61	156.35	0.00
SUBGROUP 533	POTABLE WATER	3.38	156.35	0.00
SUBGROUP 534	AUX.STEAM AND DRAINS WITHIN MACHINE. BOX	.00	0.00	0.00
SUBGROUP 535	AUX.STEAM AND DRAINS OUT OF MACHINE. BOX	.00	0.00	0.00
SUBGROUP 536	AUXILIARY FRESH WATER COOLING	.00	0.00	0.00
SUBGROUP 540	FUELS, LUBRICANTS, HANDLING AND STORAGE	.00	0.00	0.00
SUBGROUP 541	SHIP FUEL AND FUEL COMPENSATING SYSTEM	13.85	156.35	0.00
SUBGROUP 542	AVIATION AND GENERAL PURPOSE FUELS	2.14	156.35	0.00
SUBGROUP 543	AVIATION, GENERAL PURPOSE LUBE. OIL	.44	156.35	0.00
SUBGROUP 544	LIQUID CARGO	.00	0.00	0.00
SUBGROUP 545	TANK HEATING	.00	0.00	0.00
SUBGROUP 549	SPEC. FUEL, LUBE. HANDLING, STOWAGE	.00	0.00	0.00
SUBGROUP 550	AIR, GAS, AND MISC. FLUID SYSTEMS	.00	0.00	0.00
SUBGROUP 551	COMPRESSED AIR SYSTEMS	7.98	156.35	0.00
SUBGROUP 552	COMPRESSED GASES	.00	0.00	0.00
SUBGROUP 553	O2 N2 SYSTEM	.00	0.00	0.00
SUBGROUP 554	LP BLOW	.00	0.00	0.00
SUBGROUP 555	FIRE EXTINGUISHING SYSTEMS	8.83	156.35	0.00
SUBGROUP 556	HYDRAULIC FLUID SYSTEM	9.17	156.35	0.00
SUBGROUP 557	LIQUID GASES, CARGO	.00	0.00	0.00
SUBGROUP 558	SPECIAL PIPING SYSTEMS	.00	0.00	0.00
SUBGROUP 560	SHIP CONTROL SYSTEMS	.00	0.00	0.00
SUBGROUP 561	STEERING AND DIVING CONTROL STSTEMS	2.45	156.35	0.00
SUBGROUP 562	RUDDER	2.58	156.35	0.00
SUBGROUP 563	HOVERING AND DEPTH CONTROL (SUBMARINES)	.00	0.00	0.00

NAVY SWBS 3 DIGIT WEIGHT REPORT

ITEM	DESCRIPTION	WT	LCG	VCG
SUBGROUP 564	TRIM SYSTEM (SUBMARINES)	.00	0.00	0.00
SUBGROUP 565	TRIM AND HEEL SYSTEMS (SURFACE SHIPS)	.00	0.00	0.00
SUBGROUP 566	DIVING PLANES AND STABILIZING FINS (SUB)	.00	0.00	0.00
SUBGROUP 567	STRUT AND FOIL SYSTEMS	.00	0.00	0.00
SUBGROUP 568	MANEUVERING SYSTEMS	.00	0.00	0.00
SUBGROUP 570	UNDERWAY REPLENISHMENT SYSTEMS	.00	0.00	0.00
SUBGROUP 571	REPLENISHMENT-AT-SEA SYSTEMS	2.04	156.35	0.00
SUBGROUP 572	SHIP STORES AND EQUIP. HANDLING SYSTEMS	2.04	156.35	0.00
SUBGROUP 573	CARGO HANDLING SYSTEMS	.00	0.00	0.00
SUBGROUP 574	VERTICAL REPLENISHMENT SYSTEMS	.00	0.00	0.00
SUBGROUP 580	MECHANICAL HANDLING SYSTEMS	.00	0.00	0.00
SUBGROUP 581	ANCHOR HANDLING AND STOWAGE SYSTEMS	3.27	156.35	0.00
SUBGROUP 582	MOORING AND TOWING SYSTEMS	3.27	156.35	0.00
SUBGROUP 583	BOATS, BOAT HANDLING AND STOWAGE SYSTEMS	1.63	156.35	0.00
SUBGROUP 584	MECH. OPER. DOOR,GATE,RAMP,TURNTABLE SYS	.00	0.00	0.00
SUBGROUP 585	ELEVATING AND RETRACTING GEAR	.00	0.00	0.00
SUBGROUP 586	AIRCRAFT RECOVERY SUPPORT SYSTEMS	.00	0.00	0.00
SUBGROUP 587	AIRCRAFT LAUNCH SUPPORT SYSTEMS	.00	0.00	0.00
SUBGROUP 588	AIRCRAFT HANDLING, SERVICING AND STOWAGE	.00	0.00	0.00
SUBGROUP 589	MISC. MECHANICAL HANDLING SYSTEMS	.00	0.00	0.00
SUBGROUP 590	SPECIAL PURPOSE SYSTEMS	.00	0.00	0.00
SUBGROUP 591	SCIENTIFIC AND OCEAN ENGINEERING SYS.	.00	0.00	0.00
SUBGROUP 592	SWIMMER AND DIVER SUPPORT, PROTECT. SYS.	.00	0.00	0.00
SUBGROUP 593	ENVIRONMENTAL POLLUTION CONTROL SYS.	2.96	156.35	0.00
SUBGROUP 594	SUBMARINE RESCUE, SALVAGE, SURVIVAL SYS.	.00	0.00	0.00
SUBGROUP 595	TOWING,LAUNCHING,HANDLING FOR UNDERWATER	2.08	156.35	0.00
SUBGROUP 596	HANDLING SYS FOR DIVER, SUBMER. VEHICLES	.00	0.00	0.00
SUBGROUP 597	SALVAGE SUPPORT SYSTEMS	.00	0.00	0.00
SUBGROUP 598	AUXILIARY SYSTEMS OPERATING FLUIDS	5.56	156.35	0.00
SUBGROUP 599	AUX. SYSTEMS REPAIR PARTS AND TOOLS	.03	156.35	0.00
TOTAL GRP 5	AUXILIARY SYSTEMS	114.89	156.35	0.00

NAVY SWBS 3 DIGIT WEIGHT REPORT

ITEM	DESCRIPTION	WT	LCG	VCG
SUBGROUP 600	OUTFIT AND FURNISHINS, GENERAL	.00	0.00	0.00
SUBGROUP 610	SHIP FITTINGS	.00	0.00	0.00
SUBGROUP 611	HULL FITTINGS	.67	156.35	0.00
SUBGROUP 612	RAILS, STANCHIONS, AND LIFELINES	1.82	156.35	0.00
SUBGROUP 613	RIGGING AND CANVAS	.17	156.35	0.00
SUBGROUP 620	HULL COMPARTMENTATION	.00	0.00	0.00
SUBGROUP 621	NON-STRUCTURAL BULKHEADS	5.72	156.35	0.00
SUBGROUP 622	FLOOR PLATES AND GRATINGS	4.38	156.35	0.00
SUBGROUP 623	LADDERS	1.38	156.35	0.00
SUBGROUP 624	NON-STRUCTURAL CLOSURES	1.09	156.35	0.00
SUBGROUP 625	AIRPORTS, FIXED PORTLIGHTS, AND WINDOWS	1.15	156.35	0.00
SUBGROUP 630	PRESERVATIVES AND COVERINGS	.00	0.00	0.00
SUBGROUP 631	PAINTING	6.05	156.35	0.00
SUBGROUP 632	ZINC COATING	.00	0.00	0.00
SUBGROUP 633	CATHODIC PROTECTION	1.05	156.35	0.00
SUBGROUP 634	DECK COVERING	10.46	156.35	0.00
SUBGROUP 635	HULL INSULATION	11.77	156.35	0.00
SUBGROUP 636	HULL DAMPING	.00	0.00	0.00
SUBGROUP 637	SHEATHING	8.83	156.35	0.00
SUBGROUP 638	REFRIGERATED SPACES	1.73	156.35	0.00
SUBGROUP 639	RADIATION SHIELDING	.00	0.00	0.00
SUBGROUP 640	LIVING SPACES	.00	0.00	0.00
SUBGROUP 641	OFFICER BERTHING AND MESSING SPACES	4.58	156.35	0.00
SUBGROUP 642	NONCOM. OFFICER BERTH AND MESS. SPACES	.84	156.35	0.00
SUBGROUP 643	ENLISTED PERSONNEL BERTHING,MESS.SPACES	7.40	156.35	0.00
SUBGROUP 644	SANITARY SPACES AND FIXTURES	1.57	156.35	0.00
SUBGROUP 645	LEISURE AND COMMUNITY SPACES	.00	0.00	0.00
SUBGROUP 650	SERVICE SPACES	.00	0.00	0.00
SUBGROUP 651	COMMISSARY SPACES	4.81	156.35	0.00
SUBGROUP 652	MEDICAL SPACES	.54	156.35	0.00
SUBGROUP 653	DENTAL SPACES	.00	0.00	0.00
SUBGROUP 654	UTILITY SPACES	.44	156.35	0.00
SUBGROUP 655	LAUNDRY SPACES	1.09	156.35	0.00
SUBGROUP 656	TRASH DISPOSAL SPACES	.33	156.35	0.00
SUBGROUP 660	WORKING SPACES	.00	0.00	0.00
SUBGROUP 661	OFFICES	3.08	156.35	0.00
SUBGROUP 662	MACHINERY CONTROL CENTER FURNISHINGS	1.47	156.35	0.00
SUBGROUP 663	ELECTRONICS CONTROL CENTER FURNISHINGS	3.37	156.35	0.00
SUBGROUP 664	DAMAGE CONTROL STATIONS	1.46	156.35	0.00
SUBGROUP 665	WKSHOP,LAB,TEST AREAS(PRTBLE TOOL,EQUIP)	.53	156.35	0.00
SUBGROUP 670	STOWAGE SPACES	.00	0.00	0.00
SUBGROUP 671	LOCKERS AND SPECIAL STOWAGE	1.85	156.35	0.00
SUBGROUP 672	STOREROOMS AND ISSUE ROOMS	10.45	156.35	0.00
SUBGROUP 673	CARGO STOWAGE	.00	0.00	0.00
SUBGROUP 690	SPECIAL PURPOSE SYSTEMS	.00	0.00	0.00

NAVY SWBS 3 DIGIT WEIGHT REPORT

ITEM	DESCRIPTION	WT	LCG	VCG
SUBGROUP 698	OUTFIT AND FURNISHINGS OPERATING FLUIDS	.00	156.35	0.00
SUBGROUP 699	OUTFIT AND FURNISH.REPAIR PARTS AND TOOL	.67	156.35	0.00
TOTAL GRP 6	OUTFITTING, FURNISH.	100.75	156.35	0.00

NAVY SWBS 3 DIGIT WEIGHT REPORT

ITEM	DESCRIPTION	WT	LCG	VCG
SUBGROUP 700	ARMAMENT, GENERAL	.00	0.00	0.00
SUBGROUP 710	GUNS AND AMMUNITION	.00	0.00	0.00
SUBGROUP 711	GUNS	6.63	156.35	0.00
SUBGROUP 712	AMMUNITION HANDLING	.00	0.00	0.00
SUBGROUP 713	AMMUNITION STOWAGE	.00	0.00	0.00
SUBGROUP 720	MISSILES AND ROCKETS	.00	0.00	0.00
SUBGROUP 721	LAUNCHING DEVICES (MISSILES AND ROCKETS)	15.50	156.35	0.00
SUBGROUP 722	MISSILE,ROCKET,GUIDANCE CAPSULE HAND.SYS	.00	0.00	0.00
SUBGROUP 723	MISSILE AND ROCKET STOWAGE	1.20	156.35	0.00
SUBGROUP 724	MISSILE HYDRAULICS	.00	0.00	0.00
SUBGROUP 725	MISSILE GAS	.00	0.00	0.00
SUBGROUP 726	MISSILE COMPENSATING	.00	0.00	0.00
SUBGROUP 727	MISSILE LAUNCHER CONTROL	.00	0.00	0.00
SUBGROUP 728	MISSILE HEATING, COOLING, TEMP. CONTROL	.00	0.00	0.00
SUBGROUP 729	MISSILE MONITORING, TEST AND ALIGNMENT	.00	0.00	0.00
SUBGROUP 730	MINES	.00	0.00	0.00
SUBGROUP 731	MINE LAUNDHING DEVICES	.00	0.00	0.00
SUBGROUP 732	MINE HANDLING	.00	0.00	0.00
SUBGROUP 733	MINE STOWAGE	.00	0.00	0.00
SUBGROUP 740	DEPTH CHARGES	.00	0.00	0.00
SUBGROUP 741	DEPTH CHARGE LAUNCHING DEVICES	.00	0.00	0.00
SUBGROUP 742	DEPTH CHARGE HANDLING	.00	0.00	0.00
SUBGROUP 743	DEPTH CHARGE STOWAGE	.00	0.00	0.00
SUBGROUP 750	TORPEDOES	.00	0.00	0.00
SUBGROUP 751	TORPEDO TUBES	1.99	156.35	0.00
SUBGROUP 752	TORPEDO HANDLING	.00	0.00	0.00
SUBGROUP 753	TORPEDO STOWAGE	.00	0.00	0.00
SUBGROUP 754	SUBMARINE TORPEDO EJECTION	.00	0.00	0.00
SUBGROUP 760	SMALL ARMS AND PYROTECHNICS	.00	0.00	0.00
SUBGROUP 761	SM. ARMS, PYROTECHNICS LAUNCHING DEVICES	.00	0.00	0.00
SUBGROUP 762	SMALL ARMS AND PYROTECHNICS HANDLING	.00	0.00	0.00
SUBGROUP 763	SMALL ARMS AND PYROTECHNICS STOWAGE	.90	156.35	0.00
SUBGROUP 770	CARGO MUNITIONS	.00	0.00	0.00
SUBGROUP 772	CARGO MUNITIONS HANDLING	.00	0.00	0.00
SUBGROUP 773	CARGO MUNITIONS STOWAGE	.00	0.00	0.00
SUBGROUP 780	AIRCRAFT RELATED WEAPONS	.00	0.00	0.00
SUBGROUP 782	AIRCRAFT RELATED WEAPONS HANDLING	.00	0.00	0.00
SUBGROUP 783	AIRCRAFT RELATED WEAPONS STOWAGE	.00	0.00	0.00
SUBGROUP 790	SPECIAL PURPOSE SYSTEMS	.00	0.00	0.00
SUBGROUP 792	SPECIAL WEAPONS HANDLING	.00	0.00	0.00
SUBGROUP 793	SPECIAL WEAPONS STOWAGE	.00	0.00	0.00
SUBGROUP 797	MISC. ORDNANCE SPACES	.00	0.00	0.00
SUBGROUP 798	ARMAMENT OPERATING FLUIDS	.00	0.00	0.00
SUBGROUP 799	ARMAMENT REPAIR PARTS AND SPECIAL TOOLS	.08	156.35	0.00
TOTAL GRP 7	ARMAMENT	26.30	156.35	0.00
	LIGHT SHIP WITHOUT MARGIN	1324.20	163.32	0.00

NAVY SWBS 3 DIGIT WEIGHT REPORT

ITEM	DESCRIPTION	WT	LCG	VCG
SUBGROUP M00	MARGINS	.00	0.00	0.00
SUBGROUP M10	CONTRACTOR CONTROLLED MARGINS	.00	0.00	0.00
SUBGROUP M11	DESIGN AND BUILDING MARGIN	.00	0.00	0.00
SUBGROUP M12	BUILDING MARGIN (RESERVED)	.00	0.00	0.00
SUBGROUP M20	GOVT. CONTROLLED MARGIN (SURFACE SHIP)	171.76	156.35	0.00
SUBGROUP M21	CONTRACT DESIGN MARGIN (SURFACE SHIP)	.00	0.00	0.00
SUBGROUP M22	CONTRACT MODIFICATION MARGIN (SURF.SHIP)	.00	0.00	0.00
SUBGROUP M23	GFM MARGIN (SURFACE SHIP)	.00	0.00	0.00
SUBGROUP M24	FUTURE GROWTH MARGIN (SURFACE SHIP)	.00	0.00	0.00
SUBGROUP M25	SERVICE LIFE MARGIN (SURFACE SHIP)	.00	0.00	0.00
SUBGROUP M26	NUCLEAR MACHINERY MARGIN (SURFACE SHIP)	.00	0.00	0.00
SUBGROUP M30	GOVT. CONTROLLED MARGIN STATUS (SUBS)	.00	0.00	0.00
SUBGROUP M31	CONTRACT DESIGN MARGIN (SUBMARINE)	.00	0.00	0.00
SUBGROUP P32	NAVSHIPS DEVELOPMENT MARGIN (SUBS)	.00	0.00	0.00
SUBGROUP M33	NUCLEAR MACHINERY MARGIN (SUBS)	.00	0.00	0.00
SUBGROUP M34	FUTURE GROWTH MARGIN (SUBMARINE)	.00	0.00	0.00
SUBGROUP M35	STABILITY LEAD STATUS (SUBMARINE)	.00	0.00	0.00
SUBGROUP M36	TRIMMING LEAD STATUS (SUBMARINES)	.00	0.00	0.00
SUBGROUP M40	BALLAST STATUS (SUBMARINE)	.00	0.00	0.00
SUBGROUP M41	LEAD, INTERNAL (SUBMARINE)	.00	0.00	0.00
SUBGROUP M42	LEAD, EXTERNAL (SUBMARINES)	.00	0.00	0.00
SUBGROUP M43	LEAD, MBT (SUBMARINES)	.00	0.00	0.00
SUBGROUP M44	STEEL, INTERNAL (SUBMARINE)	.00	0.00	0.00
SUBGROUP M45	STEEL, EXTERNAL (SUBMARINE)	.00	0.00	0.00
SUBGROUP M46	STEEL, MBT (SUBMARINE)	.00	0.00	0.00
SUBGROUP M47	LEAD CORRECTION, MBT (SUBS)	.00	0.00	0.00
SUBGROUP M48	LEAD CORRECTION, OTHER THAN MBT (SUBS)	.00	0.00	0.00
TOTAL GRP M	MARGINS	171.76	156.35	0.00
	LIGHT SHIP WITH MARGIN	1495.96	162.52	0.00

NAVY SWBS 3 DIGIT WEIGHT REPORT

ITEM	DESCRIPTION	WT	LCG	VCG
SUBGROUP F00	LOADS (FULL LOAD CONDITION)	.00	0.00	0.00
SUBGROUP F10	SHIP FORCE, AMPHIB FORCE, TROOPS, PASSEN	.00	0.00	0.00
SUBGROUP F11	SHIPS OFFICERS	2.33	156.35	0.00
SUBGROUP F12	SHIPS NONCOMMISSIONED OFFICERS	.74	156.35	0.00
SUBGROUP F13	SHIPS ENLISTED MEN	8.34	156.35	0.00
SUBGROUP F14	MARINES	.00	0.00	0.00
SUBGROUP F15	TROOPS	.00	0.00	0.00
SUBGROUP F16	AIR WING PERSONNEL	.00	0.00	0.00
SUBGROUP F19	OTHER PERSONNEL	.00	0.00	0.00
SUBGROUP F20	MISSION RELATED EXPENDABLES AND SYSTEMS	.00	0.00	0.00
SUBGROUP F21	SHIP AMMUNITION (FOR USE BY SHIP)	24.90	156.35	0.00
SUBGROUP F22	ORDINANCE DELIVERY SYSTEMS AMMUNITION	8.69	156.35	0.00
SUBGROUP F23	ORDINANCE DELIVERY SYSTEMS	22.30	156.35	0.00
SUBGROUP F24	ORDINANCE REPAIR PARTS (SHIP AMMO)	.00	0.00	0.00
SUBGROUP F25	ORD. REPAIR PARTS (ORD. DELIV. SYS.AMMO)	.00	0.00	0.00
SUBGROUP F26	ORDINANCE DELIVERY SYS.SUPPORT EQUIP.	.00	0.00	0.00
SUBGROUP F29	SPECIAL MISSION RELATED SYS. EXPENDABLES	.00	0.00	0.00
SUBGROUP F30	STORES	.00	0.00	0.00
SUBGROUP F31	PROVISION AND PERSONNEL STORES	8.42	156.35	0.00
SUBGROUP F32	GENERAL STORES	1.89	156.35	0.00
SUBGROUP F33	MARINES STORES (FOR SHIPS COMPLEMENT)	.00	0.00	0.00
SUBGROUP F39	SPECIAL STORES	.00	0.00	0.00
SUBGROUP F40	FUELS AND LUBRICANTS	.00	0.00	0.00
SUBGROUP F41	DIESEL FUEL	276.92	156.35	0.00
SUBGROUP F42	JP-5	43.60	156.35	0.00
SUBGROUP F43	GASOLINE	.00	0.00	0.00
SUBGROUP F44	DISTILLATE FUEL	.00	0.00	0.00
SUBGROUP F45	NAVY STANDARD FUEL OIL (N.S.F.O.)	.00	0.00	0.00
SUBGROUP F46	LUBRICATING OIL	10.98	156.35	0.00
SUBGROUP F49	SPECIAL FUELS AND LUBRICANTS	.00	0.00	0.00
SUBGROUP F50	LIQUIDS AND GASES (NON-FUEL TYPE)	.00	0.00	0.00
SUBGROUP F51	SEA WATER	.00	0.00	0.00
SUBGROUP F52	FRESH WATER	3.48	156.35	0.00
SUBGROUP F53	RESERVE FEED WATER	1.00	156.35	0.00
SUBGROUP F54	HYDRAULIC FLUID	1.00	156.35	0.00
SUBGROUP F55	SANITARY TANK LIQUID	1.85	156.35	0.00
SUBGROUP F56	GAS (NON-FUEL TYPE)	.00	0.00	0.00
SUBGROUP F59	MISC. LIQUIDS (NON-FUEL TYPE)	.00	0.00	0.00
SUBGROUP F60	CARGO	.00	0.00	0.00
SUBGROUP F61	CARGO, ORDNANCE, ORDNANCE DELIVERY SYS.	.00	0.00	0.00
SUBGROUP F62	CARGO, STORES	.00	0.00	0.00
SUBGROUP F63	CARGO, FUELS AND LUBRICANTS	.00	0.00	0.00
SUBGROUP F64	CARGO, LIQUIDS (NON-FUEL TYPE)	.00	0.00	0.00
SUBGROUP F65	CARGO, CRYOGENIC AND LIQUIFIED GAS	.00	0.00	0.00
SUBGROUP F66	CARGO, AMPHIBIOUS ASSAULT SYSTEMS	.00	0.00	0.00

NAVY SWBS 3 DIGIT WEIGHT REPORT

ITEM	DESCRIPTION	WT	LCG	VCG
SUBGROUP F67	CARGO, GASES	.00	0.00	0.00
SUBGROUP F69	CARGO, MISCELLANEOUS	.00	0.00	0.00
SUBGROUP F70	SEA WATER BALLAST (SUBMARINES)	.00	0.00	0.00
SUBGROUP F71	MAIN WATER BALLAST (SUBMARINES)	.00	0.00	0.00
SUBGROUP F72	VARIABLE BALLAST WATER (SUBMARINES)	.00	0.00	0.00
SUBGROUP F73	RESIDUAL WATER (SUBMARINES)	.00	0.00	0.00
	TOTAL VARIABLE LOAD	416.43	156.35	0.00
	FULL LOAD WITH MARGIN	1912.39	161.18	0.00

NAVY SWBS 1 DIGIT WEIGHT REPORT

GROUP	DESCRIPTION	WT	LCG	VCG
TOTAL GRP 1	HULL STRUCTURE	728.24	169.02	0.00
TOTAL GRP 2	PROPULSION PLANT	238.14	156.35	0.00
TOTAL GRP 3	ELECTRIC PLANT	49.09	156.35	0.00
TOTAL GRP 4	COMMAND AND SURVEIL.	66.78	156.35	0.00
TOTAL GRP 5	AUXILIARY SYSTEMS	114.89	156.35	0.00
TOTAL GRP 6	OUTFITTING, FURNISH.	100.75	156.35	0.00
TOTAL GRP 7	ARMAMENT	26.30	156.35	0.00
	LIGHT SHIP WITHOUT MARGIN	1324.20	163.32	0.00
	MARGINS	171.76	156.35	0.00
	LIGHT SHIP WITH MARGIN	1495.96	162.52	0.00
	VARIABLE LOAD	416.43	156.35	0.00
	FULL LOAD WITH MARGIN	1912.39	161.18	0.00

APPENDIX G

AREA/VOLUME SUMMARY

NATO ASW SES CORVETTE AREA/VOLUME SUMMARY

SSCS #		AREA FT²	VOLUME FT³
	SUMMARY		
GROUP 1	MILITHRY MISSION	7117	86308
GROUP 2	HUMAN SUPPORT	6495	62506
GROUP 3	SHIP SUPPORT	7065	92441
GROUP 4	SHIP MACHINERY	1798	118,726
GROUP 5	UNASSIGNED	1590	13332
SHIP TOTAL		24,065	373,313

NATO ASW SES CORVETTE   AREA/VOLUME SUMMARY

SSCS #		AREA FT^2	VOLUME FT^3
GROUP 1			
1.11	COMM CTR & RADIO XMTR	574	5740
1.11	ELEX EQUIP	712	7120
1.12	N_2	40	360
1.12	TOWED ARRAY SONAR	468	4680
1.13	CHART ROOM	96	864
1.13	CIC	672	6720
1.13	PILOT HSE	442	3978
1.14	ECM	164	1476
1.15	IC & GYRO	220	2200
1.1	TOTAL	3388	33138
1.21	30 MM MAG	105	1050
1.22	JAV. MAG	92	920
1.22	VLS	558	4896
1.24	TORPEDOES	220	1980
1.2	TOTAL	975	8846

NATO ASW SES CORVETTE AREA/VOLUME SUMMARY

SSCS #		AREA FT²	VOLUME FT³
1.34	HANGAR	2150	38700
1.35	HELO OFFICE	132	1188
1.36	HELO SHOP	152	1368
1.38	HIFR	28	280
1.3	TOTAL	2462	41536
1.56	BATT CHG	80	720
1.92	PYRO	52	468
1.94	SM. ARMS & ARMORY	160	1600
1.9	TOTAL	212	2068
GROUP 1	TOTAL	7117	86308

GROUP 2

		FT²	FT³
2.11	CO SR	260	2340
2.11	OFFICER LVG COMPLEX	998	9980
2.12	CPO LVG COMPLEX	404	4040
2.13	CREW LVG COMPLEX	2408	22368
2.19	W/C & (PILOT HSE)	32	288
2.1	TOTAL	4102	39016
2.21	WR & OFF MESS	238	2380
2.21	CREW & C/O MESS	486	4860
2.22	GALLEY	446	4460
2.23	DRY PROV. STRM	280	2800
2.2	TOTAL	1450	14500
2.31	MED TRTMT & STORES	218	2180
2.3	TOTAL	218	2180

GROUP 2 CONT'

		FT^2	FT^3
2.41	SHIP STORES	122	1220
2.42	LAUNDRY	155	1550
2.44	BARBER	116	1160
2.46	POST OFFICE	112	1120
2.4	TOTAL	505	5050
2.5	PERSONAL STORES (TOTAL)	110	880
2.62	CBR & SP. CLOTH.	110	880
2.6	TOTAL	110	880
GROUP 2	TOTAL	6495	62506

NATO ASW SES CORVETTE AREA/VOLUME SUMMARY

SSCS #		AREA FT²	VOLUME FT³
GROUP 3			
3.11	STEERING GR	682	6820
3.22	HELO CRASH LKR	27	243
3.22	FWD REP	180	1800
3.22	AFT REP	155	1550
3.25	AFFF	81	794
3.2	TOTAL	443	4387
3.3	OFFICE COMPLEX	404	4040
3.61	ELEC SHOP & DEGAUSS	140	1400
3.61	GEN WKSP	230	2300
3.61	FILTER CLNG	100	1000
3.62	ELEX SHOP	155	1550
3.6	TOTAL	625	6250

NATO ASW SES CORVETTE AREA/VOLUME SUMMARY

SSCS #		AREA FT²	VOLUME FT³
3.71	SD STORES	850	6800
3.71	SONO BOUYS	56	504
3.74	BOSUN STORE RM	384	3840
3.74	PAINT MIX	56	504
3.74	BOAT & DK GR	105	972
3.7	TOTAL	1451	12620
3.8	PASSAGES	3460	33270
3.9	VOIDS		8230
3.9	TANKS		16324
3.9	TOTAL		24554
GROUP 3	TOTAL	7065	92441

NATO ASW SES CORVETTE AREA/VOLUME SUMMARY

SSCS #		AREA FT²	VOLUME FT³
GROUP 4			
4.1	CENTRAL CONTROL	378	3780
4.14	ER		62230
4.14	LIFT FAN		6720
4.14	INTAKES & UPTAKES		6612
4.14	LIFT FAN PLENUM		8370
4.1	TOTAL	378	87712
4.33	SS GEN #3 (#1 & #2 IN AMR)	434	434
4.33	AMR		20800
4.36	FAN RMS	986	9780
4.3	TOTAL	1420	31014
GROUP 4	TOTAL	1798	118,726

NATO ASW SES CORVETTE AREA/VOLUME SUMMARY

SSCS #		AREA FT^2	VOLUME FT^3
GROUP 5			
5.0	UNA	1590	13332
GROUP 5	TOTAL	1590	13332

APPENDIX H

BELL-TEXTRON REPORT

NEW ORLEANS OPERATIONS

Bell Aerospace TEXTRON

Division of Textron Inc

SUMMARY OF PROPELLER DESIGN PROGRAM
AND
PROPELLER DESIGN
FOR
MEDIUM-DISPLACEMENT SURFACE EFFECT SHIP (MDS)
1500 LONG TONS

CONTRACT N00024-75-C-5034

Report 7593-950002

November 30, 1981

Prepared by: R. B. Lewis

John B. Chaplin
Vice President of Engineering

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SECTION 1

PROGRAM OVERVIEW AND SUMMARY

1. PROGRAM OVERVIEW AND SUMMARY

Computer programs were formulated and used to design partially submerged supercavitating propellers (PSCPs). These programs were also employed to perform preliminary structural design of the blading and to predict propeller off-design performance over a range of submergences. Propulsion thrust was computed for installed propellers and was compared to the ship drag, taking into consideration the propulsion engine characteristics, losses, and various machinery arrangements. Predicted propeller non-dimensional characteristics and propeller forces and moments were computed and correlated with test data, in a limited effort.

1.1 Correlation of Predicted Propeller Performance and Propeller Forces with Test Data

A critical performance correlation was made to validate the off-design performance results of the SSCP computer program. This program was used for most of the off-design performance predictions during this study. The correlation compared the computed predictions of the SES-100B propeller design with model test data and full-scale test data. The results, which were favorable, are contained in TN/SES TECH/017 of July 24, 1981, figures 9 and 10. Figure 1-1 of this report is a copy of Figure 9, which shows the comparison of predicted and test efficiencies.

The work on correlation of computer-predicted forces with model test data, which was included in the original task, was deferred after it became apparent that new propeller designs would be required for additional ship configurations. Before the deferral, computations were made of both steady and fluctuating vertical and horizontal propeller forces, for the B6620 propeller, which was designed for the 900-long ton (LT) gross weight Medium-Displacement Combatant (MDC) Surface Effect Ship (SES). These results were shown on pages 2-53 through 2-56 of the initial report of December 1980. Using the available SSCP computer program, detailed time histories of fluctuating forces for this same propeller were computed, as well as the blade loads for various forward speeds. Both were computed with and without the influence of cushion outflow at the propeller. Computations included shaft inclination angles of 0, 5, and 10 degrees. These partially completed dynamic force results were presented in the program overview in September 1981, and are shown here as figure 1-2. The corresponding influence of cushion flow and shaft inclination on averaged propeller performance is shown on pages 2-57 through 2-60 of the initial report of December 1980.

Correlation work was completed to describe the geometry of the blade sections and blade planforms of the David Taylor Naval Ship Research and Development Center (DTNSRDC) 4281 and 4407 highly skewed propellers;

parameters included local skew, thickness, camber, and angle of attach at several radial sections. This made possible computerized performance predictions and force predictions. It was planned to compare predicted performance and forces with available model test data, at various blade rakes and shaft inclination angles of the 4281 propeller and the 4407 propeller. No computer runs were made, however, because further correlation work was deferred by the customer.

1.2 Propeller Designs

Five propeller designs were prepared and investigated. Four of these were new designs and the other was an existing design scaled to match the Medium-Displacement Surface Effect Ship (MDS) thrust and power requirements. These designs were made for various SES vessels, which were studied by the Navy as follows:

a. Coastal SES, 400-LT, full-load displacement

b. Medium-Displacement Combatant SES, 900 LT

c. Medium-Displacement Combatant SES, 1600 LT

d. Medium-Displacement Combatant SES, 1600 LT (scaled SES-100B propellers)

e. Medium-Displacement SES, 1500 LT.

The Coastal SES propeller is a fixed-pitch design; all the others are controllable-pitch propellers. Ship drag was supplied by the Navy. Figures 1-3 and 1-4 show various views of the MDS 1500 propeller, and table 1-I lists the design and machinery parameters.

The off-design characteristics of the propellers were computed and matched to a variety of machinery configurations for the various vessels as follows:

- Coastal SES: CODOG
- MDC 900: CODAG
- MCD 1600: (a) CODOG and (b) only two gas turbines
- MCD 1600 (100B): CODOG
- MDS 1500: (a) two gas turbines or (b) CODOG.

The gas turbine used for the smallest two ships was the Allison 570KA; for the larger SES, the General Electric (GE) LM2500 was used.

Propulsion efficiencies versus forward speed of the new designs of propellers were computed using the available PITCHOPT program (see section 1.4). The propeller installed efficiency and required pitch settings for the MDC 1600-LT vessel are shown in figure 1-5, for both on-cushion and off-cushion operations at light weight, in sea state 3. Excellent propulsion efficiencies are maintained over the speed range, using the controllable-pitch feature of the propellers. Figure 1-5 also shows the effect of operating off cushion with one propeller and one engine. Although propulsion efficiencies are reduced, the engine efficiency is improved, reducing total fuel consumption below 17 knots (shown in figure 1-6).

As shown in figure 1-6, a significant improvement was noted in one-propeller operation over two propellers for the MDC 1600 LT; however, no improvement was noted in the MDS 1500.

1.3 Reports

Six reports were issued to the Navy. As requested by Navy representatives at the program review in September 1981, copies of the earlier reports are included in this report as appendix A. These reports were issued as follows:

REPORT	DATE	VESSEL	CONTRACT
7593-933046	12/80	400 and 900 LT	Design and Performance
7593-902007	5/81	1600 LT	Design and Performance
TN/SES TECH/017	7/81	1600 LT	Expanded Performance
TN/SES TECH/019	9/81	1600 LT	Efficiency versus Forward Speed Two and One Propeller
TN/SES TECH/020	9/81	1600 LT	Scaled SES-100B Propellers
7593-950002	11/81	1500 LT	Design and Performance

In the first report, a study of propeller structural design criteria and available materials was included, which led to the selection of titanium alloy and a design stress of 18,000 lb/in^2. These characteristics were used for all the new propeller studies. For the MDS 1500 propeller, after the scaled SES-100B structural design had been studied, a 10 percent overspeed broaching requirement was added to the structural criteria, as well as a 5 percent thrust overload.

1.4 Computer Programs

Several computer programs were used in the propeller design and performance investigation. They included the following programs:

PROGRAM	USE	SAMPLE OUTPUT
SCRP	Design point	Report 7593-933046, Page 2-39, 2-40
SSCP	Off-design, optimization and propeller forces	Report 7593-933046, Page 2-41, 2-42, 2-43, 2-44, 2-45, 2-46
NEW PROP	Maximum thrust versus engine limits, gear ratios and propeller pitch setting	TN/SES TECH/017, table 1
PITCHOPT	Maximum propeller efficiency versus forward speed, minimum fuel flow with one or two engines, considering engine limits, pitch settings, and cavitation limits	TN/SES TECH/019, table 6

The SCRP program was derived from the SCPRP program listing for design of supercavitating propellers, which was originally formulated by Hydronautics, Inc. The Bell version was reformulated for typewriter terminal control on an IBM computer system (rather than card deck control on the Control Data Corporation system). This work was described in the first report. A listing of the new program with some added features was submitted to the Navy: the reformulated program exactly reproduced Hydronautics samples. Bell has proposed changes and additions to this program and its documentation to overcome certain existing limitations. The program revision would:

a. Better define peak efficiency performance and face cavitation limits

b. Modify the skew and rake reference from the blade trailing edge to the conventional center chord reference

c. Facilitate terminal input

d. Compute nonventilated performance

e. Document program changes, options, and limits, and furnish a new listing to the Navy.

1.5 Overall Index to Design Data

Table 1-II is an index to the principal design features and performance results for the various propellers.

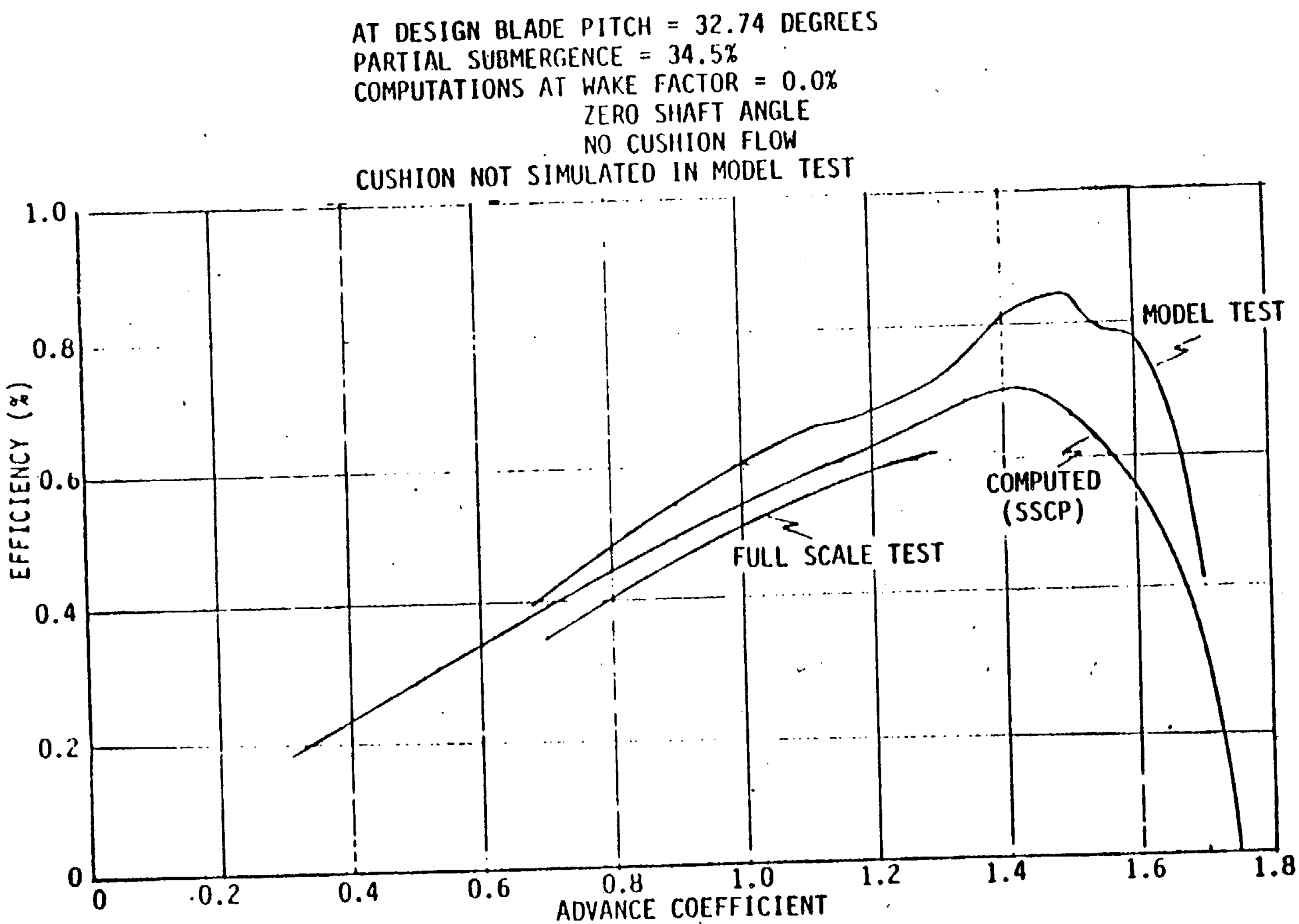


Figure 1-1 COMPUTED AND TEST PROPELLER EFFICIENCY SES-100B

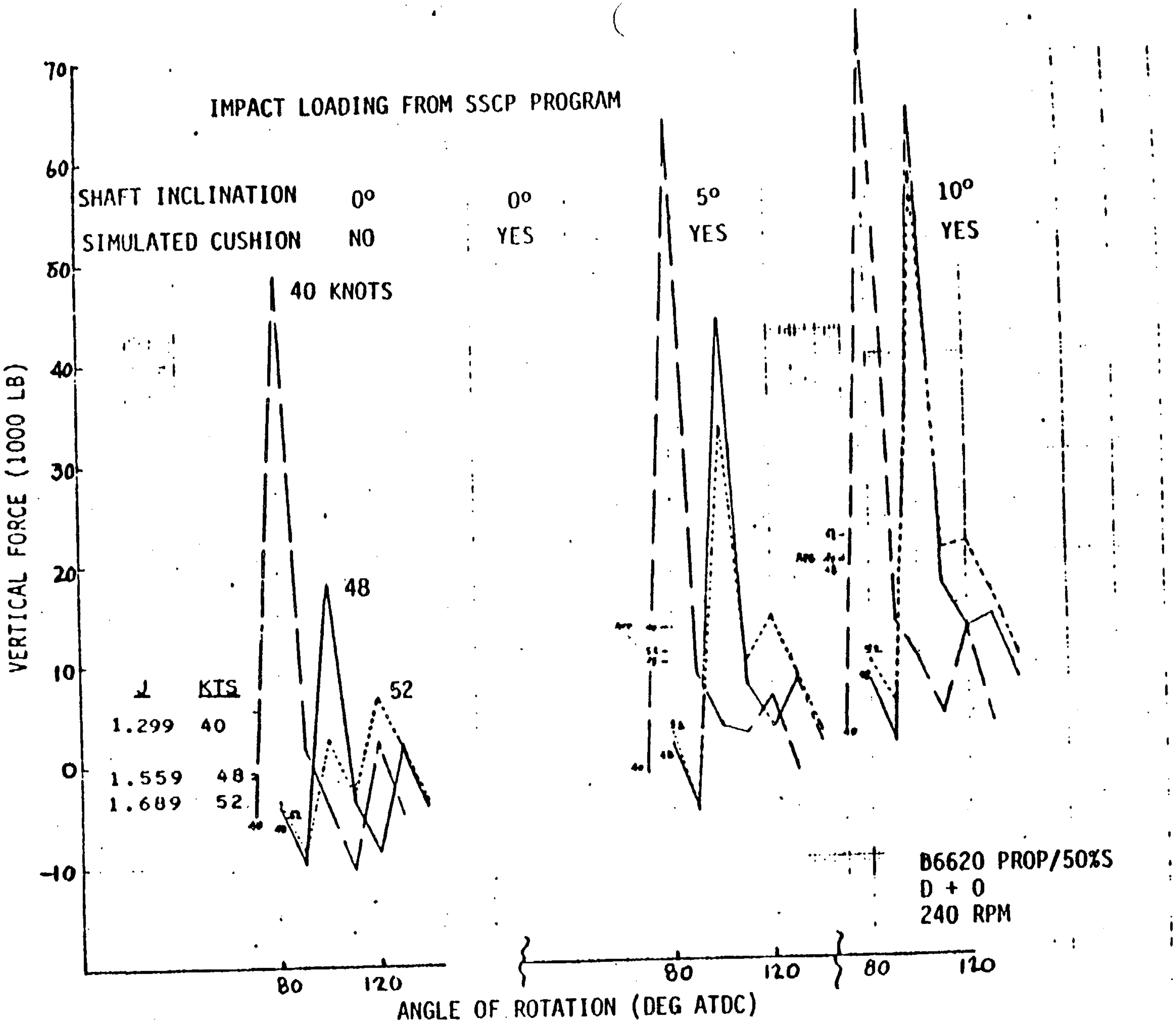


Figure 1-2 PROPELLER DYNAMIC FORCES

Bell Aerospace TEXTRON
Division of Textron Inc

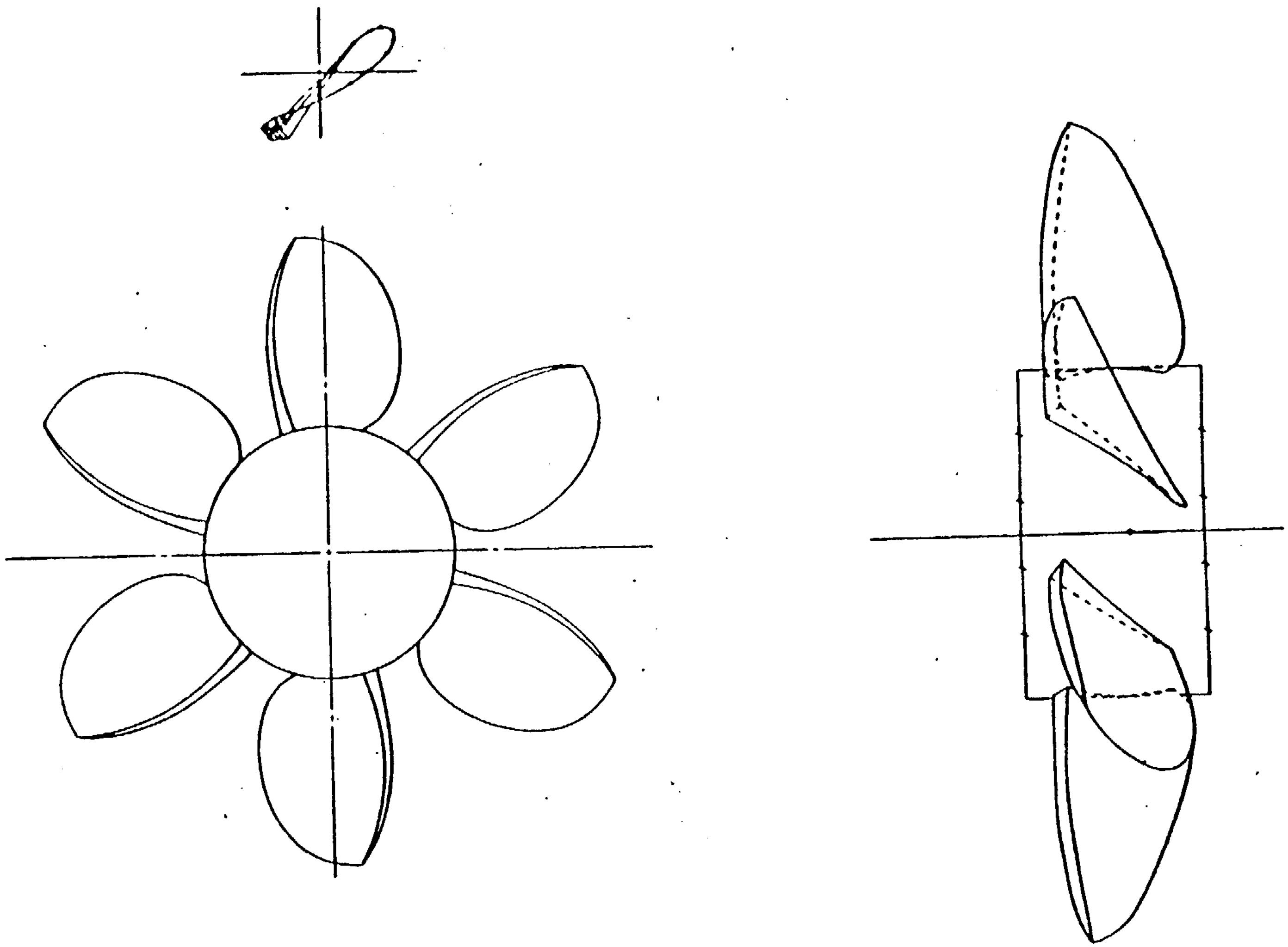


Figure 1-3 PROPELLER PROJECTED VIEWS MDS-1500 PROPELLER

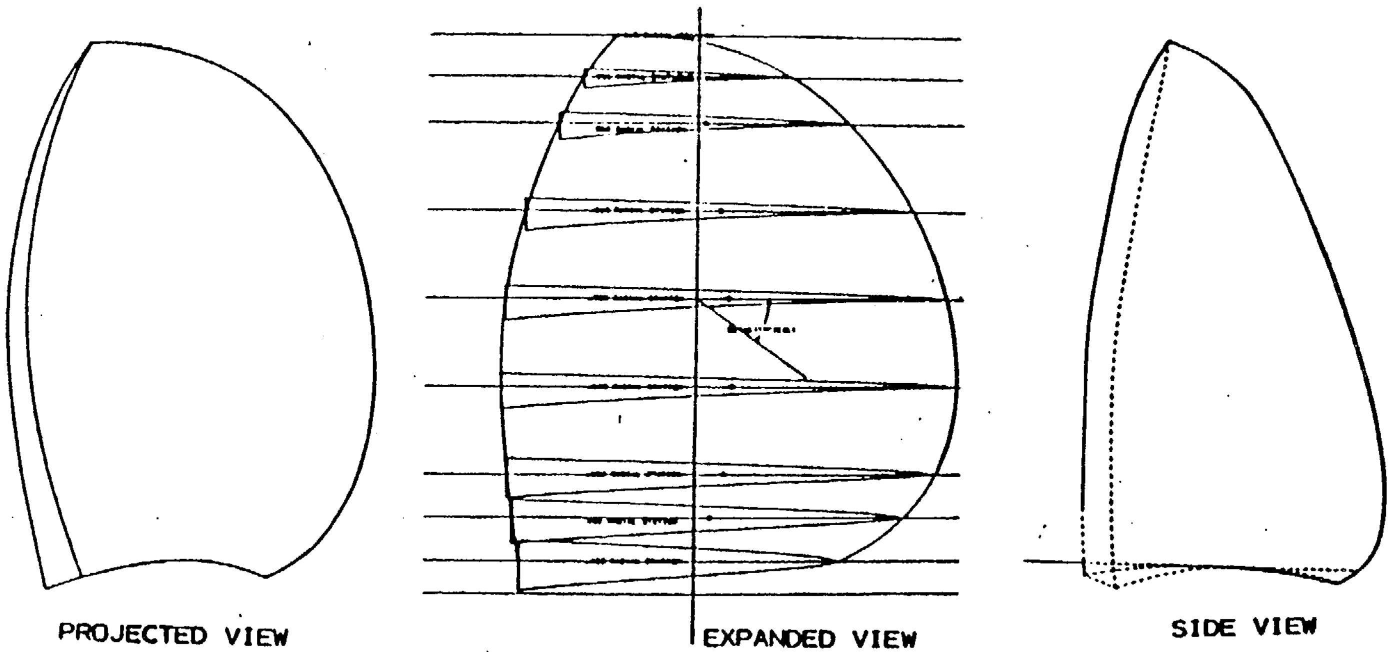


Figure 1-4 PROPELLER BLADE SECTIONS EXPANDED VIEW

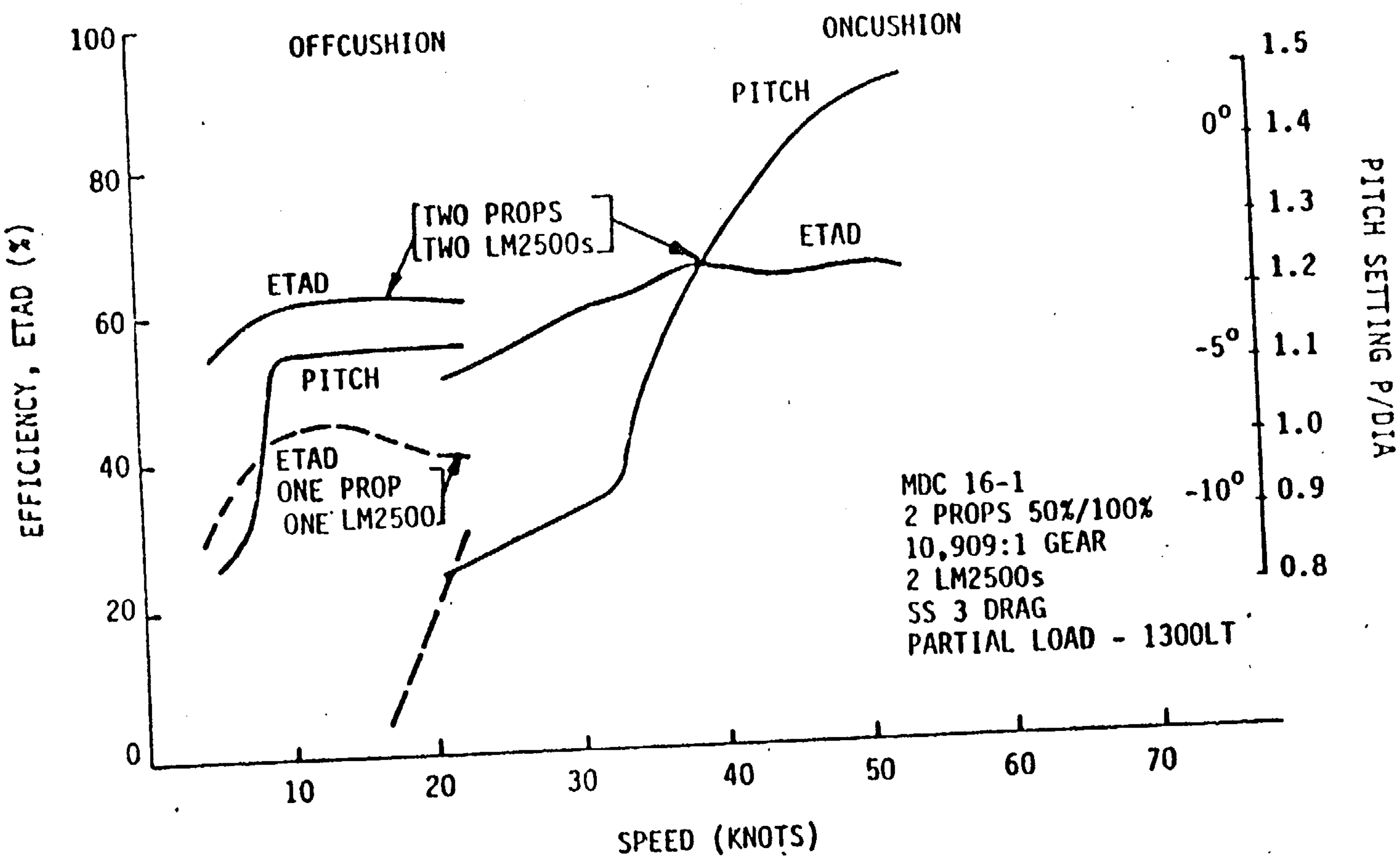


Figure 1-5 PROPULSIVE EFFICIENCY VERSUS SPEED

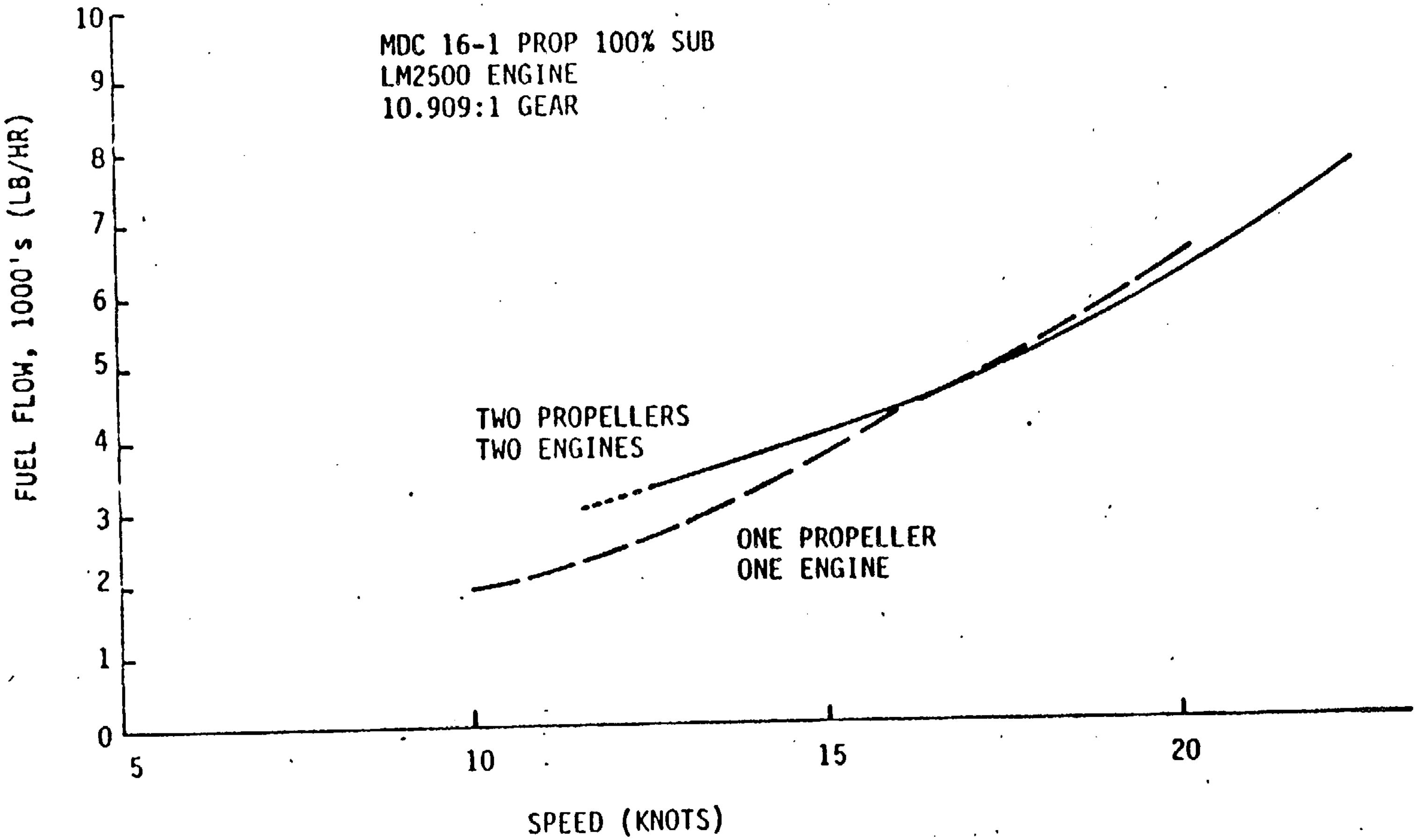


Figure 1-6 FUEL FLOW RATE - ONE/TWO PROPELLER/ENGINE

TABLE 1-I

MDS-1500 PROPELLER DESIGN AND MACHINERY PARAMETERS

Type	Controllable Pitch, Supercavitating
Forward Speed (Knots)	45
Thrust (Lb)	86,856
Diameter (Ft)	14.5
RPM	240
Expanded Area Ratio	0.50
Hub Diameter Ratio	0.40
Number of Blades	Six
Radius of Max Chord	0.70
Design Bending Stress (Lb/In^2)	18,000
Overspeed (Percent)	10
Thrust Margin (Percent)	+5
Impact Load Factor	1.75
Blade Material	TI-6A1-4V
Pitch At 0.7 Radius (Ft)	21.915
Advance Ratio	1.310
Skew, Mid Chord (Degrees)	0
Rake, Mid Chord (Degrees)	8
Submergence (Ventilated)	
On Cushion (Percent)	50
Off Cushion (Percent)	100
Power - GE LM2500 MCP (HP)	24,000
Reduction Gear	15.0:1
Alternate CODOG	
SACM 240 V16 RVR Continuous HP	5600
Diesel Reduction Gear	11.5:1

TABLE 1-II

INDEX TO DESIGNS

DESIGN	SEQUENCE REPORT NUMBER	PROPELLER DESIGN PARAMETERS	PLANFORM DRAWING	THRUST VERSUS SPEED	MAXIMUM EFFICIENCY VERSUS SPEED	NONDIMENSIONAL CHARACTERISTICS
COASTAL SES	1 7593-933046	Page 2-13	7593-440001 and page 2-15	2-16	--	
900-Ton MDC	1 7593-933046	2-28	page 2-36	2-37	--	Pages 2-51, 2-57 to 60
1600-Ton MDC	2 7593-902007	8	page 23	10	--	11, 12
	3 TN/SES TECH/017	--	--	Figure 1, 2 3, 5	--	
	4 TN/SES TECH/019	--	--	--	Table I-VI	--
SCALED SES-100B	5 TN/SES TECH/020	Table 1,2	--	17.5 ft Fig 1-4 15.75 ft Fig 5-9	--	Fig A1-A14
1500-Ton MDS	6 7593-950002	Table 1-I	Fig 1-4	Fig 2-7, 2-8 2-9	Table 2-III, 2-IV, 2-V	Fig 2-5, 2-6

490-45

SECTION 2

DESIGN AND PERFORMANCE OF PROPELLERS FOR 1500-TON MEDIUM-DISPLACEMENT SURFACE EFFECT SHIP

2. DESIGN AND PERFORMANCE OF PROPELLERS FOR 1500-TON MEDIUM-DISPLACEMENT SURFACE EFFECT SHIP

A supercavitating, partially submerged, controllable-pitch propeller was designed for the Medium-Displacement SES (MDS) of 1500 long tons (LT) gross weight.

The vessel parameters for this study were defined by the Navy. Propulsion power was provided by two General Electric LM2500 engines. An alternate configuration combined two diesel engines (used for off-cushion propulsion only) with the gas turbines (that is, in a CODOG propulsion system arrangement).

2.1 Requirements

Table 2-I lists the basic requirements and engine ratings for the propeller design. The drag curves shown in figure 2-1 were supplied by the Navy, and are based on model test data. In sea state 3, the ship is designed to operate at 45 knots, on cushion, with a full-load displacement (FLD) of 1500 LT, and at 20 knots off cushion at the same weight. Also requested was the on-cushion, top-speed performance in sea state 3, with a 1050-LT displacement.

For the alternate configuration, SACM diesel engines were selected because of their light weight and suitable power ratings. Two SACM 240 V16 RVR engines were used, one on each propeller, and were rated at 5600 metric horsepower, continuous power.

The reduction gear ratios were to be selected as those necessary to match the engines and propellers.

2.2 Parametric Analysis of Propeller Diameter, Efficiency, Rotational Speed, and Weight

A parametric analysis was made to size the propellers, using the SCRP computer program in its preliminary design mode. Diameters from 11 to 17 feet were investigated, at the 45-knot point, with a design thrust of 87,000 pounds per propeller at 50 percent submergence. A maximum thrust of 92,000 pounds was input for structural computations and the design blade stress was 18,000 lb/in^2, using titanium material. This is the same stress that was used for prior designs in this project.

Figure 2-2 shows the parametric results of efficiency versus diameter. The effects of design rpm on efficiency and pitch are also shown. At each rpm level, the efficiency increases as the diameter is increased, until a peak value of efficiency is reached; thereafter, the efficiency declines.

A propeller diameter of 14.5 feet was selected, which was the maximum efficiency that could be obtained without the blades overhanging the side-hull at the transom. The selected propeller has a design point efficiency of 72 percent, and a level of 240 rpm was selected.

Figure 2-3 shows the effect of diameter on total blade weight. The design is for six blades and, as can be seen, blade weight is almost independent of rpm. Hub weight (not included here) is expected to constitute most of the total propeller weight.

Estimation of total propeller weight is planned for the next phase of the design project. The selected design has a preliminary total blade weight of about 3230 pounds.

2.3 Selected Propeller Design and Off-Design Performance

After the parametric study was made to select the design point, final design was computed with the SCRP program, using the same design point thrust and input parameters. (See table 1-I for the principal propeller design and machinery parameters.) These values are the chosen inputs to the computer program, except for thrust, pitch, advance ratio, skew, and rake, which are program outputs. The gear ratios are found by matching engine to propeller characteristics.

Complete input and output data for the design are given as table 2-II. The first page of the table is input data and subsequent pages are the output data. The second page gives overall performance, with detailed hydrodynamic and geometric data at several radial stations. The next four pages show the geometry of the blade sections and planform, and the final two pages show the section pressure coefficients and pressures. Headings for the printout columns are defined in reference 2-1. (Section 2.6).

Figure 2-4 shows the projected and side views of the propeller blade, with the expanded outline. The two views are a plot of the geometric data given in table 2-II, which does not show the blade trailing edge thickness.

Figures 2-5 and 2-6 give the nondimensional performance of the propeller at 50 and 100 percent submergence, over a wide range of off-design advance ratios and pitch angles. Values for these plots were obtained from the existing Bell SSCP computer program. Correlation of the program's off-design results with test data is shown in the summary and in the appendix.

2.4 Maximum Thrust Performance

2.4.1 Gas Turbine Power

Maximum thrust versus speed with LM2500 power is compared to the drag in figures 2-7 (for on cushion) and 2-8 (for off cushion), with a 15.0:1 reduction gear. Results are obtained by applying engine and propeller characteristics to the NEWPROP computer program. Enough thrust is available at maximum continuous power to operate 1500 tons at 52 knots in sea state 3, and to operate 1050 tons at 57 knots. Therefore, there is a margin of thrust to operate at 45 knots at 1500 tons (full load) in sea state 3 at the propeller design pitch. The propeller face cavitation limit advance coefficient set to 95 percent is shown in figure 2-7. The face cavitation limit shown was determined by an advance coefficient of 95 percent of the peak efficiency advance coefficient.

The effect of gear reduction upon maximum thrust performance was studied, using 16.5:1 and 13.0:1 reduction gear ratios. Maximum thrusts and forward speeds were decreased with a 16.5:1 reduction ratio. Maximum thrusts were increased using a 13.0:1 gear ratio, but propeller rpm limits were encountered at lower forward speeds, so that the design was not feasible with this gear ratio.

2.4.2 Diesel Power

With alternate diesel power, figure 2-9 shows the maximum thrusts available for off-cushion operation. There is a considerable margin in thrust at 20 knots, using the SACM 240 V16 RVR engines at 5600 continuous power and a 11.5:1 reduction gear ratio.

2.5 Propulsion Installed Efficiency Versus Forward Speed

2.5.1 Gas Turbine

Tables 2-III and 2-IV give power and propeller parameters for operation in sea state 3 with thrust equal to drag at 1500 tons and 1050 tons, respectively. The propeller pitch is set for the best performance at each forward speed. These tables represent operation with gas turbine limits and a 15.0:1 gear reduction ratio.

Table 2-III shows that propulsion efficiency varies from 0.607 at 5 knots to 0.711 at 45 knots for the full-load operation at 1500 tons. The propeller pitch is -12.5 to -10 degrees off cushion to on cushion, then increasing to +5 degrees at a top speed of 50 knots. Above 50 knots, engine rpm, power, and propeller overspeed rpm limits are exceeded.

At 1050 tons (see table 2-IV), the available drag data only covers on-cushion performance, starting at 22.5 knots. Propeller pitch setting increased from -10 degrees at 22 knots to +7.5 degrees at 60 knots; above 60 knots, engine power and rpm limits are exceeded. Efficiency increased from 66 to 74 percent over the usable speed range. Top speed is approximately 60 knots.

2.5.2 Diesel

Table 2-V shows the power and propeller parameters for off-cushion operation, with diesel engines, with thrust equal to drag, at 1500 tons, in sea state 3. Again, propeller pitch is set for best performance at each forward speed; pitch increases from -15 degrees at 5 knots to +2.5 degrees at 20 knots. Propulsion efficiency increases from 0.614 at 5 knots to 0.683 at 13.5 knots, decreasing to 0.608 at 20 knots. Although the propulsion efficiency is not changed greatly for diesel compared to gas turbine operation, the engine specific fuel consumption decreases considerably. Typical gas turbine consumption at 20 knots would be 0.70 lb/hp/hr, compared to 0.40 lb/hp/hr for the diesel.

2.6 References

2-1 J. O. Scherer, P. Majumdar, and J. Bohn, *Operational Manual for the Supercavitating Propeller Design Computer Program (SCPDP)* (Hydronautics, Inc., Report 7623-6, March 1979).

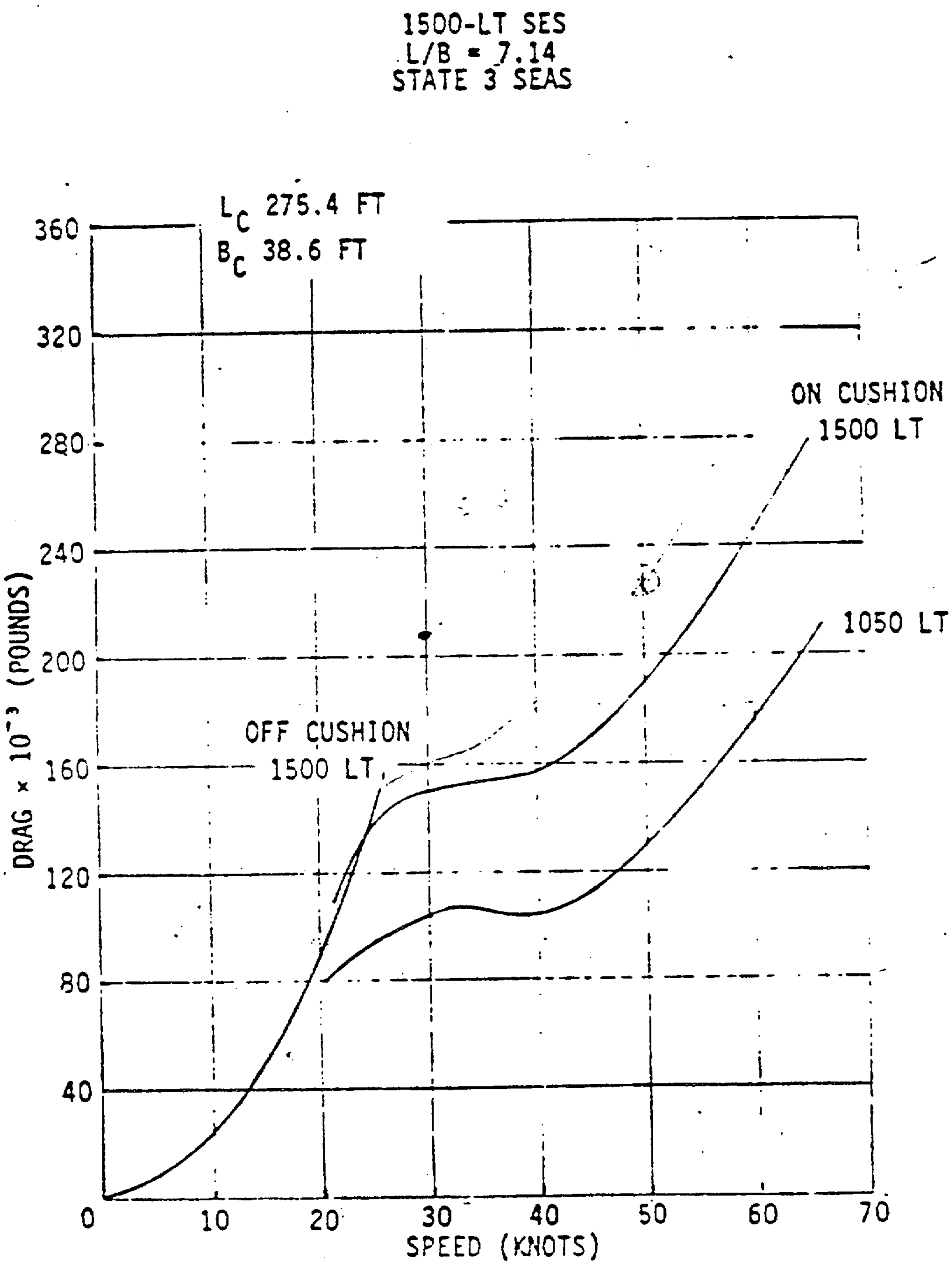


Figure 2-1 DRAG VERSUS SPEED, 1500-LT SES

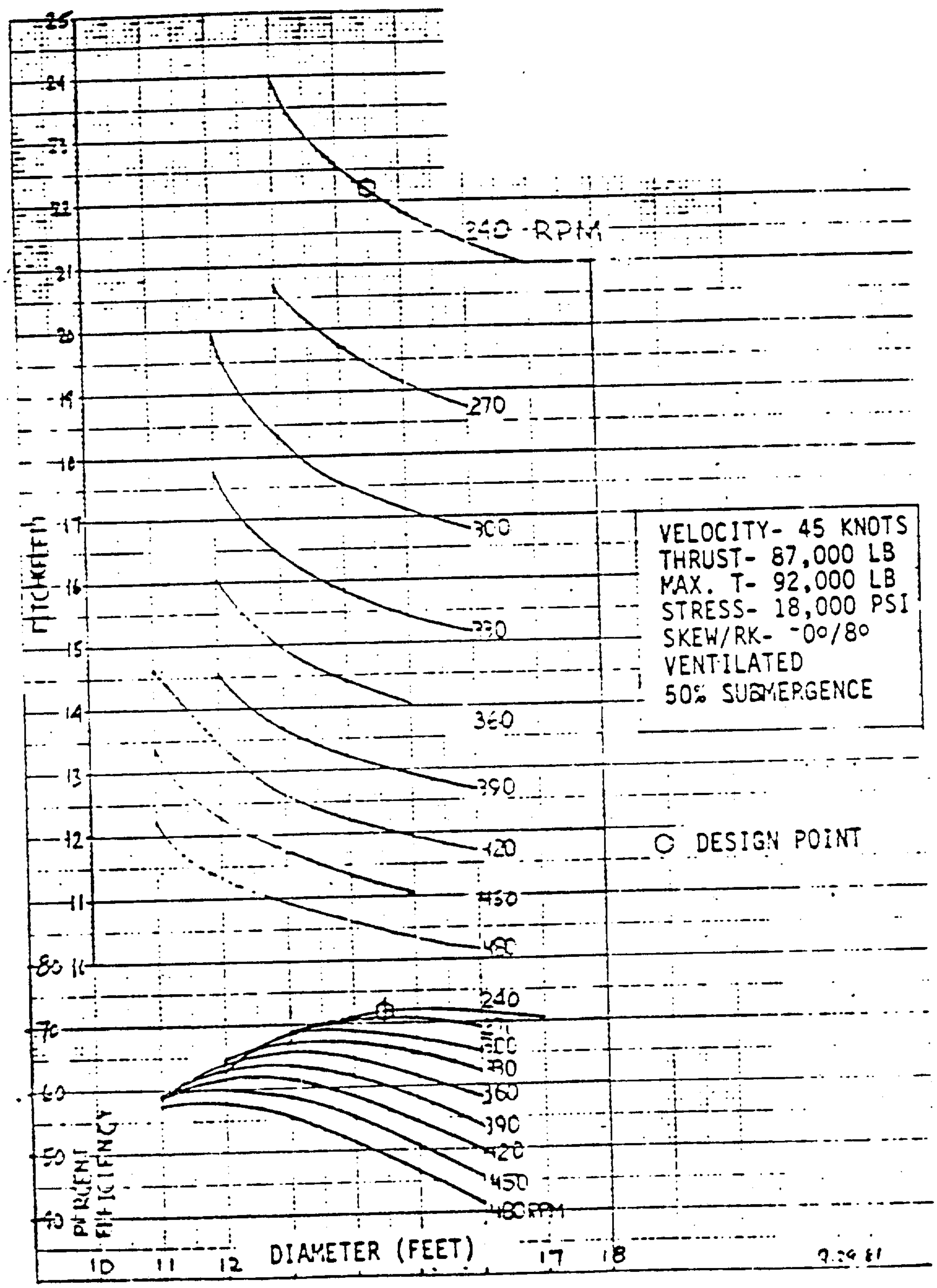


Figure 2-2 MDS 1500 PROPELLER PARAMETRIC PERFORMANCE

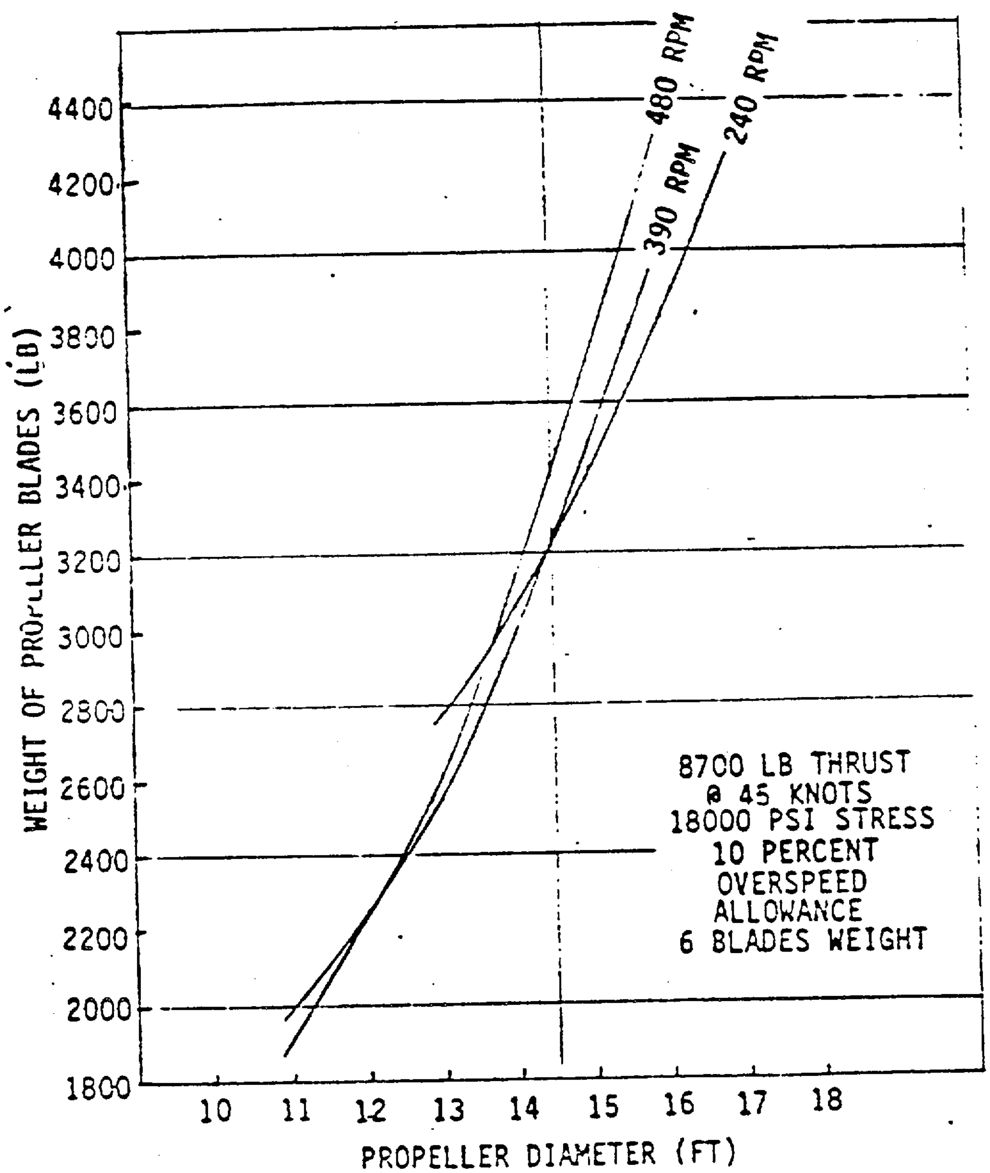


Figure 2-3 BLADE WEIGHT VERSUS SIZE

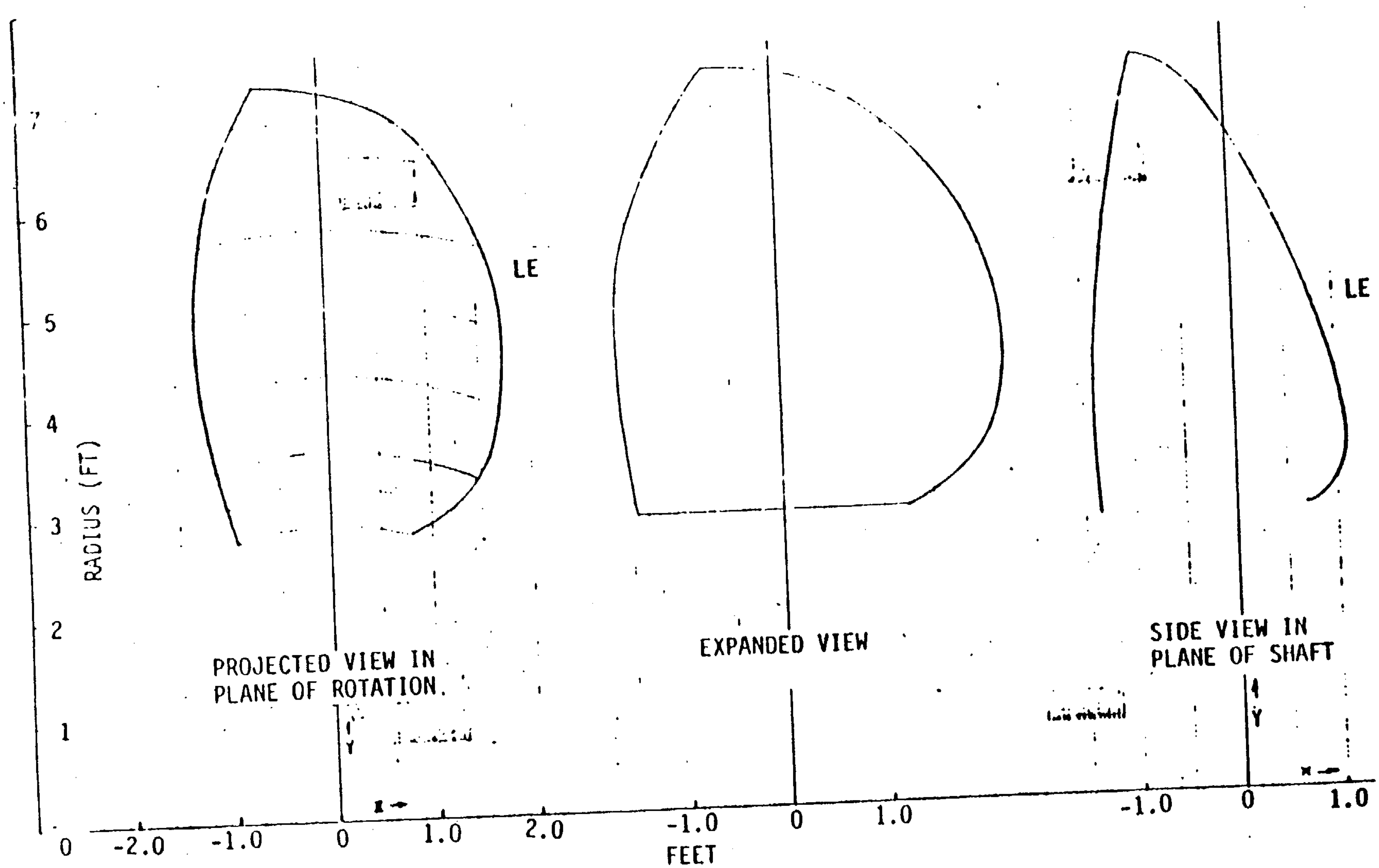


Figure 2-4 MDS 1500 PROPELLER

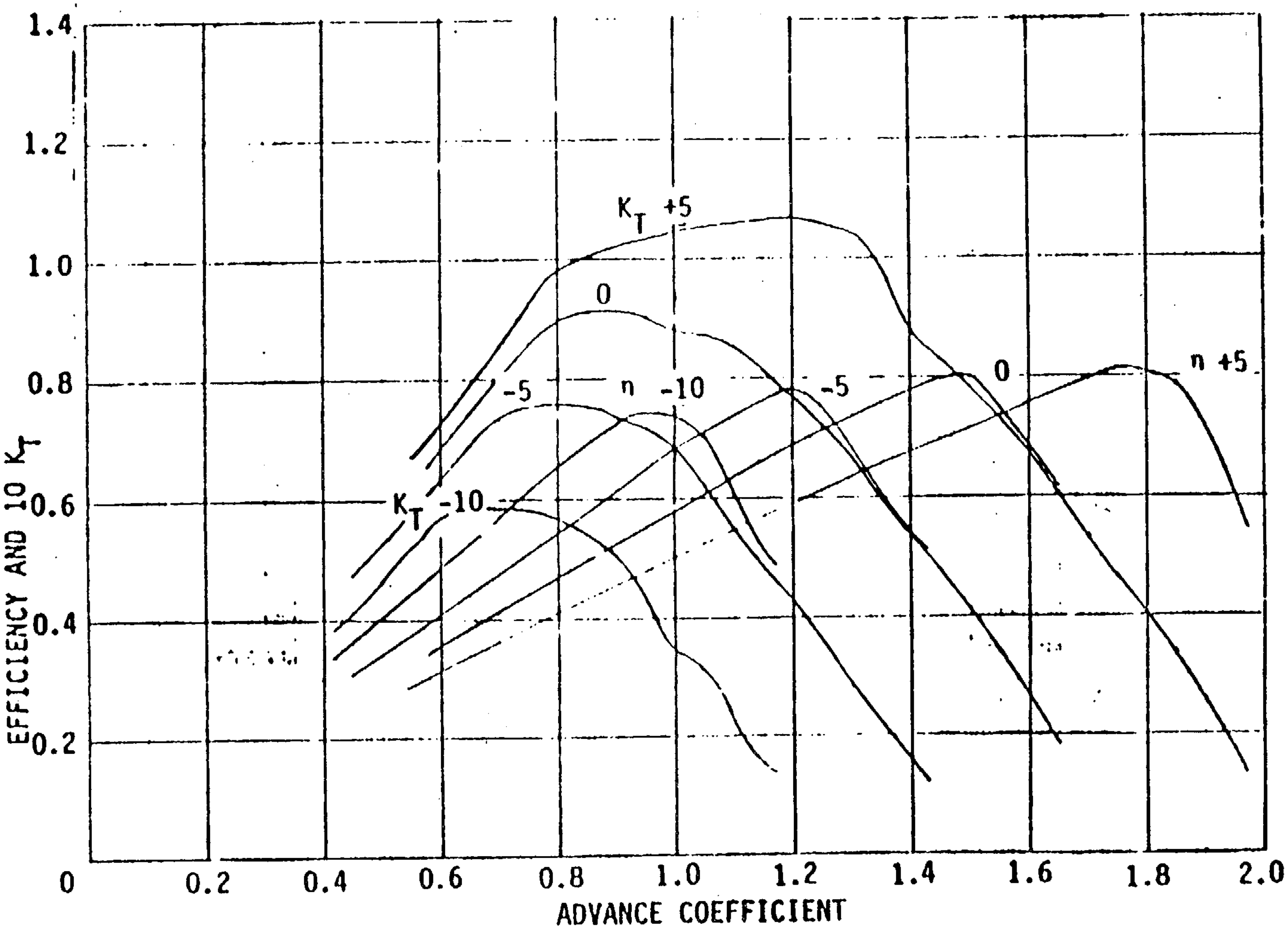


Figure 2-5 MDC 1500 PROPELLER (50 PERCENT SUBMERGED)

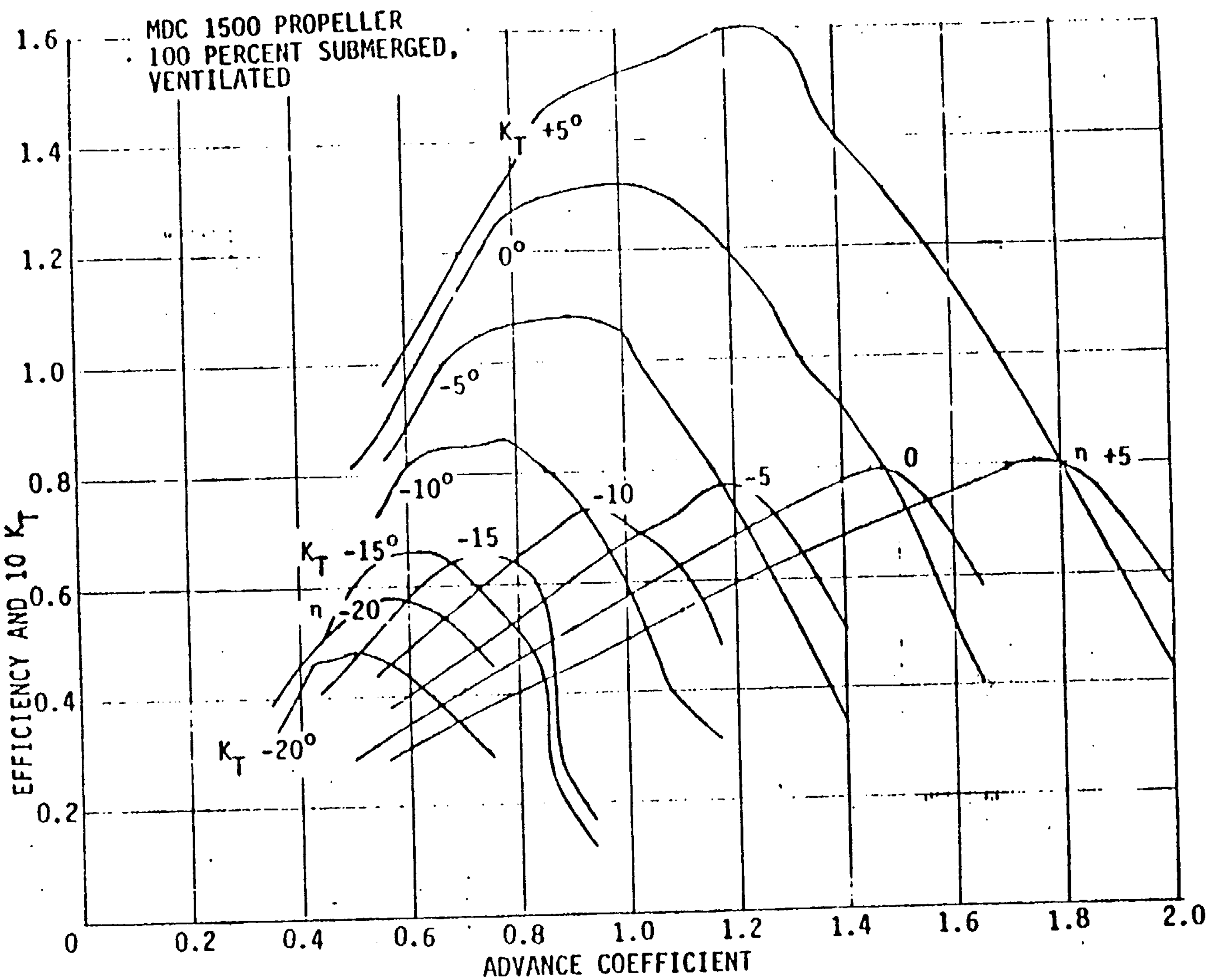


Figure 2-6 MDC 1500 PROPELLER (100 PERCENT SUBMERGED, VENTILATED)

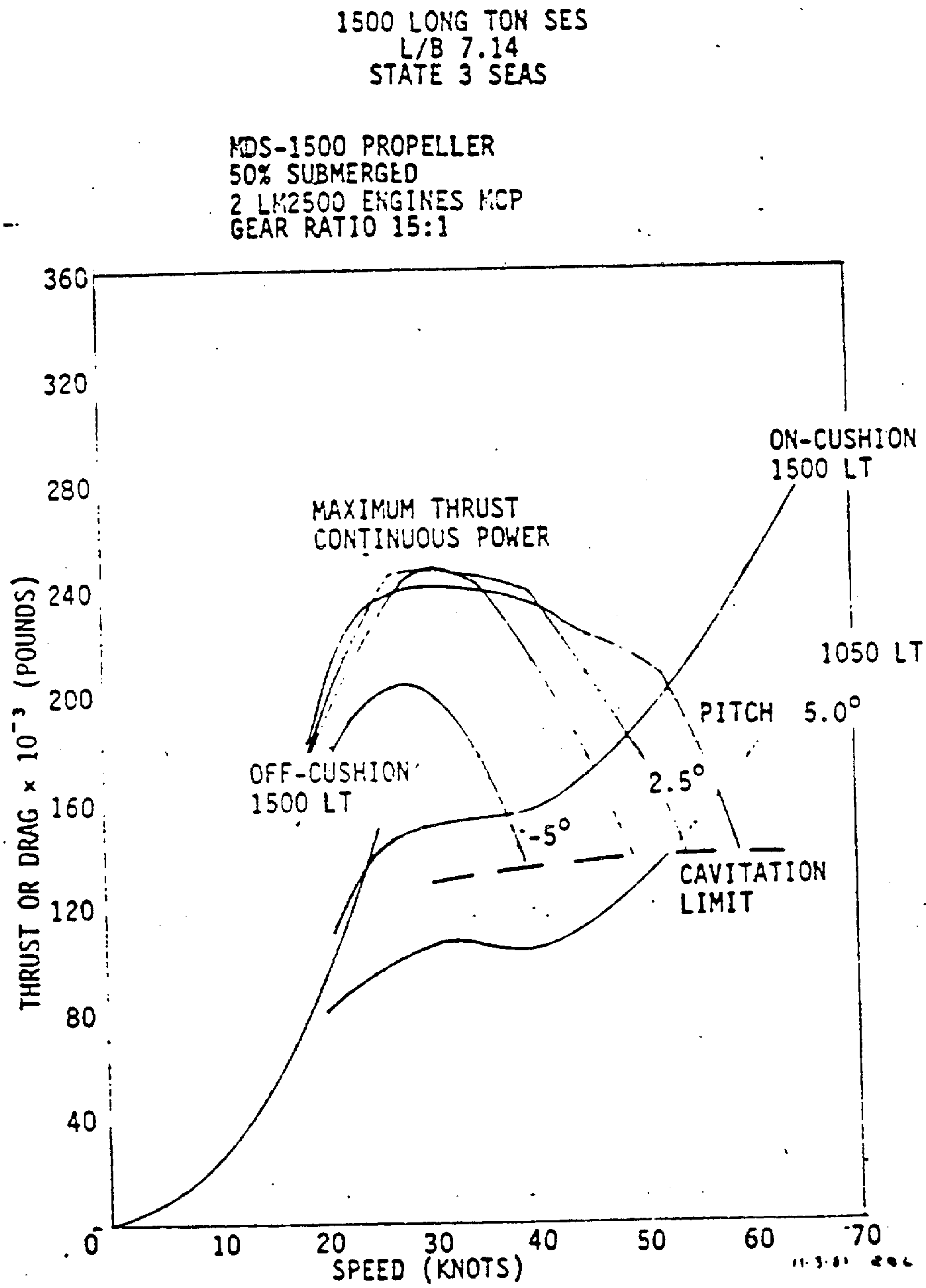


Figure 2-7 MAXIMUM THRUST ON CUSHION - LM2500 ENGINES, MCP

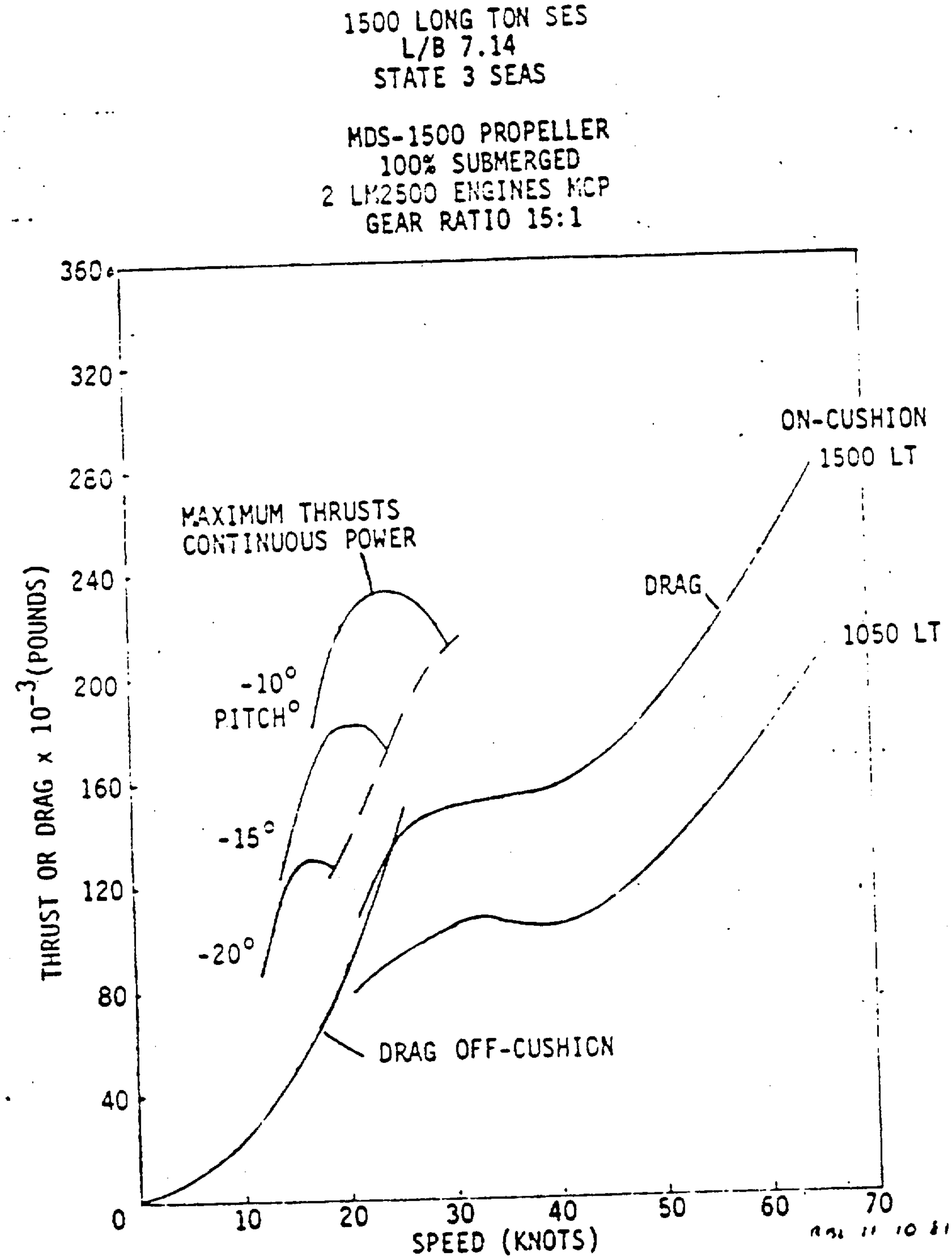


Figure 2-8 MAXIMUM THRUST OFF CUSHION - LM2500 ENGINES, MCP

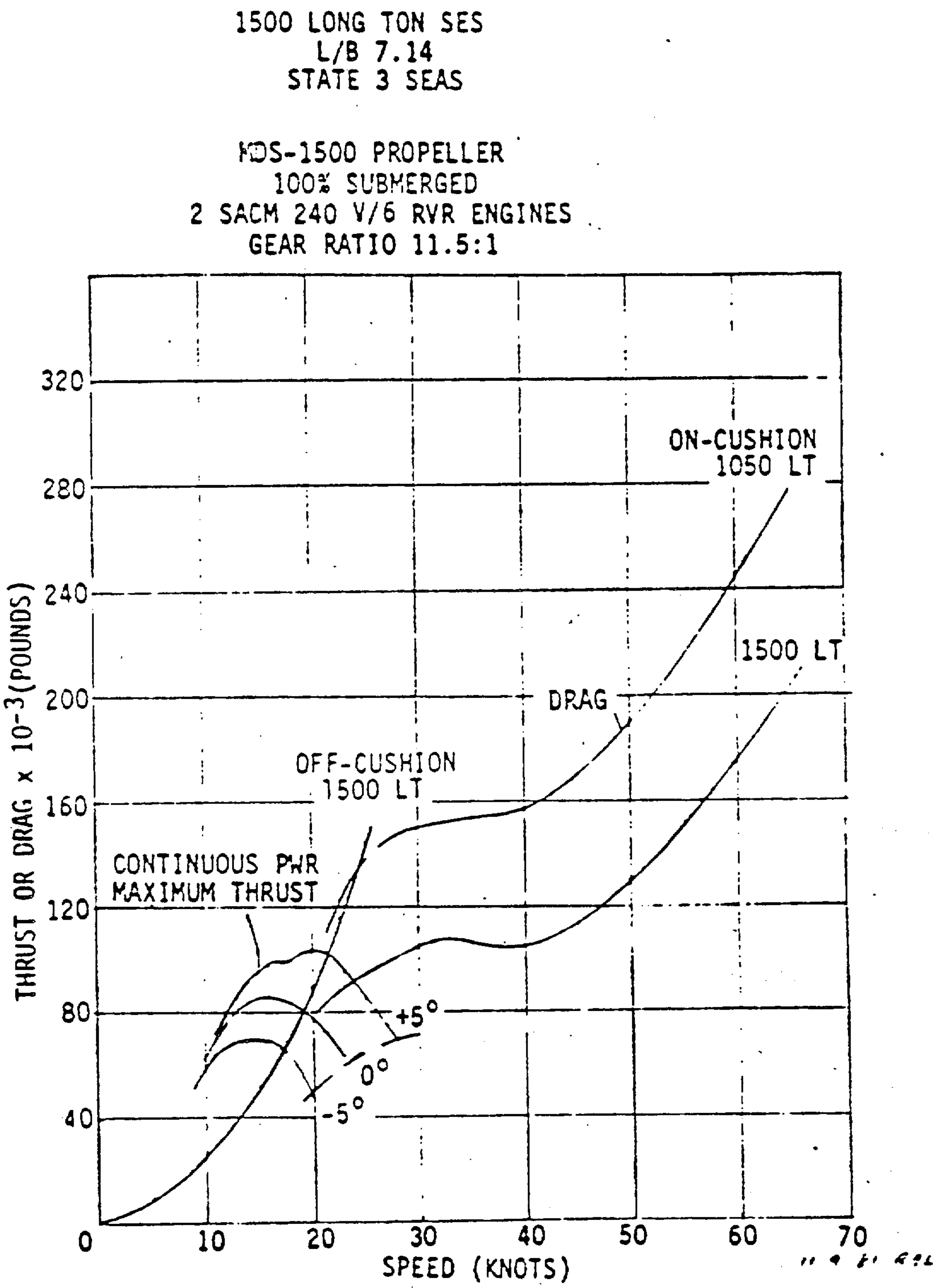


Figure 2-9 MAXIMUM THRUST OFF CUSHION - SACM ENGINES

TABLE 2-I

NAVY REQUIREMENTS FOR MDS 1500 PROPELLERS

Two supercavitating controllable pitch

Two General Electric LM2500 gas turbines (baseline)

Two CODOG diesel engines for off cushion (alternate)

Gear reduction ratios to be selected

Sidehull width at transom and chine, 14.5 feet

8-degree shaft inclination

DESIGN POINTS

On Cushion - 45 knots in sea state 3 at FLD, 1500 LT, 50 percent submergence

Off Cushion - 20 knots in sea state 3 at FLD, 1500 LT, 100 percent submergence

OFF-DESIGN POINT

On Cushion - Maximum knots in sea state 3 with partial load of 1050 LT

DRAG

170,000 lb at 45 knots, sea state 3, 1500 LT, on cushion

90,000 lb at 20 knots, sea state 3, 1500 LT, off cushion

LM2500 ENGINE RATINGS

27,000 maximum intermittent power, 3600 rpm

24,000 maximum continuous power, 3600 rpm

DIESEL ENGINE RATINGS

Engine to be selected from proven models.

TABLE 2-11

SECTION OFFSETS AND PLANFORM DIMENSIONS FOR MDS 1500 PROPELLER

SUPERCAVITATING PROPELLER DESIGN INPUT SUMMARY

DESIGN PROGRAM CONTROL SPECIFICATIONS -

7. CURVED BEAM STRUCTURAL ANALYSIS INCLUDED DURING DESIGN ITERATIONS

9. SECTION OFFSETS TABULATED

DSGNMDC15 0001 CHORD LIM. 2 NO INTERFERENCE IN EXPANDED OUTLINE

THRUST	86500.00	MAX.THRST	92000.00	SHAFT SUBM	0.	DIAMETER	14.50
REVS/SEC	4.00	VELOCITY	76.00	CAV.PRES.	2116.00	NO.BLADES	6.00
HUB RAD.	0.	HUB LENGTH	0.	HUB SURF.	0.	HUB SHAPE	0.
HUB COC	0.	PALM DIAM.	1.80	METAL DENS	8.59	MAX.RPS	4.50
STRESS	18000.00	L.E.STRESS	0.80	ANNEX THIK	0.	UNDERCUT	0.80
PROP.EAR	0.50	BLADE CHAR	0.70	BLADE XBAR	0.65		
TIP SKEW	15.00	SKEW TANG.	-20.00	SKEW EXPON	3.00		
TIP RAKE	0.	RAKE TANG.	5.00	RAKE EXPON	0.		

SPANWISE CHARACTERISTICS OF BLADE

RADIAL STATION	CT(R) (SPECIFIED)	ESTIMATED ETAC(R)	ANNEX/ HYD.CHORD	SECTION CL-DELTA	ESTIMATED CINC.FACTOR	NORMAL CHORDS	NORMAL ANNEXES
1.000	0.0043	0.8000	0.	0.300	0.001	0.	0.
0.950	0.7812	0.8000	0.	0.300	0.200	0.	0.
0.900	1.0000	0.8000	0.	0.300	0.300	0.	0.
0.800	0.9915	0.8000	0.	0.300	0.400	0.	0.
0.700	0.9612	0.8000	0.	0.300	0.550	0.	0.
0.600	0.8011	0.8000	0.	0.300	0.700	0.	0.
0.500	0.5385	0.8000	0.	0.300	0.800	0.	0.
0.450	0.4391	0.8000	0.	0.300	0.900	0.	0.
0.400	0.3360	0.8000	0.	0.300	1.000	0.	0.

TABLE 2-11 (Cont)

BELL AEROSPACE TEXTRON

PROPELLER DESIGN 0001

SUMMARY OF CALCULATED PROPELLER CHARACTERISTICS

GEOMETRIC		OPERATIONAL		PERFORMANCE INDICES (BASED ON FULL DIAM.)			
HUB RAD.RATIO=	0.4000	J (TIP) =	1.310	CT =	0.14545	DIAMETER =	14.50800
NUMBER BLADES=	6.0000	J (.7R) =	1.872	CP =	0.20225	VELOCITY =	76.000
EX.AREA RATIO=	0.5000	LAMBDA(.7R)=	0.642	KT =	0.06178	CAV. PRES. =	2116.00
TIP SKEW =	-15.0000	BETAI(.7R) =	29.431	KQ =	0.01792	SUBM =	0.50000
HYDP.TIP RAKE=	0.	PITCH(.7R) =	21.915	ETA =	0.71915	DELT. PITCH =	0.
SUBM/DIAM =	0.5000	SIG.CAV.7R =	0.000	THRST=	0.86856 LBS-5	RPS =	6.00000
BLADE WEIGHT =	3.1760 LBS-3	SIG.CAV.HUB=	0.000	POWER=	0.16689 HP-5		

BLADE SECTION CHARACTERISTICS

N.D.RAD	C(HYD) FT.	C(ANNEX) FT.	CL	CD	CD-CAV	ETA	ETAI	ETAB	ETAC	*IDEAL* CT	ACTUAL CT
1.000	0.	0.	0.	0.	0.	0.8248	1.0273	0.9761	0.8225	0.	0.00094
0.950	1.756	0.	0.1291	0.0141	0.01002	0.7996	1.0549	0.9716	0.8225	0.169	0.16645
0.900	2.451	0.	0.1290	0.0153	0.01135	0.7722	1.0728	0.8879	0.8107	0.222	0.21867
0.800	3.293	0.	0.1076	0.0128	0.00894	0.7804	1.0758	0.8750	0.8290	0.271	0.21681
0.700	3.735	0.	0.1047	0.0125	0.00860	0.7831	1.0609	0.8797	0.8390	0.217	0.21019
0.600	3.862	0.	0.0953	0.0116	0.00771	0.7890	1.0447	0.8914	0.8473	0.181	0.17518
0.500	3.632	0.	0.0813	0.0126	0.00870	0.7551	1.0331	0.9054	0.8073	0.124	0.11775
0.450	3.315	0.	0.0811	0.0149	0.01098	0.7119	1.0265	0.9108	0.7615	0.102	0.09602
0.400	2.704	0.	0.0924	0.0223	0.01825	0.6201	1.0198	0.9162	0.6636	0.000	0.07347

	DIM.RAD. FT.	DELTA 1ST ORD	KAPPA 1ST ORD	TAU	BEND.STRES PSI	LE STRES PSI	SECT.AREA SQ.FT.	ZBAR	SIGC	BETAI	BETAG	PITCH FT.
1.00	7.25		0.	0.	0.	0.	0.	0.	0.000	22.05880	22.495	18.86
0.950	6.89	1.396	0.0893	0.0137	0.	14518.	0.14	0.00028	0.000	22.58703	25.412	20.58
0.900	6.52	1.404	0.0898	0.0130	2544.	14425.	0.27	0.00027	0.000	23.36665	27.579	21.41
0.800	5.80	1.166	0.0746	0.0111	5965.	14366.	0.41	0.00019	0.000	25.92367	30.882	21.73
0.700	5.07	1.136	0.0726	0.0091	11592.	14459.	0.48	0.00017	0.000	29.43146	34.508	21.92
0.600	4.35	1.035	0.0662	0.0110	18049.	9712.	0.51	0.00017	0.000	33.79387	38.506	21.75
0.500	3.63	0.884	0.0565	0.0251	17756.	2482.	0.64	0.00031	0.000	39.03846	43.056	21.28
0.450	3.26	0.882	0.0564	0.0354	17638.	1285.	0.67	0.00049	0.000	42.17469	45.916	21.17
0.400	2.90	1.004	0.0642	0.0553	17657.	593.	0.64	0.00102	0.000	45.31093	48.839	20.84

N.D.RAD	DELTA GEOM	KAPPA(1) GEOM	U1 FPS	U* FPS	U2 FPS	OMEGA1 RAD/SEC	OMEGA* RAD/SEC	OMEGA2 RAD/SEC	W1 FPS	W* FPS	W2 FPS
1.000	0.	0.	73.944	75.638	77.333	25.146	25.122	0.047	182.3111	182.0638	181.8165
0.950	2.491	0.1191	72.059	77.338	82.617	25.158	24.850	0.617	173.2761	171.1772	169.0783
0.900	3.006	0.1330	70.844	78.266	85.689	25.160	24.652	1.014	164.1678	160.0795	157.5913
0.800	2.912	0.1232	70.644	78.518	86.393	25.142	24.444	1.396	145.8247	141.0048	137.7849
0.700	2.982	0.1272	71.643	78.660	85.678	25.127	24.277	1.699	127.5201	123.2344	118.9487
0.600	2.676	0.1182	72.751	78.437	84.122	25.114	24.153	1.921	109.2476	105.0832	100.9187
0.500	2.133	0.0992	73.566	77.834	82.101	25.102	24.074	2.056	90.9963	87.2758	83.5554
0.450	2.000	0.0961	74.042	77.640	81.218	25.094	24.003	2.182	81.8702	78.3192	74.7683
0.400	2.051	0.1033	74.517	77.446	80.375	25.086	23.931	2.309	72.7441	69.3626	65.9812

TABLE 2-II (Cont)

BELL AEROSPACE TEXTRON

SECTION OFFSETS FOR PROPELLER DESIGN 0001

1.000 RADIAL STATION

L.E.RADIUS = 0.

Y/C	Y	T-CAV	T-FACE
0.	0.	0.	0.
0.	0.	0.	0.
0.	0.	0.	0.
0.	0.	0.	0.
0.	0.	0.	0.
0.	0.	0.	0.
0.	0.	0.	0.
0.	0.	0.	0.
0.	0.	0.	0.
0.	0.	0.	0.
0.	0.	0.	0.
0.	0.	0.	0.
0.	0.	0.	0.
0.	0.	0.	0.
0.	0.	0.	0.
0.	0.	0.	0.
0.	0.	0.	0.
0.	0.	0.	0.
0.	0.	0.	0.
0.	0.	0.	0.
0.	0.	0.	0.
0.	0.	0.	0.

0.950 RADIAL STATION

L.E.RADIUS = 0.0001660

Y/C	Y	T-CAV	T-FACE
0.	0.	0.	0.
0.05	0.0878	0.0099	-0.0045
0.10	0.1756	0.0152	-0.0072
0.15	0.2634	0.0196	-0.0101
0.20	0.3513	0.0234	-0.0131
0.25	0.4391	0.0268	-0.0163
0.30	0.5269	0.0300	-0.0198
0.35	0.6147	0.0330	-0.0235
0.40	0.7025	0.0359	-0.0273
0.45	0.7903	0.0385	-0.0315
0.50	0.8781	0.0411	-0.0358
0.55	0.9659	0.0436	-0.0404
0.60	1.0538	0.0459	-0.0452
0.65	1.1416	0.0482	-0.0503
0.70	1.2294	0.0504	-0.0558
0.75	1.3172	0.0526	-0.0615
0.80	1.4050	0.0547	-0.0677
0.85	1.4928	0.0567	-0.0743
0.90	1.5806	0.0587	-0.0815
0.95	1.6684	0.0607	-0.0897
1.00	1.7563	0.0626	-0.1002
1.00	1.7563	0.	0.

0.900 RADIAL STATION

L.E.RADIUS = 0.0002061

Y/C	Y	T-CAV	T-FACE
0.	0.	0.	0.
0.05	0.1225	0.0135	-0.0053
0.10	0.2451	0.0200	-0.0087
0.15	0.3676	0.0268	-0.0124
0.20	0.4902	0.0321	-0.0165
0.25	0.6127	0.0368	-0.0209
0.30	0.7352	0.0412	-0.0256
0.35	0.8578	0.0454	-0.0308
0.40	0.9803	0.0492	-0.0363
0.45	1.1028	0.0529	-0.0421
0.50	1.2254	0.0565	-0.0483
0.55	1.3479	0.0599	-0.0549
0.60	1.4705	0.0632	-0.0620
0.65	1.5930	0.0663	-0.0694
0.70	1.7155	0.0694	-0.0773
0.75	1.8381	0.0724	-0.0858
0.80	1.9606	0.0752	-0.0949
0.85	2.0831	0.0781	-0.1047
0.90	2.2057	0.0808	-0.1155
0.95	2.3282	0.0835	-0.1278
1.00	2.4508	0.0861	-0.1437
1.00	2.4508	0.	0.

0.800 RADIAL STATION

L.E.RADIUS = 0.0002019

Y/C	Y	T-CAV	T-FACE
0.	0.	0.	0.
0.05	0.1647	0.0152	-0.0056
0.10	0.3293	0.0235	-0.0091
0.15	0.4940	0.0302	-0.0131
0.20	0.6586	0.0362	-0.0176
0.25	0.8233	0.0415	-0.0225
0.30	0.9880	0.0465	-0.0279
0.35	1.1526	0.0511	-0.0338
0.40	1.3173	0.0555	-0.0401
0.45	1.4820	0.0596	-0.0469
0.50	1.6466	0.0636	-0.0541
0.55	1.8113	0.0674	-0.0619
0.60	1.9759	0.0711	-0.0701
0.65	2.1406	0.0747	-0.0789
0.70	2.3053	0.0781	-0.0883
0.75	2.4699	0.0815	-0.0984
0.80	2.6346	0.0847	-0.1092
0.85	2.7993	0.0879	-0.1210
0.90	2.9639	0.0910	-0.1339
0.95	3.1286	0.0940	-0.1487
1.00	3.2932	0.0970	-0.1681
1.00	3.2932	0.	0.

TABLE 2-II (Cont)

BELL AEROSPACE TEXTRON

SECTION OFFSETS FOR PROPELLER DESIGN 0001

0.700 RADIAL STATION

L.E.RADIUS = 0.0001560

Y/C	Y	T-CAV	T-FACE
0.	0.	0.	0.
0.05	0.1867	0.0157	-0.0044
0.10	0.3735	0.0244	-0.0075
0.15	0.5602	0.0315	-0.0114
0.20	0.7470	0.0377	-0.0159
0.25	0.9337	0.0434	-0.0210
0.30	1.1205	0.0486	-0.0267
0.35	1.3072	0.0535	-0.0329
0.40	1.4940	0.0582	-0.0398
0.45	1.6807	0.0626	-0.0471
0.50	1.8675	0.0668	-0.0551
0.55	2.0542	0.0708	-0.0636
0.60	2.2410	0.0747	-0.0728
0.65	2.4277	0.0785	-0.0826
0.70	2.6145	0.0822	-0.0931
0.75	2.8012	0.0857	-0.1044
0.80	2.9880	0.0892	-0.1166
0.85	3.1747	0.0925	-0.1300
0.90	3.3615	0.0958	-0.1447
0.95	3.5482	0.0990	-0.1616
1.00	3.7350	0.1022	-0.1838
1.00	3.7350	0.	0.

0.600 RADIAL STATION

L.E.RADIUS = 0.0002325

Y/C	Y	T-CAV	T-FACE
0.	0.	0.	0.
0.05	0.1931	0.0166	-0.0063
0.10	0.3862	0.0256	-0.0101
0.15	0.5793	0.0328	-0.0144
0.20	0.7724	0.0392	-0.0192
0.25	0.9655	0.0450	-0.0246
0.30	1.1586	0.0503	-0.0305
0.35	1.3517	0.0553	-0.0368
0.40	1.5448	0.0600	-0.0437
0.45	1.7378	0.0644	-0.0511
0.50	1.9309	0.0687	-0.0590
0.55	2.1240	0.0728	-0.0675
0.60	2.3171	0.0767	-0.0765
0.65	2.5102	0.0805	-0.0862
0.70	2.7033	0.0842	-0.0965
0.75	2.8964	0.0878	-0.1076
0.80	3.0895	0.0913	-0.1195
0.85	3.2826	0.0947	-0.1325
0.90	3.4757	0.0980	-0.1469
0.95	3.6688	0.1013	-0.1632
1.00	3.8619	0.1044	-0.1121
1.00	3.8619	0.	0.

0.500 RADIAL STATION

L.E.RADIUS = 0.0011406

Y/C	Y	T-CAV	T-FACE
0.	0.	0.	0.
0.05	0.1816	0.0236	-0.0179
0.10	0.3632	0.0349	-0.0263
0.15	0.5448	0.0440	-0.0338
0.20	0.7265	0.0519	-0.0411
0.25	0.9081	0.0589	-0.0484
0.30	1.0897	0.0654	-0.0559
0.35	1.2713	0.0714	-0.0635
0.40	1.4529	0.0770	-0.0713
0.45	1.6345	0.0823	-0.0794
0.50	1.8161	0.0874	-0.0878
0.55	1.9977	0.0923	-0.0965
0.60	2.1794	0.0970	-0.1056
0.65	2.3610	0.1015	-0.1151
0.70	2.5426	0.1058	-0.1250
0.75	2.7242	0.1100	-0.1355
0.80	2.9058	0.1141	-0.1466
0.85	3.0874	0.1181	-0.1585
0.90	3.2690	0.1220	-0.1714
0.95	3.4507	0.1258	-0.1859
1.00	3.6323	0.1295	-0.2044
1.00	3.6323	0.	0.

0.450 RADIAL STATION

L.E.RADIUS = 0.0020742

Y/C	Y	T-CAV	T-FACE
0.	0.	0.	0.
0.05	0.1658	0.0276	-0.0241
0.10	0.3315	0.0405	-0.0350
0.15	0.4973	0.0508	-0.0444
0.20	0.6630	0.0596	-0.0531
0.25	0.8288	0.0674	-0.0616
0.30	0.9945	0.0746	-0.0700
0.35	1.1603	0.0813	-0.0784
0.40	1.3260	0.0875	-0.0869
0.45	1.4918	0.0934	-0.0955
0.50	1.6576	0.0991	-0.1044
0.55	1.8233	0.1045	-0.1134
0.60	1.9891	0.1096	-0.1228
0.65	2.1548	0.1146	-0.1324
0.70	2.3206	0.1194	-0.1424
0.75	2.4863	0.1240	-0.1528
0.80	2.6521	0.1286	-0.1638
0.85	2.8178	0.1329	-0.1754
0.90	2.9836	0.1372	-0.1879
0.95	3.1493	0.1414	-0.2018
1.00	3.3151	0.1456	-0.2191
1.00	3.3151	0.	0.

TABLE 2-II (Cont)

BELL AEROSPACE TEXTRON
SECTION OFFSETS FOR PROPELLER DESIGN 0001

0.400 RADIAL STATION
L.E.RADIUS = 0.0041367

Y/C	Y	T-CAV	T-FACE
0.	0.	0.	0.
0.05	0.1352	0.0329	-0.0317
0.10	0.2704	0.0479	-0.0458
0.15	0.4057	0.0597	-0.0574
0.20	0.5409	0.0698	-0.0680
0.25	0.6761	0.0789	-0.0780
0.30	0.8113	0.0871	-0.0878
0.35	0.9466	0.0947	-0.0973
0.40	1.0818	0.1019	-0.1068
0.45	1.2170	0.1086	-0.1163
0.50	1.3522	0.1150	-0.1259
0.55	1.4875	0.1211	-0.1356
0.60	1.6227	0.1270	-0.1454
0.65	1.7579	0.1326	-0.1555
0.70	1.8931	0.1381	-0.1658
0.75	2.0284	0.1434	-0.1764
0.80	2.1636	0.1485	-0.1875
0.85	2.2988	0.1534	-0.1991
0.90	2.4340	0.1583	-0.2114
0.95	2.5693	0.1630	-0.2249
1.00	2.7045	0.1676	-0.2414
1.00	2.7045	0.	0.

TABLE 2-II (Cont)

BELL AEROSPACE TEXTRON

PLANFORM OUTLINE FOR PROPELLER 0001
CARTESIAN COORDINATES

SKEW LINE X	SKEW LINE Y	SKEW LINE Z	LEADING EDGE X	LEADING EDGE Y	LEADING EDGE Z	TRAILING EDGE X	TRAILING EDGE Y	TRAILING EDGE Z
-0.8963	7.2224	-0.6319	-0.8963	7.2224	-0.6319	-0.8963	7.2224	-0.6319
-1.0107	6.8341	-0.8560	-0.2565	6.8491	0.7265	-1.0107	6.8341	-0.8560
-1.1101	6.4435	-1.0280	0.0246	6.4257	1.1341	-1.1101	6.4435	-1.0280
-1.2509	5.6664	-1.2376	0.4354	5.5857	1.5620	-1.2509	5.6664	-1.2376
-1.3483	4.9054	-1.3011	0.7672	4.7721	1.7271	-1.3483	4.9054	-1.3011
-1.3929	4.1652	-1.2544	1.0114	4.0029	1.7028	-1.3929	4.1652	-1.2544
-1.3886	3.4451	-1.1277	1.0912	3.3161	1.4643	-1.3886	3.4451	-1.1277
-1.3809	3.0915	-1.0424	1.0004	3.0277	1.2153	-1.3809	3.0915	-1.0424
-1.3561	2.7413	-0.9461	0.6801	2.7859	0.8056	-1.3561	2.7413	-0.9461

TABLE 2-II (Cont)

BELL AEROSPACE TEXTRON
SECTION PRESSURE COEFFICIENTS FOR PROPELLER 0001

Y/C R/RAD	0.000	0.050	0.100	0.150	0.200	0.250	0.300	0.350	0.400	0.450	0.500
1.000	1.000	0.179	0.160	0.150	0.141	0.137	0.133	0.129	0.126	0.123	0.120
0.950	1.000	0.180	0.161	0.151	0.143	0.138	0.134	0.130	0.126	0.123	0.121
0.900	1.000	0.181	0.162	0.151	0.144	0.139	0.134	0.130	0.127	0.124	0.121
0.800	1.000	0.150	0.134	0.126	0.120	0.115	0.112	0.108	0.106	0.103	0.101
0.700	1.000	0.147	0.131	0.123	0.117	0.112	0.109	0.106	0.103	0.100	0.098
0.600	1.000	0.133	0.119	0.112	0.108	0.102	0.099	0.096	0.094	0.091	0.089
0.500	1.000	0.114	0.102	0.095	0.091	0.087	0.085	0.082	0.080	0.078	0.076
0.450	1.000	0.114	0.102	0.095	0.091	0.087	0.084	0.082	0.080	0.078	0.076
0.400	1.000	0.129	0.116	0.108	0.103	0.099	0.096	0.093	0.091	0.089	0.087

Y/C R/RAD	0.550	0.600	0.650	0.700	0.750	0.800	0.850	0.900	0.950	1.000	1.050
1.000	0.117	0.115	0.113	0.110	0.108	0.105	0.103	0.100	0.097	0.089	0.
0.950	0.118	0.116	0.113	0.111	0.108	0.106	0.103	0.101	0.097	0.089	0.
0.900	0.119	0.116	0.114	0.111	0.109	0.107	0.104	0.101	0.098	0.090	0.
0.800	0.099	0.097	0.095	0.093	0.091	0.089	0.086	0.084	0.081	0.075	0.
0.700	0.096	0.094	0.092	0.090	0.088	0.086	0.084	0.082	0.079	0.073	0.
0.600	0.087	0.086	0.084	0.082	0.080	0.079	0.077	0.075	0.072	0.066	0.
0.500	0.075	0.073	0.072	0.070	0.069	0.067	0.066	0.064	0.061	0.057	0.
0.450	0.075	0.073	0.072	0.070	0.069	0.067	0.065	0.064	0.061	0.056	0.
0.400	0.085	0.083	0.081	0.080	0.078	0.076	0.074	0.072	0.070	0.064	0.

TABLE 2-11 (Cont)

BELL AEROSPACE TEXTRON

SECTION PRESSURES (PSF/1000.) FOR PROPELLER 0001

Y/C R/RAD	0.000	0.050	0.100	0.150	0.200	0.250	0.300	0.350	0.400	0.450	0.500
1.000	38.600	6.912	6.177	5.780	5.507	5.298	5.127	4.981	4.853	4.737	4.631
0.950	35.073	6.316	5.645	5.281	5.012	4.861	4.685	4.551	4.434	4.329	4.231
0.900	31.819	5.762	5.149	4.818	4.590	4.416	4.274	4.152	4.045	3.949	3.860
0.800	26.132	3.937	3.514	3.287	3.132	3.013	2.916	2.833	2.760	2.695	2.634
0.700	21.266	3.116	2.785	2.605	2.482	2.388	2.311	2.245	2.188	2.135	2.087
0.600	17.114	2.284	2.042	1.910	1.820	1.751	1.694	1.646	1.604	1.566	1.530
0.500	13.606	1.551	1.386	1.297	1.236	1.189	1.150	1.118	1.089	1.063	1.039
0.450	12.096	1.377	1.231	1.151	1.097	1.055	1.021	0.992	0.967	0.944	0.922
0.400	10.676	1.382	1.235	1.156	1.101	1.059	1.025	0.996	0.971	0.947	0.926

Y/C R/RAD	0.550	0.600	0.650	0.700	0.750	0.800	0.850	0.900	0.950	1.000	1.050
1.000	4.531	4.436	4.344	4.254	4.163	4.070	3.971	3.862	3.729	3.427	0.
0.950	4.140	4.054	3.969	3.887	3.804	3.719	3.629	3.529	3.407	3.132	0.
0.900	3.777	3.698	3.621	3.546	3.470	3.393	3.311	3.220	3.108	2.857	0.
0.800	2.577	2.523	2.471	2.419	2.368	2.315	2.259	2.197	2.121	1.949	0.
0.700	2.042	2.000	1.958	1.917	1.876	1.835	1.790	1.741	1.681	1.545	0.
0.600	1.497	1.466	1.436	1.406	1.376	1.345	1.312	1.276	1.232	1.133	0.
0.500	1.017	0.996	0.975	0.955	0.934	0.913	0.891	0.867	0.837	0.769	0.
0.450	0.903	0.884	0.865	0.847	0.829	0.811	0.791	0.769	0.743	0.683	0.
0.400	0.906	0.887	0.869	0.851	0.833	0.814	0.794	0.772	0.746	0.685	0.

TABLE 2-III

POWER AND PROPELLER PERFORMANCE ON DRAG CURVE AT 1500 TONS

VK - speed, knots
VM - speed, miles per hour
DRAG - pounds
HP - engine power required

EN - propeller rpm
RPMENG - engine rpm
SIGMA - cavitation number
CT/J**2 - thrust parameter K_T/J^2

ETAZRO - propeller efficiency
ETAD - propulsion efficiency with a 4% loss
JT - propeller advance coefficient
HPENG - horsepower per engine

PITCH - propeller blade pitch
SUB - propeller submergence

POWER REQUIREMENTS FOR 275.4 FT. BOAT OF 1500.0 TONS

PROP. DIA = 14.500
PITCH/DIA = -10.000 TO +5°
GEAR RATIO = 15.000
PROPELLER(S) = RDC-1500 100 % SUBMERGENCE { 50 % SUBMERGENCE 2 LM 2500 MCP (1500 LT)

VK	VM	DRAG	H.P.	EN	RPMENG	SIGMA	CT/J**2	ETAZRO	ETAD	JT	HPENG	PITCH	SUB
2.5	2.88	4000.00	82.03	36.43	549.44	113.141	0.279	0.390	0.374	0.477	41.0	-10.0	100.0
5.0	5.76	8500.00	215.16	49.33	739.88	28.790	0.148	0.632	0.607	0.708	107.4	-12.5	
7.5	8.44	15000.00	824.83	62.65	939.72	12.796	0.116	0.686	0.658	0.836	262.4	-10.0	
10.0	11.51	24500.00	1119.24	81.24	1218.50	7.198	0.107	0.700	0.672	0.860	557.4		
12.5	14.39	35500.00	1996.15	98.98	1484.43	4.606	0.099	0.711	0.683	0.882	990.1		
15.0	17.27	51000.00	3439.90	118.69	1780.29	3.199	0.099	0.711	0.683	0.883	1719.9		
17.5	20.18	69000.00	5424.21	138.22	2073.24	2.350	0.098	0.712	0.684	0.885	2712.1		
20.0	23.03	90000.00	8083.94	157.90	2368.45	1.799	0.098	0.712	0.684	0.885	4042.0		
22.5	25.91	115000.00	11439.17	178.15	2672.19	1.422	0.099	0.711	0.683	0.882	5819.6		100.0
24.0	27.64	134000.00	14532.07	191.49	2872.34	1.250	0.102	0.708	0.680	0.876	7266.0		50.0
25.0	28.79	138000.00	17547.26	224.92	3403.78	1.152	0.096	0.629	0.604	0.770	8773.6		
27.0	31.09	145500.00	19174.66	235.99	3539.86	0.907	0.087	0.655	0.629	0.799	9587.3	-10.0	
29.0	33.39	149500.00	20734.41	227.49	3412.32	0.856	0.078	0.669	0.642	0.891	10367.2	- 7.5	
31.0	35.70	151000.00	21546.45	233.66	3504.84	0.749	0.069	0.695	0.667	0.927	10773.2	- 7.5	
35.0	40.30	153500.00	24007.35	232.40	3486.00	0.508	0.055	0.716	0.687	1.032	12003.7	- 5.0	
38.5	44.33	155600.00	26524.37	229.24	3438.52	0.486	0.046	0.723	0.694	1.173	13263.2	- 2.5	
40.0	46.06	157000.00	27477.27	234.36	3515.41	0.450	0.043	0.731	0.702	1.192	13730.6		
41.0	47.21	159000.00	28385.08	238.29	3574.37	0.428	0.041	0.735	0.705	1.202	14192.5	- 2.5	
45.0	51.82	170000.00	33017.82	238.72	3580.81	0.355	0.037	0.741	0.711	1.317	16500.9	0.0	
50.0	57.57	190000.00	42243.18	231.02	3465.30	0.208	0.033	0.719	0.691	1.512	21121.6	5.0	
55.0	63.33	215000.00	51862.91	249.86	3747.90*	0.230	0.031	0.729	0.700	1.538	25931.5*		
60.0	69.09	245500.00	64077.19	269.89	4048.20*	0.200	0.030	0.735	0.706	1.553	32038.6*		
65.0	74.85	278500.00	78198.37	289.96	4349.44*	0.170	0.029	0.740	0.711	1.566	39099.2*	5.0	50.0

*EXCEEDS LIMIT

TABLE 2-IV

POWER AND PROPELLER PERFORMANCE ON DRAG CURVE AT 1050 TONS

3600.,24000.

POWER REQUIREMENTS FOR 275.4 FT. BOAT OF 1050.0 TONS

PROP. DIA = 14.500
PITCH/DIA = -10.000 TO +7.5*
GEAR RATIO = 15.000
PROPELLER(S) = HDC-1500 50 % SUBMERGENCE 2 LH 2500 HCP

VK	VM	DRAG	H.P.	EN	RPMENG	SIGMA	CT/J**2	ETAZRO	ETAO	JT	HPENG	PITCH	SUB
22.5	25.91	87500.00	9103.13	187.26	2800.97	1.422	0.075	0.692	0.664	0.839	4551.6	-10.0	50.
25.0	28.79	95000.00	10408.26	199.68	2995.15	1.152	0.066	0.716	0.687	0.875	5304.1	-10.0	50.
27.5	31.67	99500.00	12139.24	196.98	2954.44	0.952	0.057	0.721	0.692	0.975	6069.6	7.5	50.
30.0	34.54	104500.00	13687.75	207.99	3119.88	0.800	0.051	0.733	0.703	1.008	6843.9	-7.5	50.
32.0	36.85	107000.00	14835.27	202.86	3042.95	0.701	0.046	0.738	0.709	1.102	7417.6	-5.0	50.
33.0	38.00	107500.00	15293.41	206.84	3102.55	0.661	0.041	0.742	0.712	1.135	7646.7	-5.0	50.
35.0	40.30	106000.00	15924.00	199.49	2992.41	0.588	0.038	0.745	0.715	1.224	7962.0	-2.5	50.
39.0	44.91	101000.00	16765.49	198.16	2972.43	0.473	0.030	0.766	0.736	1.375	8382.7	0.0	50.
41.0	47.21	105500.00	17901.44	204.78	3071.69	0.428	0.027	0.773	0.742	1.399	8950.7	0.0	50.
42.5	48.94	108000.00	19177.62	197.04	2955.54	0.398	0.026	0.766	0.735	1.507	9588.8	2.5	50.
45.0	51.82	113500.00	21148.82	205.95	3089.21	0.355	0.024	0.772	0.742	1.527	10574.4	2.5	50.
50.0	57.57	130000.00	26865.57	212.34	3185.17	0.288	0.023	0.774	0.743	1.645	13432.8	5.0	50.
55.0	63.33	151000.00	34085.75	231.91	3478.70	0.238	0.022	0.779	0.748	1.657	17042.9	5.0	50.
60.0	69.09	177000.00	43739.58	238.22	3573.24	0.200	0.021	0.777	0.746	1.740	21869.8	7.5	50.
66.0	76.00	210500.00	57017.34	261.27	3919.098	0.165	0.021	0.779	0.748	1.765	28508.78	7.5	50.

*EXCEEDS LIMITS

TABLE 2-V

POWER AND PROPELLER PERFORMANCE ON DRAG CURVE WITH DIESEL POWER, OFF-CUSHION

POWER REQUIREMENTS FOR 278.4-FT BOAT OF 1800.0 TONS

PROP. DIA = 14.500

GEAR RATIO = 11.500

PROPELLER(S) = MDC-1500 100 % SUBMERGENCE (2) 8ACM240V16RVR ENGINES

VK	VN	DRAG	H.P.	EN	RPMENG	SIGMA	CT/J**2	ETAZRO	ETAD	JT	HCENG	PITCH	SUB
2.5	2.88	4000.00	92.73	40.28	463.25	115.141	0.279	0.345	0.331	0.434	44.4	-12.5	100.
5.0	5.76	8500.00	212.48	53.20	611.82	28.790	0.148	0.440	0.414	0.457	104.2	-15.0	100.
7.5	8.64	15000.00	524.88	62.65	720.45	12.796	0.116	0.686	0.658	0.836	262.4	-10.0	100.
10.0	11.51	24500.00	1119.26	81.24	934.24	7.198	0.107	0.700	0.672	0.840	339.4	-10.0	100.
12.5	14.39	35500.00	1994.15	98.98	1138.22	4.606	0.099	0.711	0.681	0.882	918.1	-10.0	100.
15.0	17.27	51000.00	3502.29	110.53	1271.09	3.199	0.099	0.699	0.671	0.948	1731.1	- 7.5	100.
17.5	20.15	69000.00	5901.72	114.16	1312.90	2.350	0.098	0.666	0.639	1.071	2900.9	- 2.5	100.
20.0	23.03	90000.00	9088.64	116.61	1341.04	1.799	0.098	0.633	0.608	1.198	4344.3	+ 2.5	100
22.5	25.91	115000.00	13091.23	131.66	1514.058	1.422	0.099	0.632	0.607	1.194	6345.68	+ 2.5	100
24.0	27.64	134000.00	16385.86	141.80	1630.718	1.250	0.102	0.628	0.603	1.182	8192.98	+ 2.5	100
25.0	28.79	138000.00	17352.12	144.77	1664.868	1.152	0.076	0.636	0.610	1.206	8674.18	+ 2.5	100

* EXCEEDS LIMITS

SECTION 3

CONCLUSIONS

3. CONCLUSIONS

An efficient 14.5-foot diameter propeller has been designed for the IDS 1500-ton ship.

Alternatives of one gas turbine per propeller, or one gas turbine and one diesel each, have significant advantages, dependent upon the use of the vessel. A demonstrator SES with only gas turbines would greatly simplify the propulsion machinery. However, the range at off-cushion speeds would be much greater with diesel power and CODOG reduction gears.

3.1 Recommendations

Continue the propeller design effort to define the propeller hub and interfaces between the propeller and the hull. The design must satisfy both performance and structural considerations.

Make the proposed improvements in the SCRP computer program, so that the experience gained in the present project will be readily available for the design of new supercavitating propellers.

APPENDIX A

PRIOR REPORTS

Report 7593-933046, *Monthly Letter Status Report No 46, Selected Problems in SES Technology*, December 1980.

Report 7593-902007, *Propeller Design for Medium Displacement Combatant Surface Effect Ship Powered by LM2500 Engine*, May 1981.

TN/SES TECH/017, *Propellers for Medium Displacement Combatant SES*, July 1981.

TN/SES TECH/019, *Medium Displacement Combatant Surface Effect Ship Propulsion Efficiency vs. Forward Speed*, September 1981.

TN/SES TECH/020, *Performance of Scaled SES-100B Propeller for the Medium Displacement Combatant SES*, September 1981.

APPENDIX I

SULZER-ESCHER WYSS REPORT

MTG Marinetechnik GmbH

SURFACE EFFECT SHIP (SES) 1500

Enclosures to Report No.:

170/00/0010-02

PROPELLER DESIGN

Wandsbeker Königstraße 62 · 2000 Hamburg 70 · Telefon (040) 6 68 10

SULZER-ESCHER WYSS Gesellschaft mit beschränkter Haftung RAVENSBURG

SULZER ESCHER WYSS

Telegrammadresse escherwyss rvsb

1. Introduction

For a SES with 1500 lt displacement a propeller was to be designed as an alternative to the design of ref. (1).

The requirements for this alternative propeller are the same as for the original one, however, the approach was different since the alternative propeller design was based on model test results. These propeller charactericts are those of a model propeller which has been developed by SEWR for an another SES and has been tested extensively in a large cavitation tunnel with a free water surface.

For details of the propeller (z = 7) see " Particulars for Blade Drawing ".

Like the propeller of ref. (1) the SEWR propeller is ventilated in the cushionborn mode, however, contrary to the former one the SEWR propeller is submerded 75 %.

In the hullborn mode the propeller is fully submersed and fully wetted.

2. Design Envelope

The design envelope is taken from fig. 2-1 of ref. (1), presented in metric units in fig. 1 of this report. The curves show the thrust requirement for several modes and sea states and the NAVY Requirements of table 2-1 of ref. (1), page 28.

3. Selection of Propeller Diameter

The propeller diameter has been selected by means of the fig. 2 which presents the thrust loading of the propeller as a function of the vehicle speed. This selection of the propeller diameter is governed by the maximum thrust loading which occurs between 10 knots and abt. 30 knots depending on the operation mode.

According to the propeller characteristics the propeller diameter should not be less then 3.00 m which is also acceptable with respect to the specific mechanical loading of the propeller hub. A propeller diameter in excess of 3.0 m does not offer a better performance.

4. Performance Prediction

In fig. 3 and 4 the results of the performance calculation have been compiled. Fig. 3 is an possible RPM-Power relationship which matches the power

SULZER-ESCHER WYSS Gesellschaft mit beschränkter Haftung RAVENSBURG

[illegible]

SULZER ESCHER WYSS

0 B 85/ 0 5 8 8

displacement at sea state 3 as well as for the 1500 lt displacement at the same sea sate and also for this displacement at sea state 6 (curve 1).

From fig. 4 can be seen that in the light condition (1050 lt) the pitch has to be increased above 30 knots in order to follow the RPM-Power schedule (1). This figures also shows that the power absorption of the propeller would be little lower when operating the propeller at 1500 lt at a higher pitch and a lower shaft speed.

At 20 knots hullborn when fully wetted the propeller has to be operated at a substantial lower speed than when fully ventilated, however the power absorbtion is much smaller in the former case.

5. Conclusion

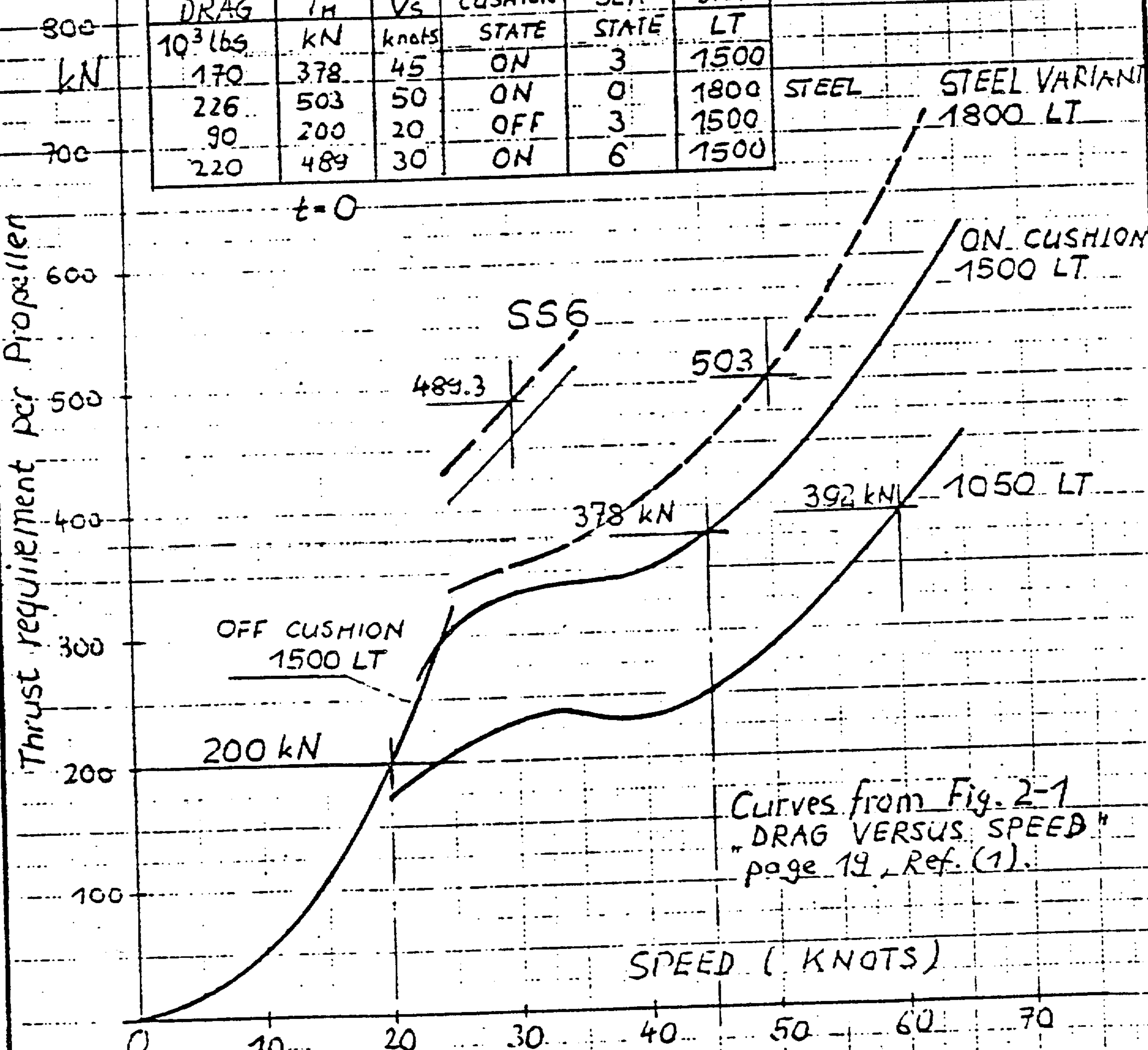
With the selected diameter the propeller satisfies the requirements. The forthcoming model tests with the NSRDC-Model no. 4281 (z = 8) will show whether an further improvement of the performance can be expected when utilising an much smaller submergence.

Reference : Report 7593-950002 , Nov. 30,1981
by Bell Aerospace Textron.

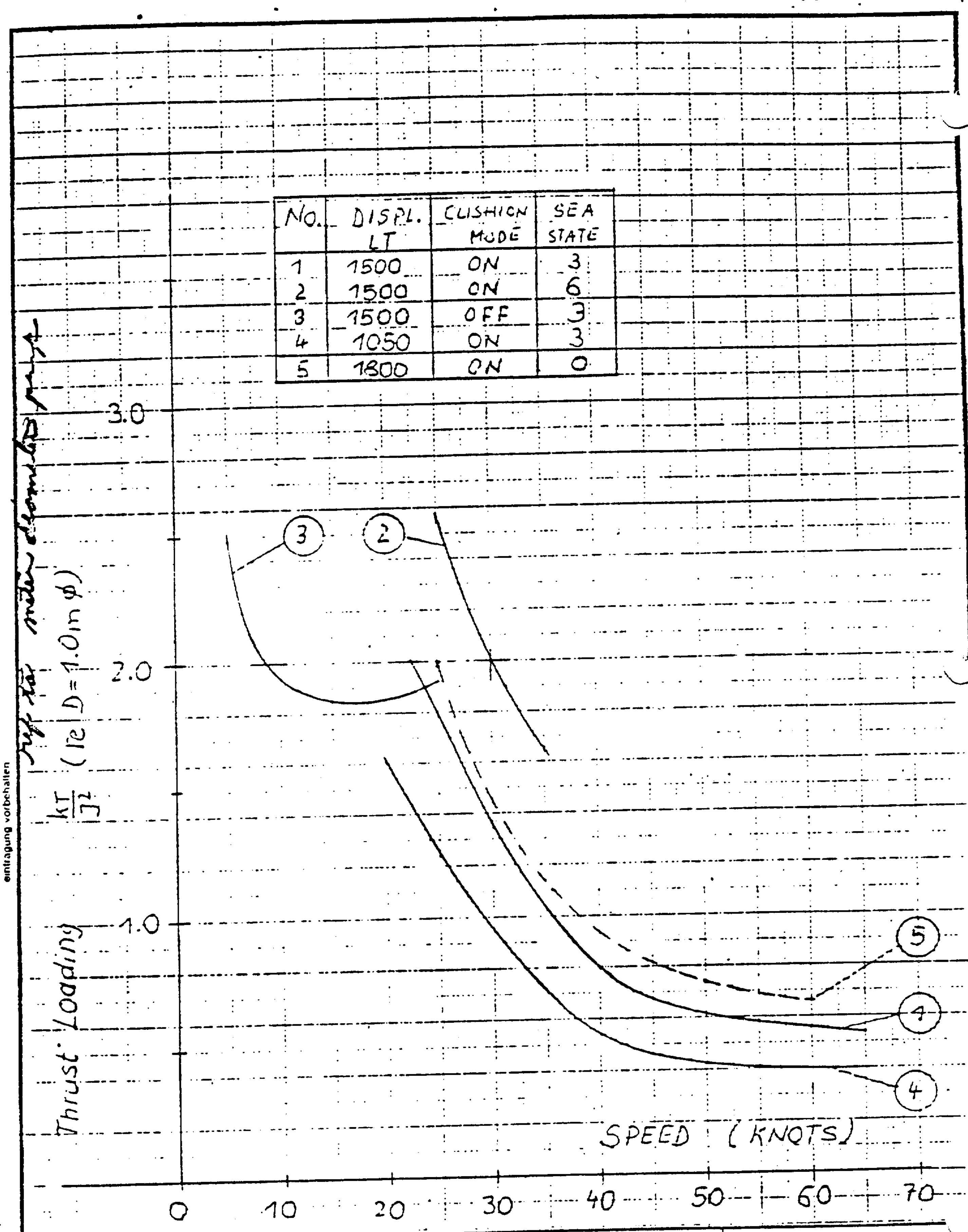
NAVY Requirements for MDS 1500

From Table 2-I, page 28, Ref. (1):

DRAG 10^3 lbs	T_H kN	V_S knots	CUSHION STATE	SEA STATE	DISP. LT
170	378	45	ON	3	1500
226	503	50	ON	0	1800
90	200	20	OFF	3	1500
220	489	30	ON	6	1500

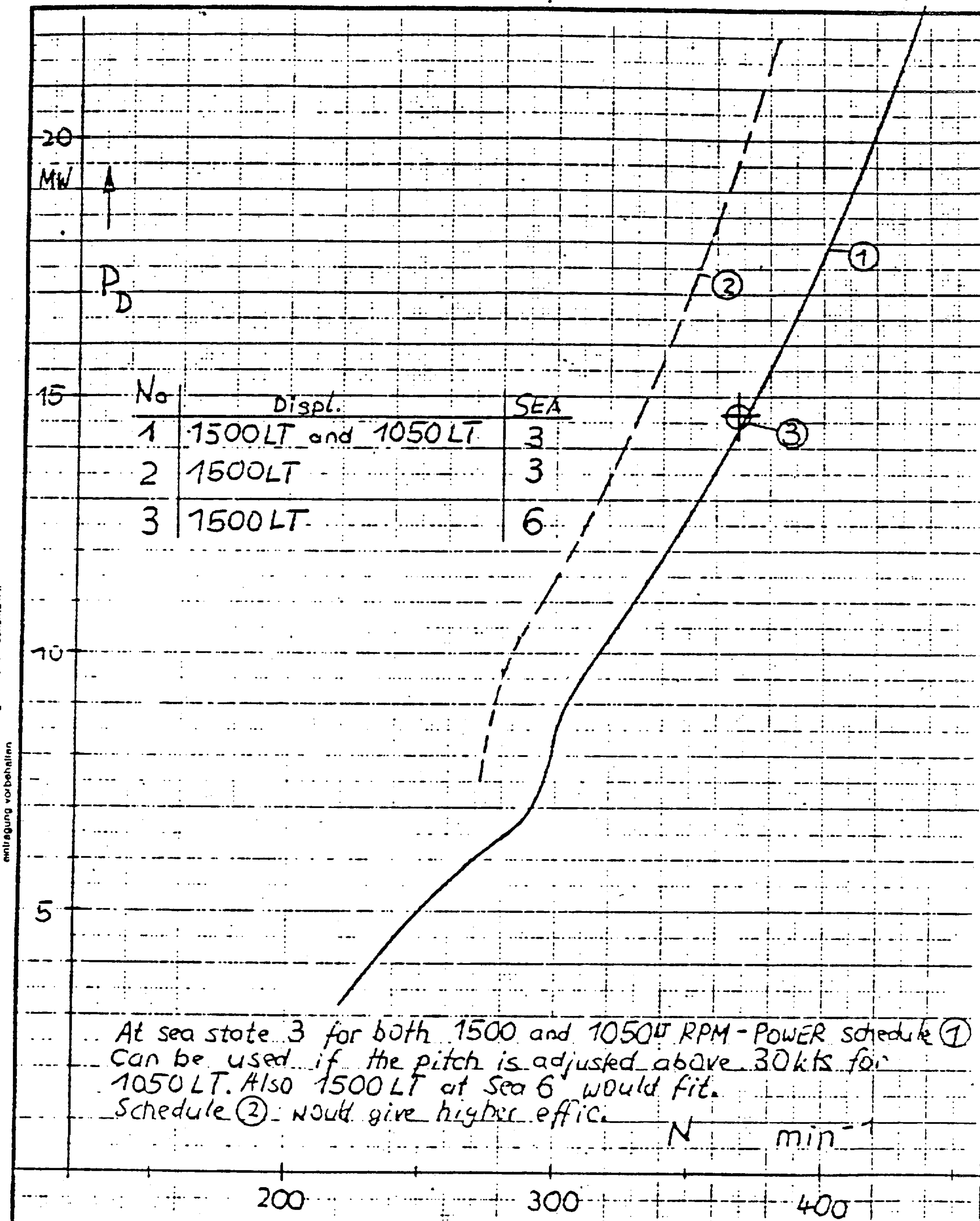


Entstand aus	Ersetzt durch	Ersatz für	Orig. Maßstab
Bezeichnung der Gruppe	Benennung		Gez. 30.12.85
Auftrags-Nr 12 90016	DESIGN ENVELOPE		Gepr.
Stichwort SES 1500			



No.	DISPL. LT	CUSHION MODE	SEA STATE
1	1500	ON	3
2	1500	ON	6
3	1500	OFF	3
4	1050	ON	3
5	1800	ON	0

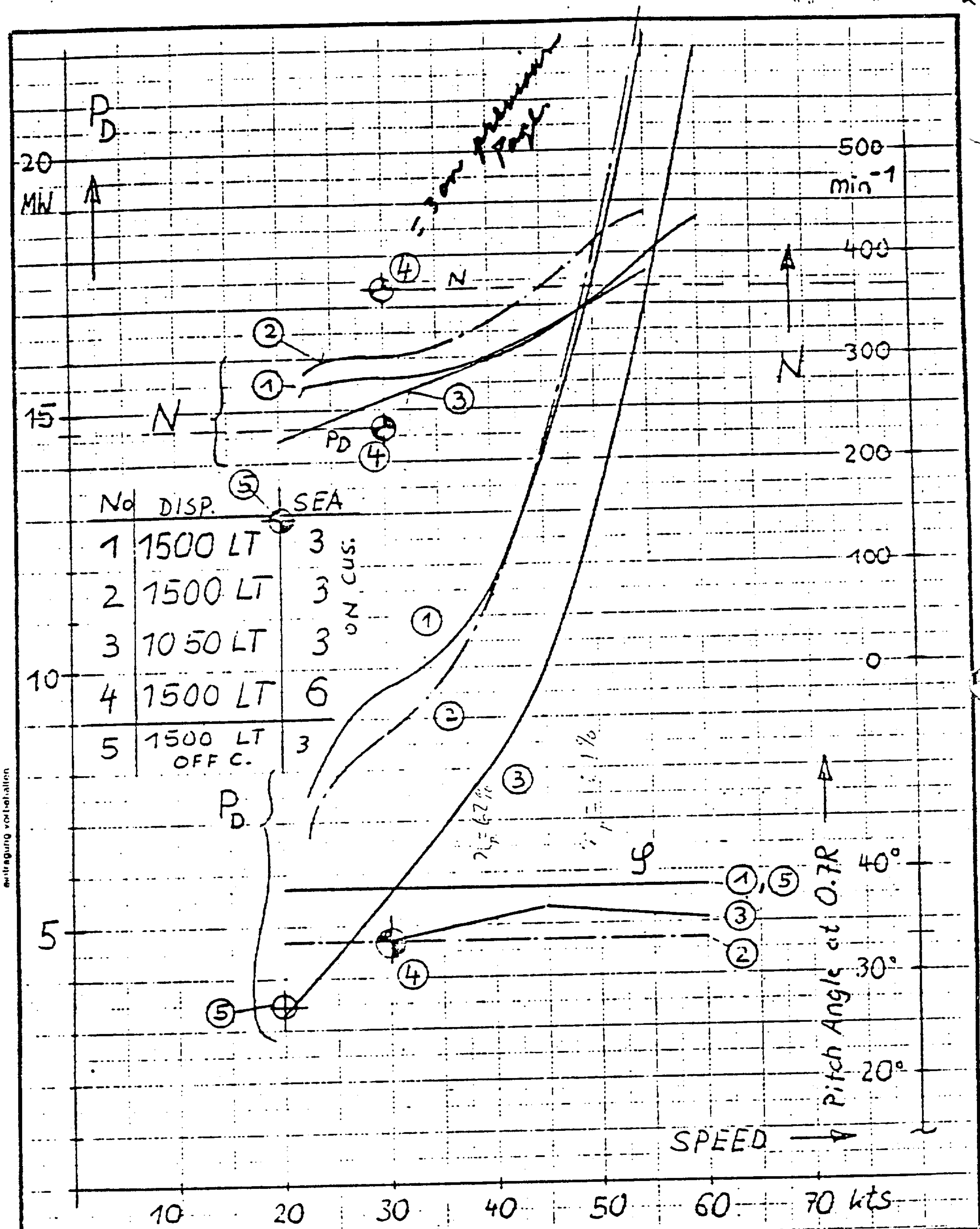
Entstand aus	Ersetzt durch	Ersatz für	Orig. Maßstab
Bezeichnung der Gruppe	Benennung	Gez.	30.12.85
Auftrags-Nr 1290016	Thrust Loading of Propeller	Gepr.	
Sachwort SES 1500			



No	Displ.	SEA
1	1500 LT and 1050 LT	3
2	1500 LT	3
3	1500 LT	6

At sea state 3 for both 1500 and 1050 LT RPM-POWER schedule ① can be used if the pitch is adjusted above 30 kts for 1050 LT. Also 1500 LT at Sea 6 would fit.
Schedule ② would give higher effic.

Entstand aus	Ersetzt durch	Ersetzt für	Orig. Maßstab
Bezeichnung der Gruppe	Benennung	Gez.	31.1.86 / [illegible]
Auftrags-Nr 1290016	RPM-POWER SCHEDULE	Gepr.	
Sachwort SES 1500			



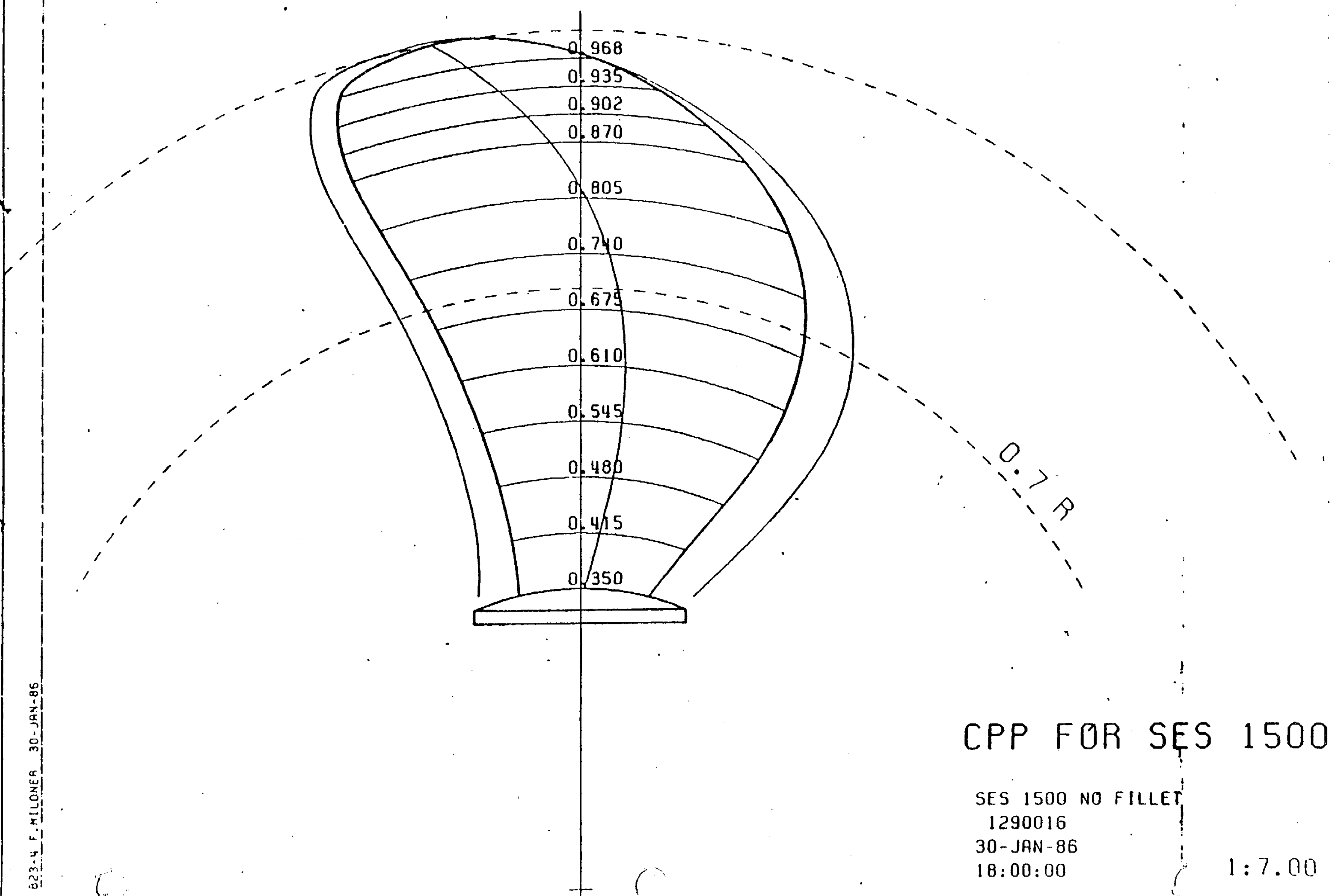
Entstand aus	Ersetzt durch	Ersatz für	Orig. Maßstab
Bezeichnung der Gruppe	Benennung		Gez. 31.1.86
Auftrags-Nr 1290016	PERFORMANCE DATA		Gepr.
Stichwort SES 1500			

SULZER-ESCHER WYSS Gesellschaft mit beschränkter Haftung RAVENSBURG

SULZER ESCHER WYSS

ANGABEN FUER DIE FLUEGELZEICHNUNG PARTICULARS FOR BLADE DRAWING

DURCHMESSER	DIAMETER	MM	3000.0
MITTL. NENN-STEIGUNG	MEAN NOMINAL PITCH	MM	4340.
NENN-STEIGUNGSVERHAELTNIS	NOMINAL PITCH RATIO	--	1.447
FLAECHENVERHAELTNIS	BLADE AREA RATIO	--	0.667
FLUEGELZAHL	NUMBER OF BLADES	--	7
DREHRICHTUNG	DIRECTION OF ROTATION		L + R
WERKSTOFF	MATERIAL		
ZUGFESTIGKEIT	TENSILE STRENGTH	N/MM2	780.
STRECKGRENZE	YIELD STRENGTH	N/MM2	540.
DEHNUNG	ELONGATION	%	15.
GEWICHTE	WEIGHTS :		
1 FLUEGEL MIT TELLER	1 BLADE WITH PALM	KG	259.
(TELLER	PALM	KG	76.0)
(NABE	HUB	KG	4100.)
PROPELLER	PROPELLER	KG	5915.
MASSENTRAEGHEITSMOMENT	INERTIA MOMENT		
1 FLUEGEL OHNE TELLER	1 BLADE WITHOUT PALM	KGM2	149.9
(NABE	HUB	KGM2	450.0)
(PROPELLER TROCKEN	PROPELLER DRY	KGM2	1499.2)
PROPELLER EINSCHLIESSLICH MITSCHWINGENDER WASSERMASSE	PROPELLER WITH ENTRAINED WATER		
IN NULLSCHUBSTELLUNG	ZERO THRUST POSITION	KGM2	1537.8
BEI PFAHLZUGBEDINGUNG	AT BOLLARD CONDITION	KGM2	
IN ENTWURFS-STELLUNG	IN DESIGN POSITION		
HERSTELLUNGSTOLERANZEN	MANUFACTURING TOLERANCES		ISO 484/1 CLASS S
KLASSIFIKATION	CLASSIFICATION		NONE
EISKLASSE	ICE CLASS		NONE
WERFT	SHIP YARD		MTG MARINETECHNIK GMBH HAMBURG
BAU - NR.	YARD - NO.		1346 / 01



CPP FØR SES 1500

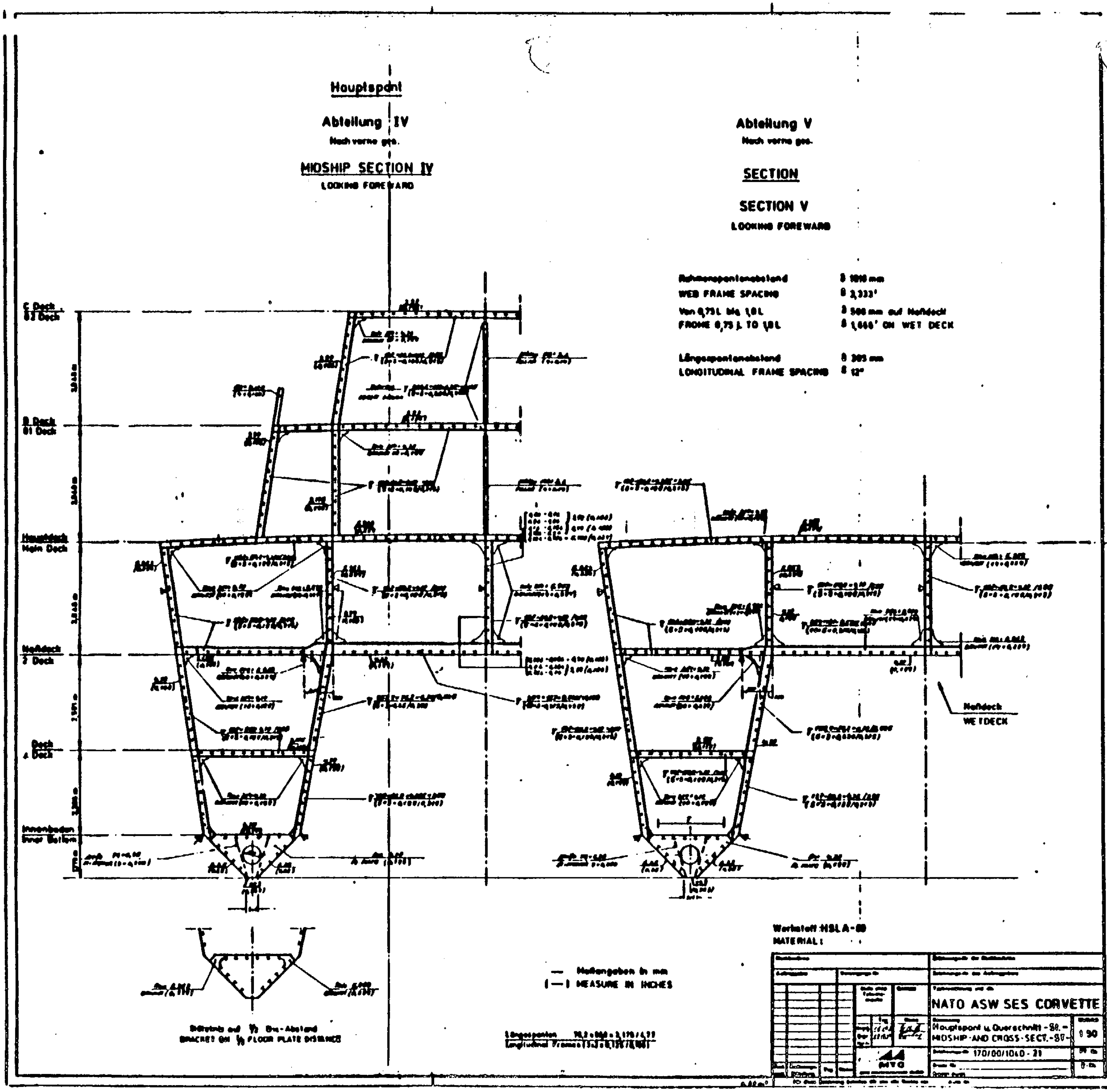
SES 1500 NO FILLET
1290016
30-JAN-86
18:00:00

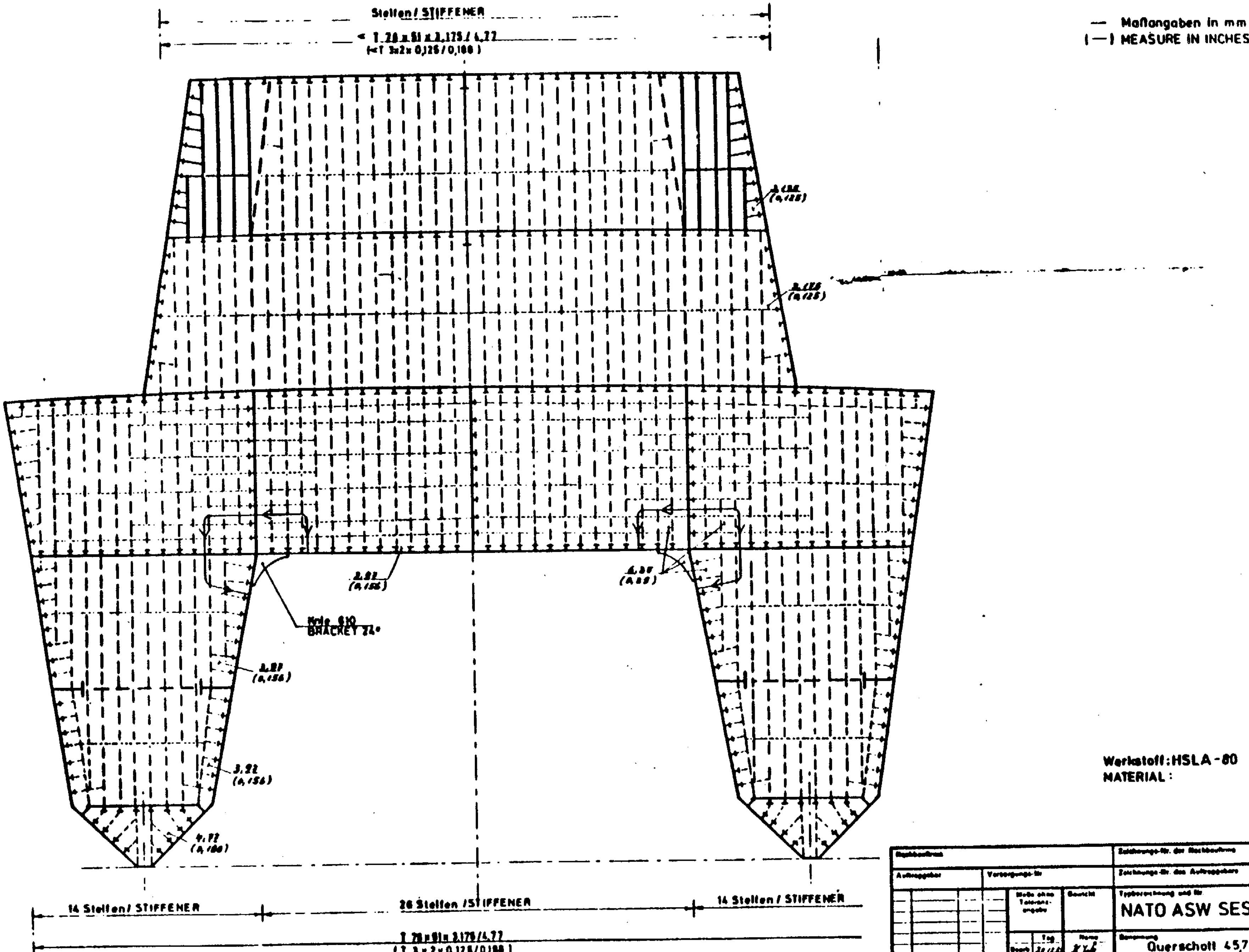
1:7.00

VP 823-4 F.MILONER 30-JAN-86

APPENDIX J

STRUCTURAL DRAWINGS


Hauptspant
Abteilung IV
MIDSHIP SECTION IV
LOOKING FOREWARD
Abteilung V
SECTION
SECTION V
LOOKING FOREWARD
WEB FRAME SPACING
LONGITUDINAL FRAME SPACING
C Deck
B Deck
Hauptdeck
Main Deck
Naßdeck
2 Deck
Deck
4 Deck
Innenboden
Inner Bottom
Naßdeck
WETDECK
Werkstoff: HSLA-80
MATERIAL:
Maßangaben in mm
MEASURE IN INCHES
BRACKET ON 1/2 FLOOR PLATE DISTANCE
NATO ASW SES CORVETTE
MIDSHIP AND CROSS-SECT.
170/00/1040-21



Nach vorne gesehen, LOOKING FOREWARD

NATO ASW SES CORVETTE

Querschott 45,72m - St-
BULKHEAD 165' - ST-

1:5

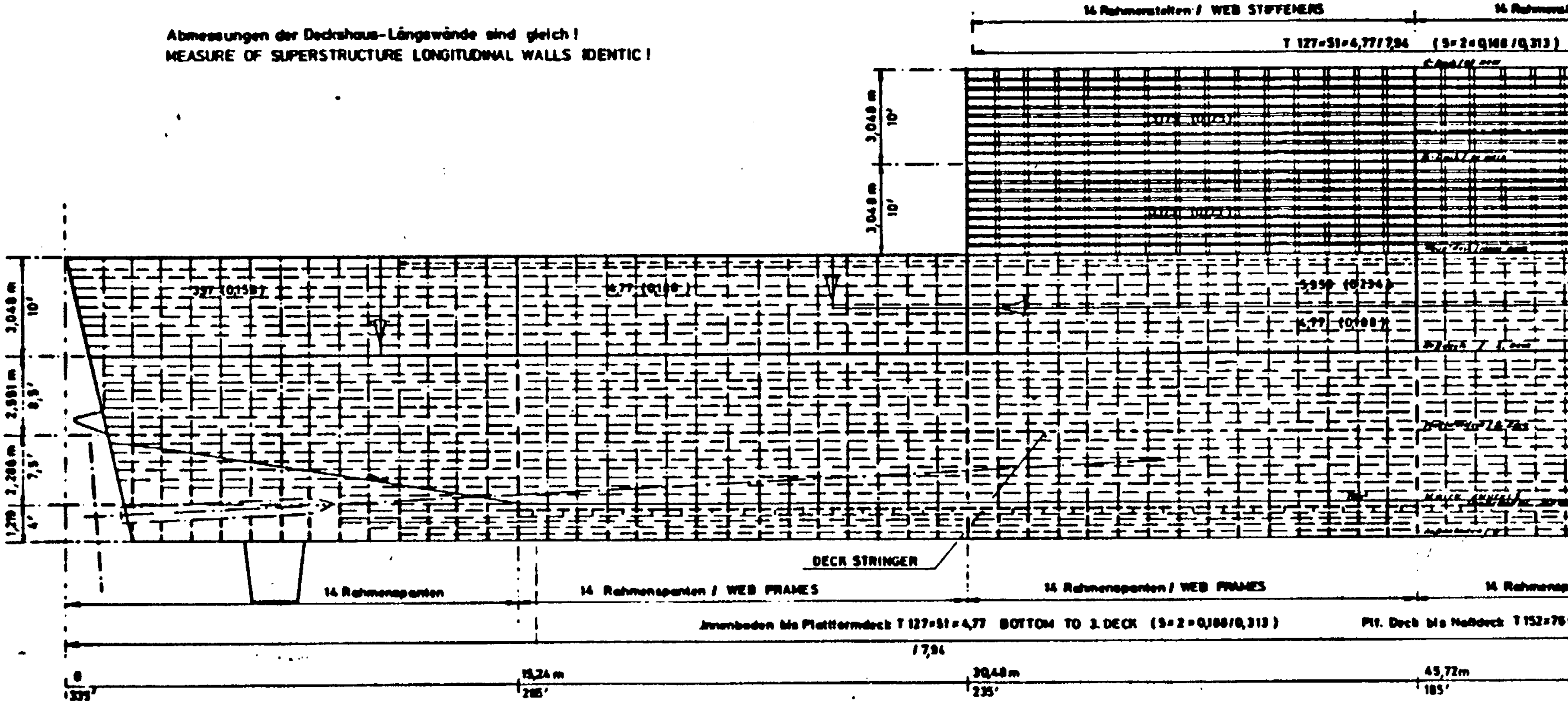
170/00/1040 - 23

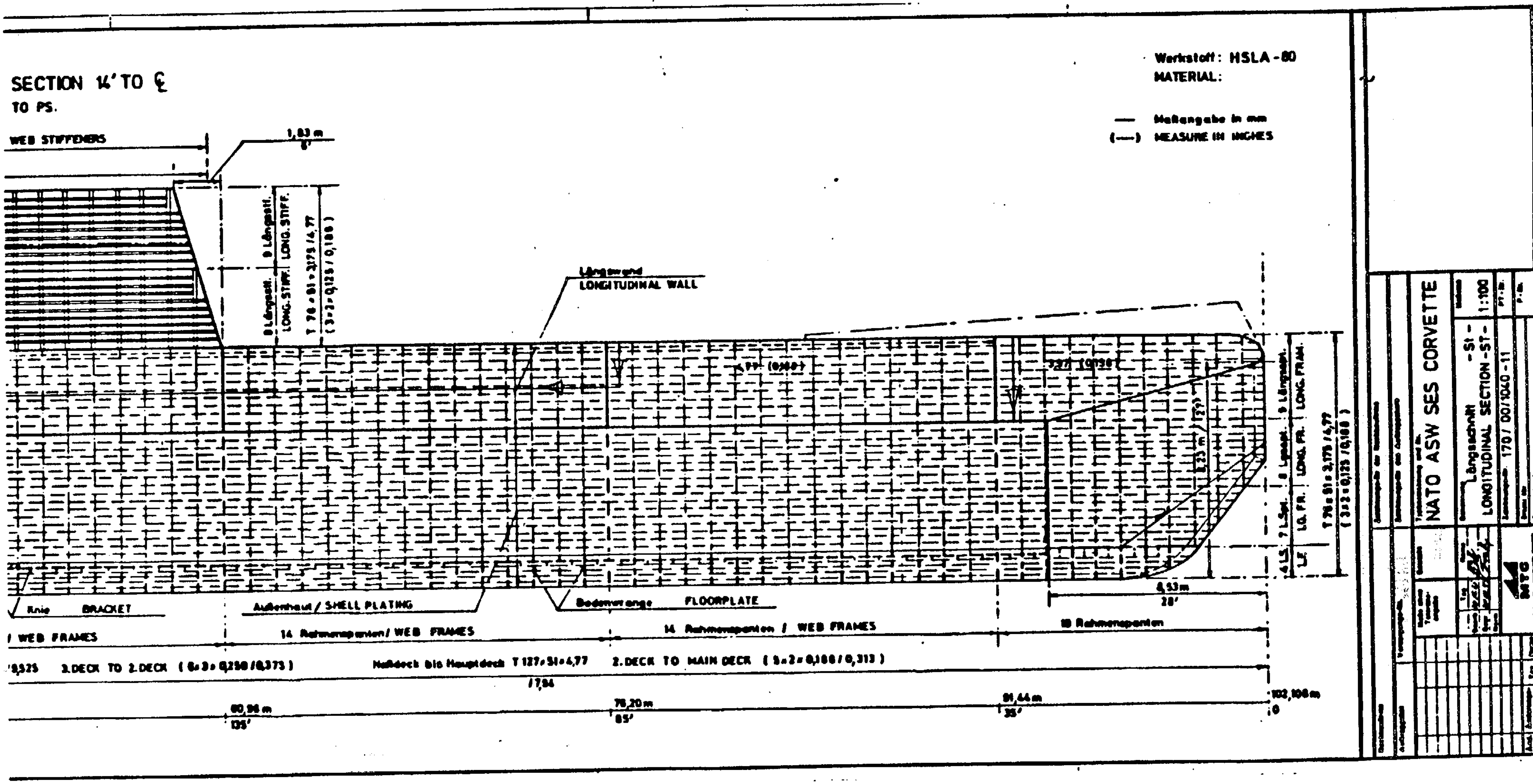
MTG

Längsschnitt 4,27 m aus M.S. LONGITUDIN

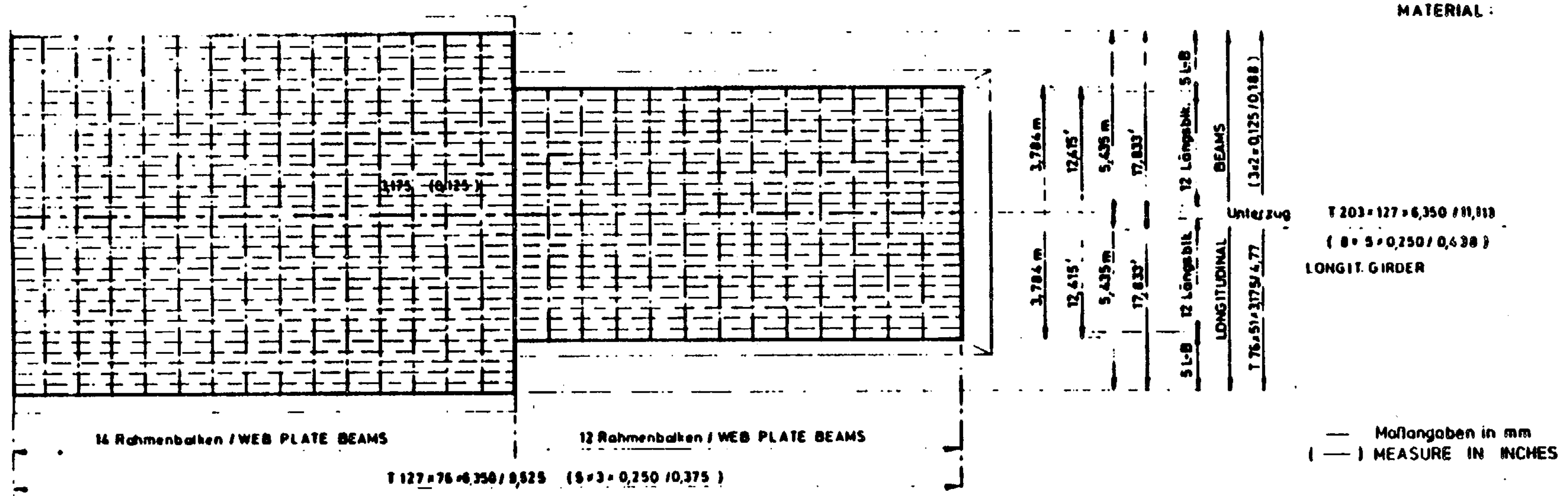
Nach Bb. gesehen. LOO

Abmessungen der Deckshaus-Längswände sind gleich!
MEASURE OF SUPERSTRUCTURE LONGITUDINAL WALLS IDENTIC!

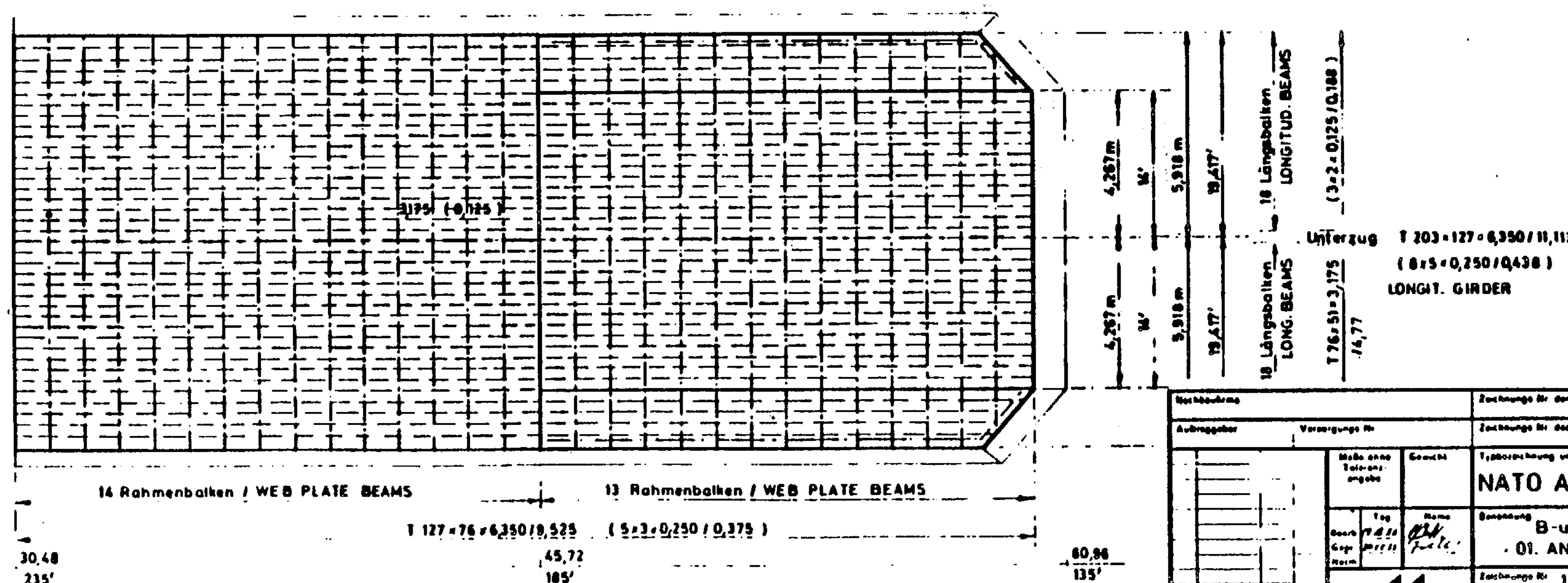



SECTION 14' TO ℄
TO PS.
Werkstoff: HSLA-80
MATERIAL:
— Maßangabe in mm
(—) MEASURE IN INCHES
WEB STIFFENERS
1,83 m
6'
Längswand
LONGITUDINAL WALL
Knie BRACKET
Außenhaut / SHELL PLATING
Bodenwrange FLOORPLATE
WEB FRAMES
14 Rahmenspanten / WEB FRAMES
14 Rahmenspanten / WEB FRAMES
18 Rahmenspanten
2.DECK TO 2.DECK
Haßdeck bis Hauptdeck T 127×51×4,77
2.DECK TO MAIN DECK
8,53 m
28'
60,96 m
135'
76,20 m
85'
91,44 m
35'
102,108 m
0
NATO ASW SES CORVETTE
Längsschnitt -St-
LONGITUDINAL SECTION -ST-
1:100
170/00/1040-11

C-Deck / 02.DECK



B-Deck / 01.DECK

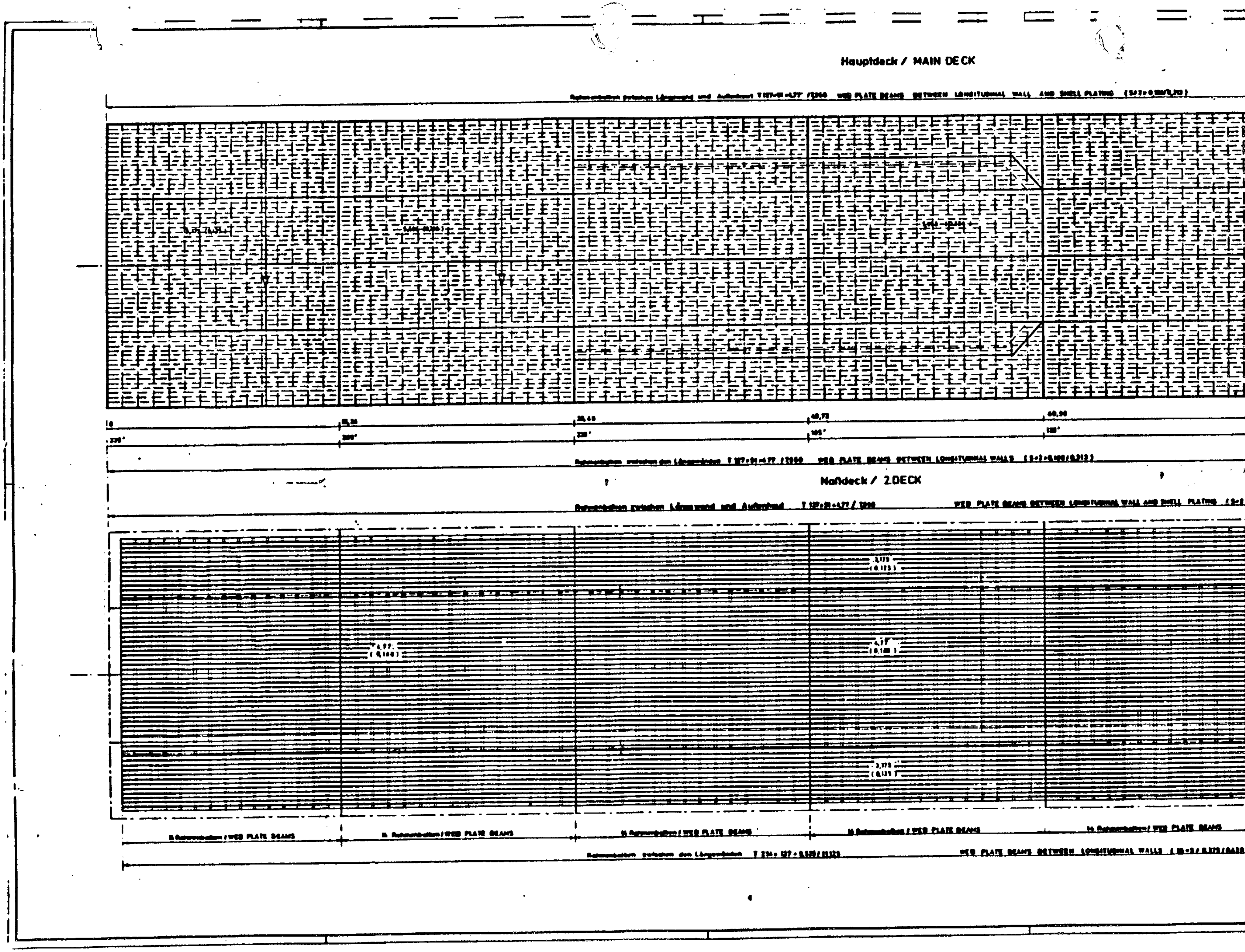


NATO ASW SES CORVETTE

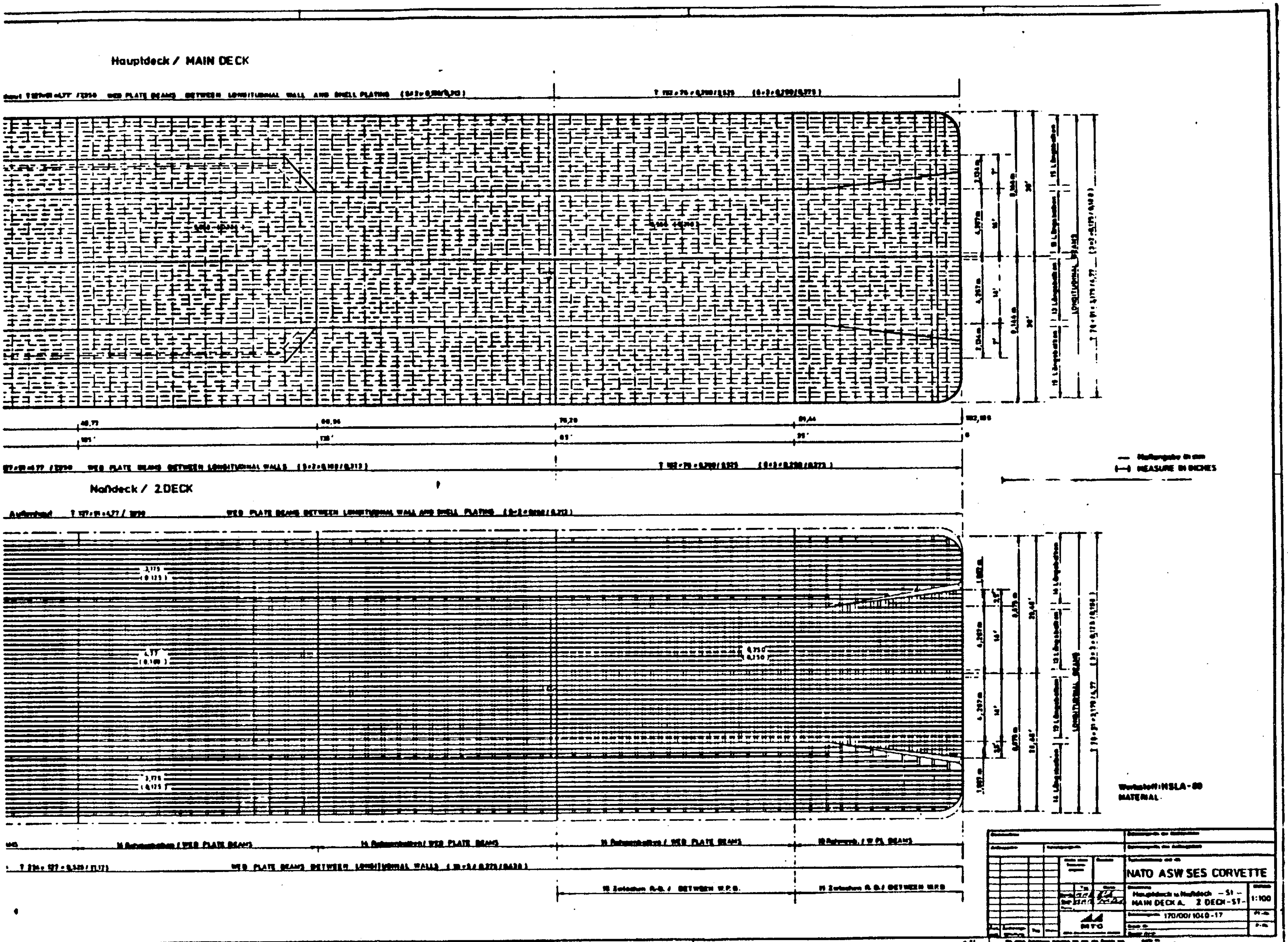
B-und C-Deck – ST –
· 01. AND 02. DECK – ST –

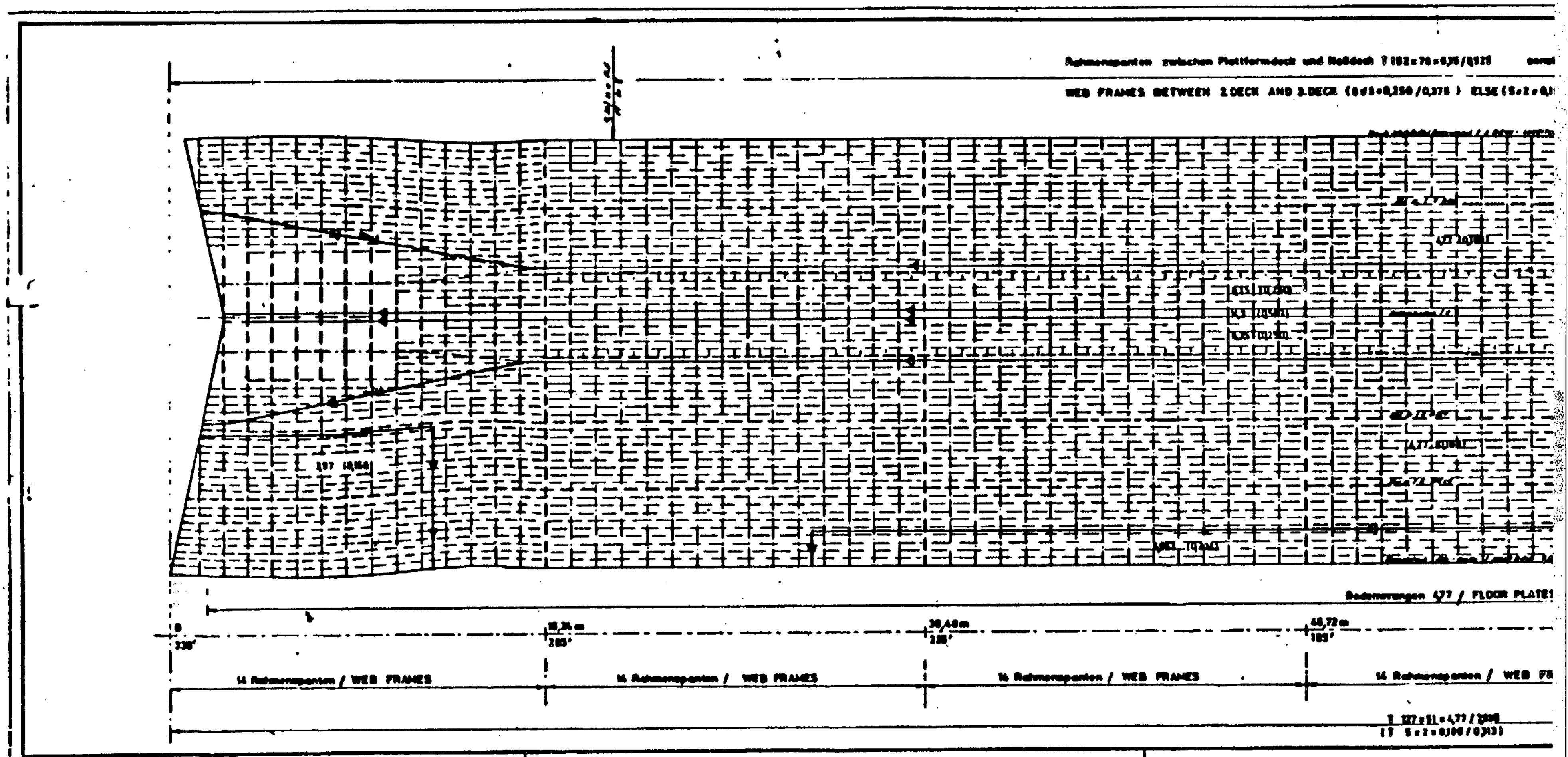
1:100

Zeichnungs-Nr. 170/00/1040-19

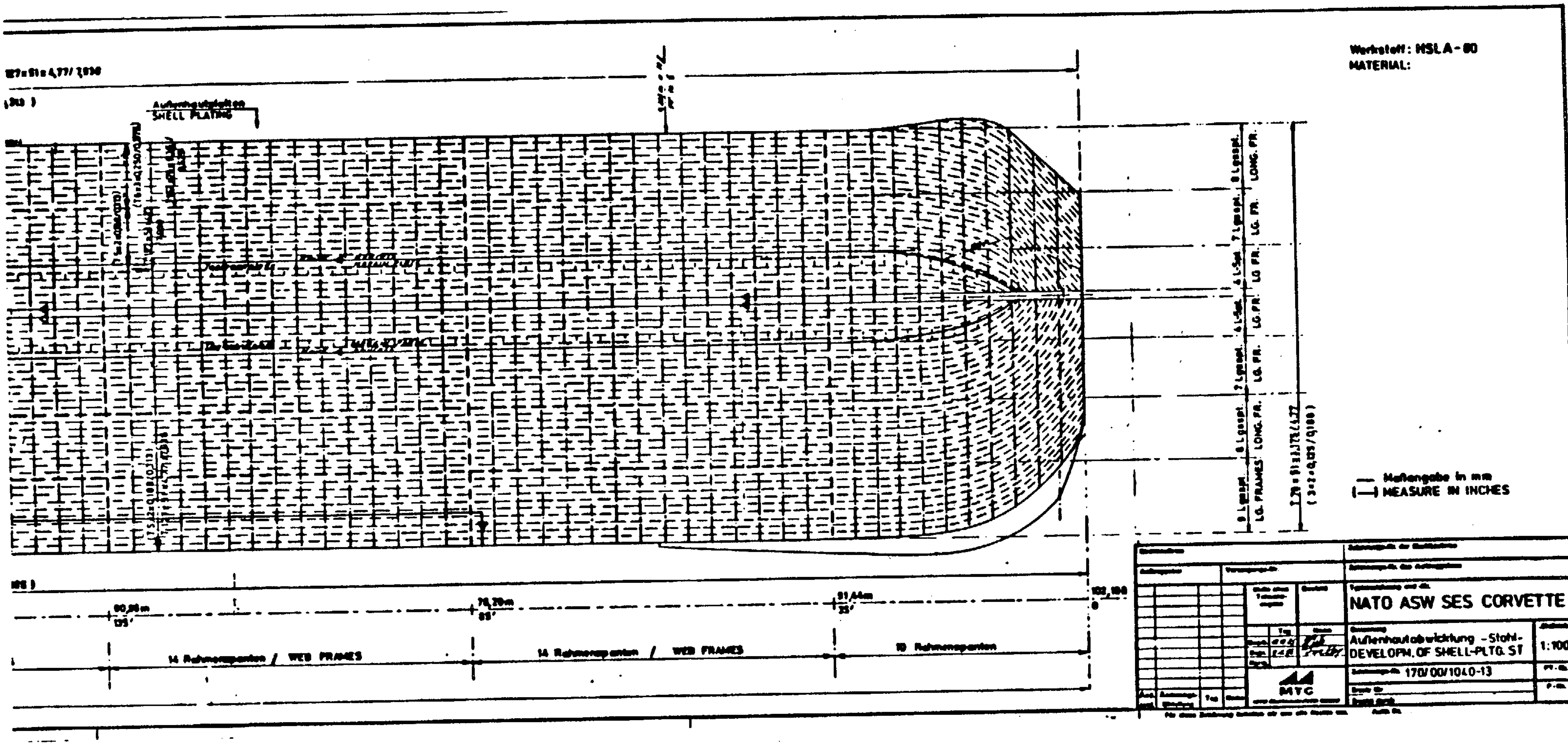


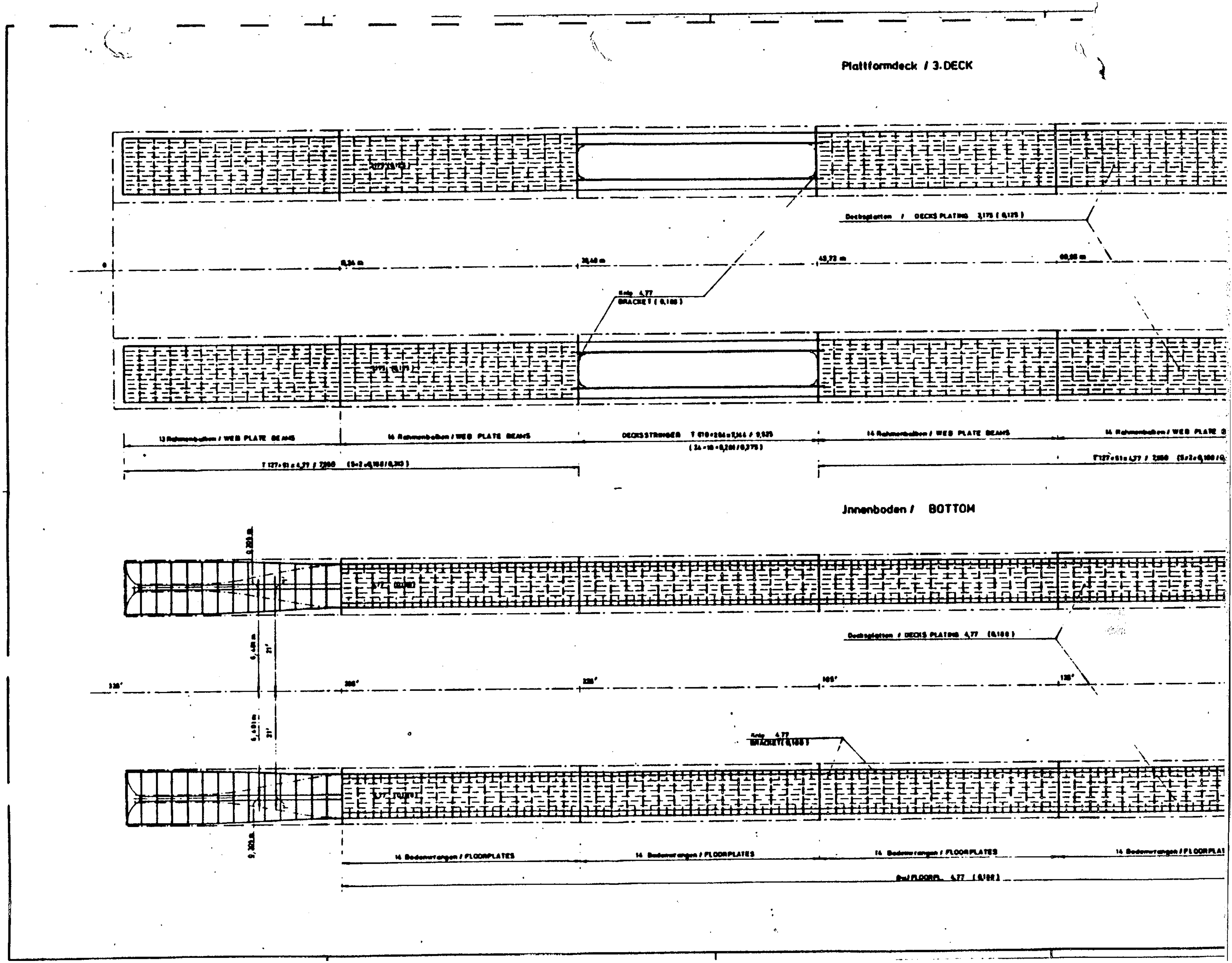
Hauptdeck / MAIN DECK
WEB PLATE BEAMS BETWEEN LONGITUDINAL WALL AND SHELL PLATING
WEB PLATE BEAMS BETWEEN LONGITUDINAL WALLS
Naßdeck / 2.DECK
WEB PLATE BEAMS BETWEEN LONGITUDINAL WALL AND SHELL PLATING
WEB PLATE BEAMS
WEB PLATE BEAMS
WEB PLATE BEAMS
WEB PLATE BEAMS
WEB PLATE BEAMS
WEB PLATE BEAMS BETWEEN LONGITUDINAL WALLS


Hauptdeck / MAIN DECK
Nañdeck / 2.DECK
MEASURE IN INCHES
MATERIAL
NATO ASW SES CORVETTE
MAIN DECK A. 2 DECK -ST-
1:100
170/00/1040-17
MTG
WEB PLATE BEAMS
WEB PLATE BEAMS BETWEEN LONGITUDINAL WALLS
WEB PLATE BEAMS BETWEEN LONGITUDINAL WALL AND SHELL PLATING
LONGITUDINAL BEAMS

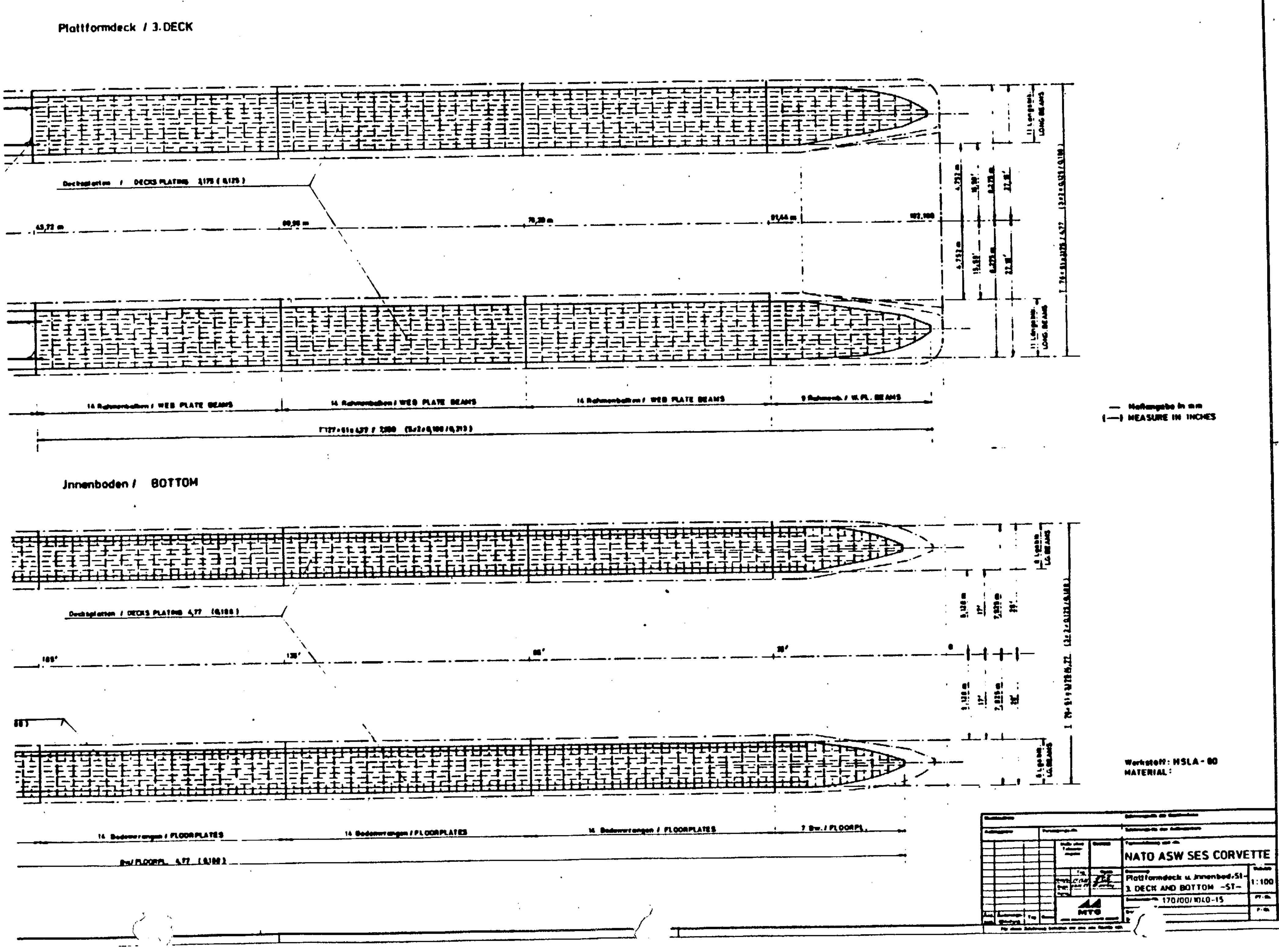


Rahmenspanten zwischen Plattformdeck und Haßdeck T 152 x 76 x 6,35/9,525
WEB FRAMES BETWEEN 2.DECK AND 3.DECK
Bodenwrangen 4,77 / FLOOR PLATES
0
15,24 m
30,48 m
45,72 m
14 Rahmenspanten / WEB FRAMES
16 Rahmenspanten / WEB FRAMES
16 Rahmenspanten / WEB FRAMES
14 Rahmenspanten / WEB FR


Werkstoff: HSLA-80
MATERIAL:
Außenhautplatten
SHELL PLATING
Maßangabe in mm
MEASURE IN INCHES
14 Rahmenspanten / WEB FRAMES
14 Rahmenspanten / WEB FRAMES
10 Rahmenspanten
NATO ASW SES CORVETTE
Außenhautabwicklung - Stahl-
DEVELOPM. OF SHELL-PLTG. ST
1:100
170/00/1040-13
MTG



Plattformdeck / 3.DECK
Deckplatten / DECKS PLATING
43,72 m
Rahmenbalken / WEB PLATE BEAMS
DECKSSTRINGER
Jnnenboden / BOTTOM
Deckplatten / DECKS PLATING 4,77
Bodenwrangen / FLOORPLATES



Plattformdeck / 3.DECK
Innenboden / BOTTOM
Maßangabe in mm
MEASURE IN INCHES
Werkstoff: HSLA - 80
MATERIAL:
NATO ASW SES CORVETTE
Plattformdeck u. Innenboden -ST-
3. DECK AND BOTTOM -ST-
1:100
170/00/1040-15

SURFACE SHIP CONTINUING CONCEPT FORMULATION (CONFORM) FY 86 FEASIBILITY DESIGN STUDY

FINAL REPORT

NATO SES ASW CORVETTE

VOLUME II-- APPENDICES

MAY 1986

NAVSEA Technical Note No. 041-501-TN-0025

TABLE OF CONTENTS

APPENDIX B

PROPELLER DESIGN

B.1 VENTILATED PROPELLER

The ventilated propellers studied are controllable pitch partially submerged types. Performance data for the propellers is given in Section 16.

The propeller blades are made from forgings machined all over to achieve accurate profiles and sections. Candidate blade materials are stainless steel, nicket based superalloy and nickel-aluminum bronze.

Each blade is replaceable externally via a bolted joint with no other disturbance of the propeller or pitch change mechanism required. The propeller blades can be changed while the ship is afloat. The blade section is a wedge with an annex section as shown in Figure B.1. This blade shape and section is similar to that used successfully on the SES-100B.

The propellers derived from this study have diameters of 3 and 4 meters and a hub to tip ratio of 0.4. The hub is an approximately cylindrical body made from corrosion resistant material which contains the pitch change mechanism. Attached to the after-end of the hub is a fairing. The propeller is mounted behind the sidehull so that 25 or 50 percent of its disc area is masked by the sidehull transom. From the propeller, the drive shaft is installed at an inclined angle up and forward. Immediately adjacent to the propeller hub is the thrust bearing module.

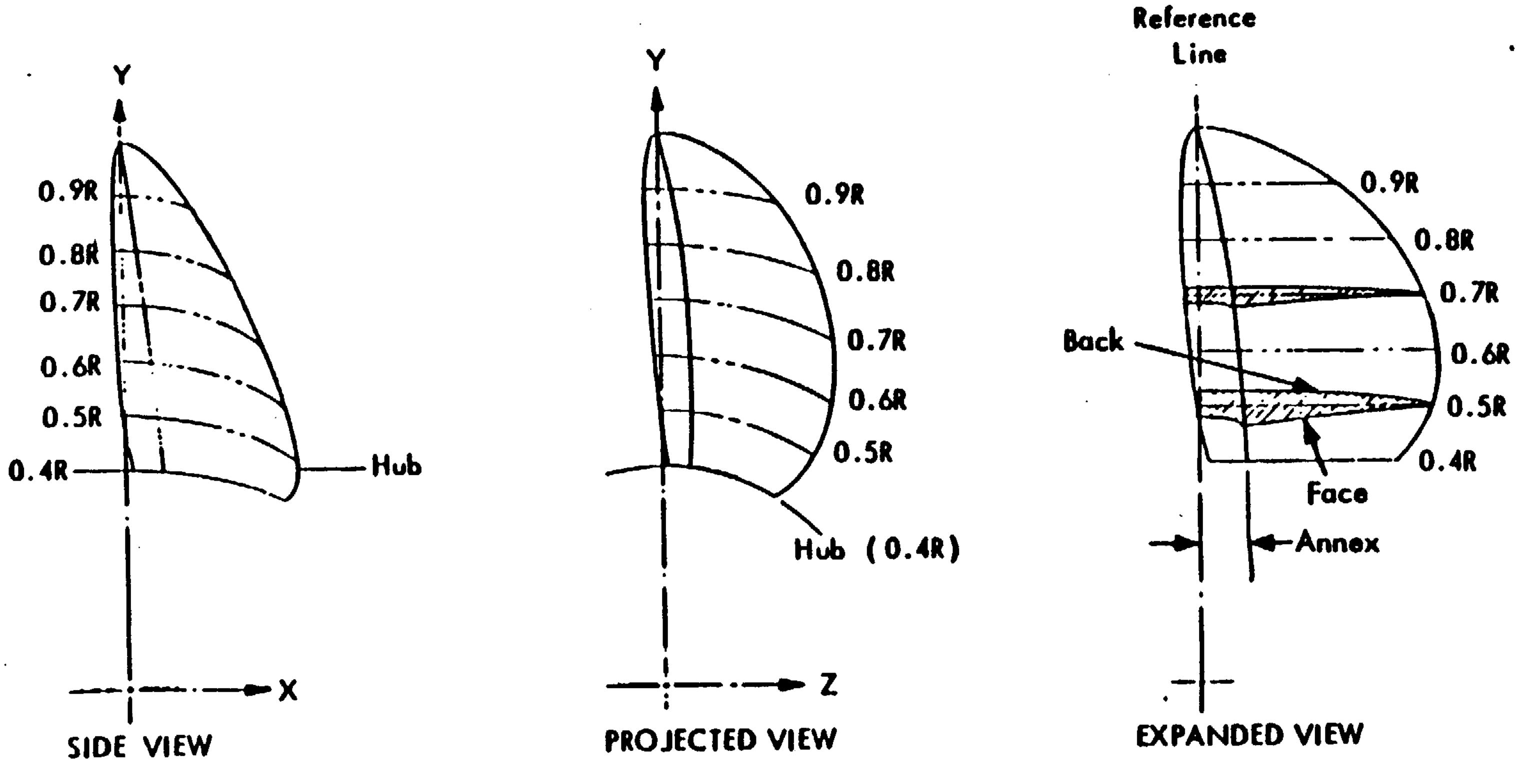


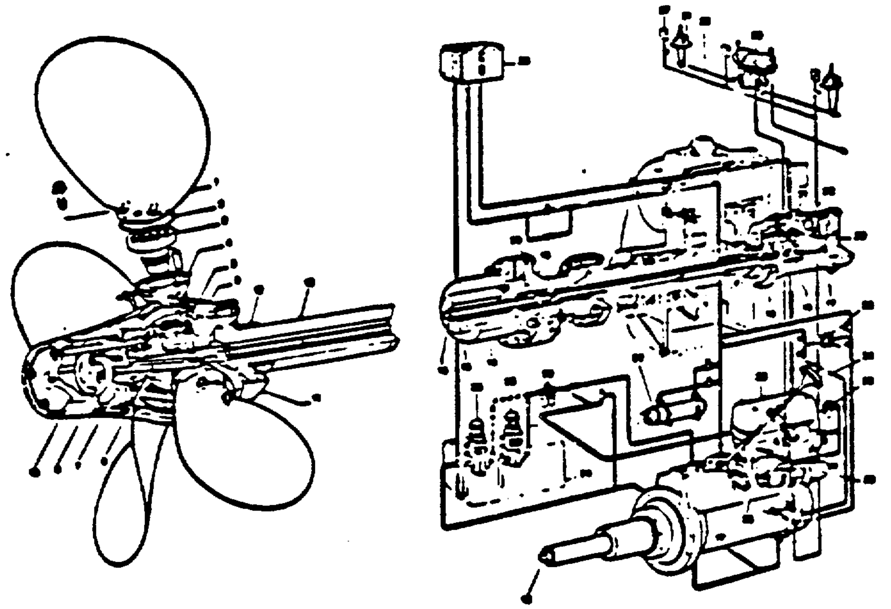
Figure B.1. Ventilated Propeller Shapes and Sections

B.2 PITCH CHANGE MECHANISM AND CONTROLS

Many modern commercial and naval ships use controllable pitch propellers to achieve operating economy and to suit the special requirements of the particular ship. Pitch change mechanisms and their controls have been fully developed as a consequence.

The Tacoma Boat/Escher Wyss type of pitch change mechanism and control is shown in Figure B.2 is briefly described as follows.

Each propeller blade is bolted to a trunnion which carries a crank arm. Each crank arm is linked to a servomotor piston. Hydraulic oil is fed to the piston via a double oil tube from an oil distribution unit mounted within the hull either on the end of the propeller shafting or around the propeller shaft. The double oil tubes are nested inside the propeller shaft. A control valve and feedback system is integral to the oil distribution unit. In response to a pitch change signal, the control valve directs pressurized oil to the servomotor piston. As the piston moves, and causes the propeller blades to rotate on their trunnions, a feedback signal is transmitted back mechanically to the control valve (via the double oil tube) so that when the input signal and propeller blade pitch agree, the control valve spool is centered and no further blade movement occurs. Pressurized oil is supplied from a tank having main and standby electric pumps. The tank is connected to a head oil tank so that when the system is unpressurized there is sufficient head in the propeller pitch change mechanism and hub to prevent ingress of the surrounding water. This mechanism plus the command transmitter, pitch



I. Propeller
- 1 Propeller blade
- 2 Blade seal
- 3 Double supported blade trunnion
- 4 Adjusting crank
- 5 Trunnion nut
- 6 Link
- 7 Cross head with double supported adjusting rod
- 8 Servomotor piston
- 9 Propeller hub
- 10 Servomotor cylinder

II. Propeller Shaft
- 11 Protecting hood for propeller shaft flange
- 12 Bushing of sterntube seal
- 13 Propeller shaft
- 14 Coupling flange
- 15 Double oil tube

III. Oil Distribution Unit
- 16 Oil distribution shaft
- 17 Oil distribution box housing
- 18 Intermediate shaft
- 19 Control housing
- 20 Feedback system
- 21 Control valve
- 22 Pilot valve

IV. Hydraulic Control System
- 23 Main and standby control oil pump with electric motor
- 24 Suction tank (yard's supply)
- 25 Head oil tank
- 26 Oil filter
- 27 Oil cooler
- 28 Hand pump for mechanical locking device
- 29 Mechanical locking device,

V. Remote Control and Pitch Indication
- 30 Command transmitter
- 31 Slave unit
- 32 Mechanical connection (yard's supply)
- 33 Pitch setter
- 34 Handwheel for local emergency control
- 35 Mechanical pitch indication
- 36 Actual pitch transmitter
- 37 Pitch indicator

Figure B.2. Typical Pitch Change Mechanism and Controls indicator, and normal hydraulic system components comprise a reliable and simple pitch change mechanism and controls. Provisions are made to allow emergency local control in the event of hydraulic failure.

B.3 THRUST BEARING

For the ventilated propeller installation, the sidehull construction in the area of the stern and transom permits placement of the thrust bearing assembly entirely within the sidehull and much closer to the propeller hub than in conventional displacement craft. The proximity of the stern bearing to the thrust bearing permits mounting both bearings in a common housing, with both bearings being lubricated and cooled by circulating oil. This assembly is called the Thrust Bearing Module. See Figure B.3.

Loads are generated by the ventilated propeller in the lateral and vertical directions, as well as in the axial direction. In addition, there is a bending moment generated by the eccentric thrust of the partially immersed propeller, and the weight load of the propeller itself.

By designing the stern bearing and the thrust bearing into a common housing, the two bearings are made to react the lateral loads, the thrust loads, and the bending moments generated by the propeller, while minimizing the risks due to wear and misalignment normally associated with water-lubricated stern bearings.

The design speed of the propellers makes possible the use of a high capacity, tapered-roller thrust bearing to absorb both the forward and

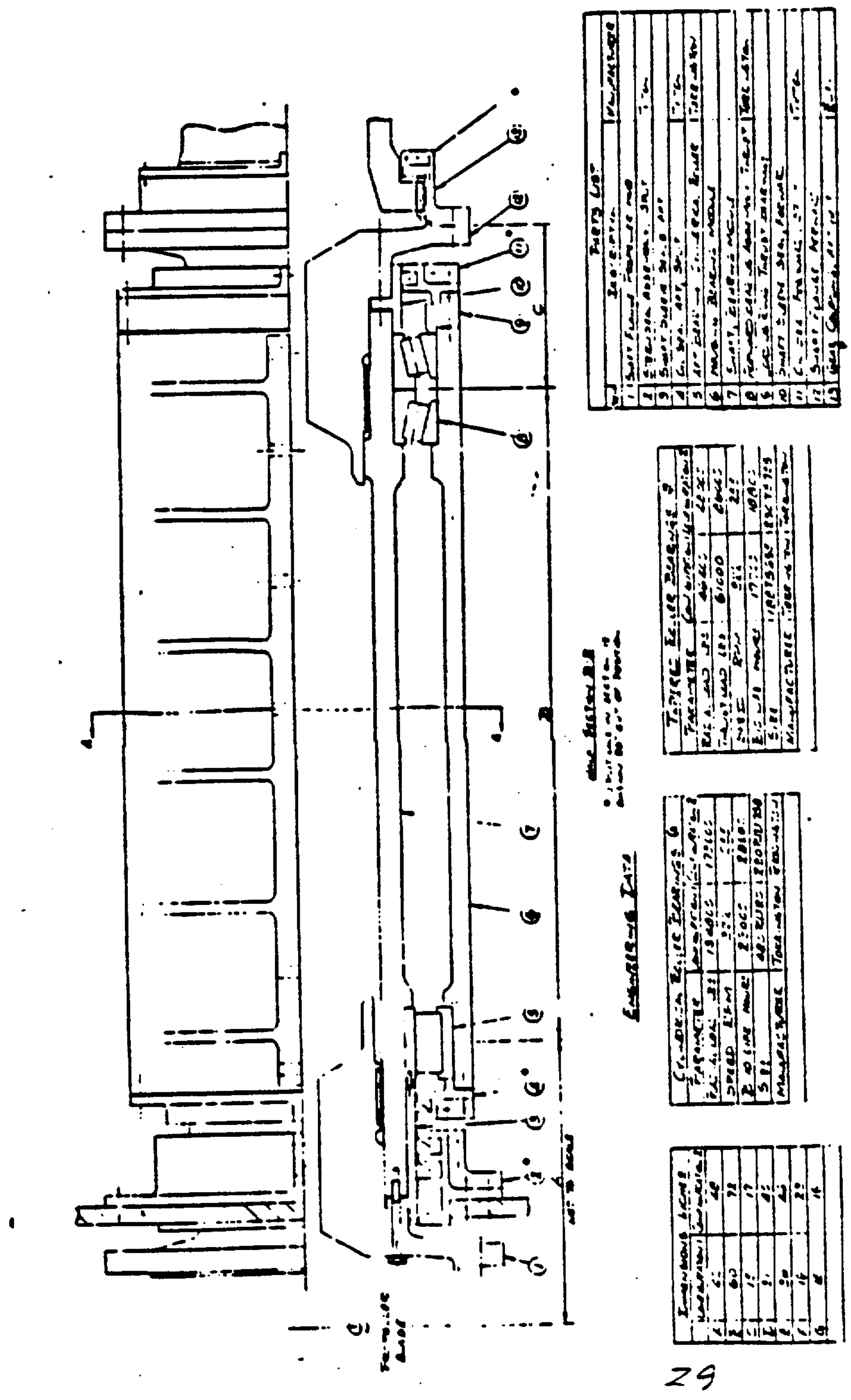


Figure B.3. Thrust Bearing Module

reverse thrust of the propeller, and a high-capacity cylindrical roller bearing to react the loads and moments due to the combined effects of propeller weight, vertical thrust, lateral thrust, and offset axial thrust.

The radial bearing is located aft, closest to the propeller, to minimize the propeller shaft bending moment. The thrust bearing is located at the forward end of the housing to react the axial thrust of the propeller and the lower radial loads that occur at this location in the drive line.

The propeller hub is flanged-bolted directly to the aft flange of the thrust bearing module. The aft half of the gear coupling that connects the propeller to the gearbox is flanged-bolted to the forward end of the bearing module.

The thrust bearing module is foot-mounted in the horizontal plane that contains the shaft centerline, to minimize the load on the hold-down bolts from the axial thrust of the propeller. Since both bearings that support the propeller are oil lubricated, rolling contact assemblies, progressive wear and resulting misalignment that occur in water-lubricated stern bearings are eliminated. This feature is of particular importance when considering the complex loading into the bearings and hull structure that occur with ventilated propellers, and the compounded adverse effects that wear in the stern bearing would produce.

This module incorporated one cylindrical roller bearing that accommodates only radial loads, and a pair of tapered roller bearings in a 'TDI' mounting, to accommodate axial thrust in either direction while providing for slight angular misalignments resulting from shaft deflections. All bearings are lubricated by circulating oil that is filtered and cooled by the system that serves the propeller gearbox. Lube oil to the bearings is supplied by a number of jets evenly spaced around one side of each bearing annulus. The oil to the thrust bearings is fed by separate jets on each side of the assembly, from where is flows through the bearings to the space between the outer races, then to the groove and a gravity drain to a sump; the oil is pumped from this sump to the sump in the gearbox.

Horizontally split oil seals are installed at each end of the module. All parts in each seal assembly may be inspected and replaced without disturbing the bearings or removing the module from its mounting.

Bearings are secured and clamped by hardened steel rings that are shimmed to the proper axial fitup at assembly.

The bearing housing is made from a steel weldment that is stress relieved prior to final machining. The housing is bolted to the ship's structure at two flanges that extend radially outward from the housing, with the bolting surface lying in the horizontal plane that contains the shaft centerline. This construction minimizes eccentric loading of the module housing as well as of the ship's structure under the action of the propeller thrust.

All exposed parts of the bearing module are treated and coated to resist corrosion.

B.4 DRIVE SHAFTS AND COUPLINGS

In order to reduce weight, forged tubular drive shafts are used to transmit torque from the gearboxes to the propeller. Shaft weights are reduced to about 50 percent of the weight of a solid shaft operating at the same design stress. In the case of the propeller shafting, the central hold is used to route the hydraulic oil feed tubes for the controllable pitch propeller from the control unit, located on the forward side of the gearbox, to the propeller hub outboard of the thrust bearing module.

All shafts are machined from through-hardened alloy steel, and are designed for combined stresses in bending and torsion that do not exceed 10,000 psi at the maximum load conditions. Exposed sections of shafting are coated to resist corrosion.

Torque through the thrust bearing module is transmitted by means of flanges splined, piloted, and bolted to the shaft ends. All splines are registered by means of a long pilot on each side of the spline. In the thrust bearing module the replaceable seal sleeves are clamped by the bolting interface for the spline to minimize the number of loose pieces; the seal sleeves serve also as the clamping rings for the inner races of the radial and thrust bearings.

The size of the drive shafting in each configuration was determined by the bore size of the thrust bearing required to react the propeller thrust load. An additional factor was the need for a hollow shaft in which to install the piping and control transfer mechanism for the controllable pitch propeller.

The weight of the drive shafting was determined by the outside diameter and the design stress level. The shafting for these applications is designed primarily to transmit the torque from the gearbox to the thrust bearing module, with a very minimum of bending. The radial loads and bending moments due to the ventilated propeller are reacted by the bearings in the thrust bearing module (thrust block) at the transom. The shaft bore size was determined on the basis of the allowable torsional shear stress, which was set at a maximum value of 6000 psi at maximum engine torque.

The shaft sizes for both propulsion plant configurations, as determined from these considerations, are tabulated in Figure B.3.

SHAFT COUPLINGS

Because of the low propeller speeds in both configurations, the large propeller shaft torques are beyond the range of most commercially available flexible couplings. Flexible couplings are considered necessary to accommodate misalignments, thermal differential expansion between the steel machinery and the aluminum sidehulls, and distortions in the sidehulls due to conditions that include off-cushion and on-cushion operation under wide ranges of loading in various sea states. A preliminary survey of available couplings indicated that the propeller torques for both propulsion plant configurations exceed the capacities of commercially available disc and diaphragm couplings. Available grease-lubricated gear couplings manufactured by Zurn (Reference 6) were found to have torque capacities adequate not only for the present torque loads, but for torque loads well in excess of present requirements. In the torque ranges in which disc couplings are available, the weights of the disc and gear couplings are comparable. Therefore, it is expected that no weight penalties will develop when gear couplings are applied to the subject drive lines. From the layouts made in the course of developing the concepts for the thrust bearing modules, the proportions of the gear couplings are consistent with those of the shafting and the thrust bearing modules.

B.5 WATERJET PERFORMANCE

Conceptual waterjet installations were reviewed to provide comparative inputs to the propeller selection process. Figure B.4 shows that, in general, waterjet propulsors have a lower efficiency than propellers. This reflects directly on range and speed performance. The conclusion is confirmed by comparison of the ALRC PHM waterjet pumps and ventilated propellers shown in Table B.1.

For low speeds, i.e., about 18 knots, the thrust/efficiency values for waterjet propulsion were calculated using two PJ-24 pumps powered by SACM195V20RVR diesel engines. This is in accordance with current practice for waterjet propelled ships whereby a separate cruise or low speed propulsion mode is furnished by a separate system. Examples of these cruise systems include the PHM hydrofoil, the "American Enterprise" crew boat and "HMS Speedy", a hydrofoil patrol ship very similar to the

"Jetfoil" hydrofoil ferry. For the NASW SES the cruise waterjet diesel would drive the lift fans in the cushion-borne mode when propulsion is by the maint LM2500 engines.

The values of thrust given in Table B.1 show that for the NASW SES, two waterjets would give approximately 5 knots less off-cushion top speed when compared to two propellers and approximately 10 knots less on-cushion top speed. These differences do not take into account the weight differences of the two installations which are judged to be in favor of the propeller ship propulsion machinery largely because of the entrained water in the inlet ducting and waterjet pump. This weight would affect, primarily, range since less fuel could be carried.

In view of these results, waterjets are eliminated early in the study phase.

B.6 FULLY SUBMERGED PROPELLER

A brief study of a fully submerged trans-cavitating propeller was sized to verify its suitability as a backup to the baseline partially submerged ventilated propellers. The performance appears to be acceptable and could be implemented if required.

SUBMERGED PROPELLER PERFORMANCE

Submerged propellers were selected using cavitation tunnel data. This data contains the effect of blade area ratio, pitch angle and cavitation

Table B.1. Comparison of Waterjets and Propellers (1500LT)

	Ship Speed Knots	Engine Power SHP [3]	Two Waterjets Thrust Lb	Two Waterjets Efficiency	Two Propellers Thrust Lb	Two Propellers Efficiency
	15	3700	46,000	.29	72,134	.46
(1)	18	3700	42,000	.31	72,127	.56
	22	3700	38,000	.35	67,159	.63
	30	22,500	153,776	.33	207,749	.44
(2)	40	22,500	141,920	.41	206,791	.58
	50	22,500	130,847	.48	189,788	.67

(1) Off-Cushion

(2) On-Cushion

(3) Rated engine power - 2 engines per ship

index of the water velocity approaching the propeller. An advantage of the submerged propeller is good performance both at speeds of at least 50 knots and at low speeds. Characteristics of the chosen design are:

Number of Blades	3
Blade Area Ratio	0.48
Hub/Tip Diameter Ratio	0.3
Thrust/Disc Area	Less than 1000 psf
Appendage Hull	0.91
Diameter	11.6 ft
RPM	214
N PROP	.72
N GB	.97
N BRGS	.98

The efficiency losses associated with each propeller type installation and the uncertainties associated with each installation differ. For the ventilated propeller there is little drag associated with its installation. A small fairing before the propeller boss and a rudder forward of the propeller are used on each sidehull, for the submerged propeller there is judged to more drag associated with its installation. A summary of rudder and appendage drag aspects follow.

RUDDER DRAG

Ventilated Propeller	Submerged Propeller
o Larger area rudder not in propeller jet.	o Smaller rudder in propeller jet.

o Propeller jet swirl not reduced by rudder ahead of propeller disc.	o Propeller jet swirl reduced by rudder; can increase propeller efficiency.
o No propulsion benefit from rudder. Effect of rudder flow into propeller requires evaluation but estimated small.	o Possible efficiency benefit requires evaluation but estimated small.

OTHER APPENDAGE DRAG

o Propeller hub drag is assumed included in Navy performance data.	o Propeller hub drag included in Newton and Radar data.
o No struts, bossings, shaft fairings.	o Drag associated with struts, bossings and shaft fairing.
o Drag of hub/thrust bearing module fairing ahead of the propeller not included in performance.	o Appendage drag of 9 percent included in submerged propeller performance predictions based on planning craft data. Requires further evaluation for SES craft.
o No appendage drag used in ventilated propeller performance. Requires evaluation.	

Both propeller types have been successfully demonstrated at high ship speeds. The ventilated propeller is fitted to the SES-100B. The submerged propeller type has been fitted to 50 knot craft and has performed well. At this time adequate performance for the NASW is indicated using either propeller type based on available data.

B.7 WEIGHTS

Weight estimates for the lift and propulsion equipment have been made based on manufacturer's data for standard off-the-shelf machinery, responses to requests for quotation where special equipment was involved and on designs and calculations based on the installation layouts. All components and subsystems have been sized in accordance with the performance requirements. The total weight of the equipment for the lift and propulsion systems is 238 long tons. Descriptions of the items in each SWBS 3-digit group follow.

DIESEL ENGINES (SWBS 233)

Four engines in two sizes are used for the propulsion and lift fan drives; these are the SACM 195V12RVR's and two are SACM 195V20RVR's. The engine weights, including their respective standard accessories packages are from catalog information.

TURBINES

An LM2500 gas turbine engine in production by the General Electric Company is installed in each sidehull. The exhaust collectors are included as part of the engine weights. The weights of the lube oil systems external to the engine are included in SWBS item number 262.

GEARING

There are six gearboxes in the lift and propulsion system; four are modified versions of standard parallel-shaft increase and are used in the lift system drives; the other two are special combination designs of parallel-shaft and planetary gearing and are used in the propulsion system. Weight estimates for the lift fan gearboxes are based on catalog data; the weights of the gearboxes for the propeller driven are based on preliminary design layouts developed by the Cincinnati Gear Company. The lube system weights for all gearing are included in SWBS item number 262.

CLUTCHES AND COUPLINGS (SWBS 242)

The weight of equipment in this category comprises those components installed or mounted remotely from the engines and gearboxes. Included in this group are the flexible couplings between the propeller gearboxes and the propeller assemblies, and the overrunning clutches installed between the gas turbines and the propeller gearboxes.

SHAFTING AND SEALS (SWBS 243)

The weights in this category include only the shafting and seals that are separate from equipment such as the engines, gearboxes, fans, etc., and involve primarily the lift fan and propeller shafting and the stern seals.

BEARINGS (SWBS 244)

Included are the special bearing assemblies designed to support the propellers and the aft ends of the turbine engine shafts. The weights of all other bearings are included in the weights of the equipment in which they are installed.

PROPELLERS AND CONTROLS (SWBS 245)

The weights tabulated comprise those of the controllable pitch propellers and the associated hydraulic actuators and controls, including piping and valves. The weights of the propeller shafting and thrust bearings are listed under SWBS 243 and 244, respectively.

LIFT FANS (SWBS 248)

Six lift fans are installed, two forward and two in each sidehull. All fans are the same size and capacity. The fan weights include inter-connecting shafting, couplings, and the ductwork required for installation.

COMBUSTION AIR SYSTEM (SWBS 251)

This equipment comprises two sets of demisters and filters, one set per sidehull, to condition the combustion air for the gas turbines. Included are the weights of the acoustic treatment and the anti-ice equipment for the duct walls.

Propulsion Control (SWBS 252)

The propulsion control equipment comprises the controls and monitoring equipment for the gas trubines and the diesel engines, but does not include the controls for the controllable gas propellers, which are included in SWBS item number 245.

Uptakes (SWBS 259)

The weights of the uptakes include the weights of the exhaust ducting for the gas trubines and for the diesel engines.

Lube Oil Systems (SWBS 262)

The lube oil systems comprise the main pumps, auxiliary pumps, heat exchangers, filters, valves, and piping for the gas turbines and the lift fan and propulsion reduction gears. The lube systems for the diesel engines are included as part of the engine accessories packages in SWBS item number 233.

Operating Fluids (SWBS 298)

The weights of the operating fluids include the lube oil and cooling water for the turbines, diesel engines, and the lift fan and propulsion gearboxes.

B.8:TECHNICAL RISK

The following subsections are a discussion of the technical risk for the prime movers, the propulsors, and the reduction gearing.

B.8.1 PRIME MOVERS

The ancillary system for the prime movers are all within the state of the art. The air inlet system, a combination of ducting, demisters with by-pass provisions, anti-ice systems and noise suppression measures have all been applied to modern ships in commercial and Navy service with excellent results. The inlet system for the SES is a completed design which was fully model tested for performance during the 3KSES Program. All gas turbine and diesel powered craft and ships have similar air inlet systems. Similarly, exhaust/uptake systems, usually comprised of gas turbine and diesel connections, ducting, sound suppression material/items and weather closures, are well known, within the state of the art and show good service.

DIESEL ENGINES -- The MTU 16V538TB82 and alternative engines are representative of modern, reliable, high specific power, high speed diesels being used in increasing numbers for all applications world-wide. These engines are fully developed rugged units with superior economy at part and full load and are considered low risk.

GAS TURBINES -- The GE LM2500 gas turbine is a fully developed free turbine unit currently in Navy inventory. Service experience includes the DD 963, the FFG 7, the PHM and ships of foreign Navies. There is low risk associated with its selection.

REDUCTION GEAR — The reduction gear design is a low risk conservative, state-of-the-art design furnished by the Cincinnati Gear Company. The design has not been compromised by small size, weight or low cost approaches which would reflect on reliability. Premium grade steels and conservative stress levels combined with a rigid casing, generous bearing areas, high capacity lube supply and fully factored loadings give confidence in the design. The reduction gear designs which are proposed do not require developmental activity or unusual manufacturing techniques.

Comparable in-service reduction gears designed and manufactured by the Cincinnati Gear Company include the parallel offset reduction gearbox for the Boeing Jetfoil and the combined drop/epicyclic gearbox for the American Enterprise craft.

B.8.2 PROPULSORS

Of the propulsors evaluated, the submerged (conventional) propeller for high speed craft, is considered to be the lowest risk. Many have been, and are currently being used, for high speed naval craft such as the PC and PCG. Vendors are therefore experienced in the manufacture of these propellers and much is known about propeller blade performance. The high speed ventilated propeller blade does not enjoy the benefit of previous service experience except in the SES-100B test craft and many smaller racing craft. It follows that manufacturing expereince for the ventilated propeller is lacking.

Pitch change mechanisms and controls have minimal technical and producibility risk when associated with submerged and ventilated propellers. These systems are now employed extensively on commercial and naval ships. The same mechanisms and controls associated with ventilated propellers also have low risk because of the extensive experience with these mechanisms on large tankers and are carriers that routinely operate partially submerged in a ventilated condition while transiting in ballast.

B.9 COMPONENT AND SYSTEM RELIABILITY

The selection process for the equipments for the propulsion machinery configurations used reliability as one of the driving parameters. The high reliability of the chosen equipments with the diesel engines used for lift power for off-cushion operations assures a very reliable ship. Redundancy for off-cushion is provided with the gas turbines, however, they will be operating inefficiently on the low end of their power curve. This case then, would be for emergency operation only.

The MTU diesels and the LM2500 gas turbine have been proven reliable. The LM2500 is currently in Navy inventory. The diesels are in commercial/industrial and European naval use. The combination of engines chosen for the arrangements offers an efficient reliable match.

The propulsion transmission trains feature Cincinnati Gear Company gearbox designs. These designs utilize conservatively loaded gears and journal bearings which result in gearboxes that are durable and reliable. A typical combat mission profile was used as a basis for reliability evaluation (Reference: Medium Displacement Combatant Surface effect Ship Technical Report, April 1981). This profile does not have any operational conditions that would affect the inherently high reliability of the proposed gearboxes, which feature conservatively designed helical hears mounted in journal bearings. The SSS overrunning clutches and the air clutches that are used to engage/disengage the diesels are mounted on the outside of the gearbox. These clutches are reliable and commonly used in marine and industrial applications. The demisters and exhaust system in all configurations are of straightforward design and are not considered to be reliability-critical. These power trains will be very reliable in any of the configurations presented.

The Tacoma Boat/Escher Wyss propeller design includes the pitch controls, instruments, sensors, the hydraulic system which contains pumps, hydraulic controls, oil collers, filters, valves and fittings, the propeller and the pitch change mechanism.

Since the ship thrust and the ship maneuvering capability are dependent on this system, high reliability of these parts are mandatory. The Tacoma Boat/Escher Wyss propeller and associated equipment, has proven capabilities on previous designs. The highest probability of failure occurs in the elements of the hydraulic system. For this reason redundancy in pump and controls is provided. Additional redundancy is provided in the manual control. In the event of a complete breakdown of the hydraulic system, the propeller can be mechanically locked in an ahead position by means of the linkage between the propeller blades and the double oil tube.

B.10 MAINTAINABILITY ASSESSMENT

The maintenance philosophy for the SES is minimum preventive maintenance while operational. Corrective maintenance onboard ship will be limited to removal and replacement of mission-essential equipment. This philosophy dictates a total maintenance concept that demands high reliability parts with most maintenance performed while the ship is in port.

Removal and replacement of major items is discussed in 4.3.2.1. The following maintainability criteria were applied in developing the concepts described in this report.

a. No secondary equipment removals required for access.

b. Adequate access doors for all equipment with sliding or hinged covers.

c. No structural cutouts for equipment access.

d. Adequate access around all equipments for inspections, checks, adjustments and corrective in-place maintenance.

e. Cathodic protection for dissimilar metal joints.

f. Standardization of fasteners/parts/materials.

g. Quick disconnect latches, cables, lines, etc.

h. Minimizing special tools and test equipment.

All the heavy components such as gear boxes, engines, etc., will have lifting lugs. Maintenance rails are provided on special removal paths through combustion air inlet or the fan air inlet for major equipment.

The Escher Wyss propeller is a highly maintainable design. The mechanical pitch change mechanisms in the propeller hub is designed for the life of the ship and requires no maintenance. The hydraulic activation system which requires some maintenance is installed in the shafting within the ship. Accessibility is provided for all scheduled and unscheduled maintenance required in the mechnism itself. Access from the engine room around the equipment is satisfactory for the various installations.

Escher Wyss has estimated a 6.9 hour MTTR for the hydraulics and controls. Ready access for these systems on the machinery arrangements presented assure that the baseline MTTR will hold at 6.9 hours.

All similar parts, including repair parts, are interchangeable without additional machining or selective assembling. Daily maintenance is minimal involving oil level and oil filter checks.

B.11 PRODUCIBILITY

All components and assemblies for the Propulsion System Configuration have a solid manufacturing base relative to state-of-the-art practices, tooling and machines.

The gas turbine and diesel engines are in series production.

The reduction gear designs as selected by RMI and Cincinnati Gear do not present producibility problems beyond learning curve development during manufacturing and test of the first reduction gear set.

Propeller size and materials for fully submerged propellers do not pose producibility problems since much larger conventional propellers in similar materials have been manufactured and are in service both in commercial and naval ships. For the ventilated propeller, there may be a need for manufacturing development since the blades will be made of harder and tougher alloys to resist the generally higher steady state and alternating stress levels used for ventilated propellers. It is held, however, that overall, the task of producing either a conventional submerged propeller or a ventilated propeller is about the same providing some manufacturing development is performed on the ventilated propeller.

The other aspects of the propeller, the CP mechanism and controls, present no producibility problems, being state of the art and familiar to vendors.

The thrust bearing module and shafting are custom designed. They present no producibility problems. The bearings and couplings are catalogue items and seals are similar to items in service.

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APPENDIX C

STRUCTURAL DESIGN

C.1 RATIONALE FOR USING RELIABILITY BASED METHODS

This appendix summarizes the rationale and methods used to estimate structural weight and provide structural design criteria for structural design when reliability based load and design methods are used.

The order of presentation is as follows: section C.1 provides the rationale for using reliability based methods, especially for vehicles for which a large experience base does not exist; section C.2 presents the method for developing loads and shows how it can be applied; section C.3 discusses design and fabrication.

It has been found from experiments that the cause of the greatest load acting on a ship's structure is different for different ship types. For a monohull, the longitudinal bending moment arising from differences between weight and buoyancy loads (W-B load) is dominant; for a SWATH, the transverse bending moment due to forces acting on the sidehulls is largest or dominant; while for SES's the off-cushion longitudinal load due to head sea slamming in survival sea states is dominant.

A reliability based method of selecting design loads was selected for the SES as a large historical data base does not yet exist. This method makes possible the extrapolation of experimental and service data, as well as analytical results. The reliability approach allows the direct use of results obtained from consideration of first principles in the various disciplines associated with ship design, and shows the effects of the variables of interest upon structural weight and reliability.

In summary, the use of reliability based methods for design allows technology independent evaluation criteria to be established for comparing ship types or variants within a given ship type and gives the engineer or project manager a method for evaluating the effect of proposed reliability level changes upon the mission effectiveness and the cost of the design.

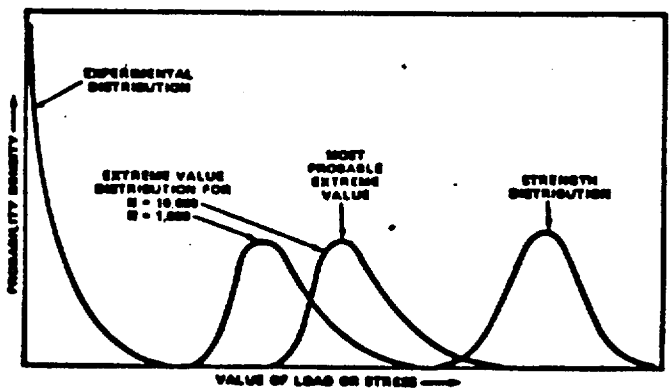
C.2 USE OF RELIABILITY METHOD IN PREDICTING STRUCTURAL WEIGHTS

Structural weight is a function of the operational profile (the table of the lifetime hours spent in each sea state and speed for each operating mode), the required reliability, the simultaneously acting loads, the materials used, and the design stress analysis methods employed.

In order to make clearer the origin of uncertainties in load and strength estimation, please refer to Figure C.1. Figure C.1 shows four probability density (not probability) curves. The curve on the left shows an experimental or parent probability distribution. The two curves in the middle show the probability density of the largest load plotted against load magnitude for two different experimental sample sizes. The right-hand curve shows the probability density of the strength (resistance) of the structure plotted against applied load magnitude.

The distribution curves shown in figure C.1 may be thought of as arising in the following manner. First, a largest load distribution curve. Suppose that a large number j of experimental runs to measure loads are made in a random seaway, each run of which has a number of wave

Figure C.1



Probability Density Distributions.

encounters resulting in n pitch cycles for the run. For each pitch cycle we record the maximum value of the load during that pitch cycle. Each run has a certain largest measured value among the loads thus recorded. If we count the number of largest values from all runs which lie between load L and L + L and divide by the toal number J of largest values we obtain an estimate of the probability density at L + L/2 which may then be plotted. If we continue in this fashion we will trace out the shape of the probability density curve of the largest load values. This probability density curve is called the extreme value distribution curve for the sample size J, and its exact shape depends also upon the statistical distribution (the experimental or parent distribution) which describes the physical process which gives the experimental load samples. Note that the shape of the load probability density curve is skewed to the right.

Second, the strength distribution curve. If we build a large number of ships having the same nominal dimensions, general arrangements, and scantlings, and then load them to failure, there will be a range of failure loads since there are strength variations due to variations in the strength of the plates and shapes, in the shape thicknesses, in the straightness of plates and shapes, in the weld strength, in the quality of fit up (alignment), in the principal dimensions and location of decks and stiffeners on decks, in the residual welding stresses, and in the amount of stress relieving. If we follow the same procedure of counting the number of occurrences in a load zone and dividing by the total number of occurrences and plotting resulting values we will approximate the shape of the strength or resistance probability density curve.

Note that most probability density curves have a peak. The magnitude of the load corresponding to the peak of the extreme load probability density load is called the most probable extreme load, and corresponds to the most often occurring, or most likely extreme or largest value measured during a test of many samples. The magnitude of the load corresponding to the peak of the strength curve is called the most probable strength.

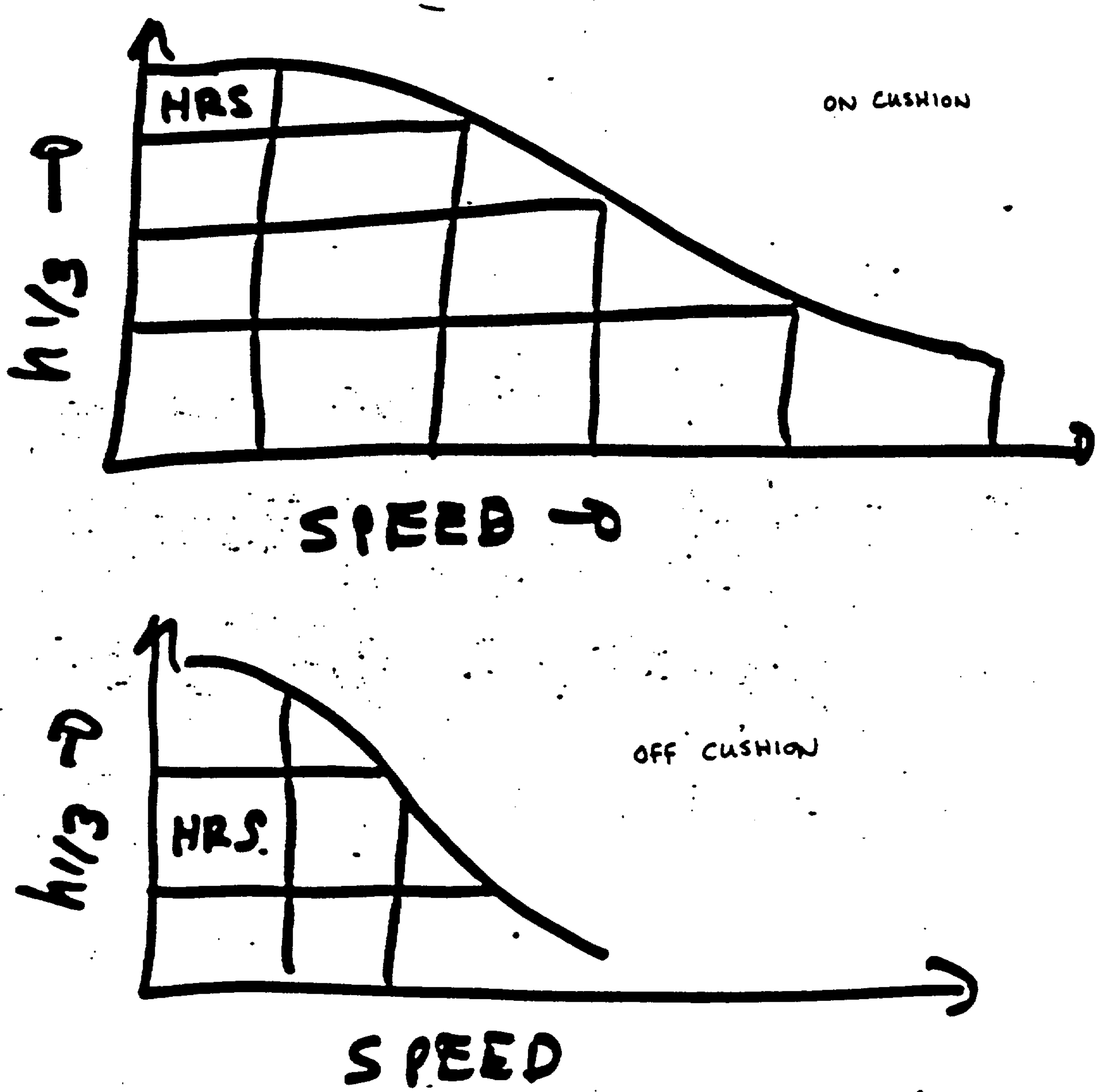
The shape and magnitude of the largest or extreme load curve can be found by applying extreme value theory, Ref. C-1, to the results of experimental tests. The exact shape and magnitude of the structural strength (resistance) curve is unknown, but ongoing work is aiding in the delineation of this curve. In the meantime, two assumptions are made: first, that the shape of the curve is Gaussian, and secondly, that the overall strength of the ship is taken to be that corresponding to the yield strength of the material in tension (not the ultimate strength), or the buckling strength of local structure as computed using Navy standard design practice, where the yield or buckling strength is taken to be that corresponding to using the as welded minimum mechanical properties. There are three elements of conservatism in using this approach (1) 99 percent of the welded joints are stronger than minimum mechanical properties, (2) the difference in strength between yield and ultimate strength is ignored, and (3) the post buckling strength of the structure, which may range from 1.3 to 2.0 times the yield buckling strength, is ignored.

C.2 LOAD ESTIMATION

Load estimation consists of using the operational profile, which specifies the lifetime hours spent in each sea state and speed combination, both hullborne and cushionborne, and then (1) finding the distribution of loads corresponding to each sea state-speed combination as a function of exposure time, and (2) finding a fixed load for design such that the risk of exceeding such fixed load over all operational profile combinations corresponds to the required reliability. Risk is here defined to be equal to (1.0 - reliability). Figure C.2 is an example of an operational profile where the number of lifetime hours is given for each sea state-speed combination. The upper number in each cell is the lifetime hours, the lower number is the number of head sea encounters in thousands.

Experimental results show that there are two physical processes contributing to SES loads in a seaway consisting of random waves. One is due to the difference between the weight and the buoyancy along the ship at any instant of time. The second is due to slamming, usually in the bow region, due to ship motion induced by the waves. Slamming is usually dominant for determining hullborne SES loads since it is often two to six times the W-B load. The frequency and severity of slamming is a function of speed, wave height, and wet deck clearance above the off cushion calm water line.

FIGURE C.2 OPERATIONAL PROFILE



There are two steps in using the load information: (1) find the statistical distribution (called the parent distribution) which best describes the data collected in a run, and (2) estimate the extreme value corresponding to this distribution, the exposure time, and the specified reliability.

PARENT DISTRIBUTION

The method of using the load magnitude information to estimate the parent distribution parameter values from experimental data is as follows: record the largest magnitude found in an interval of time long enough such that the occurrence of one event does not influence the magnitude of a subsequent event, i.e., each event is independent of other events. Order these events by magnitude from smallest to largest. Estimate the values of the parameters of the statistical distribution which best fits the data. A statistical distribution which fits both the W-B forces and the slam forces is the Weibull distribution with probability given by

$$P = 1.0 - e - ((\quad (v - Vo)^{c}) \qquad (1)$$

P = probability that the value of the variable is V or less

= scale factor

V = variable such as load or response

Vo = truncation value (value below which the probability is always zero)

c = exponent

c = 2 specifies a Rayleigh distribution which characterizes the W-B

distribution while c = 1 specifies an exponential distribution which characterizes a slam distribution. The Weibull distribution has also been found appropriate as in describing commercial ship loads, Ref. C-2.

The probability density for the parent (experimental) distribution is given by

$$p = \frac{\partial P}{\partial x} = c * ((\lambda (v - V_0))^{(c-1)}) * e^{-((\lambda(v-V_0))^c)} \quad (2)$$

Note that if we define x = (V-Vo) and substitute we obtain.

$$P = 1.0 - e^{-(x^c)} \quad (1a)$$

and

$$P = c * (x^{(c-1)}) * e^{-(x^c)} \quad (2a)$$

EXTREME VALUES

The extreme value distribution probability density equation if

$$f = n * (P^{(n-1)}) * P \quad (3)$$

Where

f = extreme (largest) value probability density distribution

n = sample size

P = parent probability distribution

P = parent probability density distribution

The extreme value distribution is a function of the parent distribution and the exposure time where n is the number of encounters or events expected during a given exposure time.

The above expression may be directly integrated to give the probability F associated with qan extreme value

$$F = P^n \qquad (4)$$

Which for the Weibull distribution as a parent distribution results in

$$F = (1 - @ - (x^c))^n \qquad (5)$$

To find the load corresponding to a specified probability od exceedance when the parent distribution and sample size are known solve eq (5) for x to obtain

$$x = \left(\ln \left(\frac{1.0}{(1.0 - F^{1/n}} \right) \right)^{(1.0/c)} \qquad (6)$$

Table C.1 lists magnitudes of x for various values of F, n, and c. f is the ratio to the area below the value of x to the total area (the probability), n is the sample size, and c is the slope of the Weibull distribution.

TABLE C.1 - VALUE OF EXCEEDANCE LOAD FOR THE WEIBULL DISTRIBUTION

PROB F	PROB OF EXCEEDANCE	NUMBER OF EVENTS, N	NON DIMENSIONAL VALUE OF LOAD C = 1.0	NON DIMENSIONAL VALUE OF LOAD C = 2.0
0.3679	0.6321	10**3	6.908	2.628
		10**4	9.210	3.035
		10**5	11.51	3.393
		10**6	13.82	3.717
0.999	10-3	10**3	13.82	3.717
		10**4	16.12	4.015
		10**5	18.42	4.292
		10**6	23.03	4.799
0.9999	10-4	10**3	16.12	4.015
		10**4	18.42	4.292
		10**5	20.72	4.552
		10**6	23.03	4.799
0.999	10-5	10**3	18.42	4.292
		10**4	20.72	4.552
		10**5	23.03	4.799
		10**6	25.33	5.033
0.999	10-6	10**3	20.72	4.552
		10**4	23.03	4.799
		10**5	25.33	5.033
		10**6	27.63	5.257

The most probably extreme value (the value at the peak of the extreme value probability density curve) occurs, for the sample sizes shown, at F = 0.368. This means that if 1,000 vessels were sent into the same sea state for the same amount of time at the same speed, heading, and initial load conditions, 632 of them would experience a load greater than the most probable (most often occurring) load. It will be noticed that the most probable load increases with the number of encounters (the exposure time).

In order to arrive at a load to be used for design in a given operating condition, the most probable load is increased by a factor corresponding to the risk (probability) of exceedance which is specified. Such a factor is the ratio for the (exceedance load/most probable load). These ratios, obtained from Table C.1 are given in Table C.2.

TABLE C.2 - RATIO OF EXCEEDANCE LOAD TO MOST PROBABLE EXTREME LOAD

PROB F	PROB OF EXCEEDANCE	NUMBER OF EVENTS, N	RATIO OF EXCEEDANCE TO MOST PROBABLE c = 1.0	c = 2.0
0.3679	0.6321	10**3	1.00	1.00
		10**4	1.00	1.00
		10**5	1.00	1.00
		10**6	1.00	1.00
0.999	10-3	10**3	2.00	1.41
		10**4	1.75	1.32
		10**5	1.60	1.27
		10**6	1.50	1.23
0.9999	10-4	10**3	2.33	1.53
		10**4	2.00	1.41
		10**5	1.80	1.34
		10**6	1.67	1.29
0.99999	10-5	10**3	2.67	1.63
		10**4	2.25	1.50
		10**5	2.00	1.41
		10**6	1.83	1.35
0.999999	10-6	10**3	3.00	1.73
		10**4	2.50	1.58
		10**5	2.20	1.48
		10**6	2.00	1.41

It will be noted that for a given probability of exceedance the ratio decreases with increasing sample size so that the greater the operational exposure in a cell, the smaller the factor required to cover a given probability of exceedance. It should also be noted that the larger the value of c, the smaller the factor required to cover a given probability of exceedance. Larger values of c correspond to non slam loadings, and so current practice from a structural loads point of view is to have a high wetdeck clearance hullborne, and to operate on cushion so as to minimize slamming frequency and slamming magnitude.

EXTREME VALUE FOR DESIGN

The extreme value used for design is the one for which the risk of exceedance, over the operational profile, meets the specified risk of exceedance. For each cell in the operational profile there is a given risk of exceedance of a specified load. The risk of exceedance for the entire operational profile is the statistical sum of exceedance for all the cells. In order to proceed we need to a) find the risk of exceedance in a given cell, and then b) sum in a probability sense the risk for all the cells.

a) Exceedance in a specific cell. Suppose the vessel has a certain strength. Determine the probability of not exceeding this strength for the operating conditions and duration specified for a particular cell in the operational profile. For example, the first line of Table C.3 shows the probability of not exceeding the strength for operating condition cell one. Denote this reliability = (1 - 3.62* 10-4) = 0.999638 by $\bar{F}1$.

b) Overall reliability and risk. Having found the reliabilities for each operating cell, find the overall reliability by using

$$Rn = \qquad Fi \qquad (7)$$

where

Rn = reliability for n cells

Fi = reliability for the ith cell

The risk is (1-Rn). Table C.3 shows typical results. it will be noted that the high sea state conditions, and the higher speeds in a given sea state, provide most of the risk. For most operating profiles, most of the risk is associated with the boundary cells which are called the operational envelope. Further, for most hull horn borne operating envelopes the high sea state operating conditions (survival conditions) provides most of the risk.

TABLE C.3 - RELIABILITY FOR HEADSEA HULLBORNE OPERATIONAL ENVELOPE OP1

CELL	ENCOUNTERS, THOUSANDS	MOST WEIBULL SLOPE = C	PROBABLE LOAD	SES STRENGTH	PROBABILITY OF EXCEEDING STRENGTH (RISK)
H3,V1	20	1.0	10	18	3.62 * 10-4
H2,V1	90	1.4	6	18	7.76 * 10-19
H2,V2	90	1.2	9	18	3.74 * 10-7
H3,V1	240	1.7	2	18	10-100
H3,V2	250	1.5	4	18	7.41 * 10-47
H3,V3	220	1.3	8	18	1.03 * 10-10

Overall reliability = 0.999638, Overall risk = 3.62 * 10-4

If the operating profile is changed, the risk can again be estimated. Table C.4 shows two such changes, one where the operating time in a high sea state cell (OE2) is changed by a factor of 2, and one where a lower sea state cell (OE3) is changed by a factor of 10.

TABLE C.4 - EFFECT ON RISK OF INCREASING NUMBER OF ENCOUNTERS

	ENVELOPE OE1		ENVELOPE OE2		ENVELOPE OE3	
CELL	ENCOUNTERS THOUSAND	RISK	ENCOUNTERS THOUSAND	RISK	ENCOUNTERS THOUSAND	RISK
H3,V1	20	3.62*10-4	40	7.25*10-4	20	3.62*10-4
H2,V2	90	3.74*10-7	90	3.74*10-7	900	3.74*10-6
H1,V3	220	1.03*10-10	220	1.03*10-10	220	1.03*10-10
Overall Encounters	330		350		1140	
Risk		3.62*10-4		7.25*10-4		3.66*10-4

The probability distribution for each cell stays the same because the sea state and speed are still the same. The change in reliability occurs because of the change in the duration or time spent in a particular operating condition. Note that in both cases the risk increases (the longer one is at sea, the greater the risk). If we compare the risk for the two changed operating conditions OE2 and OE3, we see that the risk for OE2 is greater than the risk for OE3 even though the change in the number of encounters for OE2 is much less than that for OE3. This example shows that the overall risk is primarily a function of the severity of the operating conditions in a cell, and that the overall risk must be obtained by summing the risk for each cell rather than by summing the number of encounters. Put another way, the vessel runs a higher risk by doubling the number of hours spent in a survival sea state than by increasing by a factor of 10 the number of operating hours in a less severe sea state.

CUMULATIVE FATIGUE LOADING

In order to determine whether fatigue is controlling the stress level corresponding to a given load must be estimated.

The cumulative fatigue loading may be estimated by application of a cumulative damage rule such as Miners rule:

$$\frac{ni}{Ni} = K \qquad (8)$$

ni = actual number of cycles at level i

NI = number of cycles at level i to cause failure (usually obtained from S-N curves for the material)

K = constant of summation, approximately 1/3 to 1/4 for 3 to 4 ship fatigue lifetimes

In order to apply Miner's rule, we need to know the number of loading cycles for each loading intensity. This information is known since we have the experimentally estimated probability density loading curves which were earlier used to estimate the extreme values. As before, we estimate the cumulative fatigue damage for each cell, and then sum the cumulative fatigue damage for all cells to find the overall fatigue damage. The stress which is used for computation is the nominal stress times the stress consultation factor applicable at a particular location. If the fatigue stress found for the lifetime number of loading cycles is greater than the cumulative damage stress, then the strength of the vessel is adequate. Due to uncertainties in the order of applied loads, the vessel is usually required to show a fatigue life which is 3 to 4 times greater than the estimated lifetime of the vessel.

An example of such a calculation for an operating cell is shown in Table C.5. In order to compute the ratio of (actual loading cycles)/(fatigue life) an experimentally determined S-N curve for the material involved is used. For each cell the lifetime probability density curve (not the extreme value probability density curve) is used to establish the relation between a load level and the number of times such a load occurs.

TABLE C.5 - FATIGUE LIFT CONTRIBUTIONS OF AN OPERATIONAL CELL

STRESS LEVEL (INCLUDING STRESS CONCENTRATION)	NUMBER OF CYCLES TO FAILURE	ACTUAL LIFETIME CYCLES	RATIO
70	5X10**3	1	0.000200
50	3X10**4	7	0.000233
30	10**6	41	0.000041
10	10**8	223	0.000002
Sum for the cell			

After finding the cumulative fatigue damage contribution of each cell, the overall fatigue damage estimate is found by summing the various cell contributions. The contribution of each cell is not proportional to the extreme load in each cell, but also depends upon the number of events and the Weibull slope c for a cell. Finally, the value of K should be less than 1/3 or 1/4.

If the value of K is too large then fatigue loading is controlling on the section rather than the once in a lifetime load and the scantlings will have to be increased until the value of K is satisfactory.

C.3 STRUCTURAL DESIGN

Structural Design Criteria

The structural criteria specifies the load magnitudes and their combinations, the factors of safety, and sometimes the material properties and analysis methods of guides to be used.

Combined load sets are the sets of loads which occur simultaneously on a structural element. Each set specifies the overall or global loads, such as bending and vessel motion loads such as acceleration, and local area loads such as fluid or point loads. Material properties, rather than material allowables are specified. This is consistent with using lifetime loads estimated from actual data.

In order to specify the combined factor of safety to be used in the case of combined loads interaction equations have to be developed or modified. Two points should be addressed. First, select the theory which describes the criteria for the onset of damage to the material, and secondly, determine how reliability based loads should be combined with deterministically obtained loads. One possible equation for estimating a combined factor of safety for tensile loads acting in the same direction is

$$ESC = \cfrac{1.0}{\cfrac{1.0}{\cfrac{SY / FSG}{SG}} + \cfrac{1.0}{\cfrac{SY / FSL}{SL}}}$$

where

ESC = combined factor of safety (should be 1.0)

FSG = factor of safety for global or reliability based loads, usually equal to 1.0 since the risk is already included in the magnitude of the load causing the stress SG

FSL = factor of safety for deterministically obtained load

SY = yield stress of material

SG = stress due to global or reliability based load

SL = stress due to deterministically obtained load

Combined factor of safety equations should be specified for other combined loading cases including compressive loads, out of plane loads, and loads acting in different directions in plane.

MATERIALS

Materials used to date for hulls are high strength marine service aluminum alloys of the 5000 series. Craft include the SES-100A, the SES-100B, and the SES 200. Both 5086 and 5456 alloys have been used. As SES sizes grow larger, the use of high strength steels becomes attractive, especially those having yield strengths of 80 ksi and above such as HSLA, HY80, and HY100. The choice of which material to use from a weight viewpoint is determined by comparing the weight of an aluminum structure plus any needed fire insulation sheathing against the weight of a steel structure. For special applications such as minesweeping, the use of plastic composites such as GRP is often worth considering.

Minimum guaranteed (in the case of metals usually the as welded) properties are normally specified.

STRUCTURAL DESIGN

Since as SES is supported cushionborne by an air cushion whose pressure is supplied by lift fans and whose resistance is in part caused by the cushion pressure, attention to minimum weight design pays off.

Once the structural criteria specifying the combined loads and factors of safety is available, the remainder of the design can be carried out by current design techniques including the use of structural optimization programs such as described in Hughes Ref. C-3 often using, in the case of Navy designs, current design practice as analysis guides.

The resulting structure is usually a longitudinally framed plate and grillage structure. Closely spaced longitudinal stiffeners usually result in a minimum weight design. Additionally, large amounts of permanent set are often tolerated in the wet deck area since the deck is usually close to the neutral axis and so contributes little to longitudinal strength.

Information as to the shape of structural details to minimize fatigue failure and to estimate the effect to misalignment may be found, for example, in Ref. C-3.

STRUCTURAL FABRICATION NOTES FOR DESIGN

SES's have the advantage that most of the vessel is composed of flat panels forming relatively boxlike assemblies. Since the sidehulls are narrow compared to ships of normal form, they may be shaped using flat plate elements joined together rather than being made up of curved elements. The relatively large amount of flat plate work makes the use of automatic welding machines quite attractive and minimizes the fabrication cost.

REFERENCES

Ref C-1 Gumbel, Statistics of Extremes

Ref C-2 Munse, W., et al., "Fatigue Characteristics of Fabricated Ship Details for Design," Illinois University at Urbana, Department of Civil Engineering, SSC-318, (Aug 1982)

Ref C-3 Hughes, Owen F., "Ship Structural Design - A Rationally Based, Computer Aided, Optimization Approach," Wiley-Interscience, (1983)

APPENDIX D

COMPARISON OF FRG AND US SCANTLING DIMENSIONS

D.1 ALU-ALLOY

Figure D.1 shows the midship section with elements corresponding to the text below.

The MTG-sizing is provided for smaller plate-thickness regarding the deck element No. 7, 10 and 11 as well as smaller profiles of longitudinal stiffenings regarding elements 5 to 14.

Concerning the cross-stiffenings, the MTG-version provides for a floor plate - regarding elements 1 to 4 - instead of T-profiles which are stated in the US-version. Both results are nearly equal in weight.

Within the MTG-version even more weights result from element 12. The MTG-version shows this as "continuous longitudinal wall at ___". In the US-version, this element consists of pillars.

The strength-calculation showed the necessity of this longitudinal wall. An additional weight is caused by the thicker plate used with the lower part of element 13.

Different longitudinal frame spacings were selected:

US Version: 13 inch (330 mm)

German Version: 11.8 inch (300 mm)

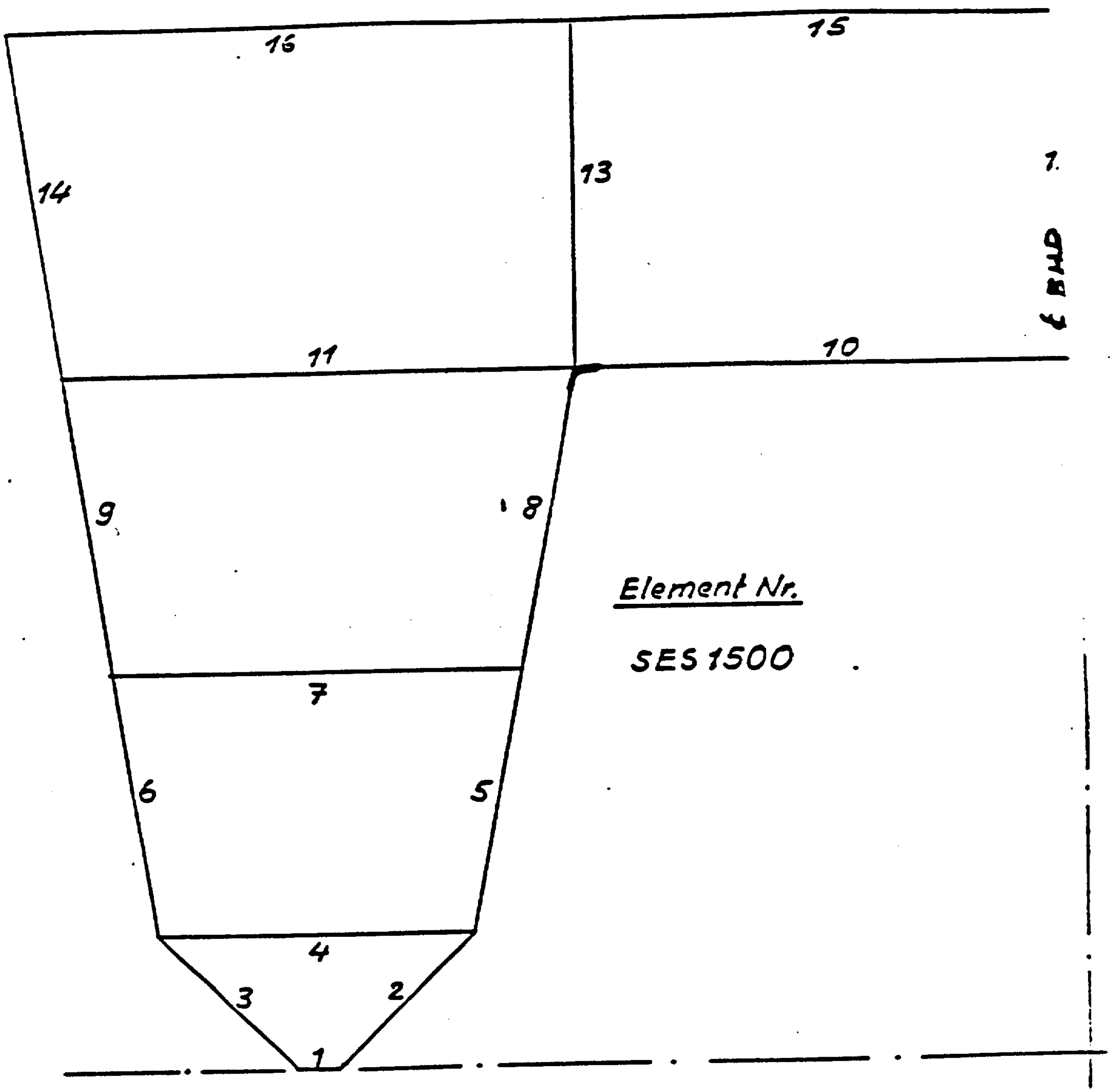


Figure D.1. ELEMENT MODEL

Similarly Web frame spacing were different:

US Version: Bulk-head spacing in drawing is 60 feet divided by 17 = 35.294 inches = 896 mm frame-spacing.

MTG Version: 50 feet = 600 inches = 15.24 m: 15 parts @ 40 inch (1016 mm) frame-spacing.

The comparison of the distance of the longitudinal stiffeners shows, that the MTG-version is provided for more "longitudinal frames" however less "web frames", which means for example: Half a wet-deck-width of 14 ft (4.267 m) contains 14 "longitudinal frames" in the MTG-version and 13 "longitudinal frames" in the US-version.

The MTG-version shows for each compartment (600" = 15.24 m) 14 "web frames" whereas the US-version plans 16 "web frames".

Steel:

The MTG-version shows smaller plate-thickness in deck-elements 7 and 11 and principally for all elements the smallest longitudinal frames as shown in the US-profile-list (T-Profile 3x2x0, 125/0, 188 weight 3.75 kg/m).

In the US-version the smallest profiles are T 4x2x0, 188/0, 133 with a weight of 6.728 kg/m."

That means, the MTG-version contains a reduced weight for "longitudinals frames" in comparison to the US-version. (The reduction of weight is 2,978 kg/m).

Regarding elements 1 to 4 the MTG-version contains as cross-stiffening a "floor plate" which is neutral in weight in comparison to the US-version. Additional weights are given in the MTG-version with higher plate-thicknesses within the upper and lower hull elements 1,2,3,14,15, and 16. Element 1 has been chosen extremely thicker because it is meant to be the keel-plate. The thickness for the other elements depends on the strength calculation.

Table D.1 presents the full structural data for the design described above.

Table D.1

Element Nr.		AL 5456 Blechdicke inch	AL 5456 Langsspauf-/balken T-Profil (inch)	AL 5456 Rabmenspauf/-balken T-Profil (inch)	Stahl HSLA-80 Blechdicke (inch)	Stahl HSLA-80 Langsspauf/-balken T-Profil (inch)	Stahl HSLA-80 Rakmenspauf/-balken (T-Profil (inch)
1	D US	0,938 0,938	ohuc ● 6x3x0,250/0,438	Bodenwrange 0,250 ● 6x3x0,250/0,375	0,563 ● 0,250	ohuc ● 4x2x0,188/0,313	Bodenwrange 0,188 ● 3x2x0,125/0,188
2	D US	0,813 0,813	6x3x0,250/0,438 6x3x0,250/0,438	Bodenwrange 0,250 ● 6x3x0,250/0,375	0,250 ● 0,188	3x2x0,125/0,188 ● 4x2x0,188/0,313	Bodenwrange 0,188 ● 3x3x0,188/0,313
3	D US	0,813 0,813	6x3x0,250/0,438 6x3x0,250/0,438	Bodenwrange 0,250 ● 6x3x0,250/0,375	0,250 ● 0,188	3x2x0,125/0,188 ● 4x2x0,188/0,313	Bodenwrange 0,188 ● 4x2x0,188/0,313
4	D US	0,375 0,375	4x3x0,188/0,313 ● 4x2x0,188/0,313	Bodenwrange 0,250 ● 8x5x0,250/0,438	0,188 ● 0,188	3x2x0,125/0,188 ● 4x2x0,188/0,313	Bodenwrange 0,188 ● 6x4x0,188/0,313
5	D US	0,375 0,375	3x2x0,125/0,188 ● 4x2x0,188/0,373	6x3x0,250/0,375 6x3x0,250/0,375	0,188 0,188	3x2x0,125/0,188 ● 4x2x0,188/0,313	5x2x0,188/0,313 ● 4x3x0,125/0,188
6	D US	0,563 0,563	3x2x0,125/0,188 ● 4x2x0,188/0,313	6x3x0,250/0,375 6x3x0,250/0,375	0,188 0,188	3x2x0,125/0,188 ● 4x2x0,188/0,313	5x2x0,188/0,313 ● 4x2x0,188/0,313
7	D US	0,188 ● 0,375	3x2x0,125/0,188 ● 4x2x0,188/0,313	6x3x0,250/0,375 6x3x0,250/0,375	0,125 ● 0,188	3x2x0,125/0,188 ● 4x2x0,188/0,313	5x2x0,188/0,313 ● 3x3x0,125/0,188
8	D US	0,375 0,375	3x2x0,125/0,188 ● 4x2x0,188/0,313	8x5x0,250/0,438 ● 6x3x0,250/0,375	0,188 0,188	3x2x0,125/0,188 ● 4x2x0,188/0,313	6x3x0,250/0,375 ● 5x2x0,188/0,313
9	D US	0,375 0,375	3x2x0,125/0,188 ● 4x2x0,188/0,313	6x3x0,250/0,375 6x3x0,250/0,375	0,188 0,188	3x2x0,125/0,188 ● 4x2x0,188/0,373	5x2x0,188/0,313 ● 3x2x0,188/0,313
		Thickness	Longitudinal Frame	Web Frame	Thickness	Longitudinal Frame	Web Frame

D = MTG Dimension
US = Amerikauisck Dimension
(US dimensions)

● = Abweichung Zwiscken Du-US Dimensioner
= Micht baubar in Verbiudung mit Langsspauf

(difference between D and US)
(not possible in connection with longit. frame)

Table D.1 (Cont.)

Element Nr.		AL 5456 Blechdicke inch	AL 5456 Langsspauf-/balken T-Profil (inch)	AL 5456 Rahmenspauf/-balken T-Profil (inch)	Stahl HSLA-80 Blechdicke (inch)	Stahl HSLA-80 Langsspauf/-balken T-Profil (inch)	Stahl HSLA-80 Rakmenspauf/-balken (T-Profil (inch)
10	D US	0,250 ● 0,375	3x2x0,188/0,313 ● 4x2x0,188/0,313	72x5x0,375/0,656 72x5x0,375/0,656	0,188 0,188	3x2x0,125/0,188 ● 4x2x0,188/0,313	10x5x0,375/0,438 ● 8x5x0,250/0,375
11	D US	0,188 ● 0,250	3x2x0,125/0,188 ● 4x2x0,188/0,313	6x3x0,250/0,375 6x3x0,250/0,375	0,125 ● 0,188	3x2x0,125/0,188 ● 4x2x0,188/0,313	5x2x0,188/0,313 ● 4x2x0,188/0,313
12	D[1/] US[2/]	U 0,250 O 0,281 ● 0,250	3x2x0,125/0,188 ● 3x2x0,125/0,188 ● 72x5x0,375/0,656	8x7x0,250/0,438 8x7x0,250/0,438 8x7x0,250/0,438	U 0,188 O 0,234 ● 0,188	3x2x0,125/0,188 ● 3x2x0,125/0,188 ● 5x4x0,188/0,250	5x2x0,188/0,313 ● 5x2x0,188/0,313 ● 3x2x0,125/0,188
13	D US	U 0,281 ● O 0,375 U 0,250 O 0,375	3x2x0,125/0,188 ● 3x2x0,125/0,188 ● 4x2x0,188/0,313 4x2x0,188/0,313	6x3x0,250/0,375 6x3x0,250/0,375 6x3x0,250/0,375 6x3x0,250/0,375	U 0,188 O 0,234 ● 0,188 0,188	3x2x0,125/0,188 ● 3x2x0,125/0,188 ● 4x2x0,188/0,313 4x2x0,188/0,313	5x2x0,188/0,313 ● 5x2x0,188/0,313 ● 3x2x0,125/0,188 3x2x0,125/0,188
14	D US	0,375 0,375	3x2x0,125/0,188 ● 4x2x0,188/0,313	6x3x0,250/0,375 6x3x0,250/0,375	0,188/0234● 0,188	3x2x0,125/0,188 ● 4x2x0,188/0,313	5x2x0,188/0,313 ● 4x2x0,188/0,313
15	D US	0,375 0,375	4x2x0,188/0,313 4x2x0,188/0,313	6x3x0,250/0,375 6x3x0,250/0,375	0,234 ● 0,188	3x2x0,125/0,188 ● 4x2x0,188/0,313	5x2x0,188/0,313 ● 5x4x0,188/0,250
16	D US	0,375 0,375	4x2x0,188/0,313 4x2x0,188/0,313	7x3x0,250/0,438 7x3x0,250/0,438	0,234 ● 0,188	3x2x0,125/0,188 ● 4x2x0,188/0,313	5x2x0,188/0,313 ● 5x4x0,188/0,250
		Thickness	Longitudinal Frame	Web Frame	Thickness	Longitudinal Frame	Web Frame

1/ Langswandauf MS
2/ 67 Stutzen (pillars)

(longitude bulkhead)

U = untere Halfte (lower part)
O = obere Halfte (upper part)
D = MTG Dimension
US = Amerikauisck Dimension (US dimensions)

● = Abweichung Zwiscken Du-US Dimensioner
= Micht baubar in Verbiudung mit Langsspauf

(difference between D and US)
(not possible in connection with longit. frame)

APPENDIX E

AUXILIARY SYSTEMS DETAILED CHARACTERISTICS

The systems discussed in Appendix E were not developed specifically for the NASW SES. They were developed and proposed for other SES designs, principally for the U.S. 3KSES. They are presented as general background only.

APPENDIX E.1

CRITICALITY ANALYSIS FOR AUXILIARY SYSTEMS

The definitions used for this analysis are as follows:

(1)	Technology Critical (rating of 5)	- A system or element which is critical for the mission but has not been previously engineered for SES applications.
(2)	Mission Critical (rating of 4)	- A basic system or element which is required to allow the craft to be operational.
(3)	Capability Critical (rating of 3)	- A system or element which is required to demonstrate capability relative to "test drivers", e.g., helicopter operations, etc.
(4)	Design Critical (rating of 2)	- A system or element which has previous SES engineering but required modifications to suit optimum craft configuration.
(5)	Non-critical (rating of 1)	- Existing technology satisfactory.

Ratings were assigned to these five definitions and all auxiliary systems evaluated as shown in Table E.1-1. The matrix was then used to develop the system priority listing shown in Table E.1-2.

A set of guidelines for each critical auxiliary subsystem was prepared to encompass: approval hierarchy, operational, performance, and design requirements. Standard commercial, U.S. Coast Guard, and U.S. Navy design criteria were used to determine system requirements and derive concepts. The major selection criteria for an applicable design were cost, weight, safety and technical risk.

Table E.1-1

AUXILIARY SYSTEMS CRITICALITY MATRIX	TECHNICAL	MISSION	CAPABILITY	DESIGN	NON-CRITICAL	CRITICALITY
SWBS RATING	5	4	3	2	1	
506 Overflows, Air Escapes and Sounding Tubes				X	1	
510 CLIMATE CONTROL						
511 Compartment Heating System					X	1
512 Ventilation System		X		X		6
513 Machinery Space Ventilation System		X	X	X		9
514 Air Conditioning System		X	X	X		9
516 Refrigeration System					X	1
520 SEA WATER SYSTEMS						
521 Firemain and Flushing (Sea Water) System	X	X	X	X		14
522 Sprinkler System		X		X		6
524 Auxiliary Sea Water System		X		X		6
526 Scuppers and Deck Drains					X	1
528 Plumbing Drainage					X	1
529 Drainage and Ballasting System			X	X		5
530 FRESH WATER SYSTEMS						
531 Distilling Plant					X	1
532 Cooling Water				X		2
533 Potable Water					X	1
534 Aux. Steam and Drains Within Machinery Box (Machinery Drains)					X	1
536 Auxiliary Fresh Water Cooling				X		2
540 FUELS AND LUBRICANTS, HANDLING AND STORAGE						
541 Ship Fuel and Fuel Compensating System		X	X	X		9
542 Aviation and General Purpose Fuels		X	X	X		9
545 Tank Heating (Diesel Heating)					X	1
549 Special Fuel and Lubricants, Handling & Stowage				X		2

Table E.1-1 (Cont.)

AUXILIARY SYSTEMS CRITICALITY MATRIX	TECHNICAL	MISSION	CAPABILITY	DESIGN	NON-CRITICAL	CRITICALITY
SWBS RATING	5	4	3	2	1	
550 AIR, GAS, AND MISC. FLUID SYSTEMS						
551 Compressed Air Systems		X		X		6
552 Compressed Gases					X	1
553 O_2 N_2 System					X	1
555 Fire Extinguishing Systems		X	X	X		9
556 Hydraulic Fluid System				X		2
560 SHIP CONTROL SYSTEMS						
561 Steering and Diving Control Systems	X	X	X	X		14
562 Rudder	X	X	X	X		14
565 Trim and Heel (Roll Stabilization)			X	X		5
570 UNDERWAY REPLENISHMENT SYSTEMS						
571 Replenishment-At-Sea			X	X		5
572 Ship Stores and Personnel and Equipment Handling					X	1
573 Cargo Handling			X	X	X	6
574 Vertical Replenishment Systems			X	X		5
580 MECHANICAL HANDLING SYSTEM						
581 Anchor Handling and Stowage Systems		X	X	X		9
582 Mooring and Towing Systems		X	X	X		9
583 Boat Handling and Stowage Systems			X	X		5
584 Mech. Operated Door, Gate, Ramp, Turntable Sys.			X	X		5
586 Aircraft Recovery Support Systems	X		X	X		10
588 Aircraft Handling, Servicing and Stowage			X	X		5
590 SPECIAL PURPOSE SYSTEMS						
593 Environmental Pollution Control Systems		X	X	X		9
598 Auxiliary Systems Operating Fluids					X	1

Table E.1-2. Modified Auxiliary Systems Priority Listing

SWBS	System	Priority
506	Overflows, Air Escapes and Sounding Tubes	1
511	Compartment Heating System	1
516	Refrigeration System	1
526	Scuppers and Deck Drains	1
528	Plumbing Drainage	1
531	Distilling Plant	1
533	Potable Water	1
534	Machinery Drains	1
545	Diesel Tank Heating	1
552	Compressed Gases	1
553	O_2/N_2 System	1
572	Ship Stores and Personnel and Equipment Handling	1
598	Auxiliary Systems Operating Fluids	1
532	Cooling Water	2
536	Auxiliary Fresh Water Cooling	2
549	Special Fuels and Lubricants, Handling & Storage	2
556	Hydraulic Fluid System	2
528	Plumbing Drainage	5
565	Trim and Heel (Roll Stabilization)	5
571	Replenishment-At-Sea	5
574	Vertical Replenishment Systems	5
583	Boat Handling and Stowage Systems	5
584	Mechanically Operated Door	5
588	Aircraft Handling, Servicing and Stowage	5
512	Ventilation System	6
522	Sprinkler System	6
524	Auxiliary Seawater System	6
551	Compressed Air System	6
573	Cargo Handling	6
513	Machinery Space Ventilation System	9
514	Air Conditioning System	9
541	Ship Fuel System	9
542	Aviation and General Purpose Fuels	9
555	Fire Extinguishing Systems	9
581	Anchor Handling and Stowage Systems	9
582	Mooring and Towing Systems	9
593	Environmental Pollution Control Systems	9
586	Aircraft Recovery Support Systems*	10
521	Firemain and Flushing (Seawater) System*	14
562	Steering Control System*	14
562	Rudder*	14

*These are the four systems that are considered critical, all others are essential.

APPENDIX E.2

DRAINAGE SYSTEMS

SYSTEM REQUIREMENTS

The ship drainage system consists of plumbing drains, scupper and deck drains, oily waste collection, and main and secondary drainage. The design requirements of the system are outlined in General Specifications for Ships of the U.S. Navy, Sections 528, 529 and 534. Specifically, the following requirements were identified for the Drainage System of the 3KSES design:

a. Segregation of soil and sanitary waste drains.

b. Plumbing drains for all plumbing fixtures.

c. Independent drainage for sanitary drains from commissary spaces and medical spaces.

d. Air gaps in drain lines from refrigerators, hot food tables and similar equipment.

e. Plumbing drains penetrating watertight transverse bulkheads have a full port ball or plug valve operable at the valve and from the damage control deck.

f. Space deck and weather deck drains provided to prevent accumulation of water on weather and hangar decks, decks of sanitary and commissary spaces and decks in other spaces where water may accumulate.

g. Independent drains for the hangar, magazines, and R.A.S. stations.

h. Main drainage to have the capability of evacuating water from propulsion engine rooms, combustion air intakes, and auxiliary pump rooms at a rate of not less than 500 gpm under emergency conditions. Seawater pump bilge injection will provide a boosted dewatering capacity to the propulsion engine rooms.

i. Secondary drainage via drain pumps provided from drain wells in lift engine rooms, auxiliary machinery rooms, electrical generator rooms, and the propulsion engine rooms.

j. Secondary drainage eductors provided for drainage of lift fan rooms, and of the combustion air intakes. Drainage requirement per lift fan is up to 33 gpm average continuous and to 116 gpm intermittent.

k. Damage flooding in compartments not served by the main drainage eductors will be handled by submersible pumps.

l. Main drainage control shall be both locally and at the damage control auxiliaries and electrical console (DCAEC).

m. The secondary (waste water) drainage system and the oily waste collection system are segregated.

n. A waste oil system which collects oils at discrete points from lift and propulsion engines, gas turbine generators, expended lube oils, oil seepage from engine gearboxes and waste oils from the aviation and general workshop. (Oily water separator drainage is part of the Pollution Control System.)

CANDIDATE CONCEPTS AND TRADEOFFS — Two candidate concepts for the plumbing drainage system were examined; the conventional seawater gravity flow and a system which utilizes fresh water flushing and vacuum collection.

Conventionally, soil and waste drains have relied solely on gravity as the driving force. Associated with this approach have been restrictions with regard to piping slopes (1/2 inch per foot minimum) and to the use of piping sizes compatible with standard gravity operated fixtures. In particular, water for flushing of water closets has usually been seawater with the resulting soil waste generation rate of 30 gallons per capita per day (GPCD). When the ship is within the prohibited discharge zone this places unnecessary loading on sewage treatment units and/or on the collection, holding and transfer tanks (CHT). Water closets are presently available which substantially reduce the quantity of soil wastes resulting from each flush. Table E.2-1 lists some of these units and the methods employed to obtain the controlled flush volumes. The quantity of water utilized by the various units (1/4 to 1/2 gallons per flush) is a reduction of approximately 90% over conventional gravity systems which require 4 to 5 gallons per flush of the non-vacuum operated systems, the GATX water closet utilizes the least quantity of waste water per capita day, but its weight (80 lbs. with necessary valves) does not represent any saving over the standard shipboard unit. The GATX unit is not vacuum operated and macerator/transfer pump(s) are used in the installation to propel the waste slurry along the piping. The Jered water closet/controlled urinal system with the resulting combined waste rate of 1.92 gallons per capita day is vacuum operated. The water closet weight is 33 lbs. complete with the necessary control and discharge valves. This is a weight reduction of 42 pounds per unit over a standard unit, for a total saving of 588 pounds for the SES, which is equipped with 14 water closets.

Vacuum collection system for soil drains, in addition to requiring conventional gravity drain piping and fittings, includes vacuum pump(s), vacuum collection tank(s), vacuum interface valves, and electrical

Table E.2-1. Reduced Volume Flush Data

	FLUSHING WATER QUANTITY, GALLONS/FLUSH	FLUSHING TIME, SECONDS	VOLUME OF SEWAGE AND WATER PER FLUSH, GALLONS	AIR USAGE PER FLUSH, SCF	ESTIMATED USAGE/MAN/DAY	FLUSHING WATER, GPCD*	SOIL WASTES, GPCD*	MANUFACTURER	REMARKS
Urinal	1/8		.22	.2	4	.5	.88	Jered	Vacuum System
Water Closet	1/2	8 to 12	.52	1 Ft^3 @ 60 psi	4	2	2.1	Microphor LF-210 LF-310	Compressed Air System
	3/8	7	.39	3 to 4.5	4	1.5	1.6	Envirovac	Vacuum System
	1/4	6	.26	1.5	4	1	1.1	Jered	Vacuum System
	3/8	10	.39	-	4	1.5	1.6	GATX	Wastes are transferred by a pump.

* Gallons per capita per day.

instrumentation and control. The vacuum interface valves are located in the drainage lines close to the urinals and control the application of vacuum and atmospheric air to the transported liquid waste. A brief weight comparison between the ship and seawater gravity drains and with the vacuum collection concept is given in Table E.2-2. The equipment weight penalty incurred by the vacuum concept is approximately .23 long tons. This weight penalty is soon absorbed when compared to the weight of liquid collected and retained when the ship is operating within prohibited discharge zones. Using an overall daily soil accumulation rate of 30 GPCD for a conventional seawater system and 1.92 GPCD for the vacuum system, the weight saving in stored liquid is illustrated in Figure E.2-1. After a twelve hour period in a non-discharge zone, a 6.3 long ton differential would exist in favor of the vacuum system. This differential increases to 9.5 long tons after 18 hours, which is the designed holding time capacity of the vacuum collection tank system.

For the ship's one day CHT holding capacity, the weight differential would be approximately 12.8 long tons. In addition to the weight savings, the following advantages of the vacuum system can be listed:

- Piping runs need not be sloped, thereby facilitating installation by standardization in the length of pipe hangers.
- Higher flush differential pressure allows the use of smaller pipe and valve sizes.
- Line leakage is from the compartment(s) into the drain lines, thereby reducing the risk of fluid contamination.
- The number of piping vent lines is greatly reduced: venting of the collection holding and transfer tank providing this function for the complete system.

Table E.2-2. Plumbing Drainage Equipment Weight Comparison

STANDARD SYSTEM		VACUUM SYSTEM	
COMPONENT	LBS	COMPONENT	LBS
- - -		Vacuum pumps, complete with motor, tanks, valves	2 @ 425 = 850 (See Appendix B)
- - -		Vacuum collection tanks, (135 gal. each with 10 gal. low level liquid)	2(175+10x8.34) = 517 (See Appendix B)
- - -		Vacuum interface valves	8 @ 10 = 80
Standard vitreous china fixtures	14 @ 75 = 1050	Lightweight fixtures complete with valves (1)	14 @ 33 = 462
Differential weight penalty for larger piping sizes due to sloping requirement	Est. @ 200	- - -	
Vent piping differential weight including hangers, etc.	Est. @ 150	- - -	
Total Weight	1400	Total Weight	1909

(1) Based on Jered, Inc. Model AVT 300

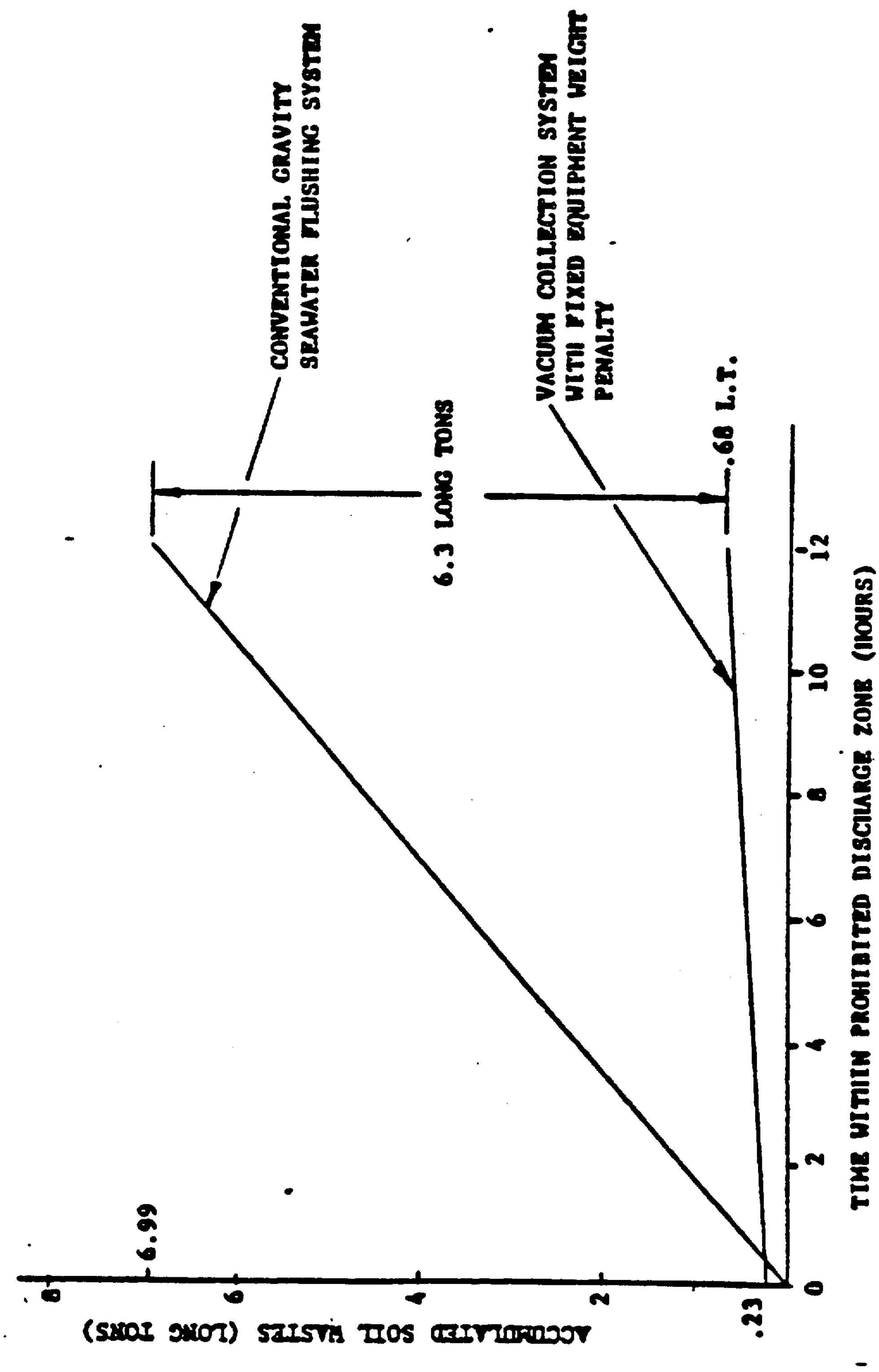


Figure E.2-1. Soil Wastes Accumulation Rates

Sewage treatment equipment was investigated in an attempt to further reduce the collection and holding tank capacity. However, it was concluded that the weight penalty of approximately 1500 pounds and increased electrical load of approximately 25 kw precluded such installation.

DRAINAGE SYSTEM DESCRIPTION AND CHARACTERISTICS

PLUMBING DRAINAGE

Plumbing drains are separated into two distinct systems; soil drains and sanitary drains (ss Figure E.2-2).

SOIL DRAINAGE

The soil drain system transports wastes of human origin emanating from the water closets and urinals, both being supplied with sea water for flushing. The soil drainage system is divided into two subsystems, a forward and an aft. Drains from the urinals and water closets of the forward system are combined in a header below the second deck and are collected into a 1850 gallon collection tank. Similarly, drains from the urinals and water closets of the aft system are collected by a 1850 gallon tank.

SANITARY DRAINAGE

Drains from lavatories, sink, showers, laundry machines, commissary equipment (including the garbage grinder) and deck drains from the galley

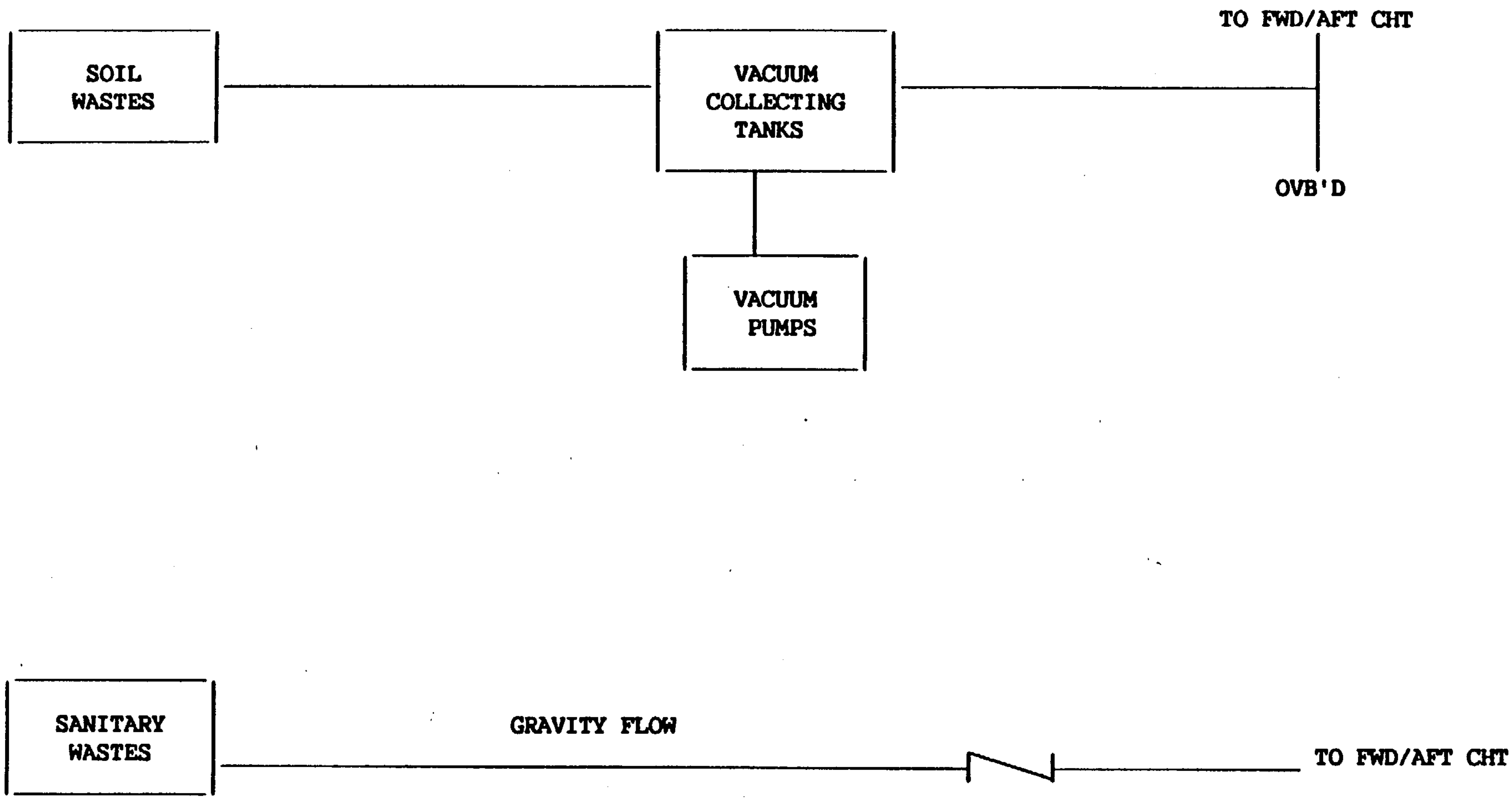


Figure E.2-2. Plumbing Drainage

and the scullery are transported by the sanitary waste drainage system. This gravity system consists of two sub-systems, one forward and one aft.

Waste drains from the vegetable peeler, dishwasher, refrigerators, steam tables, kettles, ice machines, commissary sideboards and dressers are discharged through an air gap to the drain system.

The drain piping, made of GRP material, is pitched a minimum of 0.23 inch per foot.
Drains from the medical treatment room are led independently to the forward CHT.

Piping penetrating watertight transverse bulkheads utilize motor driven full ported ball valves. These can be operated manually, or can be controlled electrically at the DCAEC.

SCUPPER AND DECK DRAINS

These drains are grouped as much as possible between watertight subdivision transverse bulkheads and led overboard via scupper valves. Valves below the damage control deck are of the gag-type and can be remotely operated from the second deck via reach rods. Piping material is aluminum. Overboard discharges are fitted with hose connections to permit attachment of portable submersible pump discharges. Drain piping from the helicopter hangar is independently led directly overboard and is trunked for fire protection. The piping material for these drains is CRES.

OILY WASTE COLLECTION

The oily waste collection system is shown in Figure E.2-3. Waste oil from propulsion, lift, gas turbine engines and diesel generators is collected by gravity. This piping leads to four 5 gallon tanks, or directly to the main waste oil drain tank located below the auxiliary machinery Rooms, and electrical generator Rooms. Associated with each local tank is a level control and pump to transfer the oil to the main waste oil drain tank.

MAIN AND SECONDARY DRAINAGE

The location of the eductors, their size, function, seawater requirements and drainage characteristics of the main and secondary drainage are summarized in Table E.2-3. Each element of this system is briefly discussed in the following paragraphs.

MAIN DRAINAGE

The main drainage system comprising eight eductors, has the capability of evacuating water from each of the main machinery spaces, combustion air intake Rooms, the port and starboard propulsion engine air plenum chambers, and auxiliary pump rooms, at a rate of not less than 500 GPM.

Four of the eight eductors provide a two flow rate drainage capability. During the lower operating rate, the ship seawater pumps are taking suction from the sea. Each eductor serving a propeller room is located (in elevation) such that a suction lift of five feet of water or less

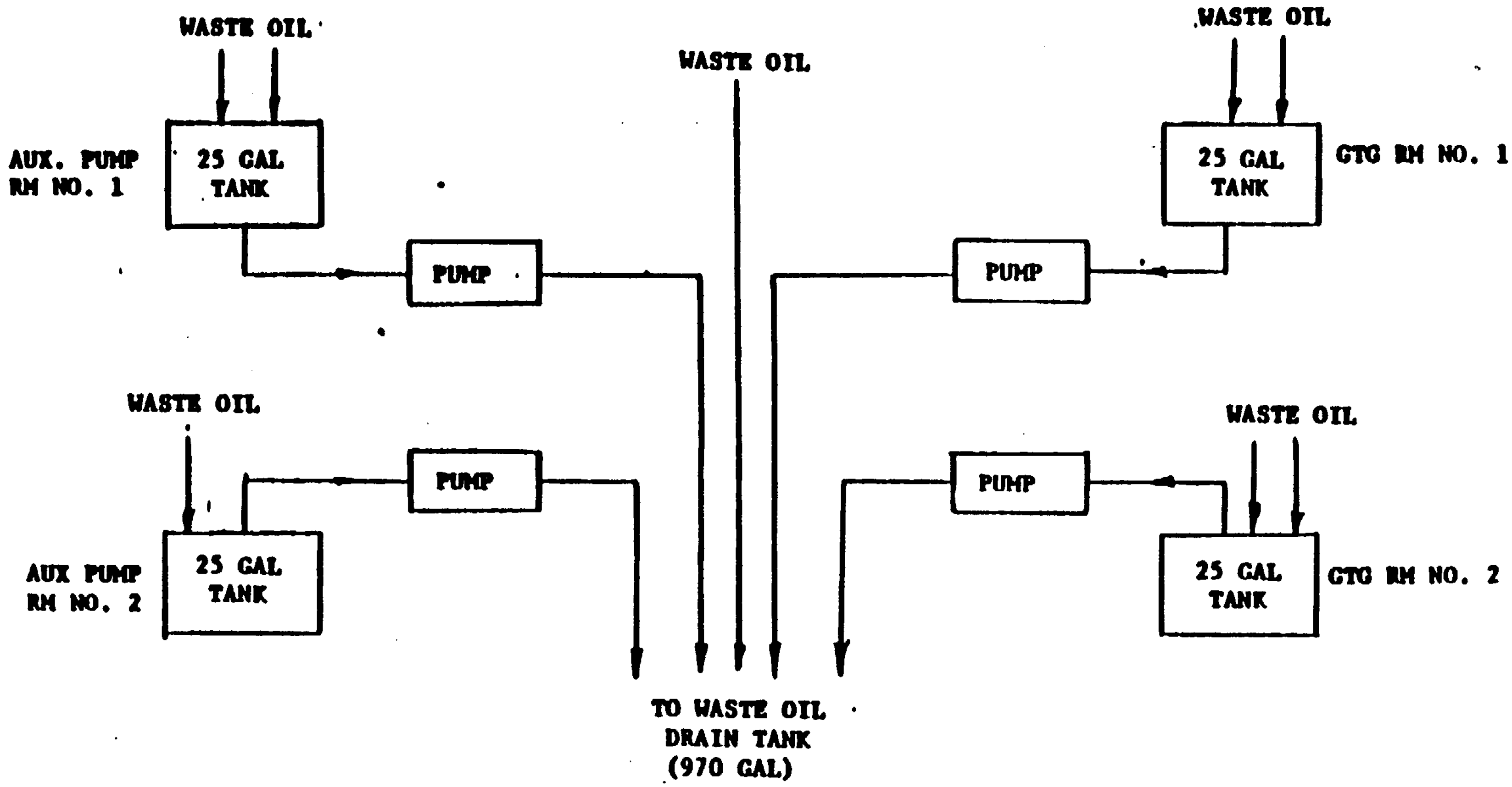


Figure E.2-3. Waste Oil Drainage

Table E.2-3. Main and Secondary Drainage Eductors

LOCATION	FUNCTION	SIZE (INCH)(2)	DRAINAGE FLOW RATE RELATED INLET LIFT, DISCHARGE HEAD (FT. H_2O)	SEAWATER SUPPLY FLOW & PRESSURE REQUIRED GPM	PSIG
Transducer/Fuel Rm No. 1 6-56-1-Q	Main drainage of Pump Room No. 1 and starboard sidewall aft segment	6 x 6 x 4	500 gpm @ 15' Lift with up to 20' Head (1)	340	100
Transducer/Fuel Rm No. 1 6-56-2-Q	Main drainage of Pump Room No. 2 and port sidewall aft segment	6 x 6 x 4	500 gpm @ 15' Lift with up to 20' Head (1)	340	100
Transducer/Fuel Rm No. 1 6-56-2-Q	Main drainage of Propulsion Engine Rms 1 & 2, Aux Pump Rm No. 1, and port propulsion engine plenum chamber	6 x 6 x 4	500 gpm @ 15' Lift with up to 20' Head (1)	340	100
Combustion Air Intake No. 1 3-38-1-Q	Main drainage of Combustion Air Intake No. 1	6 x 6 x 4	500 gpm @ 15' Lift with up to 20' Head (1)	340	100
Combustion Air Intake No. 2 3-38-1-Q	Main drainage of Combustion Air Intake No. 2	6 x 6 x 4	500 gpm @ 15' Lift with up to 20' Head	340	100
Combustion Air Intake No. 1 3-38-2-Q	Secondary drainage of Combustion Air Intake No. 2	2 x 2 x 1 1/4	40 gpm @ 15' Lift with up to 20' Head	28	100
Combustion Air Intake No. 2 3-38-2-Q	Secondary drainage of Combustion Air Intake No. 2	2 x 2 x 1 1/4	40 gpm @ 15' Life with up to 20' Head	28	100
Lift Fan Rm No. 1 4-8-1-Q	Secondary drainage of Lift Fan Rm No. 1 & 3	3 x 3 x 2	116 gpm @ 12' Lift with up to 20' Head	75	100
Lift Fan Rm No. 2 4-8-2-Q	Secondary drainage of Lift Fan Rm No. 2 & 4	3 x 3 x 2	116 gpm @ 12' Lift with up to 20' Head	175	100
Lift Fan Rm No. 1 4-8-1-Q	Secondary drainage of Lift Fan Rm No. 1 & 3	4 x 4 x 3	235 gpm @ 15' Lift with up to 20' Head	175	100
Lift Fan Rm No. 2 4-8-2-Q	Secondary drainage of Lift Fan Rm No. 2 & 4	4 x 4 x 3	235 gpm @ 15' Lift with up to 20' Head	175	100
Aux Pmp Rm No. 1	Main drainage of Aux Pump Rm	4 x 4 x 3	175 gpm @ 15' Lift with up to 20' Head	—	—
Aux Pmp Rm No. 2	Main drainage of Aux Pump Rm	4 x 4 x 3	175 gpm @ 15' Lift with up to 20' Head	—	—

Notes:

1. Drainage flow rate is 620 gpm @ 5' lift with up to 25' head.
2. Sizes given refer to the size of end connections. The first and second number apply to the suction and discharge; the last number to the driving fluid connection.

exists at the eductor inlet, thereby providing a drainage rate for propeller rooms of approximately 620 GPM, with a seawater supply pressure of 10 psig.

Similarly, the eductor located in each auxiliary pump room, being at a lower level will operate at submerged inlet conditions thereby providing a drainage rate in excess of 620 GPM for the propulsion engine rooms and/or the combustion air plenum.

By directing (valving) from the compartment to be drained, into the suction of the seawater pump(s) and closing the normal suction from the sea, (boot strapping) the water evacuation rate from the compartment is increased by 340 GPM.

SECONDARY DRAINAGE

The secondary drainage system has two, 50 GPM, 3 HP (60 Hz) positive displacement pumps which permit collection of drainage into the waste water tank, pumping directly overboard, or transfer from the tank to shore facilities. These pumps are attached to a common fore and aft header. Branches from the header provide suction through motor operated valves and check valves to drain wells. The wells are alarmed and monitored via level controls and are located in the waterjet pump rooms, the propulsion engine rooms, the auxiliary machinery rooms, electrical generator rooms, and the two lift fan engine rooms. The six eductors of the secondary drainage system (independent of the pumps) are located in the lift fan rooms and in the combustion air intake (CAI).

The secondary eductor in each CAI is employed to remove small volumes of water collected in the CAI drainwell emanating from exhaust stacks and demisters of the GTG(s), from rainwater and light spray entering directly through the CAI opening, and water from washdown of propulsion and lift engine demisters. The larger, main drainage eductor located in each CAI is employed during ship operation in higher sea states when greater flow rates are incurred.

The two secondary drainage eductors located in the lift fan rooms serve to remove water entering fan rooms through the lift air openings. Level controls in the lift fan rooms control the operation of the smaller eductor when dewatering rates of up to 33 GPM per fan are required, and control the operation of the main drainage eductor, to complement the first, to achieve a dewatering rate of up to 116 GPM per fan. This higher rate is related to ship operation at maximum fan speed, under combined conditions of dense spray and heavy rain.

For all eductors, actuation power is provided from the seawater system via motor operated valves, with watertight and explosion proof actuators and capable of local (manual) or remote (DCAEC) operation. Similarly, there are motor operated valves for the eductor suction and discharge, the latter two being combined with check valves. The check valve in the eductor inlet line serves to protect against reverse flow of water into the compartment from the actuation line caused by inadvertent or accidental operation with a closed discharge valve.

All eductors have a vacuum pressure gage installed on the suction side of the eductor, and a pressure gage on the seawater supply side. A flow switch is installed on the suction side for remote indication at the DCAEC. Flow switches are also installed on the inlet side of both secondary drainage pumps.

Normal control of the drainage system is at the DCAEC, where the following functions are monitored:

a. Area flood warning (16),
b. Eductor status ON/OFF (12),
c. Drainwell(s) high level alarm (18),
d. Pump status ON/OFF (2).

All secondary drainage pumps can be operated locally as well as via the DCAEC.

Sequencing of valve operation for operation of eductors is controlled automatically, except that:

i) All six secondary drainage eductors are provided with over-ride control at the DCAEC allowing operator start/stop.

ii) All main drainage eductors are supplied with seawater system power only at the discretion and command of the DCAEC operator.

Operation of the secondary drainage eductors and/or pumps serving compartments which are also dewatered by main drainage eductors is discontinued upon activation of the respective main eductor level control units.

Operation of secondary drainage pumps and valves is automatically controlled, the demand signal coming from level control located ub draub week(s). Each has a low and a high level triggering point, in addition to its regular monitoring capability. Control is set-up to operate the pump which is nearest the drainwell being served; should the flow rate into the drainwell exceed the outflow, the second level will demand the start-up of the second pump.

Valves are normally controlled to discharge the waste water into the waste water drain tank. An over-ride control at the DCAEC allows the operator to divert the waste water directly overboard.

At dockside, the wastewater drain tank is emptied to the shore facility by either pump (pump No. 1 on standby) after the port or the starboard dockside discharge valve is manually opened.

A low level control within the tank signals the stop of the pump and closing of the tank drainage (three way ball) valve (TDV).

During the tank drainage operation, any drainwell demand will interrupt the tank drainage by closing the TDV; the wastewater from the drainwell than being directed to the shore facility.

Tank drainage mode is automatically resumed upon the removal of the demand.

To prevent pump operation under cavitating conditions, a thermostat is installed at the drainwells in the propulsion engine rooms which prevents pump start-up until the water wash temperature in the drainwell cools to at least 100°F.

APPENDIX E.3

HVAC SYSTEM DESIGN

HVAC SYSTEM DESIGN

AIR CONDITIONING SYSTEMS

Each Air Conditioning System for a 3000 ton SES design contained two, three or four independent condensing units and refrigerant circuits located in the air conditioning fan rooms. There were four HVAC Fan Rooms aboard the SES, two of which include an additional HVAC system dedicated to electronic equipment cooling. Therefore, the total number of HVAC systems was six. Each condensing unit consisted of a compressor, condenser, condensing water control valve, receiver, suction accumulator and necessary control devices. The unit is located below its associated evaporator.

Compressor sizes are approximately 2.5, 3.0, 5.0 and 7.5 tons in combination to match loads. The six systems provide the following capacities:

System No.	Cooling Load (Tons)
1	4.8
2	14.3
3	13.3
4	13.9
5	8.6*
6	10.9*

*These systems are dedicated systems for electronic equipment loads.

CAPACITY CONTROL

Each air conditioning plant can be reduced in capacity by step sequencing compressors within the plant. The logic for the step sequence will be through control devices consisting of thermostats located within the conditioned space and signal selectors, or thermostats located in the return ducts for equipment cooling.

Each control system consists of a number of zone monitors (thermostats) and a summary control to stage A/C compressor operation.

The signal selector will accept thermostat (voltage signal) output from each zone within a multizone system and select the highest voltage for transmission to the relays controlling compressor staging. The high signal will cause compressors to come on line or drop off in proportion to its voltage level.

Within the controlled zone, the local thermostat will also cause displacement of the actuator for the variable air volume terminal proportional to the thermostat output. A final function of the zone thermostat will be to control the electric resistance heater within the air distribution duct for that space. Each controlled zone will have one variable air volume terminal and generally an electric resistance heater. The variable air volume terminal functions to control the amount of conditioned air serving a zone and thereby control the cooling capacity based on load requirements. For equipment dedicated systems, the thermostat is located to sense return air temperature. A functional block diagram for HVAC control is shown in Figure E.3-1. The concept of

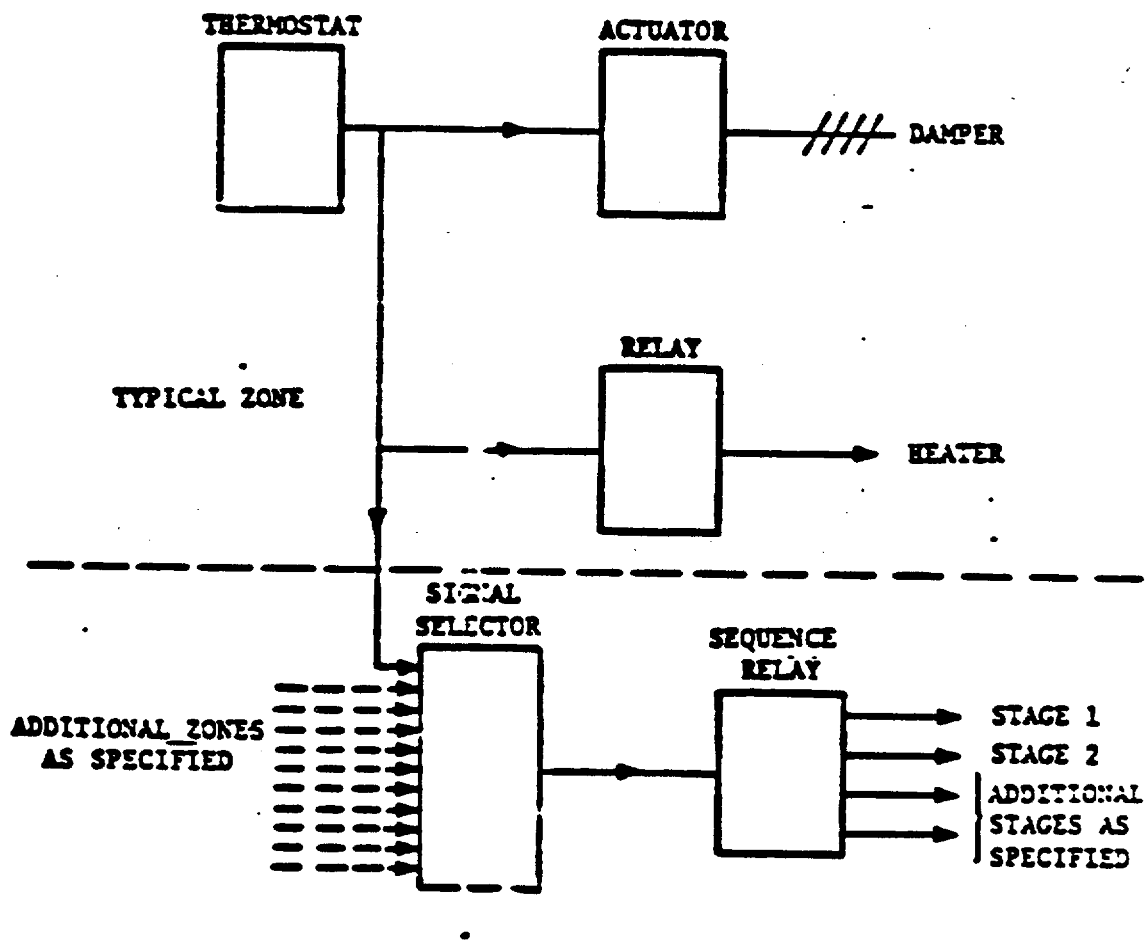


Figure E.3-1. Functional Block Diagram for HVAC Control System compressor staging with reference to zone temperature is shown in Figure E.3-2.

AIR DISTRIBUTION

A high pressure fan is located in each air conditioning plant fan room. The fan draws a mixture of replenishment and return air from the fan room and forces it through a filter and cooling coil into high velocity (2000 - 4000 feet per minute) ducting. In systems which are not equipment dedicated, variable air volume terminals in each space admit only the quantity of air necessary to cool the space to between 75°F and 80°F. The thermostatically controlled terminal has a preset maximum and minimum flow rate. Minimum flow is approximately 50% of maximum flow. Highly loaded electrical equipment spaces may be further reduced to less than 50% to reduce reheat requirements. In addition to cooling flow control, the terminal contains noise absorption materials to minimize air velocity noise. An induction feature of terminals serving occupied spaces causes secondary induction of space air through the terminal when primary air is reduced, thus maintaining nearly constant air flow through the heater and diffuser.

Return air travels back to the fan room through passages, and in some cases, is fan forced. Some of the air is expelled by exhaust fans located in water closet spaces and other designated exhaust spaces. Replenishment air from the 01 level is fed from the ventilation system to the fan rooms. The replenishment air rate is reduced in one step to 50% in the heating season to conserve electrical power.

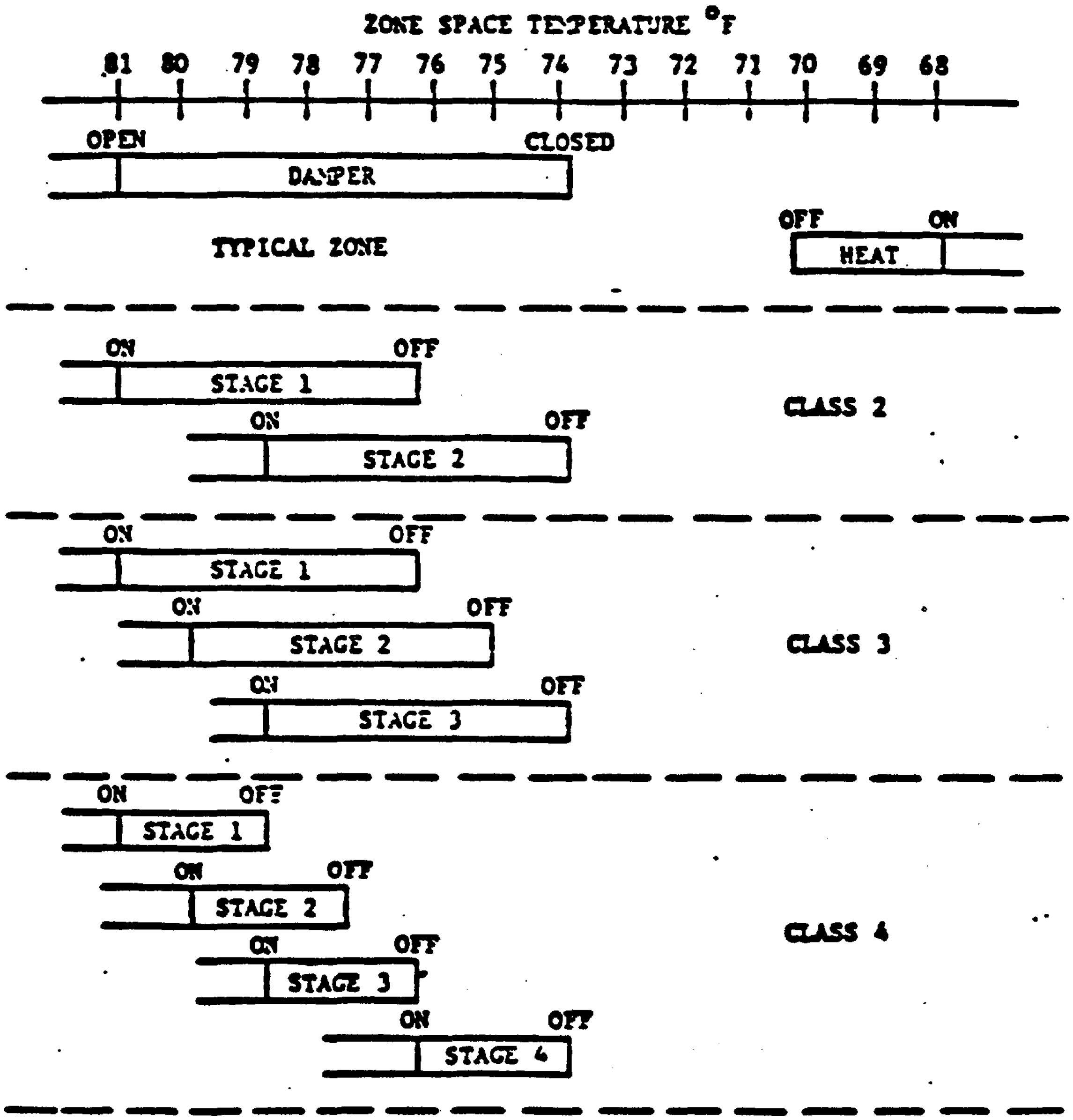


Figure E.3-2. Compressor Staging Concept

A relief or bypass damper located between the high pressure supply fan inlet and outlet dumps air directly back to the fan room or return fan as the terminals decrease air flow. This maintains relatively constant fan flow to avoid instability of the fan which could occur at less than design flow. The functional flow diagram for HVAC distribution is shown in Figure E.3-3.

HEATING AND REHEATING

Electric duct heaters are located in the supply air duct to each space or zone. In some cases, a separate space or radiant heater is used.

VENTILATION SYSTEMS

Three supply fan rooms on the 01 level deliver from the weather, via electric duct preheaters, fresh air to ventilated compartments and fan rooms of the air conditioning system.

Supply air to the medical spaces, pilot house and central control station include fumetight dampers in the ventilation supply ducts to preclude possible contamination from another space in case of casualty. Mechanical and natural supplies are used to ventilate these spaces.

The propulsion and lift engine rooms ventilation is considered part of the combustion air systems. The electrical generator rooms and auxiliary machinery rooms are provided with mechanical supply and exhaust ventilation systems.

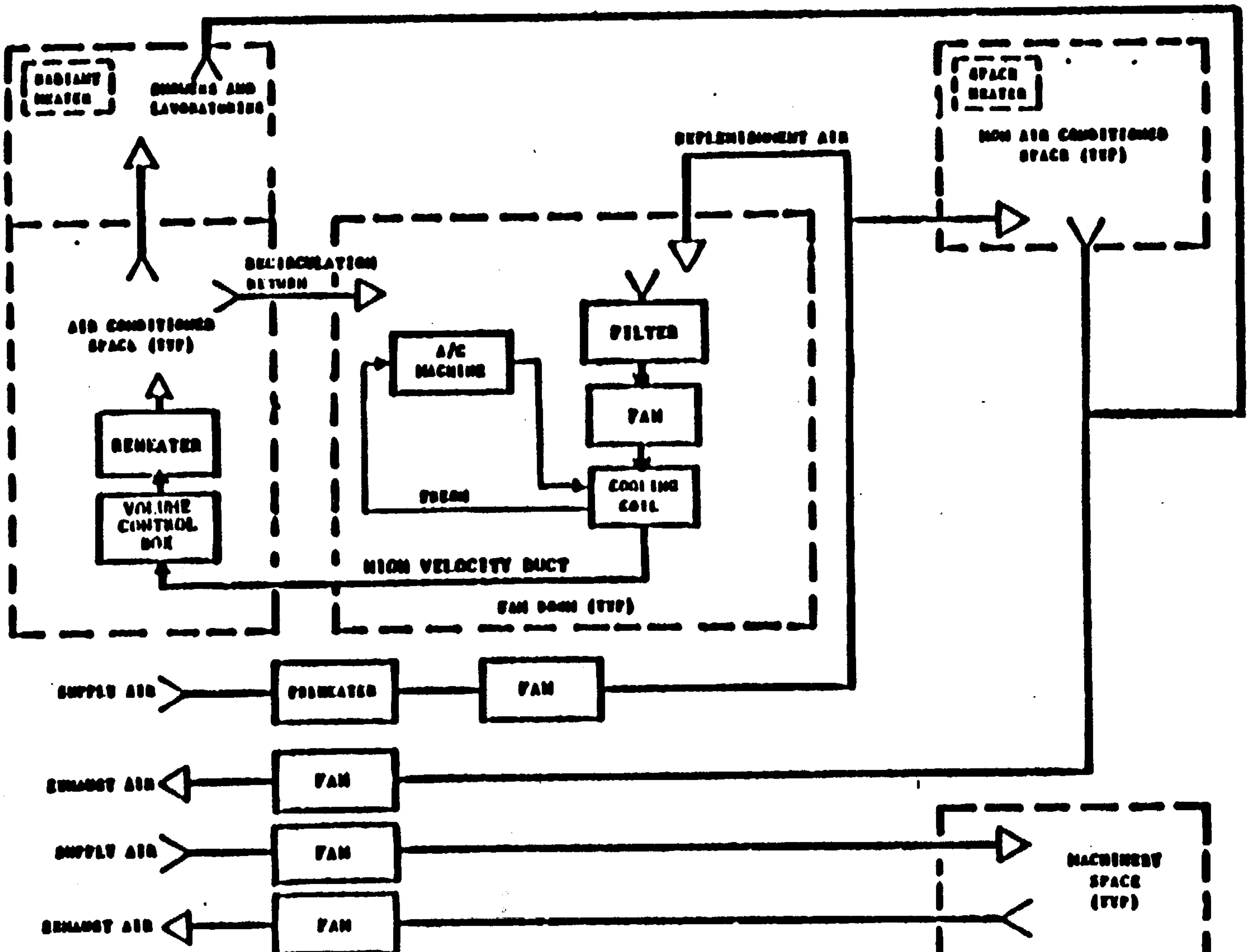


Figure E.3-3. Functional Flow Diagram - HVAC Distribution

Electric radiant heaters and mechanical exhaust to the weather are provided for all sanitary spaces.

Ventilation air flow for non-air conditioned spaces is sized to keep maximum summer compartment temperatures or rate of change in accordance with the requirement of the Design Criteria Manual. In the winter, the ventilation rate is reduced for energy conservation, by a single thermostat sensing weather ambient air.

HEATING OF VENTILATED SPACES

Spaces requiring preheated air have heaters in the air supply duct. This air is thermostatically controlled at 45°F (average). Spaces requiring warmer temperatures are provided additional duct heaters, supplemented by space heaters as necessary. These space heaters are controlled by space thermostats.

GENERATOR COOLING

While normal ventilation is supplied to generator rooms, a secondary source of air from the combustion air intake is applied directly to the generator enclosures. The secondary exhaust air becomes warmer than the primary exhaust air. Each is exhausted via separate fans. The enclosure exhaust is exhausted up the stack while the room is vented by normal exhaust.

SMOKE PROPAGATION

In the preparation of this study, the paramount hazard related to smoke propagation has been considered:

The propagation of smoke and possible failure of ventilation control aboard SES may lead to the reduction of or inability to fight the originating fire hazard. Limited visibility and the physical effect of smoke inhalation will seriously hamper or negate conventional fire fighting techniques. As such, this study has identified means of smoke and fire extinguishant containment.

The application of dampers as recommended in this study satisfies the requirements set forth in the Ship System Specification, T22000001C, Para. 3.2.2.7 in regards to a method of counteracting the effects of smoke and toxic fumes. It further fulfills the requirements of the means of such protection by planning restrictions on the ventilation system of the SES.

SAFETY RECOMMENDATIONS

1. Install dampers in ducts to machinery spaces.

2. All dampers installed serving a machinery space or a space from which machinery draws air must be provided with an interlock to insure that the damper cannot be closed until machinery in the space has ceased to operate.

3. Under current design, the SES was not provided with an automatic back-up fire extinguishing system. The incorporation of the smoke dampers specified in this study is a provision which, through the containment of smoke, or at least delay in smoke propagation, allows conventional fire-fighting techniques to be used as rapidly as personnel and equipment can be moved.

4. The build-up of residual heat in the Turbine Spaces following shut-off of the cooling fans is still being evaluated. Until the impact and amount of such residual heat is accurately determined to be structurally safe it should be remembered that the use of Halon as an extinguishing agent may be ineffective.

5. Should such be the case, an alternate, remotely actuated extinguishing system should be considered. A technique identified in Amphibious Assault Landing Craft Technology report, dated Sep 1978, recommends the use of pressurized (400 psi) water discharged as a mist. Test results indicated that a 9 ft^2 pan fire was extinguished in 4 seconds with a discharge of 2 quarts of water in a 500 cu. ft. volume space.

6. Where dampers are recommended but cannot be installed due to weight or space considerations, the space served should be provided with Halon flooding and, ideally, an additional bleed rate of Halon to compensate for loss of fire extinguishant through doors and ducts.

7. Where grills or louvered vents are placed in doors or bulkheads serving spaces for which dampers are recommended, the trills or vents should be provided with a manual closing operation that can be controlled from either side of the grill or vents.

8. Where a smoke damper requirement is satisfied by a watertight closure, the closure's mode of operation should be that recommended for a smoke damper at that location.

9. Fume-tight dampers should be manually operated and located, as far as is practicable, immediately outside the space served. Dampers should be secured open and so tagged under normal conditions.

Tradeoff studies conducted during the U.S. 2K and 3KSES programs identified some promising subsystem design options and components as follows:

ROTARY VANE COMPRESSOR

A commercial 60 Hz vane compressor is now being manufactured by the Fedders Compressor Company. The compressor is considerably lighter than the Carrier Compressor that had been tentatively selected for SES. Vane compressors are not internally vibration isolated like reciprocating compressors. The latter are not suitable in applications where external vibration or shocks are applied because excitation of the compressor motor to the limits of the internal springs ultimately results in fatigue cracking of the tubing connecting the compressor to the outside housing. Only specially modified compressors like the Carrier military compressor could be used, with a resultant high cost. The vane compressor is currently being used in mobile applications. Welco Industries of Cincinnati is currently testing 400 Hz modified vane compressors, but they are not as yet being marketed. The problem is higher rpm and life. When available, these compressors should be considered. Also, the light weight but expensive Fairchild Stratos screw compressor should be considered.

LIGHT WEIGHT DUCTING

A major consideration in the initial design of the SES was to decrease weight wherever possible.

One area where weight was saved on the HVAC system was the use of light weight, high-pressure aircraft fans rather than the much heavier Navy standard fans.

Weight-saving considerations were not fully explored for duct material specifications. The initial HVAC design used the General Specifications for Ships of the United States Navy. This general specification gives the minimum thicknesses listed in Figure E.3-4.

These material thicknesses are for use on all surface ships. However, most surface ship designs are not faced with the same weight saving considerations as SES.

Sheet for Fabricated Ductwork

	Nonwatertight		Watertight	
Diameter or longer sides (Inches)	Galvanized Steel (Inch)	Aluminum (Inch)	Galvanized Steel (Inch)	Aluminum (Inch)
Up to 6	.018	.025	.075	.106
6.5 to 12	.030	.040	.100	.140
12.5 to 18	.035	.050	.118	.160
18.5 to 30	.048	.060	.118	.160
above 30	.060	.080	.118	.160

Welded or Seamless Tubing

	Nonwatertight	Watertight
Tubing Size (Inches)	Aluminum (Inch)	Aluminum (Inch)
2 to 6	.035	.106
6.5 to 12	.050	.140

Sprially Round Duct (Nonwatertight)

Diameter (Inches)	Steel (Inch)	Aluminum (Inch)
Up to 8	.018	.025
Over 8	.030	.032

Figure E.3-4

In an effort to find an alternative to these specifications, the HVAC design section investigated other types of ductwork for applicability to SES. One promising ductwork system is produced by United Sheet Metal of Westerville, Ohio. They are specialists in spiral duct and have provided ductwork for many U.S. shipbuilders.

A new development at United Sheet Metal was of interest to the HVAC section. It involved a new process that formed a continuous raised ridge around the spiral ductwork. According to the United sales representative, the added strength of this ridge allows the use of lighter weight duct. For example, if .060 aluminum ductwork is required in a certain situation, a .050 raised ridge duct would provide the same strength at a weight savings of .183 lbs. per square foot.

Another opportunity for weight savings would be the use of spiral raised ridge flat oval ductwork in place of standard rectangular duct. Previously, marine spiral ductwork was limited to round use only. The new process at United would almost eliminate the need for rectangular duct.

It should be pointed out that spiral duct is available for straight runs only. Fittings are only available in standard weldable thicknesses.

Also, before the raised ridge duct is specified for any shipboard use, test results must be obtained to verify that a lighter weight duct could withstand the loads placed on it in high-pressure installations.

Should the strength tests prove favorable, the use of this type of ductwork would appreciably reduce the overall weight for the entire ship.

SMOKE PROPAGATION

The propagation and dispersal of smoke and noxious gases must be included during the ventilation design phase. Final recommendations included:

a) Installing smoke dampers with interlocks in ducts to machinery spaces;

b) Adding manual closing operations for louvers in doors and bulkheads.

Since smoke propagation and halon containment are a real concern, recommendations must be made prior to ventilation system design and analysis.

By breaking up these ventilation systems into smaller systems with separate fans, cross-connections can be eliminated. This will reduce the chance of smoke or halon infiltration into manner spaces during a shipboard fire.

MIL-STD-1472B offers much broader temperature and humidity ranges for its comfort zones and provides a more realistic approach to military shipboard conditions. The summer comfort zone temperature ranges from 67 to 89 degrees and humidity ranges from 10 to 90 percent. The winter comfort zone temperature ranges from 66 to 83 degrees and humidity ranges from 10 to 90 percent.

The boundaries for the MIL-STD-1472B comfort zones are based on an effective temperature (ET) scale, which shows constant physical sensation lines. These lines give the combination of temperature and humidity which provide the same comfort.

ASHRAE also has developed an effective temperature scale which varies from the MIL-STD-1472B scale. Refer to ASHRAE Fundamentals Book for further information.

TEMPERATURE REQUIREMENTS

The temperature requirements for air conditioned personnel spaces (offices, berthing, wardrooms, etc.) in summer was 80 degrees F dry bulb/55 degrees relative humidity, and in winter was 70 degrees F dry bulb/no R.H. requirement. These were the standards from which the HVAC calculations were developed. If it was possible to use more realistic requirements, the heating and cooling loads might be reduced appreciably. The lower loads would allow for smaller or less HVAC equipment with a considerable conservation of energy and wright.

HEATING SEASON

The original U.S. Navy temperature requirement for air conditioned spaces on surface ships was 65 degrees F dry bulb. That temperature was raised to 70 degrees in OPNAVINST 9330.7A, U.S. Navy Shipboard Habitability Design Standard. This standard also includes the provision that appropriate tradeoffs be conducted to derive habitability features most responsive to mission requirements.

In the case of the SES, a tradeoff study should be made to determine whether lowering the design temperature in berthing spaces to 65 degrees F dry bulb will have an effect on reducing the heating load requirements. The lower design temperature would probably be more comfortable for sleeping, since metabolism for sleeping is approximately half that of light office work.

Making a rough preliminary estimate, it was determined that lowering the design temperature of berthing spaces from 70 to 65 degrees would reduce the KW required for heating those spaces by approximately 10 percent, a considerable savings of energy. This savings would reduce the size of many heaters, thereby saving weight.

COOLING SEASON

The cooling season requirements for most air conditioning spaces (offices, berthing, etc.) on the SES is 80 degrees D.B./55 percent R.H. This design temperature condition, when plotted on the cooling season psych chart gives an effective temperature reading of 74 degrees ET, below the 75 degree ET upper boundary of the summer comfort zone.

To analyze the air conditioning systems, each system room mix temperature and relative humidity could be plotted on the psych chart to determine the effective temperature for the system. The results of this analysis are as follows:

A/C System	Room Mix Temperature	Effective Temperature
1	80.4°	72°
2	82.6°	74.5°
3	82.6°	74.7°
4	80.0°	72°
5	85.0°	76°
6	85.0°	76°

As shown above, all but two systems (numbers 5 and 6) have an effective temperature under 75 degrees and as such are within the MIL-STD-1472B summer comfort zone.

Since nine of the A/C systems have room mix temperatures under the upper boundary of the comfort zone, there is an opportunity for energy savings if the room mix temperature were allowed to increase to the upper limit.

HEAT PUMPS

The ultimate HVAC system for an SES is one which meets all of the requirements for personnel health and safety and the combat readiness of the ship at minimum weight and maximum energy efficiency.

Such a system requires a departure from traditional and Navy standards of design, equipment and materials. From preliminary studies, a water source heat pump offers promise of providing the ultimate system. The heat pump has become, in recent years, one of the outstandingly energy efficient devices for controlling an interior environment. In the commonly known heat pump, heat is removed from a space and rejected to the outside by the standard vapor cycle refrigeration system. By reversing the cycle, heat is extracted from the outside and rejected to the space. In the water source heat pump, the outside is replaced by a circulating water supply which serves as a rejection medium or the source of heat, depending on the mode of operation of the heat pump. The circulating water system is provided with means for cooling or heating as required to maintain the circulating temperature within limits which will produce efficient space heating and cooling.

Customarily, heat pumps are applied to a complex structure in small unitary machines served by a single water system. It can be seen that by this means heat can be removed from one portion of a structure and added to another part if required.

For the SES, as applied to other structure of similar complexity and compartmentation, individual heat pump units would be installed within the space being controlled and would require little or no duct work. An exception might be a series of contiguous spaces, such as berthing areas having similar environmental requirements, where one heat pump may serve several spaces with interconnecting ducts.

The advantages offered by this system is weight, efficiency and space saving are as follows:

1. The duct work required may be reduced in weight by as much as 80%, partially by reduced size and primarily by elimination.
2. The weight and complexity of electric duct heaters is eliminated entirely along with the wiring and controls.

3. Electrical load is drastically reduced for heating since heat pumps provide approximately three times the heat of resistance heaters per watt.
4. Fuel consumption for electric generation is reduced.
5. Waster heat from the exhaust of the electric generators is added to the circulating water system to provide space heating.
6. Simultaneous heating and cooling of any space is eliminated saving energy and fuel.
7. Fan rooms for HVAC are eliminated.
8. Controls become simple heating/cooling thermostats, reducing system complexity.
9. Reliability is enhanced since each heat pump is an individual system. The failure of a heat pump will only affect the area served and not affect the operation of the balances of the system.
10. Infinite zoning is possible for special temperature requirements.

The disadvantages are:

1. Additional ventilation ducting would be required since replenishment air must be piped to each heat pump. However, these are small ducts and do not add significantly to the system weight.
2. Piping would be increased by the circulating system. Such pipes are light weight fiberglass and do not require insulation.
3. A means of heat rejection and a waste heat boiler would be required adding to system weight.
4. Condensate drainage problems would be complicated by the number and dispersion of the evaporators.

Water source heat pumps have been marketed for over 20 years, and are available from a number of suppliers. However, no information is available as to their compatibility with the marine environment.

PROPULSION EXHAUST DUCTS

In the current ship configuration, the outboard propulsion exhaust ducts are located in the upper level of the 2and deck aft, both port and starboard. The extremely high temperatures in the exhaust ducts require that the pump rooms each have their own ventilation system.

The solution to this design problem is to locate the propulsion exhaust ducts outside the watertight boundary of the ship, by locating a watertight deck directly under the exhaust ducts at the 2and deck level, and providing grating above and outboard of the ducts.

The propulsion exhaust ducts would then be cooled by exposure to outside air, and would not require a separate ventilation system.

The drawback of this proposed solution is that a sizeable portion of the flight deck would be made of some type of grating, with reduced structural strength. A structural analysis would be required to determine whether additional structural members were necessary.

VORTEC COOLING SYSTEM

In reviewing the problem of backup cooling for vital equipment, the VORTEC cooling system was investigated.

The VORTEC enclosure cooling system sold by VORTEC Corporation of Cincinnati is a product which converts compressed air into two streams, one hot and one cold. The cold air is directed into the electrical enclosures, replacing the heated enclosure air which is induced and vented outside with the hot exhaust of the vortex tube. The product can be used continuously, or with a thermostat for intermittent usage.

The entire cooling system uses 25 CFM at 100 psi inlet pressure. Refrigeration is generated at the rate of 1500 BTU/Hr or 440 watts when running continuously.

As can be seen from the above figures, these products offer only a partial solution to equipment cooling. However, they might be used as a backup system in the event of A/C system failure, or as preliminary cooling for the A/C system.

As stated above, this system requires connection to the ship service air lines. Also a route must be found for the exhaust from this system to the outside.

APPENDIX E.4

FRESH WATER SYSTEMS

For the distillation plant, three options were considered:

a. An electrically heated vacuum distriller

b. A vacuum distiller which used the turbine engine exhaust waste heat,

c. A reverse osmosis process

The electronics cooling, potable and fresh water and auxiliary fresh water cooling systems adhere to standard Navy practice and no system alternatives were considers; however, some variations were considered primarily to offer a weight or water savings. As an example, Table E.4-1 outlines several showerhead options. The Low Flow Showerhead which uses 1.75 GPM was selected for the system.

The results of trade-off studies performed in the distiller area have lead to selection of a commercial, electrically heated, vacuum distillation unit. The reverse osmosis unit, even though advances have been made in membranes suitable for sea water use, was eliminated because no commercial unit specifically packaged for shipboard service was available. This process, however offers long tern potential because of modest installed weight and minimal operating power requirements. Utilization of turbine exhaust waste heat was eliminated on the basis of convenient packing of water heating coils around the GTG exhaust ducts and because of somewhat higher overall weight than the vacuum still.

Table E.4-1. Showerheads Comparison

OPTION	WATER USAGE RATE (HOT & COLD)
Standard Showerheads	2 gpm min. at 5 psig min. per GEN SPECS 5 gpm at 12 psig per commercial standards 2.5 gpm per MIL-S-955 5.3 gpm per DD 938
Low-Flow Showerheads	Approximately 1.75 gpm Installation is simple
"Minuse" System Showerheads (Minuse System, Inc. Jackson, CA)	0.5 or 0.7 gpm depending on nozzle design chosen. Electrical power required for operation. Pressure required is 35 to 125 psig. Highest cost of all.
NSRDC Handheld Unit	0.75 gpm, this system requires the user to push a button to maintain water flow.

DISTILLING PLANT

The distillation units (2) selected are of the vapor compression type (thermo-compression). The units are self-contained "package type". The units are designed for automatic operation, and is suited to remote start and monitoring.

Each unit will produce, without descaling or cleaning, an average of 2400 gallons per 24 hours of operation over a period of 10 days. The plant will produce distillate from sea water of not less than 1.32 density (32 pounds of sea water containing one point of dissolved salts) and at temperatures between 28° and 85°F. The product water will have a salinity content not exceeding 0.0325 equivalent per million of chlorides (epm) or 0.125 grains of sea salts per gallon (gpg).

The unit operates on input power sources as follows:

a. 440 V, 3-phase, 400 Hz for all pump motors, electric heaters, and compressor motors.
b. 28 V, direct current for control circuitry.
c. 110 V, 1-phase, 400 Hz for operation of the salinity indicating system.

The unit incorporates a suitable system for locally monitoring distillate purity by means of a relay meter calibrated in microhms/cm, with automatic correction to 77°F. The meter will provide adjustable set point relay contacts for local audible and visual alarms with sufficient contact rating for additional remote alarms and controls.

The distillate will be disinfected by use of two in-line (one for each distiller) proportioning brominators. Bromine concentration will be maintained at the correct level by an off-line, manually operated, recirculating brominator in the potable water storage portion of the system.

The materials of construction conform to U.S. MIL-D-16196D (Ships) Class A, for those surfaces in contact with the process fluids. In the interest of weight reduction, aluminum alloys will be used in the fabrication of the mounting skid, pipe supports and brackets. Suitable design precautions will be observed for the prevention of galvanic corrosion. Figure E.4-1 depicts the distillation plant diagrammatically.

POTABLE AND FRESH WATER SYSTEMS

The potable and fresh water service system is designed for continuous duty with suitable redundancy or duality in major equipment items. The system design is in general compliance with General Specifications, but contains some modifications designed to tailor the system to the specified needs for the SES. Hot and cold water is furnished to the ships fixtures in accordance with the GSS. The fixtures and maintenance service outlets requiring hot and cold potable water are listed in Table E.4-2.

Recirculation loops for the fore and aft portions of the system ensure that hot water is provided within 15 seconds at any outlet. An independed system provides pressurized, untreated water, at specified flows and temperatures to all of the ships turbine engines for washing.

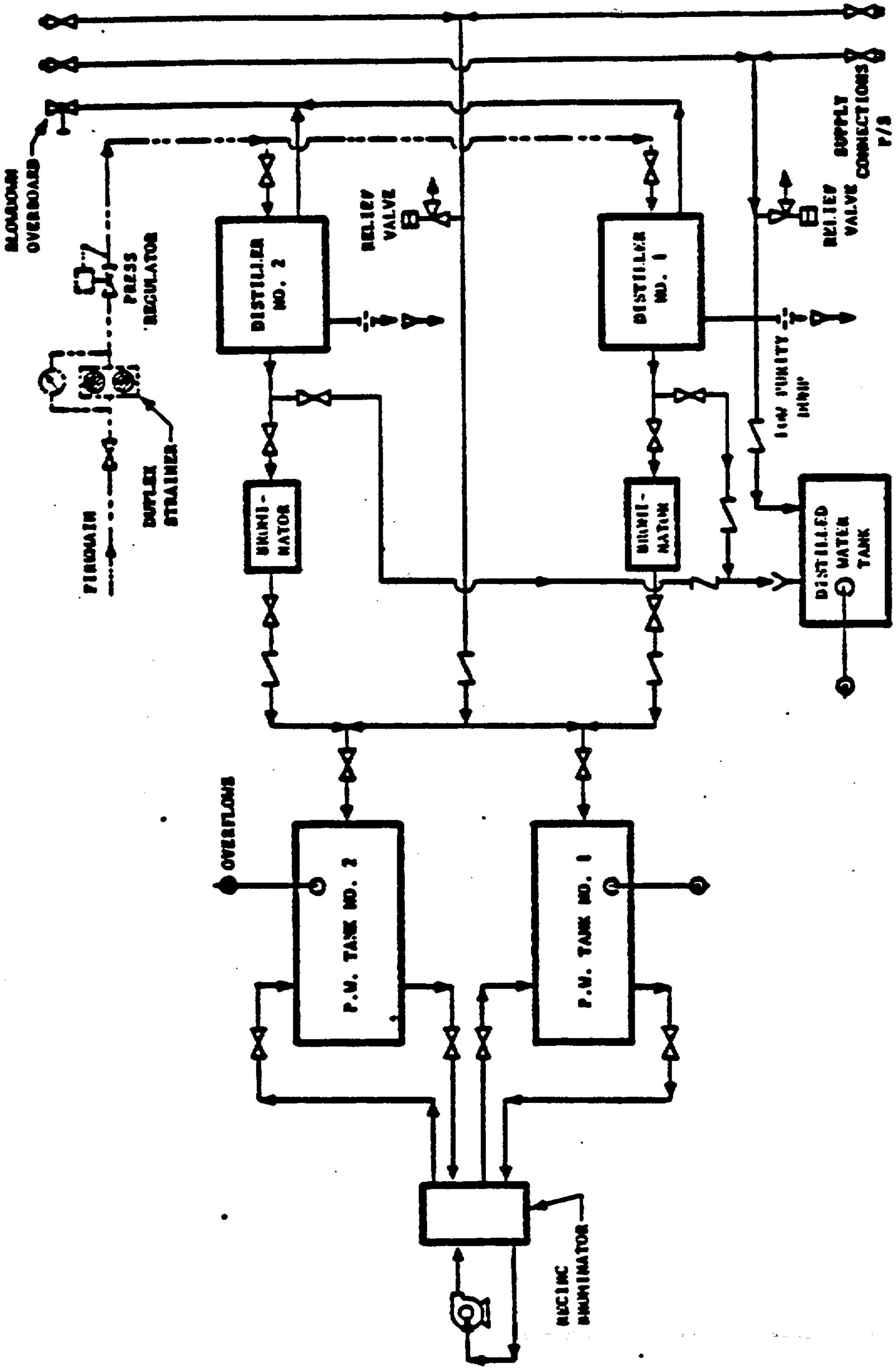


Figure E.4-1. Distilling Plant Diagram

Table E.4-2. Potable Water Service Connections

FIXTURE OR SERVICE OUTLET	QTY	INSTANTANEOUS FLOW RATE (GPM)	PRESSURE AT FIXTURE (PSI)	SUPPLY TEMP (°F)
Shower	12	1.75	10	H & C
Sink, Service	5	6	10	H & C
Sink, Scullery	1	6	10	160 & C
Lavatory	22	3	10	H & C
Veg. Peeler	1	3	10	C
Dishwasher	1	1.8	30	180
Washing Machine	2	25	40/100	H & C
Drinking Fountain	7	0.2	10	C
Ice Machine	1	3 gph	40	C
Ice Cream Dispenser	1	-	10	C
Steam Table	3	10	60	70/225
Grease Intercept Hoods	6	5.4	40/80	140/180
Water Closets	14	3.5	35	C
Urinals	8	3.5	35	C
Helo Wash Outlet	1	10	30	C
Windshield Wash Outlet	2	5	5	C
Steam Generator	1	3	20/50	H
Carbonated Beverage Dispenser	1	3	30/80	C
Coffee Urn/Maker	3	5	15/45	H
Booster Heater	1	6	30	H
Lift Fan Room Outlet	4	10	30	C
Combustion Air Room Outlet	2	10	30	C
Filter Cleaning Hood	1	7.9	40/80	140/180
Trash Compactor Room	1	5	30	C
Propulsion Room Outlet	2	10	30	C
Propulsor Room Outlet	2	10	30	C
Auxiliary Machinery Room Outlet	4	5	30	C

Provision is made for proportioning detergents into the wash water, as specified by the turbine manufacturers.

Figure E.4-2 illustrates the potable and fresh water service system.

ELECTRONIC COOLING WATER SYSTEM

The electronic cooling water system delivers 59°F fresh water to electronic units. The system is comprised of standard package type water chiller, with an electrically powered compressor and a sea water cooled condenser, distribution piping (essentially CRES), two pumps, flow balancing valves, expansion tank and pressure, temperature and flow instrumentation of both local and remote indication type. Figure E.4-3 depicts the system schematically.

AUXILIARY FRESH WATER COOLING

The system design is based on the system described in Navy Mechanical Standards Drawing No. 803-225-1137 entitled "Electronics Cooling Water System". A standby heat exchanger is not included in the system design. The system, constructed essentially of CRES, provides demineralized water at 105°F and the purity specified in MIL-STD-11399; which is a standard governing cooling water to be used in support of electronic equipment. The system is initially charged with water of this quality and is maintained at this level of purity by a demineralizer located in a bypass loop of the system. The bypass loop is sized at 5 percent of the total system flow. Figure E.4-4 depicts, schematically, the system elements.

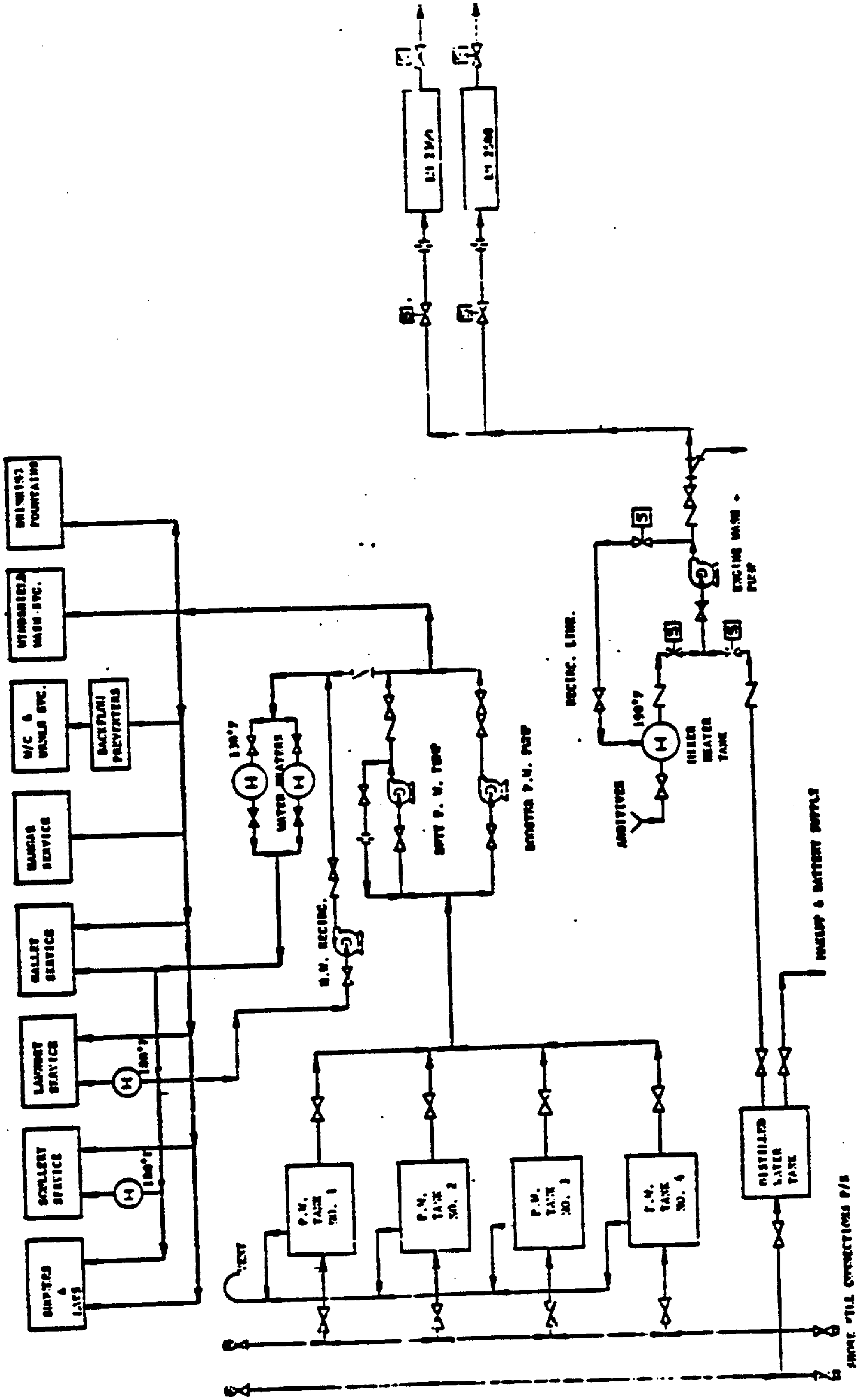


Figure E.4-2. Potable and Fresh Water Service Diagram

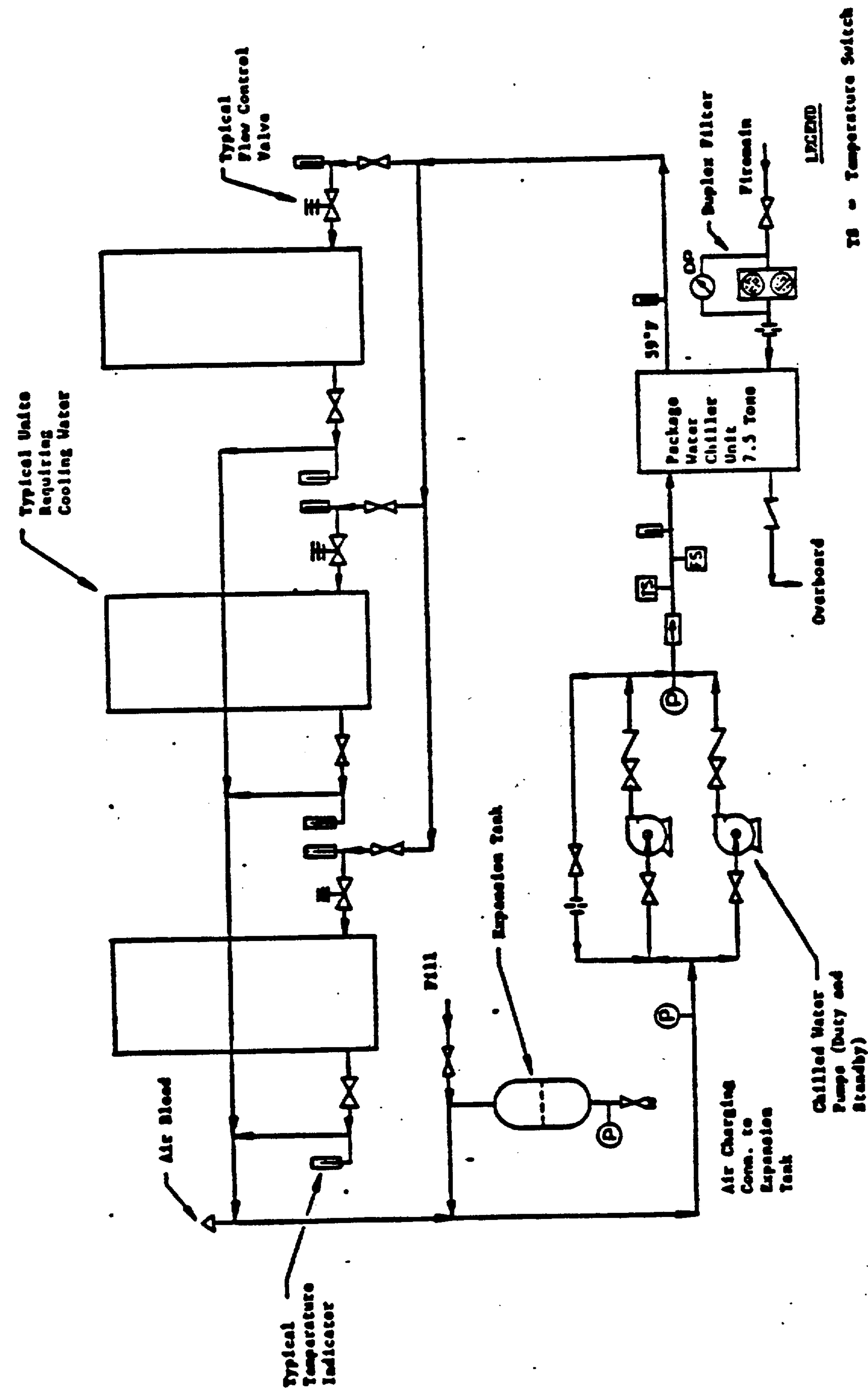


Figure E.4-3. Chilled Water Cooling System (SWBS 532)

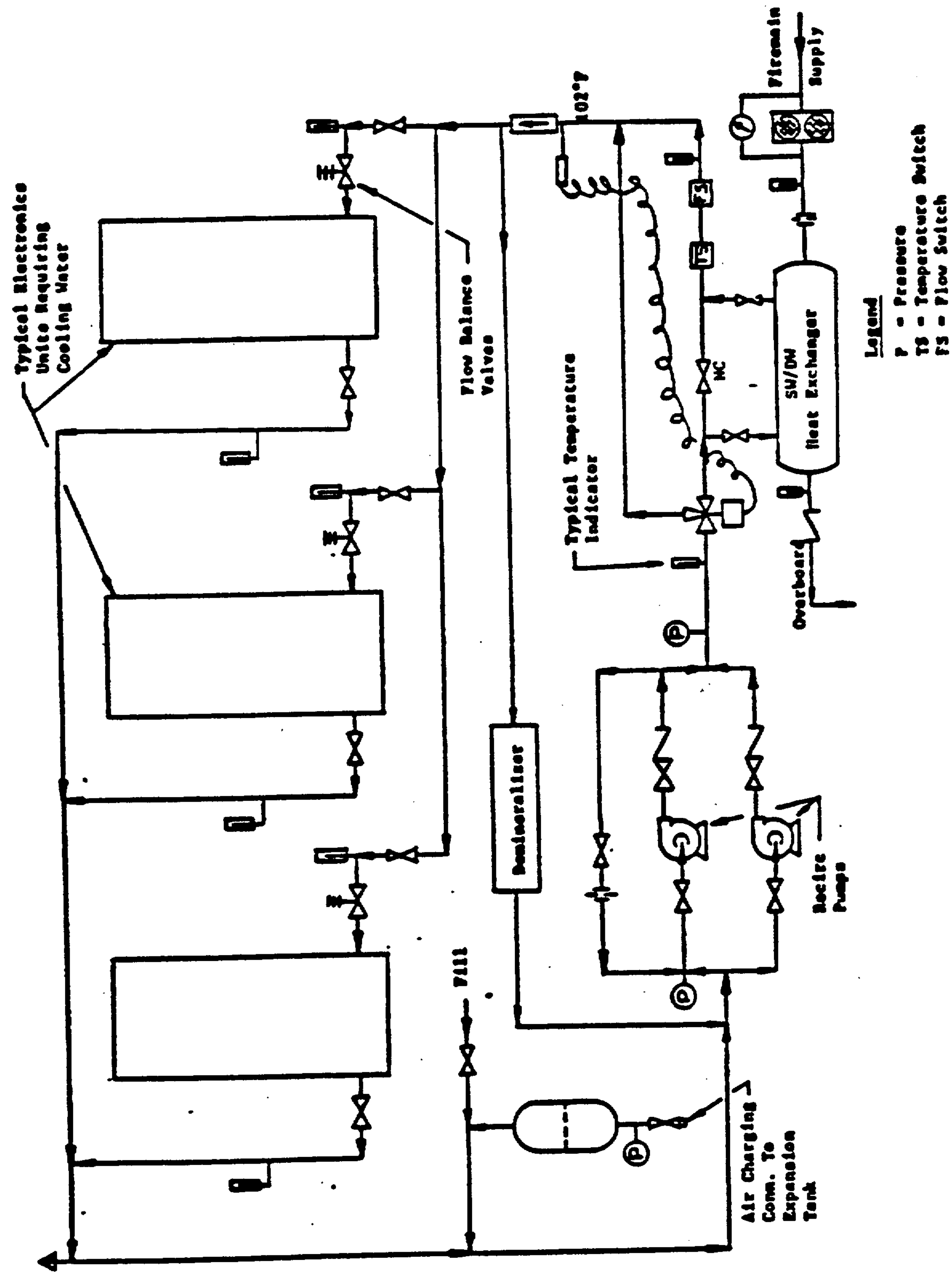


Figure E.4-4. Auxiliary Fresh Water Cooling System

APPENDIX E.5

FUEL SYSTEMS

FUEL OIL SYSTEM

The fuel oil system had three basic functions; service, transfer and trim, and stripping. The service subsystem served the fuel demands of the propulsion plant the lift system, the electric plant and also provide "clean" fuel to the helicopter service tanks.

Table 2-10 provides a summary of the Fuel Oil Service operating parameters.

Table E.5-1. SES Fuel Oil Service System Requirements

Fuel	MIL-T-5624 (Grade UP-5)
Fuel Pressure	5 to 50 psig
Fuel Temperature	15° above cloud point to 150°F
Particle Size	10 u absolute
Particle Quantity	10 mg/gal
Maximum Entrained Water Content (per volume) at 70°F	40 ppm
Maximum Flow Rate (all services)	350 gpm
Black Ship Flow Rate	12 gpm (28 VDC Motor Driven Pump)

The SES Fuel Oil Service System originated at the ship's service tank. Fuel was drawn from the fuel oil storage or fuel oil trim/storage tanks, processed through a set of duplex filter separators and transferred to the dedicated Fuel Oil Service tanks. When the fuel oil is delivered to these tanks, it is no longer available for trimming, thereby reducing air and water contamination. The fuel oil service subsystem took suction on the service tanks, and a second set of filter separators processed the fuel again before delivering it to the propulsion, lift and electrical engines. The Fuel Oil Service System is divided into port and starboard distribution systems. Each system incorporated dedicated pumping, filtering, and flow control components. By cross-connecting the starboard and port systems, complete redundancy is afforded the SES. Components included are:

- Two service tanks
- Two service manifolds
- Two prefilter-filter/separators
- Two service pumps
- Vents and overflows
- Liquid level indicators
- Damage control valving
- Flow control valves

The heart of the service system is its distribution center or fuel oil service manifolds. The manifolds are designed to integrate into one unit; a high flow (350 gpm) centrifugal aircraft pump, a low flow (12 gpm) centrifugal pump, and cartridge type isolation valves.

The high flow service pump is for normal operating conditions, the low flow pump will be used for "start-up" and black ship operation. The high flow service pump is driven by a 400 VAC - 30 - 60 Hz electric motor, the low flow pump is powered by a 28 VDC electric motor.

The concept behind manifolding the service components is to reduce weight, eliminate tubing joints, and provide a local center of control.

The filter-separators conform to MIL-F-15618 and are designed for 350 gpm, 10 u absolute particle size, and 40 ppm entrained H_2O at 70°F. The units are designed with a prefiltering stage to eliminate particulate contamination at the filtering elements thus maintaining high performance and long life.

The trim and transfer system receives the ship fuel from the refueling stations and distribute it to the fuel oil storage and fuel oil trim/storage tanks. The system incorporates 2 pumping stations or manifolds, for trim and transfer. Each has a capacity of 350 gpm at 80 psi. The transfer system supplies fuel to the service tank through a set of duplex filter separators similar to the service system. The trim system route fuel to and from the trim/storage tanks, and if required the storage tanks, to adjust the craft center of gravity as required by the operating profile.

The transfer and trim manifolds were designed with the same basic idea of the service manifold, and incorporated similar components. Redundancy was obtained by pairing the trim manifold with the transfer manifold. The distribution system was symmetrical about the centerline of the ship, thereby providing equal pressure drop and an even fueling rate during refueling operations. The transfer and trim system consisted of the following components:

Transfer System

- One fuel oil storage tank
- One transfer manifolds
- One 350 gpm, 80 psi, 440 VAC - 30 - 400 Hz centrifugal pump'
- One duplex filter/separators per MIL-F-15618
- Damage control valves
- Vents and overflows
- Liquid level indicators

Trim System

- Four trim-storage tanks
- One trim manifolds
- One 350 gpm, 80 psi, 440 VAC - 30-400 Hz, centrifugal pump
- Damage control valves

A stripping subsystem was incorporated into the overall fuel oil system to remove water contamination. Contaminated fuel oil is collected and processed to the Contaminated Fuel Tank (CFT). The contaminate is then transferred from the CFT to a dedicated contaminated fuel holding tank (CFHT), and retained here until discharge to a proper facility is available. The stripping system is independent of the fuel oil system and served all fuel oil tanks.

The stripping system consisted of:

- Two stripping manifolds
- Two centrifugal 100 gpm, 50 psi, 400 VAC - 30 - 400 Hz electric motor driven pumps

Refueling and defueling operations are performed at refueling at sea stations (RAS). The fueling replenishment at sea equipment was designed, located and installed in agreement with U.S. Navy Document NWP 38D. The requirements of fuel replenishment at sea are defined as "side by side replenishment, at a maximum of 3,000 gpm using U.S. Navy standard equipment." The requirement of 3,000 gallons per minute replenishment rate was satisfied through transfer stations (7" hose, single proble receiver) port and starboard. The receiving station included the required equipment to handle the 300 foot heavy weather rig. Dockside fueling of the craft was performed through the same fueling equipment used for underway fueling.

The design of the controls for the fuel system was based on a combination of manual and automatic control. All valves were electrically (24VDC) operated with manual redundancy and position indicators. The use of the functional manifolds allows the controls to be set to any function (alignment of the system) and powering the system to achieve predetermined tank levels.

Fuel control functions were performed manually and electrically. At each manifold, a centralized electric control station and a local control station was provided. The display was: (a) digital and warning light for the fuel level, (b) digital and warning light for the pressure indicators (selector switch), (c) warning lights for filter P, (d) functional lights for pumps, filter, filter coalescer, (e) digital indicator for fuel temperature at service tanks (selector switch), (f) digital indicator for fuel temperature at engine inlet (engine instrumentation), and (g) readout for strapped-on flow meter (selector switch).

Fuel systems design integration was represented by the central control where all the functions of the system are monitored and all the functions except the helicopter fueling functions are controlled.

Through fuel management, the proper ship center of gravity can be controlled for the best attitude and performance of the craft. The central control together with the monitoring devices and instruments make fuel management possible.

AVIATION FUEL SYSTEMS (JP-5)

The aviation fuel system (JP-5) was designed and engineered in accordance with Section 542 of the GSS. The JP-5 Aviation Fuel System from the JP-5 service tanks is an independent system in its operation and control. The tanks are filled from the SES JP-5 service tanks through the prefilter-filter/separator units of the SES fuel system service subsystem.

The JP-5 system included a manifold that integrated the fuel pumps and valves (identical to the one of the SES DFM Fuel Oil System), electric motor operated valves, a filter/separator, and a control station just below main deck level that included the hose reel for inflight refueling and connections for deck fueling, defueling and fuel recirculation. Since the pumping equipment was of the centrifugal type, the differential pressure increase during inflight refueling reduced the flow capability to 150 gpm.

MATERIALS

The Fuel Oil System on the SES has the advantage of being compatible with existing aircraft materials and components. Except for the large size components and filters, aircraft hardware was utilized to its maximum potential.

Tubing is a corrosion resistant steel of high strength per AMS 5561, commonly known as 21-6-9 CRES or ARMCO Nitronic 40. This high tensile strength alloy allowed the use of thin wall tubing that together with the reliability improved the system installation with a large margin of safety. The resistance to corrosion is compatible with CRES 316l.

A survey of the market indicated that the fuel valves as used in aircraft fuel systems were suitable and compatible with all the conditions. The only modification required was the change of the aluminum alloy butterfly disc to stainless steel to increase the pressure rating of the valves. All valves incorporated thermal relief.

APPENDIX E.6

COMPRESSED AIR AND NITROGEN SYSTEMS

STARTING AIR SYSTEM REQUIREMENTS

The system requirements for the 3KSES were established by the FT9 (propulsion engine) and LM2500 (lift engine) starters, propulsor (waterjet) priming and engine motoring (wash). Table E.6-1 summarizes these requirements.

Table E.6-1

Starting Air System Requirements

SYSTEM	DUTY	FLOW, LBS/MIN	PRESSURE, PSIA (MIN)	TEMP., °F (MAX)	AVAILABILITY
Start Air					
	Start LM2500	194	49.7	450	
	Prime Propulsor	116	59	425	Intermittent
	Wash LM2500	119	40	200	

HIGH PRESSURE COMPRESSED AIR REQUIREMENTS

MK32 torpedo tubes launch system required 1500 psig charged flasks (900 cu. in.) for torpedo launching. In addition, 250 psig for the VLS is required. This was an intermittent service.

SERVICE AIR SYSTEM REQUIREMENTS

The service air provided uninterrupted service to vital systems by the use of a priority valve. Dry air was provided for wave guide pressurization and other equipment as required. Regenerative type desicant dehydrator was used to assure air quality per MIL-D-23523 for Type II dehydrators. Outlets for non-vital services were fitted with in-line filter, regulators and gauges as required. Table E.6-2 provides a summary of service air requirements.

NITROGEN SYSTEM REQUIREMENTS

Nitrogen System provided oil-free nitrogen at 4 to 3000 psig in accordance with Federal Specification BB-N-411, Type 1, Grade A, Class I. Distribution and outlet discharge pressures of nitrogen stations satisfied those requirements of NAVAIR Bulletin 1C to accomplish certification. System demand for nitrogen is provided in Table E.6-3, Nitrogen System Requirements.

SYSTEM DESIGN

The Start Air System is shown in Figure E.6-1. The source of start air was three load compressors driven by 3 diesel generator sets. Each DGS drove one load compressor as required. The load compressors could be de-clutched when not required. One load compressor was capable of starting one propulsion engine at a time or one lift engine at a time. The propulsion engines could also be started by cross bleeding, one at a

Table E.6-2. Service Air Requirements

ITEM	USE	LOCATION	TOTAL FLOW, SCFM	PRESS, PSIG	DRY AIR YES	DRY AIR NO	FILTER REQUIRED	REMARKS
1.	Collecting & Holding Tank	Wet Deck Aft FR 57 Aft FR 2	20	5		X	No	Emergency
2.	Wave Guide Oper. (radar) SPS 49	Radar Room 1-1-0-C	5	80 to 100	Dew Pt -40°F & 80 psig		98% 8μ	Continuous
3.	Wave Guide Oper. (radar)	Radar Room 1-1-0-C	10	80 to 100	Dew Pt +60°F +20°F		* Yes	Emergency
4.	Air Driven Intensifier for Nitrogen Sys (helo serv)	Hangar Main Deck	30	100		X	Line Filter	Intermittent
5.	Shop Air, Hose Connections	12 places: Aux Mach Room 3, Gen Rooms, Armory, Lift Fan Rooms, Refrig Mach Room, Elec Maint., Aviat & Gen. Work Shop, Filter Cleaning	40-80	50-100		X	Line Filter	Intermittent
6.	Rescue Boat Lift	Main Deck Aft Frame 52	85 (2 to 3 min.)	90		X	No	Intermittent, emergency
7.	Aux.Fresh Water Cooling Sys (compression tank charging)	Aux. Mach. Room #1	No flow	50-80		X	No	Intermittent, once a day
8.	Thermostat Control	About 60 Thermostats	less than 1	20-25	X		No	Continuous
9.	Valve Operation, Distiller #1 and 2	AMR #3 and #4	10-20	100		X	No	Intermittent
10.	Chilled Water Cooling Tank Charging	AMR #2	3	80		X	No	Intermittent, once a day
11.	Windshield Wash	01 Level & Pilot House	5	80		X	No	Intermittent, once a day
12.	Buffer Air ([redacted]h)	Propulsion Engine Room	180	50		X	No	Intermittent
13.	Sea Chest (2)	Propulsion Engine Room	20-30	50		X	No	Intermittent

*011 .8 gram/lb air; moisture saturated at 80 psig

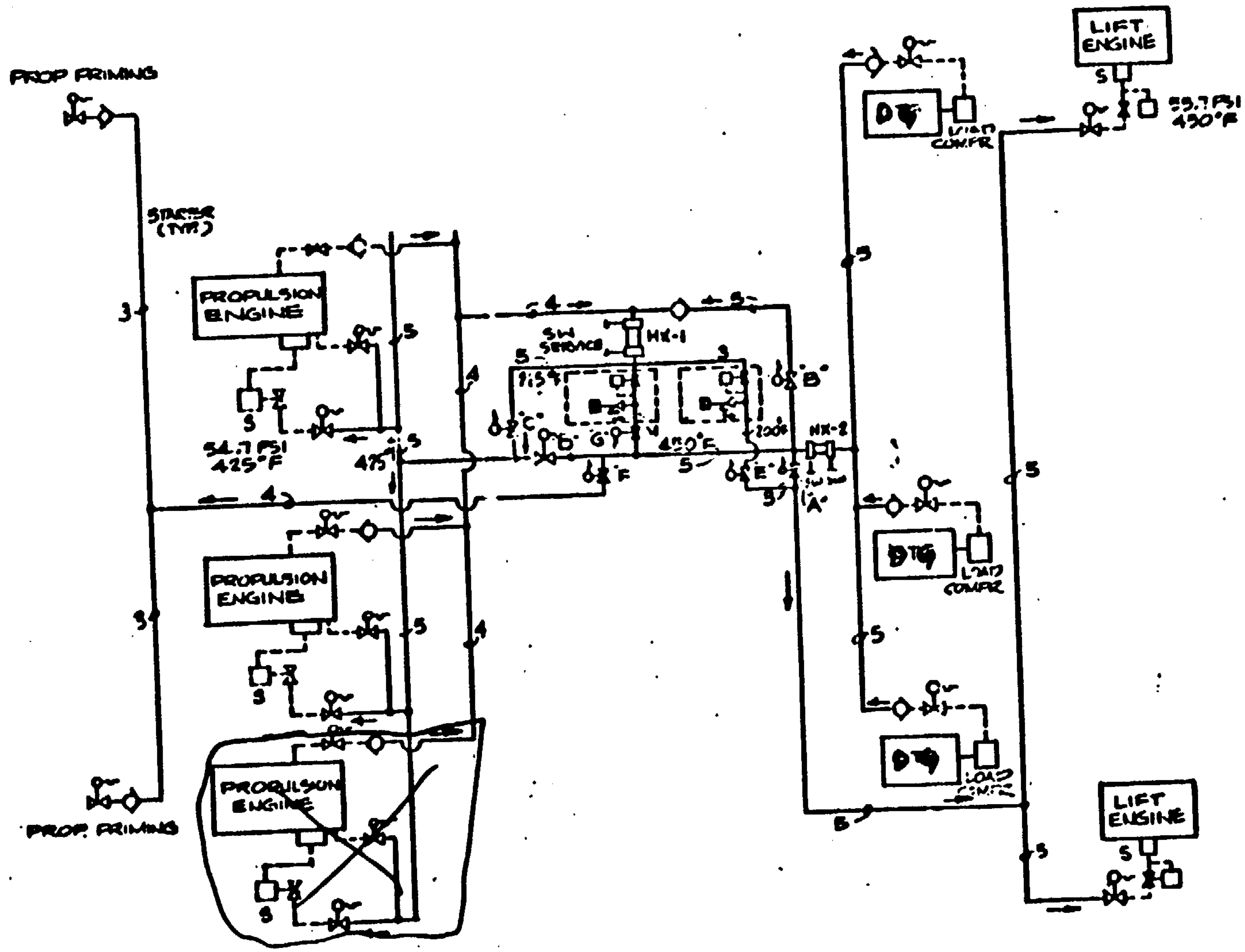


Figure E.6-1. Start Air System

Table E.6-3

Nitrogen System Requirements

*Service	Pressure, PSIG
Tires	75 - 250
Landing Gear Struts	1500
Emergency Gear Extension	3000
Rotor Blade Fold Accumulator	1500
Auxiliary Flotation Cylinders	3000
Tailwheel Centering Cylinders	425
Rotor Blade Inspection	4 - 16

* (15-50 SCIM)

time. During cross-bleed start, the propulsion turbine bleed air is to be routed via a heat exchanger and reducing valves to lower the temperature and pressure to the turbine-starter requirements in accordance with manufacturer's requirements.

The control and monitoring of the start air system is from PLCC and monitoring is also accomplished at the DCAEC Panel. In an emergency, the start air system can also be controlled at the LOP.

A detailed tradeoff study and analysis was made to evaluate the best method of starting the propulsion and lift engines. s This study was made on the basis of least weight and cost in meeting performance requirements. It was ascertained that the load compressors driven by diesel generator sets was the method to be adopted. A weight efficient SES would delete existing cross-bleed due to triple starting redundancy, thereby reducing system weight and cost.

The start air system as shown in Figure E.6-1 performs the following functions:

- o Start propulsion engines, one at a time, using air from a load compressor.
- o Start lift fan engines, one at a time, using air from a load compressor.
- o Start propulsion engines, one at a time, using cooled and pressure reduced bleed air from an operating propulsion engine.
- o Provide air for propulsor priming from a load compressor.
- o Provide air for propulsor priming using cooled bleed air from an operating propulsion engine.
- o Provide buffer air during propulsion engine starter motoring for engine water wash using cooled air from a load compressor.

All piping, fittings, valves (including solenoid valves), heat exchangers and components are to be of stainless steel since this system was required to withstand 104°F intermittently, which produces very high piping thermal stresses.

The lightweight stainless steel system, with thermal expansion joints and bends, meets the overall weight and displacement objective as well as performance requirements of the system.

HIGH PRESSURE COMPRESSED AIR SYSTEM

The high pressure compressed air system is a 3000 psig system with two 1500 psig branches for torpedo charging. This system is capable of charging one flask (900 cu. in.) in about 6 minutes. The system used CRES piping and deliveries clean (50 microns), dry air to the torpedo charing stations.

A multi-stage high pressure compressor feeds into a half cubic foot separator flask and then into an air dyer and purifier unit. The system is then divided into port and starboard branches (3/8" CRES piping). Each branch containing four cubic foot flask charged to 3000 psig and terminating in a torpedo charging station including an air filter, a needle valve, a pressure reducing valve and a pressure relief valve.

SHIP SERVICE AIR SYSTEM

The Ship Service Air System is in accordance with Figure E.6-2. The source of air was two air compressors each with discharging at 125 psig and 110°F (max). One air compressor is capable of servicing the whole ships service air requirements. The other air compressor is for standby. The compressors are hooked up electrically so that on low pressure in the receiver tank (110 psig), the compressor would automatically cut-in; and cut-out at 125 psig. In case of failure of one

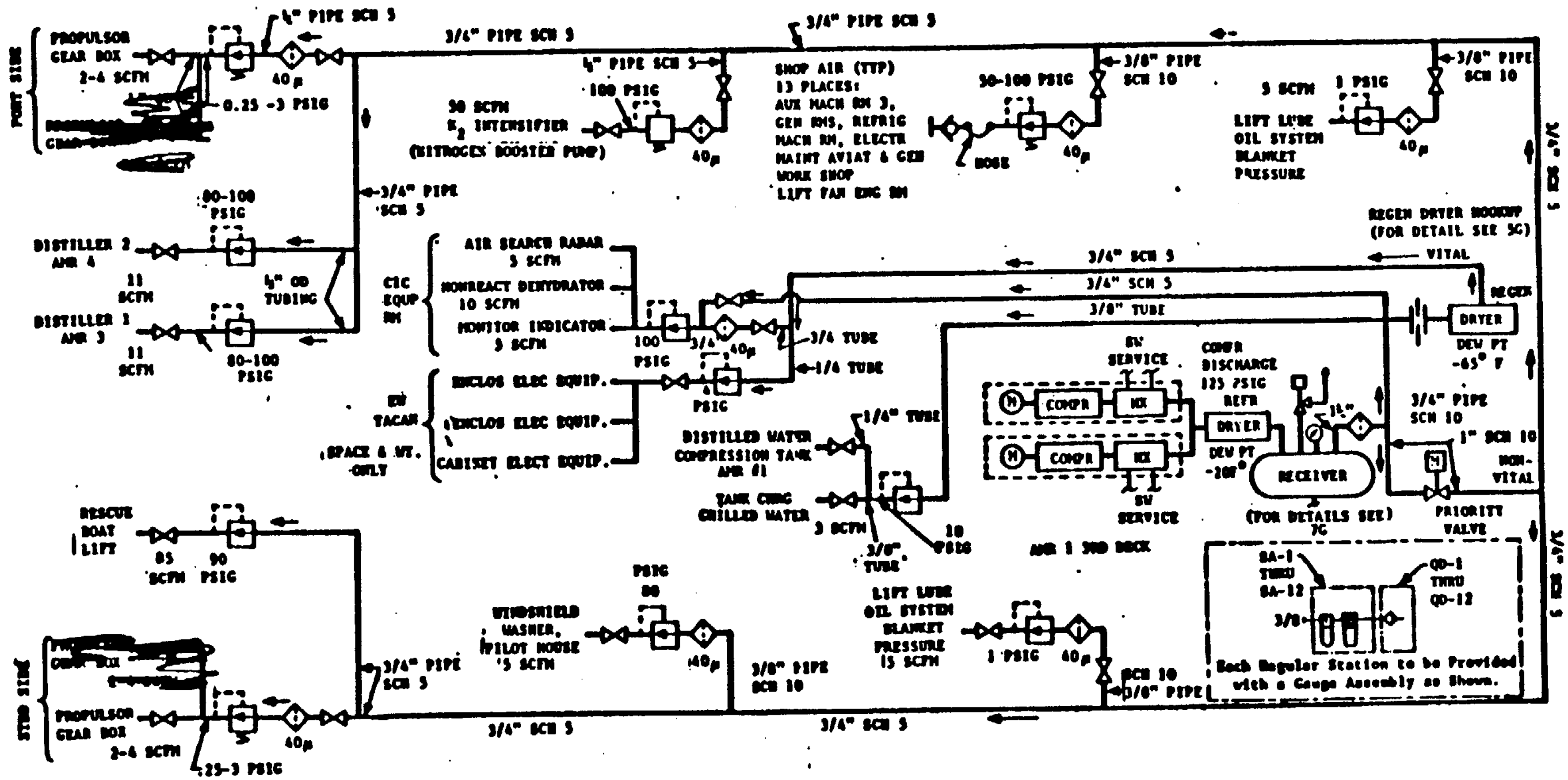


Figure E.6-2. Ship Service Air System

compressor, the other compressor would automatically cut-in. The air is filtered and dried before delivery to various service points throughout the ship. The control of these compressors would be located on the DCAEC panel as well as locally. Monitoring is also done at both locations.

The air supply was divided into two systems, vital and non-vital. The vital supply via a regenerative dryer fed wave guides and electronic equipment. The non-vital could be closed off by a motor operated priority valve.

Two independent dedicated low pressure air compressors are used on the SES to support the ship service air requirements. All piping is to be stainless steel and all fittings will be socket welded. The valves are of stainless steel and to be socket welded to a 150 psig rating. The system pressures were below 150 psig and the maximum temperature of service air was 110°F.

NITROGEN SYSTEM

This system is a dry, oil-free nitrogen system provided from two cylinders with distribution CRES piping to supply nitrogen for servicing helicopters.

Service stations are provided to service the helicopter in its normal landing position on the flight deck and also in the hangar area. Each low pressure outlet is to be regulated by an adjustable pressure reducing valve with inlet and outlet pressure gauges.

The nitrogen is to be pre-purified dry, per Type I, Class 1, Grade A, Specification BB-N-411b, and stored in cylinders per MS-39224-6 with service pressure of 2265 psi and 230 SCF capacity (cylinder volume is 2640 cu. in.). To provide nitrogen at 3000 psig, an air-driven booster was used. The booster was a 30:1 ratio and is driven by 100 psig air from the service air system.

APPENDIX E.7

FIRE EXTINGUISHING SYSTEMS

HALON 1301 SYSTEM

Areas containing flammable fluids are protected by dedicated Halon 1301 system designed in accordance with NFPA Manual 12A. Each area protected is supplied with a primary and secondary supply of halon. Concentration levels of 5.0 to 7.0 percent by volume are developed within protected spaces by a 10 second halon discharge initiated remotely by the fire detection system.

Halon (FE 1301) fixed flooding system is provided for propulsion engine rooms, waterjet pump rooms, fuel oil pump rooms, machinery rooms, electric generator rooms, lift fan engine rooms, flammable liquids storerooms, the gas turbine generator enclosure and the electronic equipment enclosures.

Halon containers are located outside the compartment served. Halon containers for gas turbine generator and electronic equipment enclosures are located local to the equipment. Operation of system is local and remote from DCAEC, manual release is accessible outside the compartment of enclosure served.

FOAM SYSTEMS

The AFFF system will supply only the aviation facility (landing platform, hangar, VERTREP and HIFR). Application rates of 0122 gal/sq ft overhead area for helicopter hangar foam/water sprinkler systems are maintained. The landing platform coverage afforded the SES is 011 gal/sq ft. of foam.

The AFFF system has one 90-1000 GPM delivery from a 2000 gallon capacity foam proportioning system utilizing a 3% "lightwater" foam concentrate capable of supplying the worst hazard with foam for a continuous operation of 10 minutes.

PORTABLE EXTINGUISHING

Portable fire extinguishers are located through the crew's living areas, work spaces and areas where small fire hazards may exist. Halon 1211 portable fire extinguishers replaced the conventional CO_2 extinguishers in their use as described by General Ship Specifications.

This represented in weight and an increase in system performance. Halon 1211 units were augmented with dry chemical (PKP) and Portable "Lightwater" AFFF units depending on the fire hazard.

APPENDIX E.8

HYDRAULIC SYSTEM

The hydraulic system has four separate subsystems located in the general ship areas where the hydraulic power is generated and where the power actuation is required.

Figure E.8-1 shows the four separate subsystems and functions performed by each subsystem.

An operating mode evaluation indicated that each of the four subsystems can obtain hydraulic power from two identical pumps driven by the engine gearboxes. Four small auxiliary electric motor-driven pumps are used when all engines are shut down for checkout and maintenance, as well as anchor and sonar retraction.

The hydraulic functions for each subsystem are as follows:

Subsystem No. 1, Starboard, Forward

Bow Seal Retraction

Lift Fan Variable Geometry Nos. 1, 3 and 5

Lift System Gearbox Holding Brake No. 1

Anchor Windlass

Sonar Retraction

Shut-off Valve Lift Fans Nos. 1 and 3

Subsystem No. 2 Port, Forward

Lift Fan Variable Geometry Nos. 2, 4 and 6

Lift System Gearbox Holding Brake No. 2

Shut-off Valves Lift Fans Nos. 2 and 4

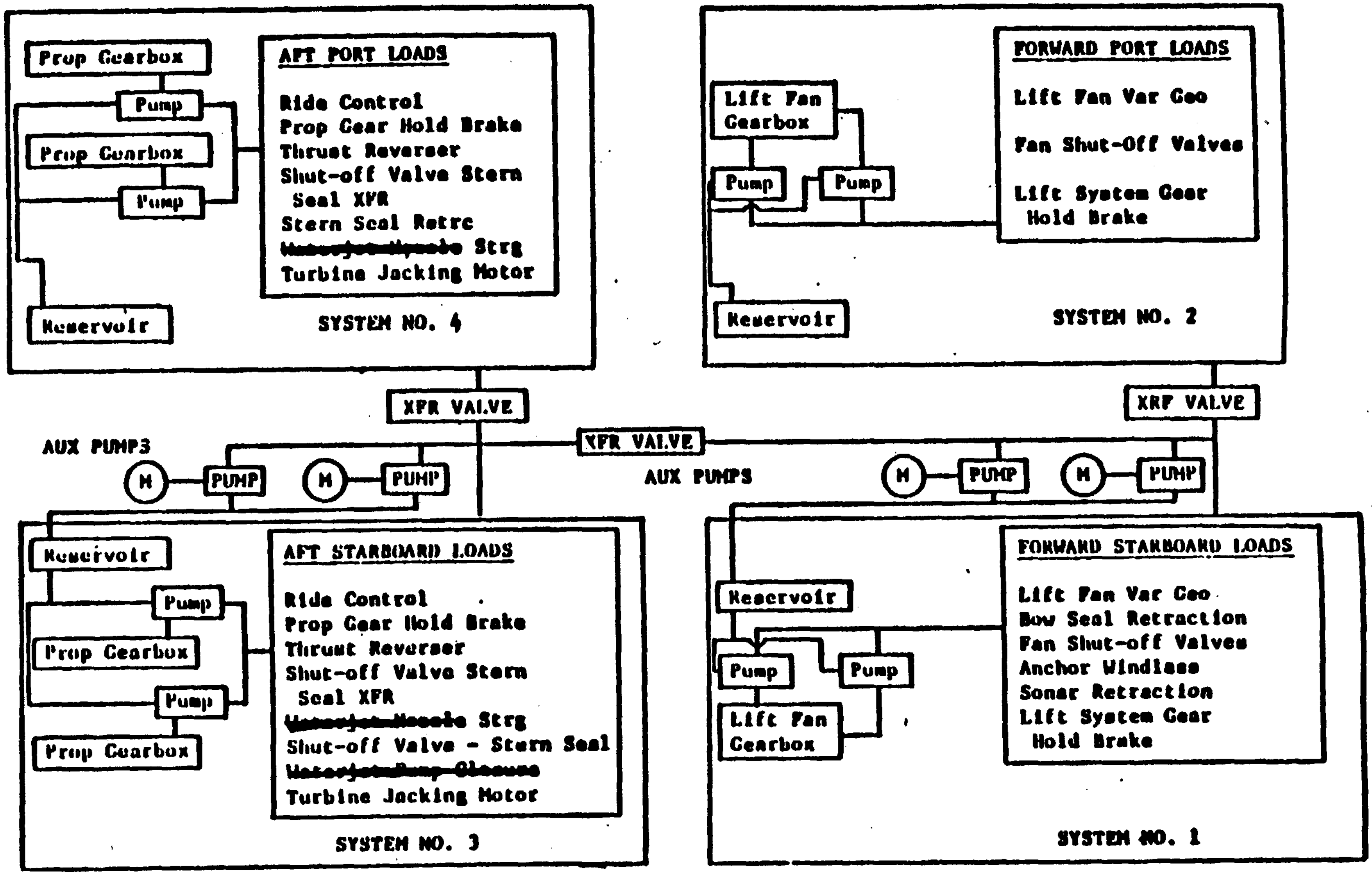


Figure E.8-1. Hydraulic System

Subsystem No. 3, Starboard, Aft

Ride Control (Vent) Valves Nos. 1 and 3

Shut-off Valve Stern Seal Transfer No. 1

Steering No. 1

Thrust Reverser No. 1

Propulsor Gearbox Holding Brake Nos. 1 and 2

Shut-off Valve Stern Seal No. 1 (Fan No. 5)

Jacking Motors Nos. 1 and 2

Subsystem No. 4, Port, Aft

Stern Seal Retraction

Ride Control (Vent) Valves Nos. 2 and 4

Shut-off Valve, Stern Seal Transfer No. 2

Shut-off Valve Stern Seal No. 2 (Fan No. 6)

Steering No. 2

Thrust Reverser No. 4

Propulsor Gearbox Holding Brakes Nos. 3 and 4

Jacking Motors Nos. 3 and 4

During operation without one of the two banks of lift fans, subsystems 1 and 2 may be interconnected by a solenoid valve operation. For emergency purposes any system can be interconnected to any other system through interconnecting solenoid valves.

Each of the four hydraulic subsystems are powered by two identical 3.0 cu. in./rev., 3000 psig, variable displacement piston pumps. The No. 1 pump of each subsystem would be set for 3100 psig at zero output flow and would have full flow at 3000 psig. The second, or No. 2 pump, would be set at 3000 psig for zero flow and would have full flow at 2900 psig. Thus, the No. 2 pump would only be pumping output flow when the system demand exceeds that of the No. 1 pump.

Four electric motor-driven pumps are used for auxiliary power subsystem checkout and other operations. These are small variable displacement pumps with a total flow capability of 40 gpm.

The four hydraulic subsystems as shown in Figure E.8-1, consist of the hydraulic power supplies, the description lines and the activated mechanical subsystems. All power supply components, actuators, motors and different types of valves (as required) are diagramatically shown in TB556001 using American National Standard (ANS) symbols.

Due to subsystem dynamic or functional requirements some of the mechanical subsystems are required to be linearly or rotary activated, some must be servo controlled, and others must be two or multi-purpose controlled.

SYSTEM REQUIREMENTS

The ship hydraulic system is required to be capable of delivering 3000 psig hydraulic power at a rate of sufficient to meet propulsion, lift, and other auxiliary system requirements. A list of hydraulic system functions is as follows:

- Thrust Reversers
- Propulsor Brakes

Bow Seal Retraction

Stern Seal Retraction

Lift Duct Valves (including Fan Shut-off Valves and Stern Seal Transfer Valves)

Ride Control Valves

Lift Fan Variable Geometry

Anchor Windlass

Sonar Retraction

Propulsor Jacking Gear

Tables E.8-1. E.8-2, and E.8-3 summarize the function flow requirements. It is desired that the system have lightweight, flexible power distribution and be capable of rapid response.

CANDIDATE CONCEPTS

These candidate concepts for major component arrangement were explored.

a. Central System — The Central System has one main pressure and return line running the length of the ship to supply the various subsystems.

This system contains five hydraulic pumps. Two of the pumps, with a displacement of 4 cu. in./rev., are lift fan gearbox driven while the remaining three pumps, with a displacement of approximately 1 cu. in./rev., are electric motor-driven. For maintenance and reliability, two complete reservoir, filtration and cooling systems are provided.

Table E.8-1. Hydraulic System Flow Requirements During Combined Subsystem Operation

SUBSYSTEM	3KSES OPERATING MODE										
	MAX. FLOW RATE GPM	DOCK SIDE	OFF-CUSH. OPER. SEA STATE 0-5	PARTIAL CUSH. OPER. SEA STATE 6-9	ON CUSHION LOW SPEED: LOW SEA STATE 0-3	ON CUSHION LOW SPEED: HIGH SEA STATE 4-6	HIGH SPEED CRUISE SEA STATE 0-6	OPER. WHILE CRAFT STOPPED	EMERGENCY STOP: INITIAL	EMERGENCY STOP: FINAL	ANCHOR RECOVERY
Bow Seal Retraction (1)*	40	-	2.5	2.5	2.5	2.5	2.5	2.5	40	2.5	2.5
Lift Fan Variable Geometry (6)*	120	-	31.2	62	62	120	120	3	31..2	3	3
Turbine Reduction Gear Holding Brake (6)	.78	-	.52	.26	-	-	-	.78	-	.78	.52
Shut-off Valve-Lift Fan (4)**	.65	-	-	-	-	-	-	-	-	-	-
Shut-off Valve-Stern Seal (2)											
Anchor Windlass (1)	20	-	-	-	-	-	-	-	-	-	20
Sonar Operation (1)	12	-	-	-	-	-	-	12	-	-	-
Ride Control Valve (4)*	68.8	-	1.6	16.5	34	68.8	68.8	9	17.5	9	-
Shut-off Valve Stern Seal Transfer (2)	1.3	-	1.3	-	-	-	-	-	-	1.3	-
Steering Vectoring (4)*	24	2.7	24	24	24	24	24	2.7	24	2.7	24
Thrust Reverser (2)*	17.6	3	3	3	3	3	3	3	17.6	3	17.6
Stern Seal Retraction (1)	20.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	20.5	2.5	2.5
TOTAL FLOW REQUIRED (GPM)	-	25.7	38.4	79.96	128	220.8	220.8	35.48	150.8	24.8	25.12

* Servo Valve Leakage
** Valves oper. before or after fan oper.
*** Operated one at a time
**** Servo Valve Systems shut-off at dockside

Table E.8-2. Hydraulic System Pump Data

SUBSYSTEM NO.	GEARBOX DRIVE	MAXIMUM PUMP SPEED, RPM	PUMP DISPLACEMENT CU. IN./REV.	FLOW PER PUMP AT MAXIMUM PUMP SPEED GPM	NUMBER OF PUMPS PER SUBSYSTEM	TOTAL PUMP DISPLACEMENT CU. IN/REV.	TOTAL PUMP FLOW GPM
1	No. 1 Lift Reduction Gear	5600	3.0	70	2	6.0	140
2	No. 2 Lift Reduction Gear	5600	3.0	70	2	6.0	140
3	No. 1 Propulsor Reduction Gear	4800	3.0	59			
	No. 2 Propulsor Reduction Gear	4800	3.0	59	2	6.0	118
4	No. 3 Propulsor Reduction Gear	4800	3.0	59			
	No. 4 Propulsor Reduction Gear	4800	3.0	59	2	6.0	118

Table E.8-3. Auxiliary Pump Data

NUMBER OF PUMPS	ELECTRIC MOTOR DRIVE SPEED, RPM	PUMP DISPLACEMENT CU. IN/REV.	PUMP FLOW EACH PUMP, GPM	HP
4	7600	0.4	10	20

b. Modified Central System — This system includes two pumps per lift fan gearbox; otherwise, it is the same as the central system.

c. Dual System —The Dual System divides the baseline system into two separate subsystems, port and starboard. Each subsystem is powered by three main system pumps. One 4 cu. in./rev. pump is driven by the lift fan gearbox while two 3 cu. in./rev pumps are mounted on the two propulsor gearboxes (totaling six pumps for the Dual System). This system also provides two auxiliary electric motor-driven pumps of 0.42 cu. in./rev.capability each for system maintenance and for operating the waterjet pump closures prior to startup of the engines. The system also contains two reservoir-filter - cooler groups, one in each subsystem.

d. Quad System — The Quad System divides the baseline system into 4 separate hydraulic subsystems. These separate hydraulic subsystems are located in areas adjacent to pump power suppliers. The Quad System uses eight hydraulic pumps (3 cu. in./rev. each) - two pumps for each of the four subsystems. The system also provides four electric motor-driven pumps of 0.42 cu. in./rev. each; these units are used for system maintenance.

The major weight of hydraulic systems is concentrated in the piping and associated hydraulic fluid. The Central system has large pressure and return lines running the length of the ship. The Dual System contains slightly smaller pressure and return lines with two sets running the length of the ship. The Quad System has the smallest pressure and return lines. These lines are located in the area adjacent to their pump power supply.

The Central System cannot be effective during a single lift engine operation nor during a lift engine-driven failure. The modified Central System does have adequate flow capability during the aforementioned condition; total pump displacement is 19 cu. in./rev. (CIR).

The Dual System with a total of 3 major pumps and a combined displacement of 24 CIR provides the desired total flow margin and also provides functional growth capability for added ship functions.

PUMP SELECTION

A variety of hydraulic pumps are available. Some of these can operate only at low system pressure while others are capable of operating at high pressure. The selected system pressure is 3000 psi, which narrows the field to the use of piston type pumps. Piston pumps are made in either fixed or variable displacement.

The fixed displacement pump will always deliver its maximum flow rate are driven speed. If the required flow rate at some time is less than the maximum then the excess flow is bypassed through a relief valve which adds heat into the system. The pump delivery requirement for different ship operative modes indicates a flow rate range of from 2 to 64 gpm in one of the four Quad Systems. This would mean almost continuous operation of the relief valve.

Variable displacement axial piston pumps maintain a nearly constant system pressure range by varying the output flow rate to meet system demand. The displacement or output flow is pressure controlled. If there is no system demand, the pump yoke will position the piston assembly for minimum displacement to hold 3000 psi pressure. When a system demand is made, by usually opening a valve to a subsystem, the pressure starts to drop. The pump pressure control senses this pressure drop and positions displacement (and output flow) to hold the pressure. The pump will have minimum flow at 3000 psi and maximum flow at approximately 2900 psi pressure. Thus, the added heat to the system is minimized by using a variable displacement pump with its normal mechanical and volumetric efficiency losses only approximately 13% of the rated input power.

The pump type selected is the variable displacement type.

HYDRAULIC FLUID SELECTION

Many hydraulic fluids are available of different formulation and characteristics but all are essentially one of two basic types; petroleum base and synetic. The synthetic type fluids can be separated in chemically compounded and water base hydraulic fluids. Synthtic fluids are formulated from compounds which are made chemically resistant to burning by the addition of snuffer agents, usually water, to flammable compounds to form water base fluids. Water alone, or with soluble oil additives to increase lubricity and reduce ruting, is used in some industrial applications where large quantities of fluid due to its restrictive liquid range, high viscosity, low lubricity and corrosive capability.

Two types of hydraulic fluids are presently in use or being planned for future operation of surface effect ships; hydraulic fluid in accordance with MIL-H-5605 is employed in the SES 100-Ton Testcraft, and fluid per MIL-H-83282 will be used in the Amphibious Assault Landing Craft. Hydrofoil crafts such as PCH-1 and Dennison have phosphate ester based (Skydrol) hydraulic fluid in their system.

Hydraulic fluid that meets Specification MIL-H-5606 has been in use for more than 30 years and is generally accepted as the hydraulic fluid in industry. It is a petroleum-base fluid, it possesses desirable characteristics of viscosity behavior with temperature variation and good lubricity for moving components. The drawback is its low flash point.

Phosphate ester hydraulic fluid (Skydrol) was developed primarily for aircraft systems to improve the fire resistant properties over MIL-H-5606. However, this fluid is toxic and incompatible with many materials such as standard seals of Buna N and Vitou materials, painted surfaces, electric wire insulation etc.

Historically, fire resistant phosphate ester base fluid, in accordance with MIL-H-19457, has been used in some Navy ship applications. However, this fluid has the problems of toxicity, seal compatibility and few aircraft type components qualified for it. To overcome these types of problems, MIL-H-83282 fluid has recently been developed.

MIL-H-83282 fluid is a new synthesized hydrocarbon fluid that was developed to provide both improved performance and safety as compared to existing hydraulic fluids. Some of the advantages of this fluid are:

a. High operating temperatures and improved thermal characteristics which allow system operation to at least 400°F.

b. Improved fire resistance flammability characteristics, resulting in reduced hydraulic fire hazards related to petroleum-base hydraulic fluids.

c. It is non-toxic and requires no special precautions such as required by phosphate ester or similar fluids.

PIPING MATERIAL

The hydraulic lines considered here are the high pressure and return lines consisting of rigid and flexible material. Lines of rigid material will be used in general, and lines of flexible material will be used to locally connect the pumps and actuators to rigid main distribution lines.

a. (1) Rigid Tubing —CRES 304-L is the selected material for rigid tubing; it is readily available in the required tube diameters, relatively easy to bend and weld, and is appreciably less costly than tubing made from 21 Cr-6Ni-9Mn that requires the procurement of mill runs in sizes greater than 1.25 O.D Swaged and weld fittings were selected in preference to the use of flared fittings in the interest of minimizing the potential of leakage. Welding is preferred to brazing because successful brazing requires an inordinate degree of care and cleanliness, which is costly and difficult to endure under ship building conditions. In addition, brazed lines must be flushed with water many times to remove the flux, followed by drying of the system with acetone followed by alcohol. Inspection is facilitated, since welded joints can be ultrasonically inspected, whereas brazed joints are not readily inspectable.

(2) Flexible Tubing -- Wherever flexible tubing is used, it will be Teflon-lined, since rubber turing takes on a static charge and picks up and holds dirt despite best efforts to clean the internal surfaces. Rubber tubing also "sluffs off" particles which can damage servo valves. Fittings that are particularly designed not to damage the Teflon lining will be employed with this tubing.

b. Hydraulic Line Jointing -- The primary fittings will be of the swage and weld type configuration to eliminate line leakage. Where separable lines must be used, the Deutsch or Dynatube fittings or equivalent is recommended.

APPENDIX E.9

REFRIGERATION SYSTEM

The refrigeration capacity of each plant is 3/4 ton. Freon 22 has been chosen as the most practical refrigerant. The following information gives equipment description and function in detail.

COMPRESSOR

The compressor type is 60 Hz heavy duty reciprocating accessible hermetic. It is provided with suction and discharge service valves, and has a force feed lubricating system. The compressor motor is provided with thermal overload protection as a safety measure.

CONDENSER

The condenser is the shell and tube type in which water circulates through the tubes within the shell. The condenser is equipped with a seawater flow valve which is controlled by the refrigerant discharge pressure.

RECEIVER

The refrigerant receiver has the capacity to hold at least 110 percent of the normal operating refrigerant charge. The liquid outlet is covered by liquid at all times during pitch or roll conditions of the ship. The receiver has two fused quartz sight glasses equipped with float bills to determine the refrigerant level. The receiver is designed for a test pressure of 450 psig.

PRESSURE SWITCH

Pressure switches are provided in the suction and discharge lines from the compressor. The suction pressure switch is a single pole, single throw switch with automatic reset on pressure rise. It will shut down the compressor when there is a low level of refrigerant or when refrigerant flow is stopped by the liquid solenoid valves. The discharge pressure switch is a single pole double throw switch with manual reset. It will shut down the compressor and actuate an alarm circuit in the event of an overpressure condition.

FILTER-DRYER

The filter/dryer is the replaceable core type. The core material removes water, acid, and particulate matter from the refrigerant. It is installed with isolation valves,f which are used while replacing the core.

SIGHT GLASS

A refrigerant flow sight glass is provided in the liquid line to the evaporator. The sight glass incorporates a color code moisture indicator. The sight glass with moisture indicator is combined with the filter/dryer cartridge fitting.

EVAPORATOR

The evaporators are the fan forced circulation type. There are two in both the Chill and Freeze rooms. The evaporator coil is the copper tube type and is mechanically bonded to the aluminum fins. Fin spacing is compatible with sub-zero evaporating temperatures. The evaporators and fans are enclosed in an aluminum housing arranged for overhead mounting.

EXPANSION VALVE

Each evaporator is served by a thermostatic expansion valve. The valve is compatible with both the operating mode and the defrost mode. It is constructed so that all working parts may be replaced without removing the valve body from the piping system

SOLENOID VALVE

Each evaporator is controlled by a solenoid valve which is energized by the refrigerated space thermostat.

SUCTION PRESSURE REGULATOR

The chiller room evaporator suction lines are provided with suction pressure regulators. They control the evaporating temperature needed to produce the capacity required in the chiller mode without freezing of the evaporator. The regulators are internally regulated. A full line-size manual bypass valve is provided for operation in the freezer mode.

CRANKCASE PRESSURE REGULATOR

The compressor regulator which is provided in the suction line to each condensing unit. The regulator prevents the suction pressure from rising beyond a pre-determined limit during a period of pull-down, when the room temperatures are abnormally high. This control is optional depending on compressor selection.

HEAT EXCHANGER

Heat exchangers are used to fully vaporize the suction gas, or to further sub-cool the liquid refrigerant. This component is optional depending on compressor selection.

MANUAL VALVES

Manual valves are of the diaphragm globe type in full line size.

CONTROL REQUIREMENTS

The refrigeration system requires both remote and local controls systems.

REMOTE CONTROLS DESCRIPTION

The refrigeration system remote controls command the operation of the evaporators and fans for system Number 1 and system Number 2. Refrigeration system Number 1 controls one evaporator and one fan in the Freeze Room, and one evaporator and one fan in the Chill Room. Similar controls apply to refrigeration system Number 2. The off command is the only remote control required for DCAEC (in the Central Control Station) from the refrigeration system.

The refrigeration system is normally in continuous operation and would be shut down only during the defrost mode or an emergency condition. Reference G.E. Ship Control Drawing SK56137-61-20 for the refrigeration system DCAEC Control Panel layout.

The refrigeration system command controls and monitor controls will interface with Data Terminal Number 3, which will receive and transmit these signals to and from the DCAEC panel in the central control station.

REMOTE CONTROL FUNCTIONS

Remote control functions are as follows:

a. Commands

   1. Refrigeration System No. 1 - off control only
   2. Refrigeration System No. 2 - off control only

b. Monitors

   1. Freeze Room high temperature alarm
   2. Chill Room high temperature alarm
   3. Refrigeration System No. 1 status
   4. Refrigeration System No. 2 status
   5. Refrigeration System No. 1 fault alarm
   6. Refrigeration System No. 2 fault alarm

LOCAL CONTROL DESCRIPTION

The local control panel is located in the Refrigeration Machinery Room. The local operator will be able to perform all operations and controls of system Number 1 and, including start, stop, and defrost functions. THe front panel contains switches and indicators labeled according to their function. The rear of the panel contains relays, contactors, and terminal boards.

LOCAL CONTROL FUNCTIONS

The main function of the local control panel is to start up refrigeration system Number ql and Number 2, and maintain continuous operation until defrosting or maintenance is required. The local control operator may then shut down the system by either depressing the on/off switch to the off position, or depressing the defrost switch. The later action turns on the defrost heater(s) that begin the defrost sequence. After defrost or maintenance is completed, the on/off switch is depressed to the on position, and normal operation is resume.

There are two maintenance switches, one for system No. 1, one for system No. 2. These switches are used to trouble-shoot the freeze and chill systems by opening the thermostat paths and also the paths to the refrigerant valves, isolating problem areas.

The chill room has the capacity to be used as either a chill or freeze space. Therefore, a chiller/freezer select switch has been proved on the local control panel to select the desired mode for the space. The local/remote select switch is used to put the system either in local or remote control mode. If in the local mode of operation, the system cannot be turned off by the remote operator. If in the remote mode of operation, only the remote operator will shut down the system. See Refrigeration System Controls Diagram, Figure E.9-1.

The 3KSES Auxiliary Systems Specification was developed in accordance with the ship specification and implicates Section 516 of the GSS and MIL-R-16743.

The intent of Section 516 has been followed in the development of the Refrigeration system, but not strictly adhered to. In an effort to reduce weight and complexity without sacrificing performance or safety, the following requirements per Section 516 have not been incorporated in the Refrigeration system.

a. Interchanger on the liquid line with shut off valve. (Having two refrigerant plants eliminates the need for this valve).

b. Replacement charge of R-22 and lubricating oil, one per plant, (Two independent plants eliminates the need for redundant service materials).

c. NAVSHIPS Drawing No. 810-1385899 to be used for refrigeration box penetrations. (This standard penetration was determined to be too complicated and unnecessary).

d. Hot gas by-pass between compressor discharge and expansion valve. Hot gas control valve, and additional solenoid valve. (Function replaced by evaporator pressure regulator and electric defrost).

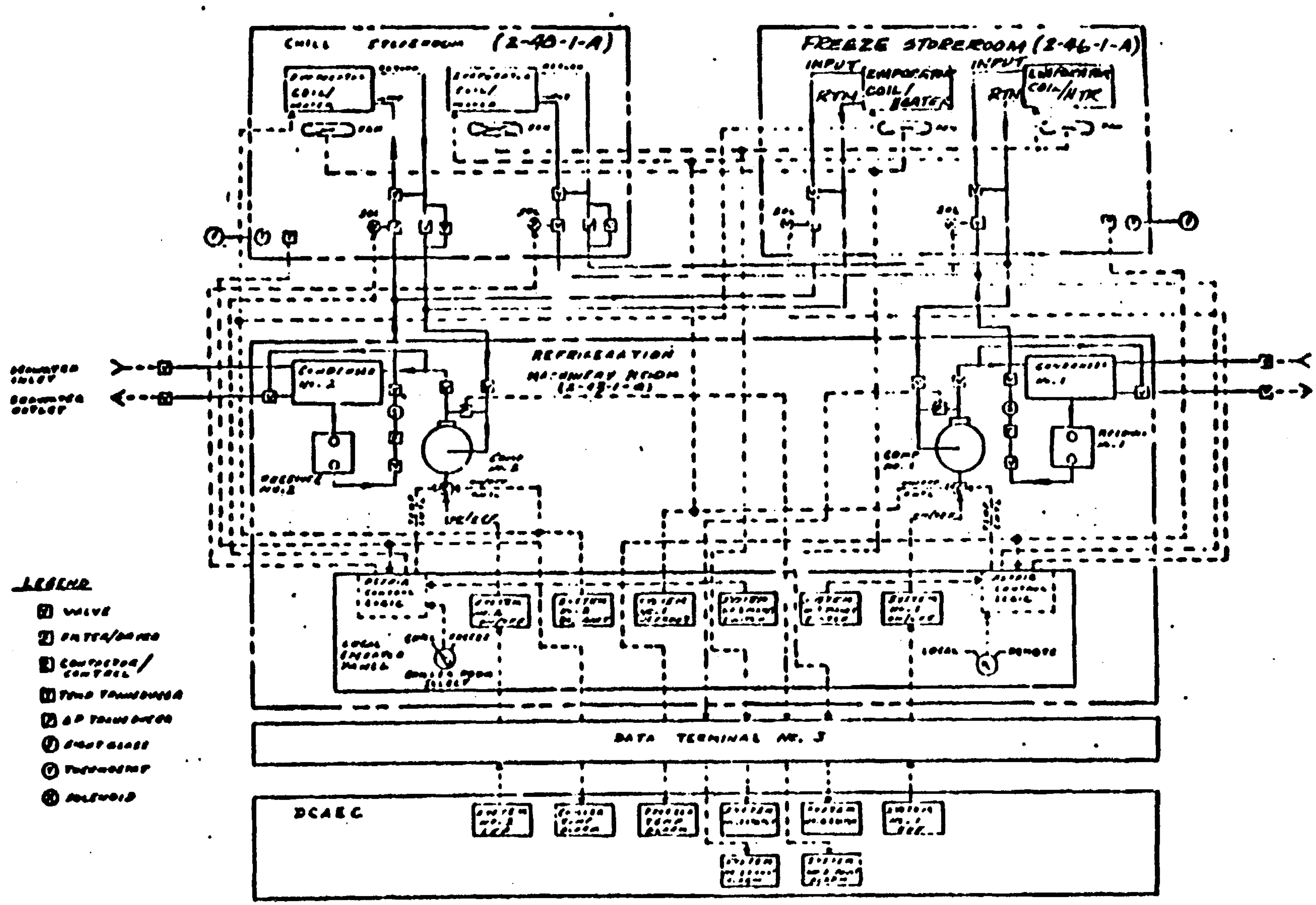


Figure E.9-1. Refrigeration System Control Diagram

e. Portable vacuum pump, hoses, and adaptor for evacuating and dehydrating refrigeration system to be stored onboard. (Impractical from a weight standpoint. See Item b.).

f. Provide separate refrigeration circuits for each refrigerated space, with valves to cut off service.. (In effect, there are separate circuits for each space because of two separate systems. Because the refrigeration system is not a standard system, the valves are not needed).

g. Distribute air by means of duct work. (Compartment size is such ducting is not required).

h. Coil defrost to be accomplished by means of hot seawater spray. (From a weight standpoint (additional piping system) and system simplification, electric defrost was determined to be a more practical defrosting method).

i. All safety control as invoked by MIL-R-16743.

The 3KSES Auxiliary System was reviewed by the Navy. They requested the following be added to the specification: "The refrigerating units shall be provided with operating and safety controls as required by MIL-R-16743". Because the refrigeration system is not the type usually installed in Naval vessels, this could not be added without redesigning the system, adding the weight and complexity of a typical system. The Navy then agreed that we would instead follow the intent of MIL-R-16743, without sacrificing safety or performance. This has been accomplished, and listed below are the operating or safety controls not relevant to the current design configuration.

a. Oil failure switch

b. Oil indicator

c. Water failure switch

d. Shut-off valve (between condenser and receiver)

e. Pressure relief valve (bypasses shut-off between condenser and receiver).

f. Hand expansion valve (bypass there expansion valve).

g. Shut-off valves (at evaporator outlet for each cooling coil).

h. Liquid line strainer (in addition to dehydrator/filter).

i. Suction line strainer (between suction shut-off and compressor).

j. Moisture indicator (in addition to sight flow indicator).

Heat load circulation for the refrigeration system have been performed in accordance with DDS 516-1, and equipment is sized and selected accordingly. There have been some tradeoffs with regard to equipment. Initially, a centrifugal type compressor was considered, but commercial availability was poor, and it was not particularly suited to the system. A 60 Hz hermetic compressor is the current selection; it is heavier, but less expensive, readily available, and suits the refrigeration application. The major tradeoff in the refrigeration system is the use of the split system, which was chosen over the standard system primarily for reliability. Each system serves the chill and freeze room. In the event of a system failure, the other system will be employed, insuring maintained compartment temperatures.

APPENDIX F

WEIGHT ESTIMATE

NAVY SWBS 3 DIGIT WEIGHT REPORT

ITEM	DESCRIPTION	WT	LCG	VCG
SUBGROUP 100	HULL STRUCTURE, GENERAL	.00	0.00	0.00
SUBGROUP 110	SHELL AND SUPPORTING STRUCTURE	.00	0.00	0.00
SUBGROUP 111	SHELL PLATING, SURF.SHIP AND SUB PRESS.H	129.45	170.64	0.00
SUBGROUP 112	SHELL PLATING, SUB NON-PRESSURE HULL	.00	0.00	0.00
SUBGROUP 113	INNER BOTTOM	19.01	170.64	0.00
SUBGROUP 114	SHELL APPENDAGES	.00	0.00	0.00
SUBGROUP 115	STANCHIONS	3.28	156.35	0.00
SUBGROUP 116	LONG.FRAMING,SURF.SHIP AND SUB PRESS.HLL	69.13	170.64	0.00
SUBGROUP 117	TRANS.FRAMING,SURF.SHIP AND SUB PRES.HLL	34.57	170.64	0.00
SUBGROUP 118	LONG.AND TRANS.SUB NON-PRESS.HULL FRAMIN	.00	0.00	0.00
SUBGROUP 119	LIFT SYSTEM FLEXIBLE SKIRTS AND SEALS	15.36	156.35	0.00
SUBGROUP 120	HULL STRUCTURAL BULKHEADS	.00	0.00	0.00
SUBGROUP 121	LONGITUDINAL STRUCTURAL BULKHEADS	29.52	156.35	0.00
SUBGROUP 122	TRANSVERSE STRUCTURAL BULKHEADS	31.00	170.64	0.00
SUBGROUP 123	TRUNKS AND ENCLOSURES	.00	0.00	0.00
SUBGROUP 124	BULKHEADS IN TORPEDO PROTECTION SYSTEM	.00	0.00	0.00
SUBGROUP 125	SUBMARINE HARD TANKS	.00	0.00	0.00
SUBGROUP 126	SUBMARINE SOFT TANKS	.00	0.00	0.00
SUBGROUP 130	HULL DECKS	.00	0.00	0.00
SUBGROUP 131	MAIN DECK	129.27	170.64	0.00
SUBGROUP 132	2ND DECK	129.27	170.64	0.00
SUBGROUP 133	3RD DECK	41.12	170.64	0.00
SUBGROUP 134	4TH DECK	.00	0.00	0.00
SUBGROUP 135	5TH DECK AND DECKS BELOW	.00	0.00	0.00
SUBGROUP 136	01 HULL DECK (FORCASTLE AND POOP DECKS)	.00	0.00	0.00
SUBGROUP 137	02 HULL DECK	.00	0.00	0.00
SUBGROUP 138	03 HULL DECK	.00	0.00	0.00
SUBGROUP 139	04 HULL DECK	.00	0.00	0.00
SUBGROUP 140	HULL PLATFORMS AND FLATS	.00	0.00	0.00
SUBGROUP 141	1ST PLATFORM	.00	0.00	0.00
SUBGROUP 142	2ND PLATFORM	.00	0.00	0.00
SUBGROUP 143	3RD PLATFORM	.00	0.00	0.00
SUBGROUP 144	4TH PLATFORM	.00	0.00	0.00
SUBGROUP 145	5TH PLATFORM	.00	0.00	0.00
SUBGROUP 149	FLATS	.00	0.00	0.00
SUBGROUP 150	DECK HOUSE STRUCTURE	31.20	170.64	0.00
SUBGROUP 151	DECK HOUSE STRUCTURE TO FIRST LEVEL	.00	0.00	0.00
SUBGROUP 152	1ST DECK HOUSE LEVEL	.00	0.00	0.00
SUBGROUP 153	2ND DECK HOUSE LEVEL	.00	0.00	0.00
SUBGROUP 154	3RD DECK HOUSE LEVEL	.00	0.00	0.00
SUBGROUP 155	4TH DECK HOUSE LEVEL	.00	0.00	0.00
SUBGROUP 156	5TH DECK HOUSE LEVEL	.00	0.00	0.00
SUBGROUP 157	6TH DECK HOUSE LEVEL	.00	0.00	0.00
SUBGROUP 158	7TH DECK HOUSE LEVEL	.00	0.00	0.00
SUBGROUP 159	8TH DECK HOUSE LEVEL AND ABOVE	.00	0.00	0.00

NAVY SWBS 3 DIGIT WEIGHT REPORT

ITEM	DESCRIPTION	WT	LCG	VCG
SUBGROUP 160	SPECIAL STRUCTURES	.00	0.00	0.00
SUBGROUP 161	STRUCT. CAST.,FORGINGS, AND EQUIV.WELDMT	6.18	170.64	0.00
SUBGROUP 162	STACKS AND MACKS (COMBINED STACK, MAST)	.00	0.00	0.00
SUBGROUP 163	SEA CHESTS	.88	170.64	0.00
SUBGROUP 164	BALLISTIC PLATING	.00	0.00	0.00
SUBGROUP 165	SONAR DOMES	.00	0.00	0.00
SUBGROUP 166	SPONSONS	.00	0.00	0.00
SUBGROUP 167	HULL STRUCTURAL CLOSURES	4.71	170.64	0.00
SUBGROUP 168	DECKHOUSE STRUCTURAL CLOSURES	.00	0.00	0.00
SUBGROUP 169	SPECIAL PURPOSE CLOSURES AND STRUCTURES	6.18	170.64	0.00
SUBGROUP 170	MASTS, KINGPOSTS, AND SERVICE PLATFORMS	8.36	156.35	0.00
SUBGROUP 171	MASTS, TOWERS, TETRAPODS	.00	0.00	0.00
SUBGROUP 172	KINGPOSTS AND SUPPORT FRAMES	.00	0.00	0.00
SUBGROUP 179	SERVICE PLATFORMS	.00	0.00	0.00
SUBGROUP 180	FOUNDATIONS	.00	0.00	0.00
SUBGROUP 181	HULL STRUCTURE FOUNDATIONS	.00	0.00	0.00
SUBGROUP 182	PROPULSION PLANT FOUNDATIONS	11.91	156.35	0.00
SUBGROUP 183	ELECTRIC PLANT FOUNDATIONS	3.21	156.35	0.00
SUBGROUP 184	COMMAND AND SURVEILLANCE FOUNDATIONS	2.68	156.35	0.00
SUBGROUP 185	AUXILIARY SYSTEMS FOUNDATIONS	5.64	156.35	0.00
SUBGROUP 186	OUTFIT AND FURNISHINGS FOUNDATIONS	1.41	156.35	0.00
SUBGROUP 187	ARMAMENT FOUNDATIONS	.91	156.35	0.00
SUBGROUP 190	SPECIAL PURPOSE SYSTEMS	13.98	170.64	0.00
SUBGROUP 191	BALLAST,FIXED OR FLUID,AND BUOYANCY UNIT	.00	0.00	0.00
SUBGROUP 197	WELDING	.00	0.00	0.00
SUBGROUP 198	FREE FLOODING LIQUIDS	.00	0.00	0.00
SUBGROUP 199	HULL REPAIR PARTS AND SPECIAL TOOLS	.00	0.00	0.00
TOTAL GRP 1	HULL STRUCTURE	728.24	169.02	0.00

NAVY SWBS 3 DIGIT WEIGHT REPORT

ITEM	DESCRIPTION	WT	LCG	VCG
SUBGROUP 200	PROPULSION PLANT, GENERAL	.00	0.00	0.00
SUBGROUP 210	ENERGY GENERATING SYSTEM (NUCLEAR)	.00	0.00	0.00
SUBGROUP 211	(RESERVED)	.00	0.00	0.00
SUBGROUP 212	NUCLEAR STEAM GENERATOR	.00	0.00	0.00
SUBGROUP 213	REACTORS	.00	0.00	0.00
SUBGROUP 214	REACTOR COOLANT SYSTEM	.00	0.00	0.00
SUBGROUP 215	REACTOR COOLANT SERVICE SYSTEM	.00	0.00	0.00
SUBGROUP 216	REACTOR PLANT AUXILIARY SYSTEMS	.00	0.00	0.00
SUBGROUP 217	NUCLEAR POWER CONTROL AND INSTRMENTATION	.00	0.00	0.00
SUBGROUP 218	RADIATION SHIELDING (PRIMARY)	.00	0.00	0.00
SUBGROUP 219	RADIATION SHIELDING (SECONDARY)	.00	0.00	0.00
SUBGROUP 220	ENERGY GENERATING SYSTEM (NON-NUCLEAR)	.00	0.00	0.00
SUBGROUP 221	PROPULSION BOILERS	.00	0.00	0.00
SUBGROUP 222	GAS GENERATORS	.00	0.00	0.00
SUBGROUP 223	MAIN PROPULSION BATTERIES	.00	0.00	0.00
SUBGROUP 224	MAIN PROPULSION FUEL CELLS	.00	0.00	0.00
SUBGROUP 230	PROPULSION UNITS	.00	0.00	0.00
SUBGROUP 231	PROPULSION STEAM TURBINES	.00	0.00	0.00
SUBGROUP 232	PROPULSION STEAM ENGINES	.00	0.00	0.00
SUBGROUP 233	PROPULSION INTERNAL COMBUSTION ENGINES	28.40	156.35	0.00
SUBGROUP 234	PROPULSION GAS TURBINES	17.60	156.35	0.00
SUBGROUP 235	ELECTRIC PROPULSION	.00	0.00	0.00
SUBGROUP 236	SELF-CONTAINED PROPULSION SYSTEMS	.00	0.00	0.00
SUBGROUP 237	AUXILIARY PROPULSION DEVICES	.00	53.49	0.00
SUBGROUP 238	SECONDARY PROPULSION (SUBMARINES)	.00	0.00	0.00
SUBGROUP 239	EMERGENCY PROPULSION (SUBMARINES)	.00	0.00	0.00
SUBGROUP 240	TRANSMISSION AND PROPULSOR SYSTEMS	.00	0.00	0.00
SUBGROUP 241	PROPULSION REDUCTION GEARS	60.00	156.35	0.00
SUBGROUP 242	PROPULSION CLUTCHES AND COUPLINGS	2.15	156.35	0.00
SUBGROUP 243	PROPULSION SHAFTING	30.00	156.35	0.00
SUBGROUP 244	PROPULSION SHAFT BEARINGS	8.68	156.35	0.00
SUBGROUP 245	PROPULSORS	26.00	156.35	0.00
SUBGROUP 246	PROPULSOR SHROUDS AND DUCTS	.00	0.00	0.00
SUBGROUP 247	WATER JET PROPULSORS	.00	0.00	0.00
SUBGROUP 248	LIFT SYSTEM FANS AND DUCTING	13.00	156.35	0.00
SUBGROUP 250	PROP. SUPPORT SYS.(EXCEPT FUEL,LUBE OIL)	.00	0.00	0.00
SUBGROUP 251	COMBUSTION AIR SYSTEM	8.00	156.35	0.00
SUBGROUP 252	PROPULSION CONTROL SYSTEM	8.16	156.35	0.00
SUBGROUP 253	MAIN STEAM PIPING SYSTEM	.00	0.00	0.00
SUBGROUP 254	CONDENSORS AND AIR EJFCTORS	.00	0.00	0.00
SUBGROUP 255	FEED AND CONDENSATE SYSTEM	.00	0.00	0.00
SUBGROUP 256	CIRCULATING AND COOLING SEA WATER SYS.	3.20	156.35	0.00
SUBGROUP 258	H.P. STEAM DRAIN SYSTEM	.00	0.00	0.00
SUBGROUP 259	UPTAKES (INNER CASING)	5.00	156.35	0.00
SUBGROUP 260	PROP. SUPPORT SYS. (FUEL AND LUBE OIL)	.00	0.00	0.00

NAVY SWBS 3 DIGIT WEIGHT REPORT

ITEM	DESCRIPTION	WT	LCG	VCG
SUBGROUP 261	FUEL SERVICE SYSTEM	6.69	156.35	0.00
SUBGROUP 262	MAIN PROPULSION LUBE OIL SYSTEM	8.20	156.35	0.00
SUBGROUP 263	SHAFT LUBE OIL SYSTEM (SUBMARINES)	.00	0.00	0.00
SUBGROUP 264	LUBE OIL FILL, TRANS. AND PURIFICATION	5.76	156.35	0.00
SUBGROUP 290	SPECIAL PURPOSE SYSTEMS	.00	0.00	0.00
SUBGROUP 298	PROPULSION PLANT OPERATING FLUIDS	2.00	156.35	0.00
SUBGROUP 299	PROP. PLANT REPAIR PARTS, SPECIAL TOOLS	5.30	156.35	0.00
TOTAL GRP 2	PROPULSION PLANT	238.14	156.35	0.00

NAVY SWBS 3 DIGIT WEIGHT REPORT

ITEM	DESCRIPTION	WT	LCG	VCG
SUBGROUP 300	ELECTRIC PLANT, GENERAL	.00	0.00	0.00
SUBGROUP 310	ELECTRIC POWER GENERATION	.00	0.00	0.00
SUBGROUP 311	SHIP SERVICE POWER GENERATION	11.25	156.35	0.00
SUBGROUP 312	EMERGENCY GENERATORS	.00	0.00	0.00
SUBGROUP 313	BATTERIES AND SERVICE FACILITIES	.58	156.35	0.00
SUBGROUP 314	POWER CONVERSION EQUIPMENT	3.60	156.35	0.00
SUBGROUP 320	POWER DISTRIBUTION SYSTEMS	.00	0.00	0.00
SUBGROUP 321	SHIP SERVICE POWER CABLE	9.12	156.35	0.00
SUBGROUP 322	EMERGENCY POWER CABLE SYSTEM	.00	0.00	0.00
SUBGROUP 323	CASUALTY POWER CABLE SYSTEM	.32	156.35	0.00
SUBGROUP 324	SWITCHGEAR AND PANELS	5.25	156.35	0.00
SUBGROUP 330	LIGHTING SYSTEM	.00	0.00	0.00
SUBGROUP 331	LIGHTING DISTRIBUTION	2.42	156.35	0.00
SUBGROUP 332	LIGHTING FIXTURES	2.92	156.35	0.00
SUBGROUP 340	POWER GENERATION SUPPORT SYSTEMS	.00	0.00	0.00
SUBGROUP 341	SSTG LUBE OIL	.00	0.00	0.00
SUBGROUP 342	DIESEL SUPPORT SYSTEMS	.00	0.00	0.00
SUBGROUP 343	TURBINE SUPPORT SYSTEMS	9.15	156.35	0.00
SUBGROUP 390	SPECIAL PURPOSE SYSTEMS	.00	0.00	0.00
SUBGROUP 398	ELECTRIC PLANT OPERATING FLUIDS	3.00	156.35	0.00
SUBGROUP 399	ELEC.PLANT REPAIR PARTS, SPECIAL TOOLS	1.50	156.35	0.00
TOTAL GRP 3	ELECTRIC PLANT	49.09	156.35	0.00

NAVY SWBS 3 DIGIT WEIGHT REPORT

ITEM	DESCRIPTION	WT	LCG	VCG
SUBGROUP 400	COMMAND AND SURVEILLANCE, GENERAL	.00	0.00	0.00
SUBGROUP 410	COMMAND AND CONTROL SYSTEMS	.00	0.00	0.00
SUBGROUP 411	DATA DISPLAY GROUP	1.05	156.35	0.00
SUBGROUP 412	DATA PROCESSING GROUP	2.00	156.35	0.00
SUBGROUP 413	DIGITAL DATA SWITCHBOARDSS	.00	0.00	0.00
SUBGROUP 414	INTERFACE EQUIPMENT	.00	0.00	0.00
SUBGROUP 415	DIGITAL DATA COMMUNICATIONS	.00	0.00	0.00
SUBGROUP 417	COMMAND AND CONTROL ANALOG SWITCHBOARDS	.00	0.00	0.00
SUBGROUP 420	NAVIGATION SYSTEMS	.00	0.00	0.00
SUBGROUP 421	NON-ELECTRIC/ELECTRONIC NAVIGATION AIDS	.10	156.35	0.00
SUBGROUP 422	ELECTRICAL NAVIG. AIDS(INCL.NAVIG.LIGHT)	.18	156.35	0.00
SUBGROUP 423	ELECTRONIC NAVIGATION SYSTEMS, RADIO	.61	156.35	0.00
SUBGROUP 424	ELECTRONIC NAVIGATION SYS. ACOUSTICAL	.27	156.35	0.00
SUBGROUP 425	PERISCOPES	.00	0.00	0.00
SUBGROUP 426	ELECTRICAL NAVIGATION SYSTEMS	.30	156.35	0.00
SUBGROUP 427	INERTIAL NAVIGATION SYSTEMS	.18	156.35	0.00
SUBGROUP 428	NAVIGATION CONTROL MONITORING	.00	0.00	0.00
SUBGROUP 430	INTERIOR COMMUNICATIONS	.00	0.00	0.00
SUBGROUP 431	SWITCHBOARDS FOR I.C. SYSTEMS	.15	156.35	0.00
SUBGROUP 432	TELEPHONE SYSTEMS	.03	156.35	0.00
SUBGROUP 433	ANNOUNCING SYSTEMS	.15	156.35	0.00
SUBGROUP 434	ENTERTAINMENT AND TRAINING SYSTEMS	.51	156.35	0.00
SUBGROUP 435	VOICE TUBES AND MESSAGE PASSING SYSTEMS	.08	156.35	0.00
SUBGROUP 436	ALARM, SAFETY, AND WARNING SYSTEMS	.00	0.00	0.00
SUBGROUP 437	INDICATING, ORDER,AND METERING SYSTEMS	.00	0.00	0.00
SUBGROUP 438	INTEGRATED CONTROL SYSTEMS	.29	156.35	0.00
SUBGROUP 439	RECORDING AND TELEVISION SYSTEMS	.03	156.35	0.00
SUBGROUP 440	EXTERIOR COMMUNICATIONS	.00	0.00	0.00
SUBGROUP 441	RADIO SYSTEMS	3.93	156.35	0.00
SUBGROUP 442	UNDERWATER SYSTEMS	.55	156.35	0.00
SUBGROUP 443	VISUAL AND AUDIBLE SYSTEMS	.72	156.35	0.00
SUBGROUP 444	TELEMETRY SYSTEMS	.00	0.00	0.00
SUBGROUP 445	TTY AND FACSIMILE SYSTEMS	.18	156.35	0.00
SUBGROUP 446	SECURITY EQUIPMENT SYSTEMS	.19	156.35	0.00
SUBGROUP 450	SURVEILLANCE SYSTEMS (SURFACE)	.00	0.00	0.00
SUBGROUP 451	SURFACE SEARCH RADAR	.16	156.35	0.00
SUBGROUP 452	AIR SEARCH RADAR (2D)	.00	0.00	0.00
SUBGROUP 453	AIR SEARCH RADAR (3D)	.00	0.00	0.00
SUBGROUP 454	AIRCRAFT CONTROL APPROACH RADAR	.00	0.00	0.00
SUBGROUP 455	IDENTIFICATION SYSTEMS (IFF)	.87	156.35	0.00
SUBGROUP 456	MULTIPLE MODE RADAR	1.00	156.35	0.00
SUBGROUP 459	SPACE VEHICLE ELECTRONIC TRACKING	.00	0.00	0.00
SUBGROUP 460	SURVEILLANCE SYSTEMS (UNDERWATER)	.00	0.00	0.00
SUBGROUP 461	ACTIVE SONAR	.00	0.00	0.00
SUBGROUP 462	PASSIVE SONAR	.00	0.00	0.00

NAVY SWBS 3 DIGIT WEIGHT REPORT

ITEM	DESCRIPTION	WT	LCG	VCG
SUBGROUP 463	MULTIPLE MODE SONAR	7.96	156.35	0.00
SUBGROUP 464	CLASSIFICATION SONAR	2.65	156.35	0.00
SUBGROUP 465	BATHYTHERMOGRAPH	.00	0.00	0.00
SUBGROUP 470	COUNTERMEASURES	.00	0.00	0.00
SUBGROUP 471	ACTIVE ECM (INCL COMBO. ACTIVE/PASSIVE)	4.38	156.35	0.00
SUBGROUP 472	PASSIVE ECM	.00	0.00	0.00
SUBGROUP 473	TORPEDO DECOYS	.00	0.00	0.00
SUBGROUP 474	DECOYS (OTHER)	3.70	156.35	0.00
SUBGROUP 475	DEGAUSSING	29.69	156.35	0.00
SUBGROUP 476	MINE COUNTERMEASURES	.00	0.00	0.00
SUBGROUP 480	FIRE CONTROL SYSTEMS	.00	0.00	0.00
SUBGROUP 481	GUN FIRE CONTROL SYSTEMS	.00	0.00	0.00
SUBGROUP 482	MISSILE FIRE CONTROL SYSTEMS	.00	0.00	0.00
SUBGROUP 483	UNDERWATER FIRE CONTROL SYSTEMS	3.28	156.35	0.00
SUBGROUP 484	INTEGRATED FIRE CONTROL SYSTEMS	1.48	156.35	0.00
SUBGROUP 489	WEAPON SYSTEM SWITCHBOARDS	.00	0.00	0.00
SUBGROUP 490	SPECIAL PURPOSE SYSTEMS	.00	0.00	0.00
SUBGROUP 491	ELEC. TEST, CKOUT, AND MONITORING EQUIP.	.00	0.00	0.00
SUBGROUP 492	FLIGHT CONTROL AND INSTRMT LANDING SYS.	.00	0.00	0.00
SUBGROUP 493	NON COMBAT DATA PROCESSING SYSTEMS	.00	0.00	0.00
SUBGROUP 494	METEOROLOGICAL SYSTEMS	.00	0.00	0.00
SUBGROUP 495	SPECIAL PURPOSE INTELLIGENCE SYSTEMS	.00	0.00	0.00
SUBGROUP 498	COMMAND AND SURVEILLANCE OPERATING FLUID	.00	0.00	0.00
SUBGROUP 499	COMMAND, SURV. REPAIR PARTS, SPEC. TOOLS	.10	156.35	0.00
TOTAL GRP 4	COMMAND AND SURVEIL.	66.78	156.35	0.00

NAVY SWBS 3 DIGIT WEIGHT REPORT

ITEM	DESCRIPTION	WT	LCG	VCG
SUBGROUP 500	AUXILIARY SYSTEMS, GENERAL	.00	0.00	0.00
SUBGROUP 510	CLIMATE CONTROL	.00	0.00	0.00
SUBGROUP 511	COMPARTMENT HEATING SYSTEM	.65	156.35	0.00
SUBGROUP 512	VENTILATION SYSTEM	3.27	156.35	0.00
SUBGROUP 513	MACHINERY SPACE VENTILATION SYSTEM	2.61	156.35	0.00
SUBGROUP 514	AIR CONDITIONING SYSTEM	15.89	156.35	0.00
SUBGROUP 515	AIR REVITALIZATION SYSTEMS(SUBMARINES)	.00	0.00	0.00
SUBGROUP 516	REFRIGERATION SYSTEM	.90	156.35	0.00
SUBGROUP 517	AUXILIARY BOILERS AND OTHER HEAT SOURCES	.00	0.00	0.00
SUBGROUP 520	SEA WATER SYSTEMS	.00	0.00	0.00
SUBGROUP 521	FIREMAN AND FLUSHING (SEA WATER) SYSTEM	2.29	156.35	0.00
SUBGROUP 522	SPRINKLER SYSTEM	.13	156.35	0.00
SUBGROUP 523	WASHDOWN SYSTEM	.00	0.00	0.00
SUBGROUP 524	AUXILIARY SEA WATER SYSTEM	.65	156.35	0.00
SUBGROUP 526	SCUPPERS AND DECK DRAINS	.25	156.35	0.00
SUBGROUP 527	FIREMAN ACTUATED SERVICES - OTHER	.00	0.00	0.00
SUBGROUP 528	PLUMBING DRAINAGE	4.58	156.35	0.00
SUBGROUP 529	DRAINAGE AND BALLASTING SYSTEM	1.47	156.35	0.00
SUBGROUP 530	FRESH WATER SYSTEMS	.00	0.00	0.00
SUBGROUP 531	DISTILLING PLANT	5.88	156.35	0.00
SUBGROUP 532	COOLING WATER	2.61	156.35	0.00
SUBGROUP 533	POTABLE WATER	3.38	156.35	0.00
SUBGROUP 534	AUX.STEAM AND DRAINS WITHIN MACHINE. BOX	.00	0.00	0.00
SUBGROUP 535	AUX.STEAM AND DRAINS OUT OF MACHINE. BOX	.00	0.00	0.00
SUBGROUP 536	AUXILIARY FRESH WATER COOLING	.00	0.00	0.00
SUBGROUP 540	FUELS, LUBRICANTS, HANDLING AND STORAGE	.00	0.00	0.00
SUBGROUP 541	SHIP FUEL AND FUEL COMPENSATING SYSTEM	13.85	156.35	0.00
SUBGROUP 542	AVIATION AND GENERAL PURPOSE FUELS	2.14	156.35	0.00
SUBGROUP 543	AVIATION, GENERAL PURPOSE LUBE. OIL	.44	156.35	0.00
SUBGROUP 544	LIQUID CARGO	.00	0.00	0.00
SUBGROUP 545	TANK HEATING	.00	0.00	0.00
SUBGROUP 549	SPEC. FUEL, LUBE. HANDLING, STOWAGE	.00	0.00	0.00
SUBGROUP 550	AIR, GAS, AND MISC. FLUID SYSTEMS	.00	0.00	0.00
SUBGROUP 551	COMPRESSED AIR SYSTEMS	7.98	156.35	0.00
SUBGROUP 552	COMPRESSED GASES	.00	0.00	0.00
SUBGROUP 553	O2 N2 SYSTEM	.00	0.00	0.00
SUBGROUP 554	LP BLOW	.00	0.00	0.00
SUBGROUP 555	FIRE EXTINGUISHING SYSTEMS	8.83	156.35	0.00
SUBGROUP 556	HYDRAULIC FLUID SYSTEM	9.17	156.35	0.00
SUBGROUP 557	LIQUID GASES, CARGO	.00	0.00	0.00
SUBGROUP 558	SPECIAL PIPING SYSTEMS	.00	0.00	0.00
SUBGROUP 560	SHIP CONTROL SYSTEMS	.00	0.00	0.00
SUBGROUP 561	STEERING AND DIVING CONTROL STSTEMS	2.45	156.35	0.00
SUBGROUP 562	RUDDER	2.58	156.35	0.00
SUBGROUP 563	HOVERING AND DEPTH CONTROL (SUBMARINES)	.00	0.00	0.00

NAVY SWBS 3 DIGIT WEIGHT REPORT

ITEM	DESCRIPTION	WT	LCG	VCG
SUBGROUP 564	TRIM SYSTEM (SUBMARINES)	.00	0.00	0.00
SUBGROUP 565	TRIM AND HEEL SYSTEMS (SURFACE SHIPS)	.00	0.00	0.00
SUBGROUP 566	DIVING PLANES AND STABILIZING FINS (SUB)	.00	0.00	0.00
SUBGROUP 567	STRUT AND FOIL SYSTEMS	.00	0.00	0.00
SUBGROUP 568	MANEUVERING SYSTEMS	.00	0.00	0.00
SUBGROUP 570	UNDERWAY REPLENISHMENT SYSTEMS	.00	0.00	0.00
SUBGROUP 571	REPLENISHMENT-AT-SEA SYSTEMS	2.04	156.35	0.00
SUBGROUP 572	SHIP STORES AND EQUIP. HANDLING SYSTEMS	2.04	156.35	0.00
SUBGROUP 573	CARGO HANDLING SYSTEMS	.00	0.00	0.00
SUBGROUP 574	VERTICAL REPLENISHMENT SYSTEMS	.00	0.00	0.00
SUBGROUP 580	MECHANICAL HANDLING SYSTEMS	.00	0.00	0.00
SUBGROUP 581	ANCHOR HANDLING AND STOWAGE SYSTEMS	3.27	156.35	0.00
SUBGROUP 582	MOORING AND TOWING SYSTEMS	3.27	156.35	0.00
SUBGROUP 583	BOATS, BOAT HANDLING AND STOWAGE SYSTEMS	1.63	156.35	0.00
SUBGROUP 584	MECH. OPER. DOOR,GATE,RAMP,TURNTABLE SYS	.00	0.00	0.00
SUBGROUP 585	ELEVATING AND RETRACTING GEAR	.00	0.00	0.00
SUBGROUP 586	AIRCRAFT RECOVERY SUPPORT SYSTEMS	.00	0.00	0.00
SUBGROUP 587	AIRCRAFT LAUNCH SUPPORT SYSTEMS	.00	0.00	0.00
SUBGROUP 588	AIRCRAFT HANDLING, SERVICING AND STOWAGE	.00	0.00	0.00
SUBGROUP 589	MISC. MECHANICAL HANDLING SYSTEMS	.00	0.00	0.00
SUBGROUP 590	SPECIAL PURPOSE SYSTEMS	.00	0.00	0.00
SUBGROUP 591	SCIENTIFIC AND OCEAN ENGINEERING SYS.	.00	0.00	0.00
SUBGROUP 592	SWIMMER AND DIVER SUPPORT, PROTECT. SYS.	.00	0.00	0.00
SUBGROUP 593	ENVIRONMENTAL POLLUTION CONTROL SYS.	2.96	156.35	0.00
SUBGROUP 594	SUBMARINE RESCUE, SALVAGE, SURVIVAL SYS.	.00	0.00	0.00
SUBGROUP 595	TOWING,LAUNCHING,HANDLING FOR UNDERWATER	2.08	156.35	0.00
SUBGROUP 596	HANDLING SYS FOR DIVER, SUBMER. VEHICLES	.00	0.00	0.00
SUBGROUP 597	SALVAGE SUPPORT SYSTEMS	.00	0.00	0.00
SUBGROUP 598	AUXILIARY SYSTEMS OPERATING FLUIDS	5.56	156.35	0.00
SUBGROUP 599	AUX. SYSTEMS REPAIR PARTS AND TOOLS	.03	156.35	0.00
TOTAL GRP 5	AUXILIARY SYSTEMS	114.89	156.35	0.00

NAVY SWBS 3 DIGIT WEIGHT REPORT

ITEM	DESCRIPTION	WT	LCG	VCG
SUBGROUP 600	OUTFIT AND FURNISHINS, GENERAL	.00	0.00	0.00
SUBGROUP 610	SHIP FITTINGS	.00	0.00	0.00
SUBGROUP 611	HULL FITTINGS	.67	156.35	0.00
SUBGROUP 612	RAILS, STANCHIONS, AND LIFELINES	1.82	156.35	0.00
SUBGROUP 613	RIGGING AND CANVAS	.17	156.35	0.00
SUBGROUP 620	HULL COMPARTMENTATION	.00	0.00	0.00
SUBGROUP 621	NON-STRUCTURAL BULKHEADS	5.72	156.35	0.00
SUBGROUP 622	FLOOR PLATES AND GRATINGS	4.38	156.35	0.00
SUBGROUP 623	LADDERS	1.38	156.35	0.00
SUBGROUP 624	NON-STRUCTURAL CLOSURES	1.09	156.35	0.00
SUBGROUP 625	AIRPORTS, FIXED PORTLIGHTS, AND WINDOWS	1.15	156.35	0.00
SUBGROUP 630	PRESERVATIVES AND COVERINGS	.00	0.00	0.00
SUBGROUP 631	PAINTING	6.05	156.35	0.00
SUBGROUP 632	ZINC COATING	.00	0.00	0.00
SUBGROUP 633	CATHODIC PROTECTION	1.05	156.35	0.00
SUBGROUP 634	DECK COVERING	10.46	156.35	0.00
SUBGROUP 635	HULL INSULATION	11.77	156.35	0.00
SUBGROUP 636	HULL DAMPING	.00	0.00	0.00
SUBGROUP 637	SHEATHING	8.83	156.35	0.00
SUBGROUP 638	REFRIGERATED SPACES	1.73	156.35	0.00
SUBGROUP 639	RADIATION SHIELDING	.00	0.00	0.00
SUBGROUP 640	LIVING SPACES	.00	0.00	0.00
SUBGROUP 641	OFFICER BERTHING AND MESSING SPACES	4.58	156.35	0.00
SUBGROUP 642	NONCOM. OFFICER BERTH AND MESS. SPACES	.84	156.35	0.00
SUBGROUP 643	ENLISTED PERSONNEL BERTHING,MESS.SPACES	7.40	156.35	0.00
SUBGROUP 644	SANITARY SPACES AND FIXTURES	1.57	156.35	0.00
SUBGROUP 645	LEISURE AND COMMUNITY SPACES	.00	0.00	0.00
SUBGROUP 650	SERVICE SPACES	.00	0.00	0.00
SUBGROUP 651	COMMISSARY SPACES	4.81	156.35	0.00
SUBGROUP 652	MEDICAL SPACES	.54	156.35	0.00
SUBGROUP 653	DENTAL SPACES	.00	0.00	0.00
SUBGROUP 654	UTILITY SPACES	.44	156.35	0.00
SUBGROUP 655	LAUNDRY SPACES	1.09	156.35	0.00
SUBGROUP 656	TRASH DISPOSAL SPACES	.33	156.35	0.00
SUBGROUP 660	WORKING SPACES	.00	0.00	0.00
SUBGROUP 661	OFFICES	3.08	156.35	0.00
SUBGROUP 662	MACHINERY CONTROL CENTER FURNISHINGS	1.47	156.35	0.00
SUBGROUP 663	ELECTRONICS CONTROL CENTER FURNISHINGS	3.37	156.35	0.00
SUBGROUP 664	DAMAGE CONTROL STATIONS	1.46	156.35	0.00
SUBGROUP 665	WKSHOP,LAB,TEST AREAS(PRTBLE TOOL,EQUIP)	.53	156.35	0.00
SUBGROUP 670	STOWAGE SPACES	.00	0.00	0.00
SUBGROUP 671	LOCKERS AND SPECIAL STOWAGE	1.85	156.35	0.00
SUBGROUP 672	STOREROOMS AND ISSUE ROOMS	10.45	156.35	0.00
SUBGROUP 673	CARGO STOWAGE	.00	0.00	0.00
SUBGROUP 690	SPECIAL PURPOSE SYSTEMS	.00	0.00	0.00

NAVY SWBS 3 DIGIT WEIGHT REPORT

ITEM	DESCRIPTION	WT	LCG	VCG
SUBGROUP 698	OUTFIT AND FURNISHINGS OPERATING FLUIDS	.00	156.35	0.00
SUBGROUP 699	OUTFIT AND FURNISH.REPAIR PARTS AND TOOL	.67	156.35	0.00
TOTAL GRP 6	OUTFITTING, FURNISH.	100.75	156.35	0.00

NAVY SWBS 3 DIGIT WEIGHT REPORT

ITEM	DESCRIPTION	WT	LCG	VCG
SUBGROUP 700	ARMAMENT, GENERAL	.00	0.00	0.00
SUBGROUP 710	GUNS AND AMMUNITION	.00	0.00	0.00
SUBGROUP 711	GUNS	6.63	156.35	0.00
SUBGROUP 712	AMMUNITION HANDLING	.00	0.00	0.00
SUBGROUP 713	AMMUNITION STOWAGE	.00	0.00	0.00
SUBGROUP 720	MISSILES AND ROCKETS	.00	0.00	0.00
SUBGROUP 721	LAUNCHING DEVICES (MISSILES AND ROCKETS)	15.50	156.35	0.00
SUBGROUP 722	MISSILE,ROCKET,GUIDANCE CAPSULE HAND.SYS	.00	0.00	0.00
SUBGROUP 723	MISSILE AND ROCKET STOWAGE	1.20	156.35	0.00
SUBGROUP 724	MISSILE HYDRAULICS	.00	0.00	0.00
SUBGROUP 725	MISSILE GAS	.00	0.00	0.00
SUBGROUP 726	MISSILE COMPENSATING	.00	0.00	0.00
SUBGROUP 727	MISSILE LAUNCHER CONTROL	.00	0.00	0.00
SUBGROUP 728	MISSILE HEATING, COOLING, TEMP. CONTROL	.00	0.00	0.00
SUBGROUP 729	MISSILE MONITORING, TEST AND ALIGNMENT	.00	0.00	0.00
SUBGROUP 730	MINES	.00	0.00	0.00
SUBGROUP 731	MINE LAUNDHING DEVICES	.00	0.00	0.00
SUBGROUP 732	MINE HANDLING	.00	0.00	0.00
SUBGROUP 733	MINE STOWAGE	.00	0.00	0.00
SUBGROUP 740	DEPTH CHARGES	.00	0.00	0.00
SUBGROUP 741	DEPTH CHARGE LAUNCHING DEVICES	.00	0.00	0.00
SUBGROUP 742	DEPTH CHARGE HANDLING	.00	0.00	0.00
SUBGROUP 743	DEPTH CHARGE STOWAGE	.00	0.00	0.00
SUBGROUP 750	TORPEDOES	.00	0.00	0.00
SUBGROUP 751	TORPEDO TUBES	1.99	156.35	0.00
SUBGROUP 752	TORPEDO HANDLING	.00	0.00	0.00
SUBGROUP 753	TORPEDO STOWAGE	.00	0.00	0.00
SUBGROUP 754	SUBMARINE TORPEDO EJECTION	.00	0.00	0.00
SUBGROUP 760	SMALL ARMS AND PYROTECHNICS	.00	0.00	0.00
SUBGROUP 761	SM. ARMS, PYROTECHNICS LAUNCHING DEVICES	.00	0.00	0.00
SUBGROUP 762	SMALL ARMS AND PYROTECHNICS HANDLING	.00	0.00	0.00
SUBGROUP 763	SMALL ARMS AND PYROTECHNICS STOWAGE	.90	156.35	0.00
SUBGROUP 770	CARGO MUNITIONS	.00	0.00	0.00
SUBGROUP 772	CARGO MUNITIONS HANDLING	.00	0.00	0.00
SUBGROUP 773	CARGO MUNITIONS STOWAGE	.00	0.00	0.00
SUBGROUP 780	AIRCRAFT RELATED WEAPONS	.00	0.00	0.00
SUBGROUP 782	AIRCRAFT RELATED WEAPONS HANDLING	.00	0.00	0.00
SUBGROUP 783	AIRCRAFT RELATED WEAPONS STOWAGE	.00	0.00	0.00
SUBGROUP 790	SPECIAL PURPOSE SYSTEMS	.00	0.00	0.00
SUBGROUP 792	SPECIAL WEAPONS HANDLING	.00	0.00	0.00
SUBGROUP 793	SPECIAL WEAPONS STOWAGE	.00	0.00	0.00
SUBGROUP 797	MISC. ORDNANCE SPACES	.00	0.00	0.00
SUBGROUP 798	ARMAMENT OPERATING FLUIDS	.00	0.00	0.00
SUBGROUP 799	ARMAMENT REPAIR PARTS AND SPECIAL TOOLS	.08	156.35	0.00
TOTAL GRP 7	ARMAMENT	26.30	156.35	0.00
	LIGHT SHIP WITHOUT MARGIN	1324.20	163.32	0.00

NAVY SWBS 3 DIGIT WEIGHT REPORT

ITEM	DESCRIPTION	WT	LCG	VCG
SUBGROUP M00	MARGINS	.00	0.00	0.00
SUBGROUP M10	CONTRACTOR CONTROLLED MARGINS	.00	0.00	0.00
SUBGROUP M11	DESIGN AND BUILDING MARGIN	.00	0.00	0.00
SUBGROUP M12	BUILDING MARGIN (RESERVED)	.00	0.00	0.00
SUBGROUP M20	GOVT. CONTROLLED MARGIN (SURFACE SHIP)	171.76	156.35	0.00
SUBGROUP M21	CONTRACT DESIGN MARGIN (SURFACE SHIP)	.00	0.00	0.00
SUBGROUP M22	CONTRACT MODIFICATION MARGIN (SURF.SHIP)	.00	0.00	0.00
SUBGROUP M23	GFM MARGIN (SURFACE SHIP)	.00	0.00	0.00
SUBGROUP M24	FUTURE GROWTH MARGIN (SURFACE SHIP)	.00	0.00	0.00
SUBGROUP M25	SERVICE LIFE MARGIN (SURFACE SHIP)	.00	0.00	0.00
SUBGROUP M26	NUCLEAR MACHINERY MARGIN (SURFACE SHIP)	.00	0.00	0.00
SUBGROUP M30	GOVT. CONTROLLED MARGIN STATUS (SUBS)	.00	0.00	0.00
SUBGROUP M31	CONTRACT DESIGN MARGIN (SUBMARINE)	.00	0.00	0.00
SUBGROUP M32	NAVSHIPS DEVELOPMENT MARGIN (SUBS)	.00	0.00	0.00
SUBGROUP M33	NUCLEAR MACHINERY MARGIN (SUBS)	.00	0.00	0.00
SUBGROUP M34	FUTURE GROWTH MARGIN (SUBMARINE)	.00	0.00	0.00
SUBGROUP M35	STABILITY LEAD STATUS (SUBMARINE)	.00	0.00	0.00
SUBGROUP M36	TRIMMING LEAD STATUS (SUBMARINES)	.00	0.00	0.00
SUBGROUP M40	BALLAST STATUS (SUBMARINE)	.00	0.00	0.00
SUBGROUP M41	LEAD, INTERNAL (SUBMARINE)	.00	0.00	0.00
SUBGROUP M42	LEAD, EXTERNAL (SUBMARINES)	.00	0.00	0.00
SUBGROUP M43	LEAD, MBT (SUBMARINES)	.00	0.00	0.00
SUBGROUP M44	STEEL, INTERNAL (SUBMARINE)	.00	0.00	0.00
SUBGROUP M45	STEEL, EXTERNAL (SUBMARINE)	.00	0.00	0.00
SUBGROUP M46	STEEL, MBT (SUBMARINE)	.00	0.00	0.00
SUBGROUP M47	LEAD CORRECTION, MBT (SUBS)	.00	0.00	0.00
SUBGROUP M48	LEAD CORRECTION, OTHER THAN MBT (SUBS)	.00	0.00	0.00
TOTAL GRP M	MARGINS	171.76	156.35	0.00
	LIGHT SHIP WITH MARGIN	1495.96	162.52	0.00

NAVY SWBS 3 DIGIT WEIGHT REPORT

ITEM	DESCRIPTION	WT	LCG	VCG
SUBGROUP F00	LOADS (FULL LOAD CONDITION)	.00	0.00	0.00
SUBGROUP F10	SHIP FORCE, AMPHIB FORCE, TROOPS, PASSEN	.00	0.00	0.00
SUBGROUP F11	SHIPS OFFICERS	2.33	156.35	0.00
SUBGROUP F12	SHIPS NONCOMMISSIONED OFFICERS	.74	156.35	0.00
SUBGROUP F13	SHIPS ENLISTED MEN	8.34	156.35	0.00
SUBGROUP F14	MARINES	.00	0.00	0.00
SUBGROUP F15	TROOPS	.00	0.00	0.00
SUBGROUP F16	AIR WING PERSONNEL	.00	0.00	0.00
SUBGROUP F19	OTHER PERSONNEL	.00	0.00	0.00
SUBGROUP F20	MISSION RELATED EXPENDABLES AND SYSTEMS	.00	0.00	0.00
SUBGROUP F21	SHIP AMMUNITION (FOR USE BY SHIP)	24.90	156.35	0.00
SUBGROUP F22	ORDINANCE DELIVERY SYSTEMS AMMUNITION	8.69	156.35	0.00
SUBGROUP F23	ORDINANCE DELIVERY SYSTEMS	22.30	156.35	0.00
SUBGROUP F24	ORDINANCE REPAIR PARTS (SHIP AMMO)	.00	0.00	0.00
SUBGROUP F25	ORD. REPAIR PARTS (ORD. DELIV. SYS.AMMO)	.00	0.00	0.00
SUBGROUP F26	ORDINANCE DELIVERY SYS.SUPPORT EQUIP.	.00	0.00	0.00
SUBGROUP F29	SPECIAL MISSION RELATED SYS. EXPENDABLES	.00	0.00	0.00
SUBGROUP F30	STORES	.00	0.00	0.00
SUBGROUP F31	PROVISION AND PERSONNEL STORES	8.42	156.35	0.00
SUBGROUP F32	GENERAL STORES	1.89	156.35	0.00
SUBGROUP F33	MARINES STORES (FOR SHIPS COMPLEMENT)	.00	0.00	0.00
SUBGROUP F39	SPECIAL STORES	.00	0.00	0.00
SUBGROUP F40	FUELS AND LUBRICANTS	.00	0.00	0.00
SUBGROUP F41	DIESEL FUEL	276.92	156.35	0.00
SUBGROUP F42	JP-5	43.60	156.35	0.00
SUBGROUP F43	GASOLINE	.00	0.00	0.00
SUBGROUP F44	DISTILLATE FUEL	.00	0.00	0.00
SUBGROUP F45	NAVY STANDARD FUEL OIL (N.S.F.O.)	.00	0.00	0.00
SUBGROUP F46	LUBRICATING OIL	10.98	156.35	0.00
SUBGROUP F49	SPECIAL FUELS AND LUBRICANTS	.00	0.00	0.00
SUBGROUP F50	LIQUIDS AND GASES (NON-FUEL TYPE)	.00	0.00	0.00
SUBGROUP F51	SEA WATER	.00	0.00	0.00
SUBGROUP F52	FRESH WATER	3.48	156.35	0.00
SUBGROUP F53	RESERVE FEED WATER	1.00	156.35	0.00
SUBGROUP F54	HYDRAULIC FLUID	1.00	156.35	0.00
SUBGROUP F55	SANITARY TANK LIQUID	1.85	156.35	0.00
SUBGROUP F56	GAS (NON-FUEL TYPE)	.00	0.00	0.00
SUBGROUP F59	MISC. LIQUIDS (NON-FUEL TYPE)	.00	0.00	0.00
SUBGROUP F60	CARGO	.00	0.00	0.00
SUBGROUP F61	CARGO, ORDNANCE, ORDNANCE DELIVERY SYS.	.00	0.00	0.00
SUBGROUP F62	CARGO, STORES	.00	0.00	0.00
SUBGROUP F63	CARGO, FUELS AND LUBRICANTS	.00	0.00	0.00
SUBGROUP F64	CARGO, LIQUIDS (NON-FUEL TYPE)	.00	0.00	0.00
SUBGROUP F65	CARGO, CRYOGENIC AND LIQUIFIED GAS	.00	0.00	0.00
SUBGROUP F66	CARGO, AMPHIBIOUS ASSAULT SYSTEMS	.00	0.00	0.00

NAVY SWBS 3 DIGIT WEIGHT REPORT

ITEM	DESCRIPTION	WT	LCG	VCG
SUBGROUP F67	CARGO, GASES	.00	0.00	0.00
SUBGROUP F69	CARGO, MISCELLANEOUS	.00	0.00	0.00
SUBGROUP F70	SEA WATER BALLAST (SUBMARINES)	.00	0.00	0.00
SUBGROUP F71	MAIN WATER BALLAST (SUBMARINES)	.00	0.00	0.00
SUBGROUP F72	VARIABLE BALLAST WATER (SUBMARINES)	.00	0.00	0.00
SUBGROUP F73	RESIDUAL WATER (SUBMARINES)	.00	0.00	0.00
	TOTAL VARIABLE LOAD	416.43	156.35	0.00
	FULL LOAD WITH MARGIN	1912.39	161.18	0.00

NAVY SWBS 1 DIGIT WEIGHT REPORT

GROUP	DESCRIPTION	WT	LCG	VCG
TOTAL GRP 1	HULL STRUCTURE	728.24	169.02	0.00
TOTAL GRP 2	PROPULSION PLANT	238.14	156.35	0.00
TOTAL GRP 3	ELECTRIC PLANT	49.09	156.35	0.00
TOTAL GRP 4	COMMAND AND SURVEIL.	66.78	156.35	0.00
TOTAL GRP 5	AUXILIARY SYSTEMS	114.89	156.35	0.00
TOTAL GRP 6	OUTFITTING, FURNISH.	100.75	156.35	0.00
TOTAL GRP 7	ARMAMENT	26.30	156.35	0.00
	LIGHT SHIP WITHOUT MARGIN	1324.20	163.32	0.00
	MARGINS	171.76	156.35	0.00
	LIGHT SHIP WITH MARGIN	1495.96	162.52	0.00
	VARIABLE LOAD	416.43	156.35	0.00
	FULL LOAD WITH MARGIN	1912.39	161.18	0.00

APPENDIX G

AREA/VOLUME SUMMARY

NATO ASW SES CORVETTE AREA/VOLUME SUMMARY

SSCS #		AREA FT²	VOLUME FT³
	SUMMARY		
GROUP 1	MILITHRY MISSION	7117	86308
GROUP 2	HUMAN SUPPORT	6495	62506
GROUP 3	SHIP SUPPORT	7065	92441
GROUP 4	SHIP MACHINERY	1798	118,726
GROUP 5	UNASSIGNED	1590	13332
SHIP TOTAL		24,065	373,313

NATO ASW SES CORVETTE AREA/VOLUME SUMMARY

SSCS #		AREA FT^2	VOLUME FT^3
GROUP 1			
1.11	COMM CTR & RADIO XMTR	574	5740
1.11	ELEX EQUIP	712	7120
1.12	N_2	40	360
1.12	TOWED ARRAY SONAR	468	4680
1.13	CHART ROOM	96	864
1.13	CIC	672	6720
1.13	PILOT HSE	442	3978
1.14	ECM	164	1476
1.15	IC & GYRO	220	2200
1.1	TOTAL	3388	33138
1.21	30 MM MAG	105	1050
1.22	JAV. MAG	92	920
1.22	VLS	558	4896
1.24	TORPEDOES	220	1980
1.2	TOTAL	975	8846

NATO ASW SES CORVETTE AREA/VOLUME SUMMARY

SSCS #		AREA FT²	VOLUME FT³
1.34	HANGAR	2150	38700
1.35	HELO OFFICE	132	1188
1.36	HELO SHOP	152	1368
1.38	HIFR	28	280
1.3	TOTAL	2462	41536
1.56	BATT CHG	80	720
1.92	PYRO	52	468
1.94	SM. ARMS & ARMORY	160	1600
1.9	TOTAL	212	2068
GROUP 1	TOTAL	7117	86308

GROUP 2

		FT²	FT³
2.11	CO SR	260	2340
2.11	OFFICER LVG COMPLEX	998	9980
2.12	CPO LVG COMPLEX	404	4040
2.13	CREW LVG COMPLEX	2408	22368
2.19	W/C & (PILOT HSE)	32	288
2.1	TOTAL	4102	39016
2.21	WR & OFF MESS	238	2380
2.21	CREW & C/O MESS	486	4860
2.22	GALLEY	446	4460
2.23	DRY PROV. STRM	280	2800
2.2	TOTAL	1450	14500
2.31	MED TRTMT / STORES	218	2180
2.3	TOTAL	218	2180

GROUP 2 CONT'

		FT^2	FT^3
2.41	SHIP STORES	122	1220
2.42	LAUNDRY	155	1550
2.44	BARBER	116	1160
2.46	POST OFFICE	112	1120
2.4	TOTAL	505	5050
2.5	PERSONAL STORES (TOTAL)	110	880
2.62	CBR & SP. CLOTH.	110	880
2.6	TOTAL	110	880
GROUP 2	TOTAL	6495	62506

NATO ASW SES CORVETTE   AREA/VOLUME SUMMARY

SWBS #		AREA FT^2	VOLUME FT^3
GROUP 3			
3.11	STEERING GR	682	6820
3.22	HELO CRASH LKR	27	243
3.22	FWD REP	180	1800
3.22	AFT REP	155	1550
3.25	AFFF	81	794
3.2	TOTAL	443	4387
3.3	OFFICE COMPLEX	404	4040
3.61	ELEC SHOP & DEGAUSS	140	1400
3.61	GEN WKSP	230	2300
3.61	FILTER CLNG	100	1000
3.62	ELEX SHOP	155	1550
3.6	TOTAL	625	6250

NATO ASW SES CORVETTE AREA/VOLUME SUMMARY

SSCS #		AREA FT²	VOLUME FT³
3.71	SD STORES	850	6800
3.71	SONO BOUYS	56	504
3.74	BOSUN STORE RM	384	3840
3.74	PAINT MIX	56	504
3.74	BOAT & DK GR	105	972
3.7	TOTAL	1451	12620
3.8	PASSAGES	3460	33220
3.9	VOIDS		8230
3.9	TANKS		16324
3.9	TOTAL		24554
GROUP 3	TOTAL	7065	92441

NATO ASW SES CORVETTE AREA/VOLUME SUMMARY

SSCS #		AREA FT²	VOLUME FT³
GROUP 4			
4.1	CENTRAL CONTROL	378	3780
4.14	ER		62230
4.14	LIFT FAN		6720
4.14	INTAKES & UPTAKES		6612
4.14	LIFT FAN PLENUM		8370
4.1	TOTAL	378	87712
4.33	SS GEN #3 (#1 & #2 IN AMR)	434	434
4.33	AMR		20800
4.36	FAN RMS	986	9780
4.3	TOTAL	1420	31014
GROUP 4	TOTAL	1798	118,726

NATO ASW SES CORVETTE AREA/VOLUME SUMMARY

SSCS #		AREA FT^2	VOLUME FT^3
GROUP 5			
5.0	UNA	1590	13332
GROUP 5	TOTAL	1590	13332

APPENDIX H

BELL-TEXTRON REPORT

NEW ORLEANS OPERATIONS

Bell Aerospace TEXTRON

Division of Textron Inc

SUMMARY OF PROPELLER DESIGN PROGRAM
AND
PROPELLER DESIGN
FOR
MEDIUM-DISPLACEMENT SURFACE EFFECT SHIP (MDS)
1500 LONG TONS

CONTRACT N00024-75-C-5034

Report 7593-950002

November 30, 1981

Prepared by: R. B. Lewis

John B. Chaplin
Vice President of Engineering

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SECTION 1

PROGRAM OVERVIEW AND SUMMARY

1. PROGRAM OVERVIEW AND SUMMARY

Computer programs were formulated and used to design partially submerged supercavitating propellers (PSCPs). These programs were also employed to perform preliminary structural design of the blading and to predict propeller off-design performance over a range of submergences. Propulsion thrust was computed for installed propellers and was compared to the ship drag, taking into consideration the propulsion engine characteristics, losses, and various machinery arrangements. Predicted propeller non-dimensional characteristics and propeller forces and moments were computed and correlated with test data, in a limited effort.

1.1 Correlation of Predicted Propeller Performance and Propeller Forces with Test Data

A critical performance correlation was made to validate the off-design performance results of the SSCP computer program. This program was used for most of the off-design performance predictions during this study. The correlation compared the computed predictions of the SES-100B propeller design with model test data and full-scale test data. The results, which were favorable, are contained in TN/SES TECH/017 of July 24, 1981, figures 9 and 10. Figure 1-1 of this report is a copy of Figure 9, which shows the comparison of predicted and test efficiencies.

The work on correlation of computer-predicted forces with model test data, which was included in the original task, was deferred after it became apparent that new propeller designs would be required for additional ship configurations. Before the deferral, computations were made of both steady and fluctuating vertical and horizontal propeller forces, for the B6620 propeller, which was designed for the 900-long ton (LT) gross weight Medium-Displacement Combatant (MDC) Surface Effect Ship (SES). These results were shown on pages 2-53 through 2-56 of the initial report of December 1980. Using the available SSCP computer program, detailed time histories of fluctuating forces for this same propeller were computed, as well as the blade loads for various forward speeds. Both were computed with and without the influence of cushion outflow at the propeller. Computations included shaft inclination angles of 0, 5, and 10 degrees. These partially completed dynamic force results were presented in the program overview in September 1981, and are shown here as figure 1-2. The corresponding influence of cushion flow and shaft inclination on averaged propeller performance is shown on pages 2-57 through 2-60 of the initial report of December 1980.

Correlation work was completed to describe the geometry of the blade sections and blade planforms of the David Taylor Naval Ship Research and Development Center (DTNSRDC) 4281 and 4407 highly skewed propellers;

parameters included local skew, thickness, camber, and angle of attach at several radial sections. This made possible computerized performance predictions and force predictions. It was planned to compare predicted performance and forces with available model test data, at various blade rakes and shaft inclination angles of the 4281 propeller and the 4407 propeller. No computer runs were made, however, because further correlation work was deferred by the customer.

1.2 Propeller Designs

Five propeller designs were prepared and investigated. Four of these were new designs and the other was an existing design scaled to match the Medium-Displacement Surface Effect Ship (MDS) thrust and power requirements. These designs were made for various SES vessels, which were studied by the Navy as follows:

a. Coastal SES, 400-LT, full-load displacement

b. Medium-Displacement Combatant SES, 900 LT

c. Medium-Displacement Combatant SES, 1600 LT

d. Medium-Displacement Combatant SES, 1600 LT (scaled SES-100B propellers)

e. Medium-Displacement SES, 1500 LT.

The Coastal SES propeller is a fixed-pitch design; all the others are controllable-pitch propellers. Ship drag was supplied by the Navy. Figures 1-3 and 1-4 show various views of the MDS 1500 propeller, and table 1-I lists the design and machinery parameters.

The off-design characteristics of the propellers were computed and matched to a variety of machinery configurations for the various vessels as follows:

- Coastal SES: CODOG
- MDC 900: CODAG
- MCD 1600: (a) CODOG and (b) only two gas turbines
- MCD 1600 (100B): CODOG
- MDS 1500: (a) two gas turbines or (b) CODOG.

The gas turbine used for the smallest two ships was the Allison 570KA; for the larger SES, the General Electric (GE) LM2500 was used.

Propulsion efficiencies versus forward speed of the new designs of propellers were computed using the available PITCHOPT program (see section 1.4). The propeller installed efficiency and required pitch settings for the MDC 1600-LT vessel are shown in figure 1-5, for both on-cushion and off-cushion operations at light weight, in sea state 3. Excellent propulsion efficiencies are maintained over the speed range, using the controllable-pitch feature of the propellers. Figure 1-5 also shows the effect of operating off cushion with one propeller and one engine. Although propulsion efficiencies are reduced, the engine efficiency is improved, reducing total fuel consumption below 17 knots (shown in figure 1-6).

As shown in figure 1-6, a significant improvement was noted in one-propeller operation over two propellers for the MDC 1600 LT; however, no improvement was noted in the MDS 1500.

1.3 Reports

Six reports were issued to the Navy. As requested by Navy representatives at the program review in September 1981, copies of the earlier reports are included in this report as appendix A. These reports were issued as follows:

REPORT	DATE	VESSEL	CONTRACT
7593-933046	12/80	400 and 900 LT	Design and Performance
7593-902007	5/81	1600 LT	Design and Performance
TN/SES TECH/017	7/81	1600 LT	Expanded Performance
TN/SES TECH/019	9/81	1600 LT	Efficiency versus Forward Speed Two and One Propeller
TN/SES TECH/020	9/81	1600 LT	Scaled SES-100B Propellers
7593-950002	11/81	1500 LT	Design and Performance

In the first report, a study of propeller structural design criteria and available materials was included, which led to the selection of titanium alloy and a design stress of 18,000 lb/in^2. These characteristics were used for all the new propeller studies. For the MDS 1500 propeller, after the scaled SES-100B structural design had been studied, a 10 percent overspeed broaching requirement was added to the structural criteria, as well as a 5 percent thrust overload.

1.4 Computer Programs

Several computer programs were used in the propeller design and performance investigation. They included the following programs:

PROGRAM	USE	SAMPLE OUTPUT
SCRP	Design point	Report 7593-933046, Page 2-39, 2-40
SSCP	Off-design, optimization and propeller forces	Report 7593-933046, Page 2-41, 2-42, 2-43, 2-44, 2-45, 2-46
NEW PROP	Maximum thrust versus engine limits, gear ratios and propeller pitch setting	TN/SES TECH/017, table 1
PITCHOPT	Maximum propeller efficiency versus forward speed, minimum fuel flow with one or two engines, considering engine limits, pitch settings, and cavitation limits	TN/SES TECH/019, table 6

The SCRP program was derived from the SCPRP program listing for design of supercavitating propellers, which was originally formulated by Hydronautics, Inc. The Bell version was reformulated for typewriter terminal control on an IBM computer system (rather than card deck control on the Control Data Corporation system). This work was described in the first report. A listing of the new program with some added features was submitted to the Navy: the reformulated program exactly reproduced Hydronautics samples. Bell has proposed changes and additions to this program and its documentation to overcome certain existing limitations. The program revision would:

a. Better define peak efficiency performance and face cavitation limits

b. Modify the skew and rake reference from the blade trailing edge to the conventional center chord reference

c. Facilitate terminal input

d. Compute nonventilated performance

e. Document program changes, options, and limits, and furnish a new listing to the Navy.

1.5 Overall Index to Design Data

Table 1-II is an index to the principal design features and performance results for the various propellers.

7593-950002

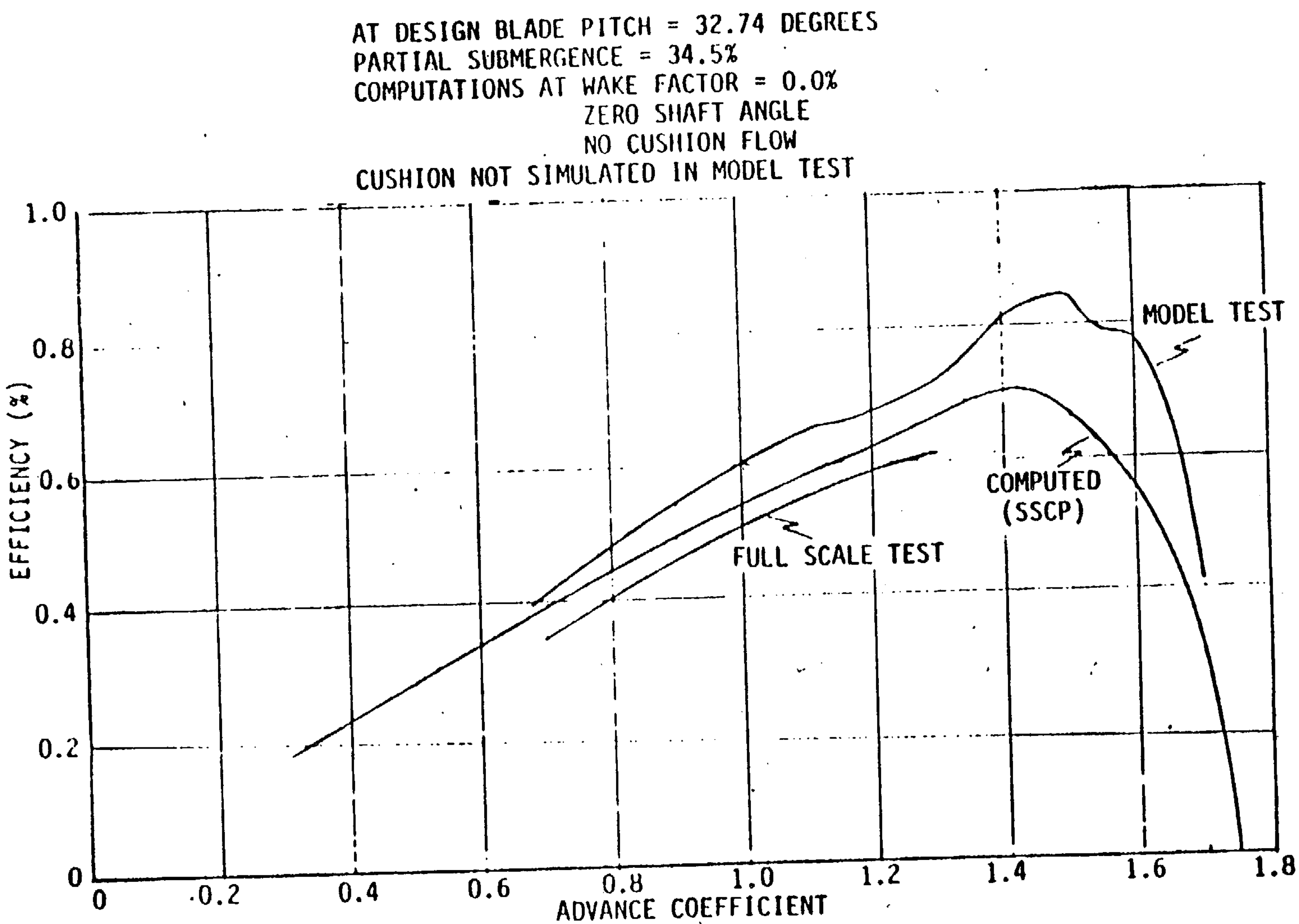

Figure 1-1 COMPUTED AND TEST PROPELLER EFFICIENCY SES-100B

Bell Aerospace TEXTRON
Division of Textron Inc

7593-950002

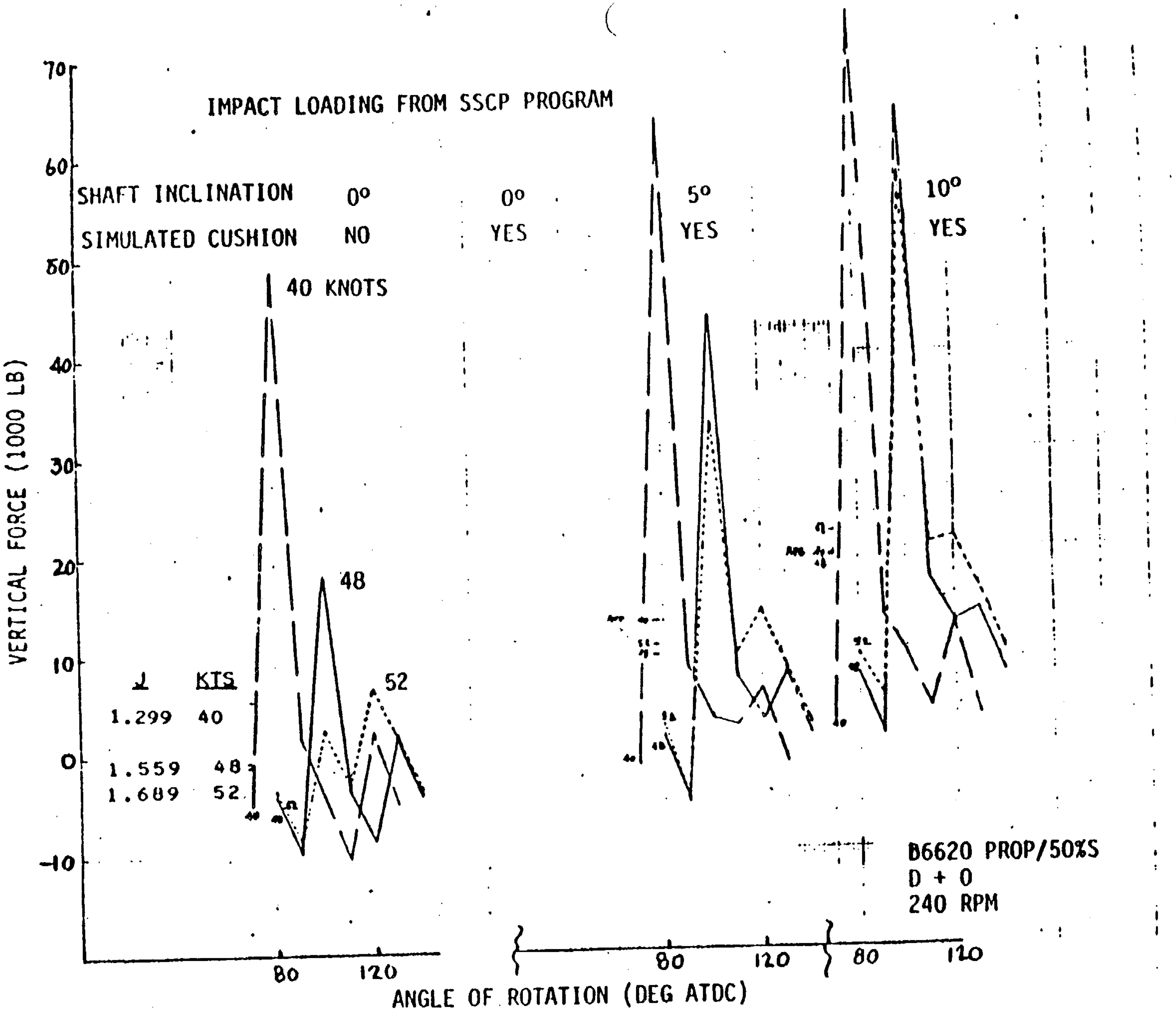

Figure 1-2 PROPELLER DYNAMIC FORCES

Bell Aerospace TEXTRON
Division of Textron Inc

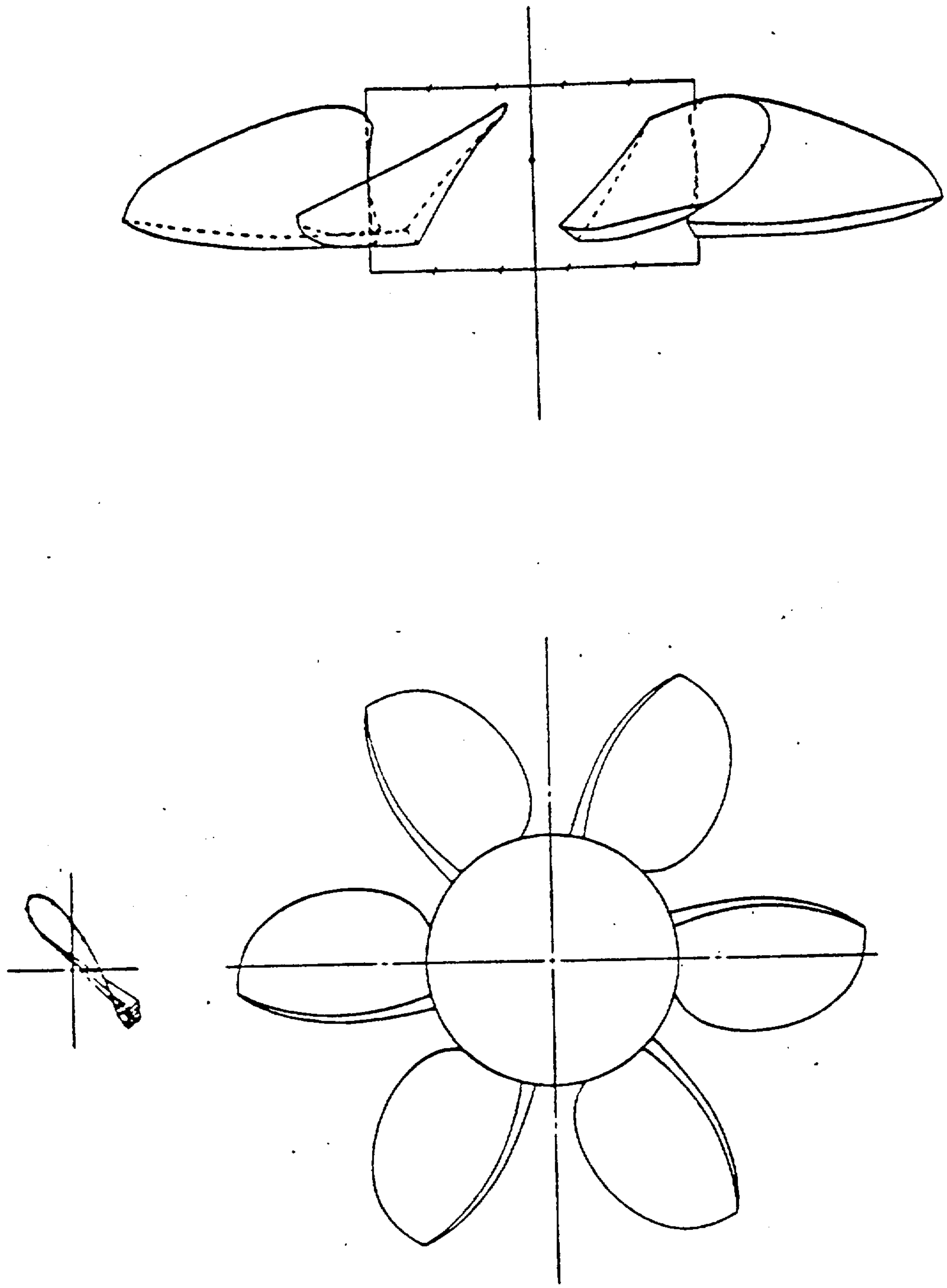

Figure 1-3 PROPELLER PROJECTED VIEWS MDS-1500 PROPELLER

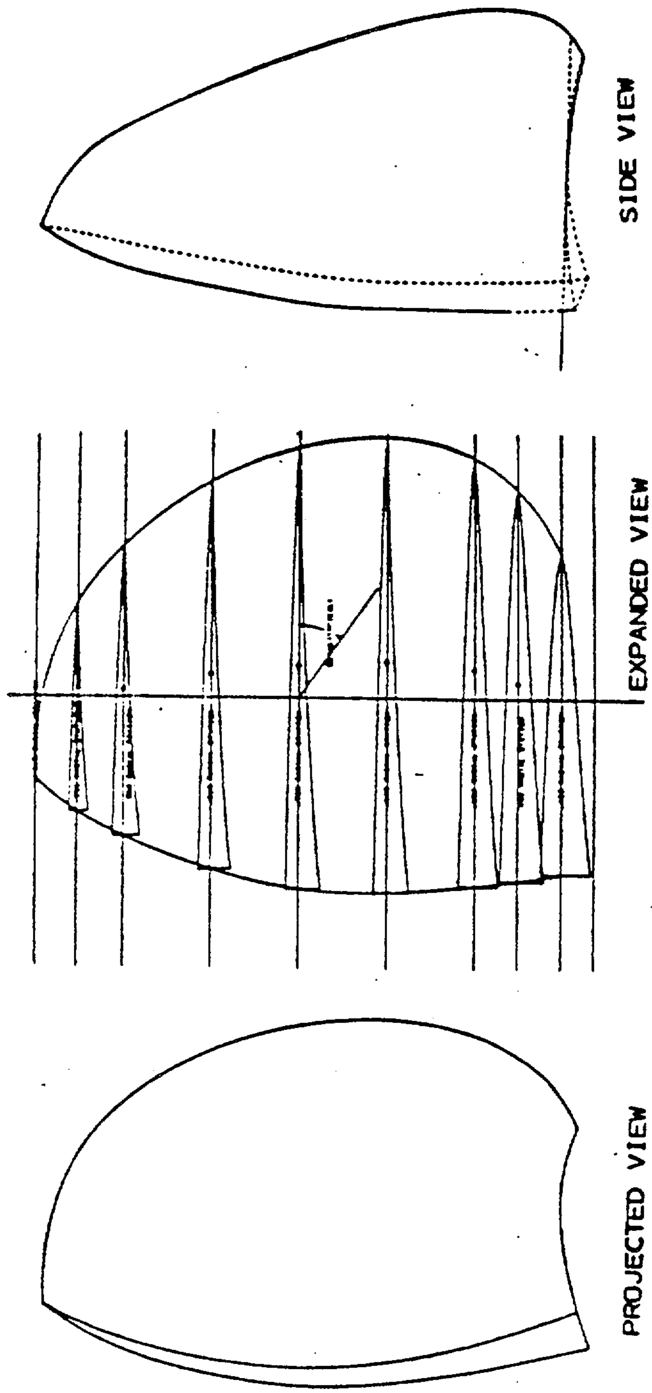

Figure 1-4 PROPELLER BLADE SECTIONS EXPANDED VIEW

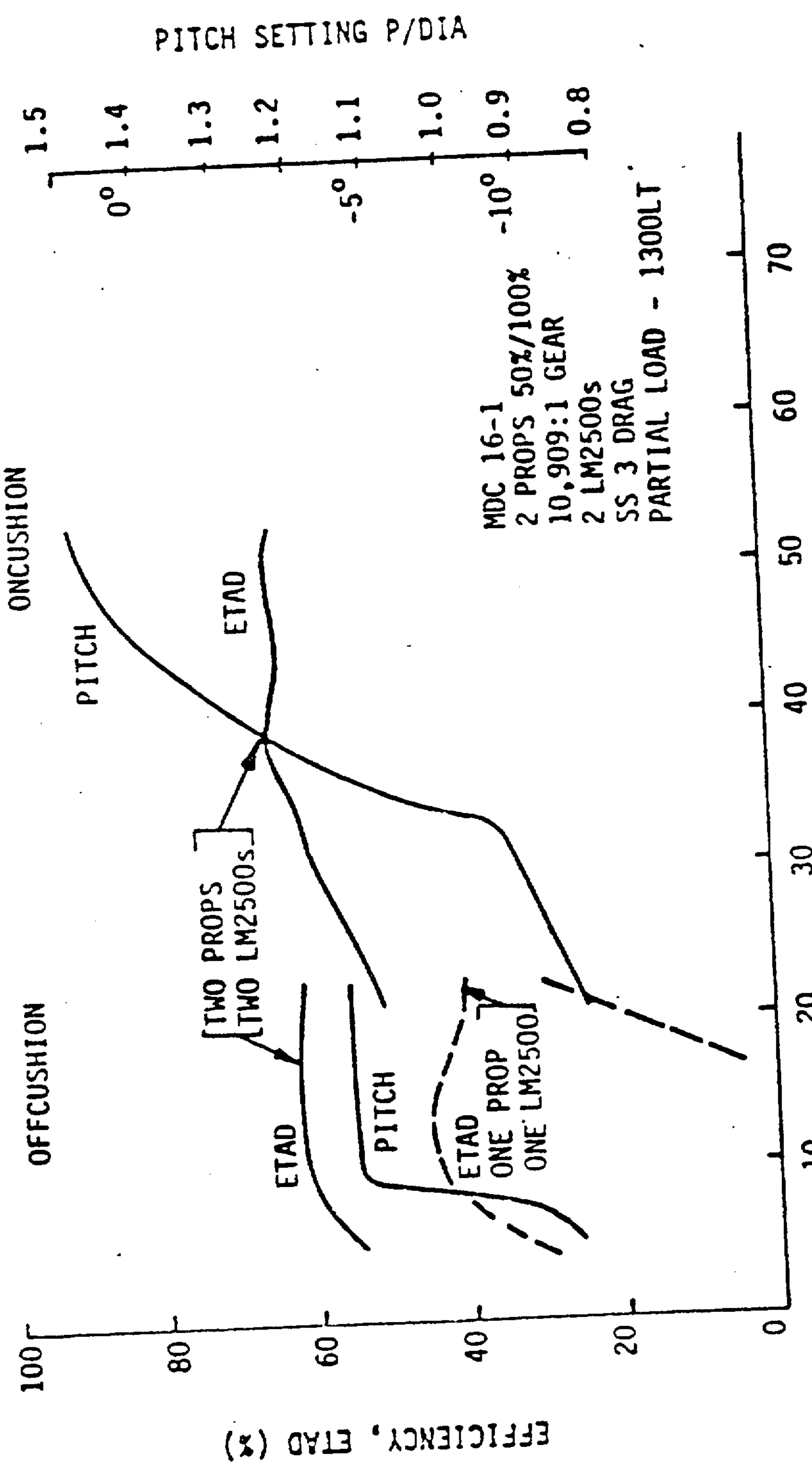

Figure 1-5 PROPULSIVE EFFICIENCY VERSUS SPEED

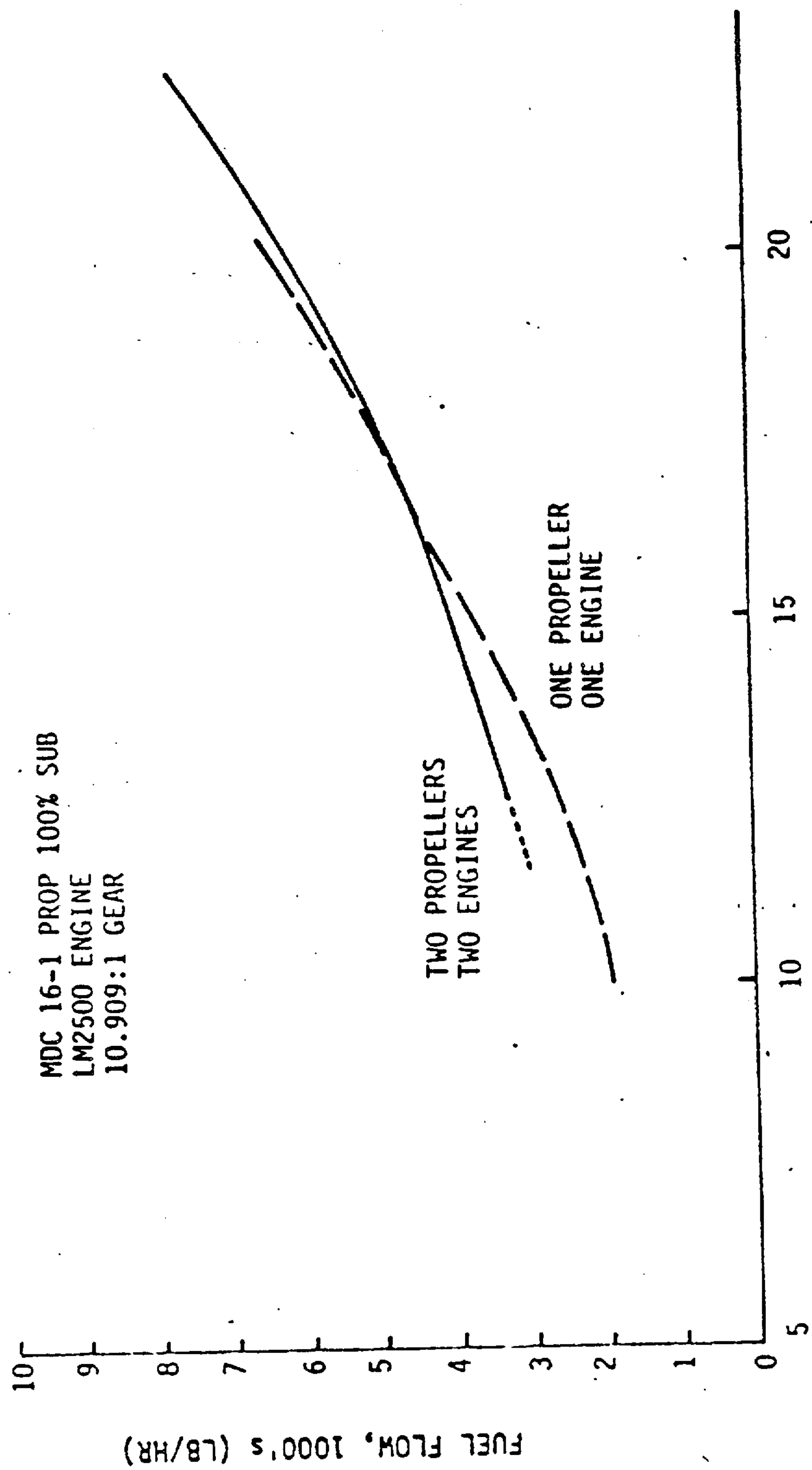

Figure 1-6 FUEL FLOW RATE - ONE/TWO PROPELLER/ENGINE

TABLE 1-I

MDS-1500 PROPELLER DESIGN AND MACHINERY PARAMETERS

Type	Controllable Pitch, Supercavitating
Forward Speed (Knots)	45
Thrust (Lb)	86,856
Diameter (Ft)	14.5
RPM	240
Expanded Area Ratio	0.50
Hub Diameter Ratio	0.40
Number of Blades	Six
Radius of Max Chord	0.70
Design Bending Stress (Lb/In^2)	18,000
Overspeed (Percent)	10
Thrust Margin (Percent)	+5
Impact Load Factor	1.75
Blade Material	TI-6A1-4V
Pitch At 0.7 Radius (Ft)	21.915
Advance Ratio	1.310
Skew, Mid Chord (Degrees)	0
Rake, Mid Chord (Degrees)	8
Submergence (Ventilated)	
On Cushion (Percent)	50
Off Cushion (Percent)	100
Power - GE LM2500 MCP (HP)	24,000
Reduction Gear	15.0:1
Alternate CODOG	
SACM 240 V16 RVR Continuous HP	5600
Diesel Reduction Gear	11.5:1

TABLE 1-II

INDEX TO DESIGNS

DESIGN	SEQUENCE REPORT NUMBER	PROPELLER DESIGN PARAMETERS	PLANFORM DRAWING	THRUST VERSUS SPEED	MAXIMUM EFFICIENCY VERSUS SPEED	NONDIMENSIONAL CHARACTERISTICS
COASTAL SES	1 7593-933046	Page 2-13	7593-440001 and page 2-15	2-16	--	
900-Ton MDC	1 7593-933046	2-28	page 2-36	2-37	--	Pages 2-51, 2-57 to 60
1600-Ton MDC	2 7593-902007	8	page 23	10	--	11, 12
	3 TN/SES TECH/017	--	--	Figure 1, 2 3, 5	--	
	4 TN/SES TECH/019	--	--	--	Table 1-VI	--
SCALED SES-100B	5 TN/SES TECH/020	Table 1,2	--	17.5 ft Fig 1-4 15.75 ft Fig 5-9	--	Fig A1-A14
1500-Ton MDS	6 7593-950002	Table 1-I	Fig 1-4	Fig 2-7, 2-8 2-9	Table 2-III, 2-IV, 2-V	Fig 2-5, 2-6

490-45

SECTION 2

DESIGN AND PERFORMANCE OF PROPELLERS FOR 1500-TON MEDIUM-DISPLACEMENT SURFACE EFFECT SHIP

2. DESIGN AND PERFORMANCE OF PROPELLERS FOR 1500-TON MEDIUM-DISPLACEMENT SURFACE EFFECT SHIP

A supercavitating, partially submerged, controllable-pitch propeller was designed for the Medium-Displacement SES (MDS) of 1500 long tons (LT) gross weight.

The vessel parameters for this study were defined by the Navy. Propulsion power was provided by two General Electric LM2500 engines. An alternate configuration combined two diesel engines (used for off-cushion propulsion only) with the gas turbines (that is, in a CODOG propulsion system arrangement).

2.1 Requirements

Table 2-I lists the basic requirements and engine ratings for the propeller design. The drag curves shown in figure 2-1 were supplied by the Navy, and are based on model test data. In sea state 3, the ship is designed to operate at 45 knots, on cushion, with a full-load displacement (FLD) of 1500 LT, and at 20 knots off cushion at the same weight. Also requested was the on-cushion, top-speed performance in sea state 3, with a 1050-LT displacement.

For the alternate configuration, SACM diesel engines were selected because of their light weight and suitable power ratings. Two SACM 240 V16 RVR engines were used, one on each propeller, and were rated at 5600 metric horsepower, continuous power.

The reduction gear ratios were to be selected as those necessary to match the engines and propellers.

2.2 Parametric Analysis of Propeller Diameter, Efficiency, Rotational Speed, and Weight

A parametric analysis was made to size the propellers, using the SCRP computer program in its preliminary design mode. Diameters from 11 to 17 feet were investigated, at the 45-knot point, with a design thrust of 87,000 pounds per propeller at 50 percent submergence. A maximum thrust of 92,000 pounds was input for structural computations and the design blade stress was 18,000 lb/in^2, using titanium material. This is the same stress that was used for prior designs in this project.

Figure 2-2 shows the parametric results of efficiency versus diameter. The effects of design rpm on efficiency and pitch are also shown. At each rpm level, the efficiency increases as the diameter is increased, until a peak value of efficiency is reached; thereafter, the efficiency declines.

A propeller diameter of 14.5 feet was selected, which was the maximum efficiency that could be obtained without the blades overhanging the side-hull at the transom. The selected propeller has a design point efficiency of 72 percent, and a level of 240 rpm was selected.

Figure 2-3 shows the effect of diameter on total blade weight. The design is for six blades and, as can be seen, blade weight is almost independent of rpm. Hub weight (not included here) is expected to constitute most of the total propeller weight.

Estimation of total propeller weight is planned for the next phase of the design project. The selected design has a preliminary total blade weight of about 3230 pounds.

2.3 Selected Propeller Design and Off-Design Performance

After the parametric study was made to select the design point, final design was computed with the SCRP program, using the same design point thrust and input parameters. (See table 1-I for the principal propeller design and machinery parameters.) These values are the chosen inputs to the computer program, except for thrust, pitch, advance ratio, skew, and rake, which are program outputs. The gear ratios are found by matching engine to propeller characteristics.

Complete input and output data for the design are given as table 2-II. The first page of the table is input data and subsequent pages are the output data. The second page gives overall performance, with detailed hydrodynamic and geometric data at several radial stations. The next four pages show the geometry of the blade sections and planform, and the final two pages show the section pressure coefficients and pressures. Headings for the printout columns are defined in reference 2-1. (Section 2.6).

Figure 2-4 shows the projected and side views of the propeller blade, with the expanded outline. The two views are a plot of the geometric data given in table 2-II, which does not show the blade trailing edge thickness.

Figures 2-5 and 2-6 give the nondimensional performance of the propeller at 50 and 100 percent submergence, over a wide range of off-design advance ratios and pitch angles. Values for these plots were obtained from the existing Bell SSCP computer program. Correlation of the program's off-design results with test data is shown in the summary and in the appendix.

2.4 Maximum Thrust Performance

2.4.1 Gas Turbine Power

Maximum thrust versus speed with LM2500 power is compared to the drag in figures 2-7 (for on cushion) and 2-8 (for off cushion), with a 15.0:1 reduction gear. Results are obtained by applying engine and propeller characteristics to the NEWPROP computer program. Enough thrust is available at maximum continuous power to operate 1500 tons at 52 knots in sea state 3, and to operate 1050 tons at 57 knots. Therefore, there is a margin of thrust to operate at 45 knots at 1500 tons (full load) in sea state 3 at the propeller design pitch. The propeller face cavitation limit advance coefficient set to 95 percent is shown in figure 2-7. The face cavitation limit shown was determined by an advance coefficient of 95 percent of the peak efficiency advance coefficient.

The effect of gear reduction upon maximum thrust performance was studied, using 16.5:1 and 13.0:1 reduction gear ratios. Maximum thrusts and forward speeds were decreased with a 16.5:1 reduction ratio. Maximum thrusts were increased using a 13.0:1 gear ratio, but propeller rpm limits were encountered at lower forward speeds, so that the design was not feasible with this gear ratio.

2.4.2 Diesel Power

With alternate diesel power, figure 2-9 shows the maximum thrusts available for off-cushion operation. There is a considerable margin in thrust at 20 knots, using the SACM 240 V16 RVR engines at 5600 continuous power and a 11.5:1 reduction gear ratio.

2.5 Propulsion Installed Efficiency Versus Forward Speed

2.5.1 Gas Turbine

Tables 2-III and 2-IV give power and propeller parameters for operation in sea state 3 with thrust equal to drag at 1500 tons and 1050 tons, respectively. The propeller pitch is set for the best performance at each forward speed. These tables represent operation with gas turbine limits and a 15.0:1 gear reduction ratio.

Table 2-III shows that propulsion efficiency varies from 0.607 at 5 knots to 0.711 at 45 knots for the full-load operation at 1500 tons. The propeller pitch is -12.5 to -10 degrees off cushion to on cushion, then increasing to +5 degrees at a top speed of 50 knots. Above 50 knots, engine rpm, power, and propeller overspeed rpm limits are exceeded.

At 1050 tons (see table 2-IV), the available drag data only covers on-cushion performance, starting at 22.5 knots. Propeller pitch setting increased from -10 degrees at 22 knots to +7.5 degrees at 60 knots; above 60 knots, engine power and rpm limits are exceeded. Efficiency increased from 66 to 74 percent over the usable speed range. Top speed is approximately 60 knots.

2.5.2 Diesel

Table 2-V shows the power and propeller parameters for off-cushion operation, with diesel engines, with thrust equal to drag, at 1500 tons, in sea state 3. Again, propeller pitch is set for best performance at each forward speed; pitch increases from -15 degrees at 5 knots to +2.5 degrees at 20 knots. Propulsion efficiency increases from 0.614 at 5 knots to 0.683 at 13.5 knots, decreasing to 0.608 at 20 knots. Although the propulsion efficiency is not changed greatly for diesel compared to gas turbine operation, the engine specific fuel consumption decreases considerably. Typical gas turbine consumption at 20 knots would be 0.70 lb/hp/hr, compared to 0.40 lb/hp/hr for the diesel.

2.6 References

2-1 J. O. Scherer, P. Majumdar, and J. Bohn, *Operational Manual for the Supercavitating Propeller Design Computer Program (SCPDP)* (Hydronautics, Inc., Report 7623-6, March 1979).

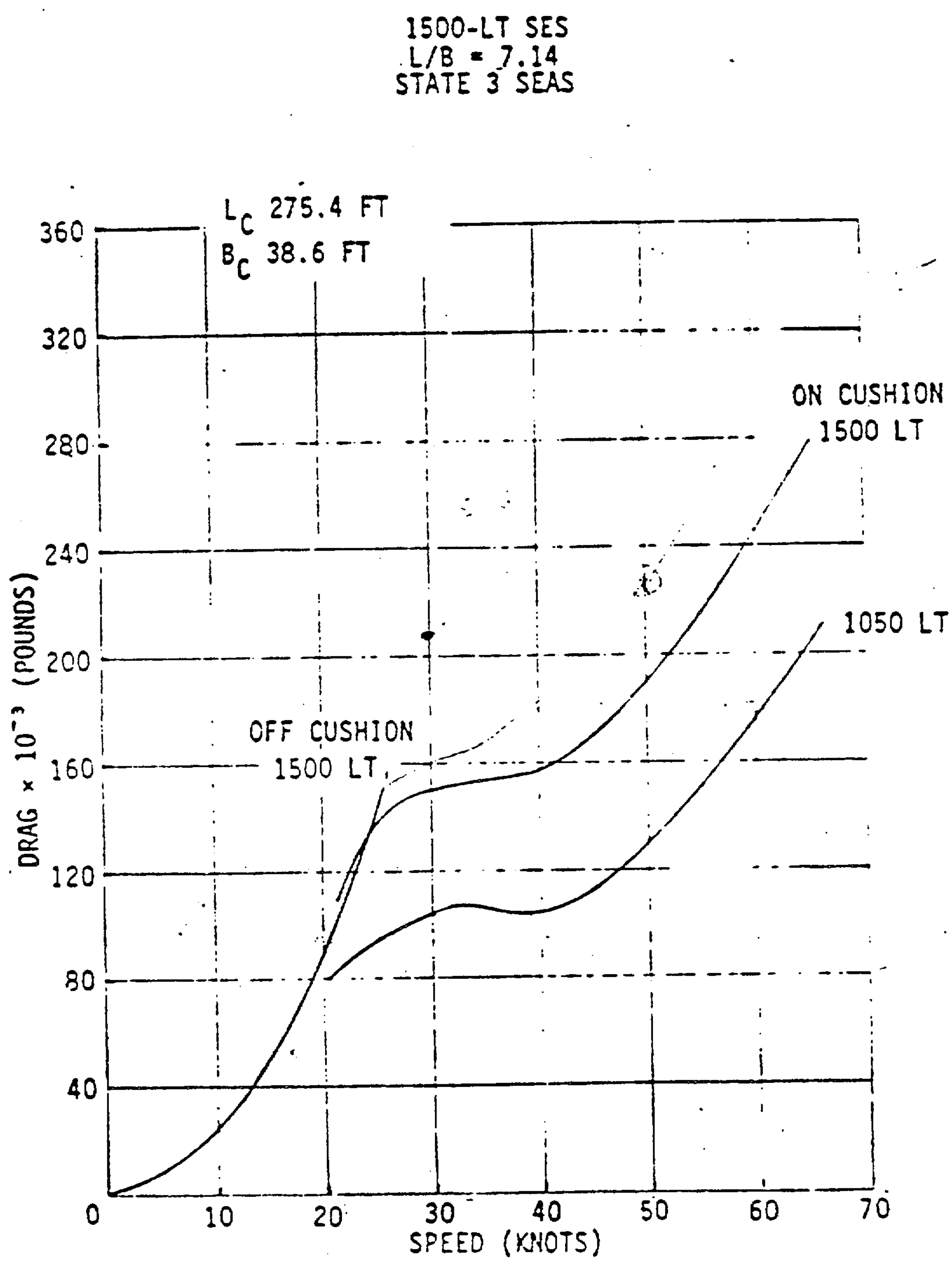

Figure 2-1 DRAG VERSUS SPEED, 1500-LT SES

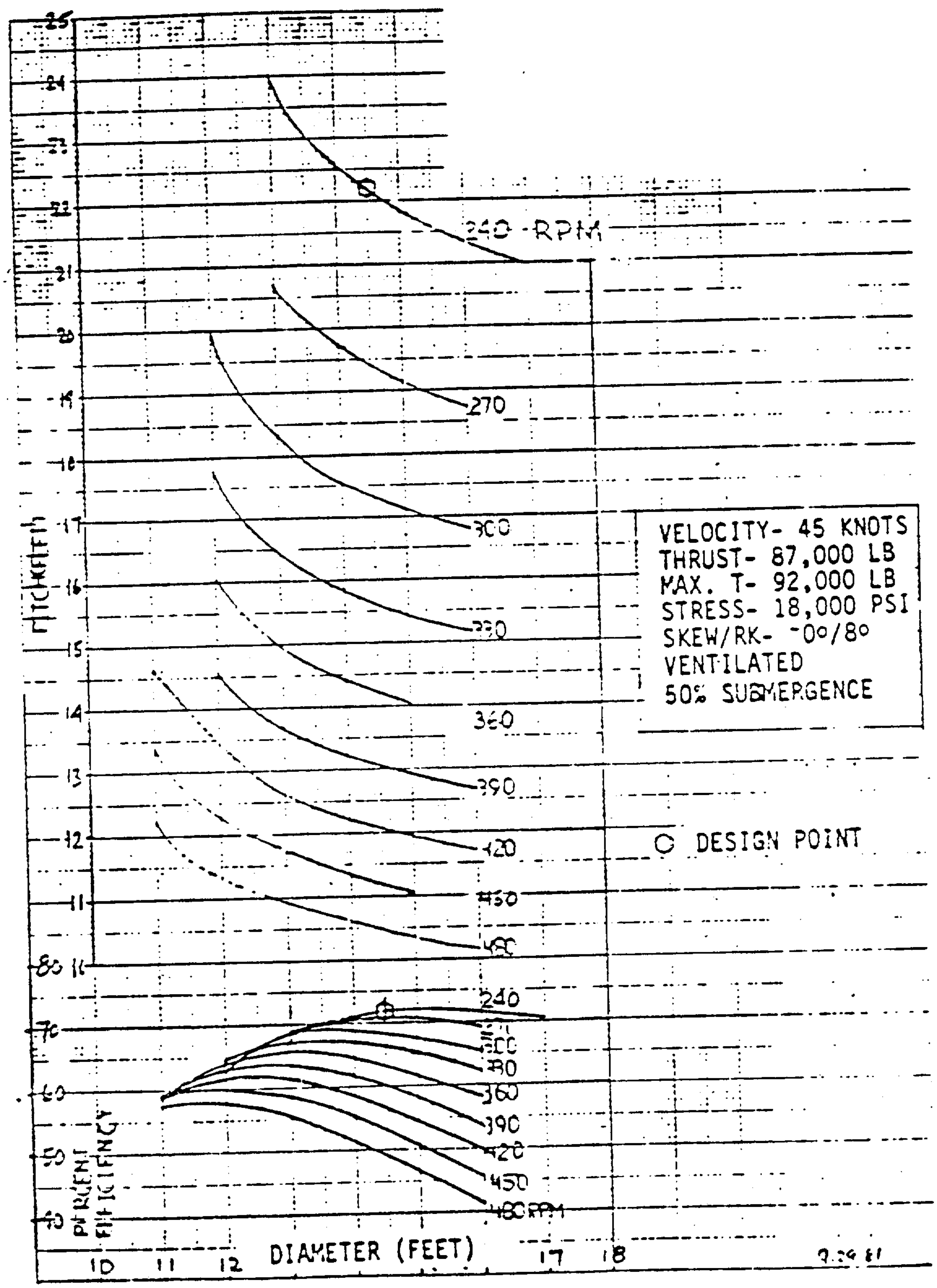

Figure 2-2 MDS 1500 PROPELLER PARAMETRIC PERFORMANCE

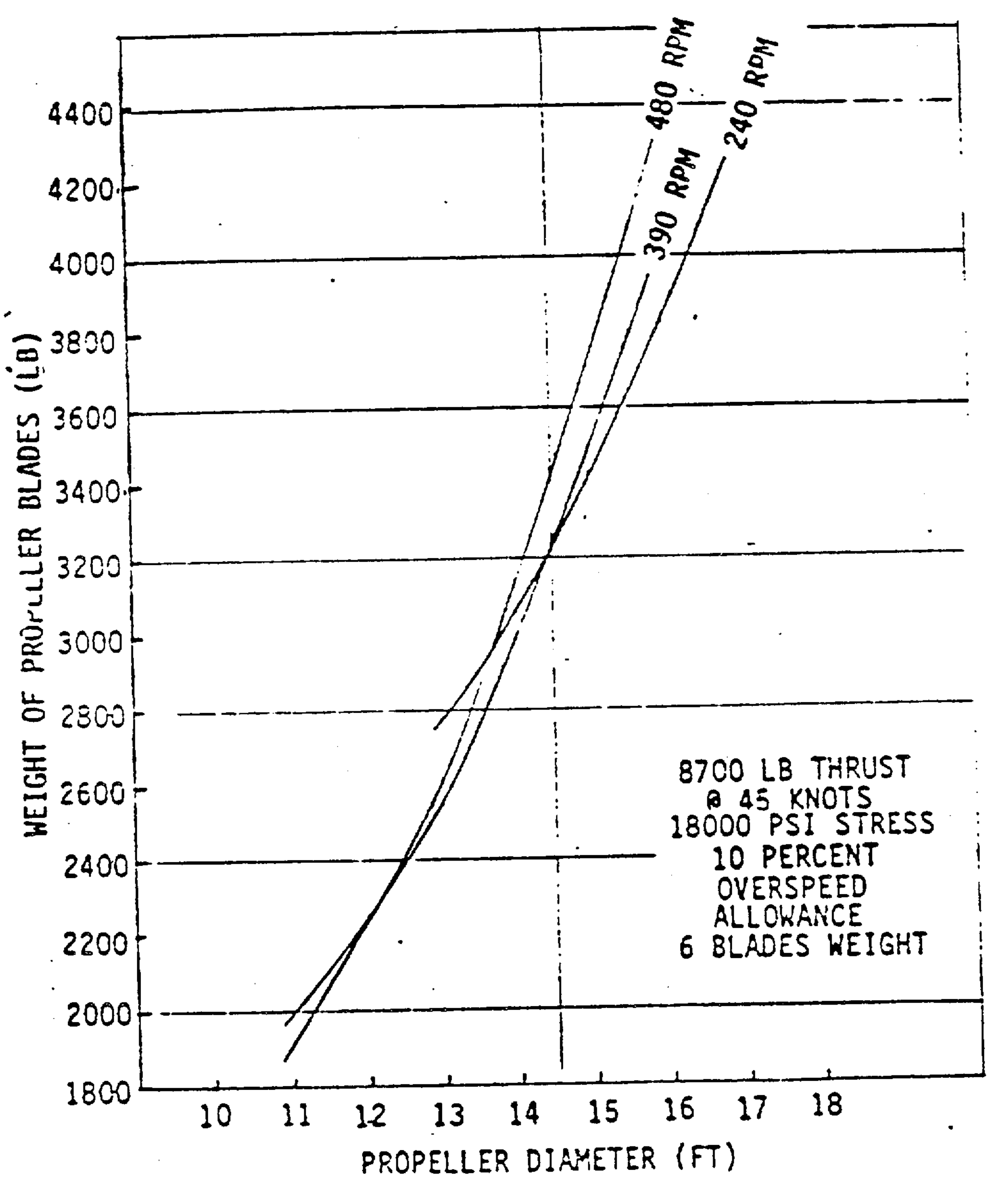

Figure 2-3 BLADE WEIGHT VERSUS SIZE

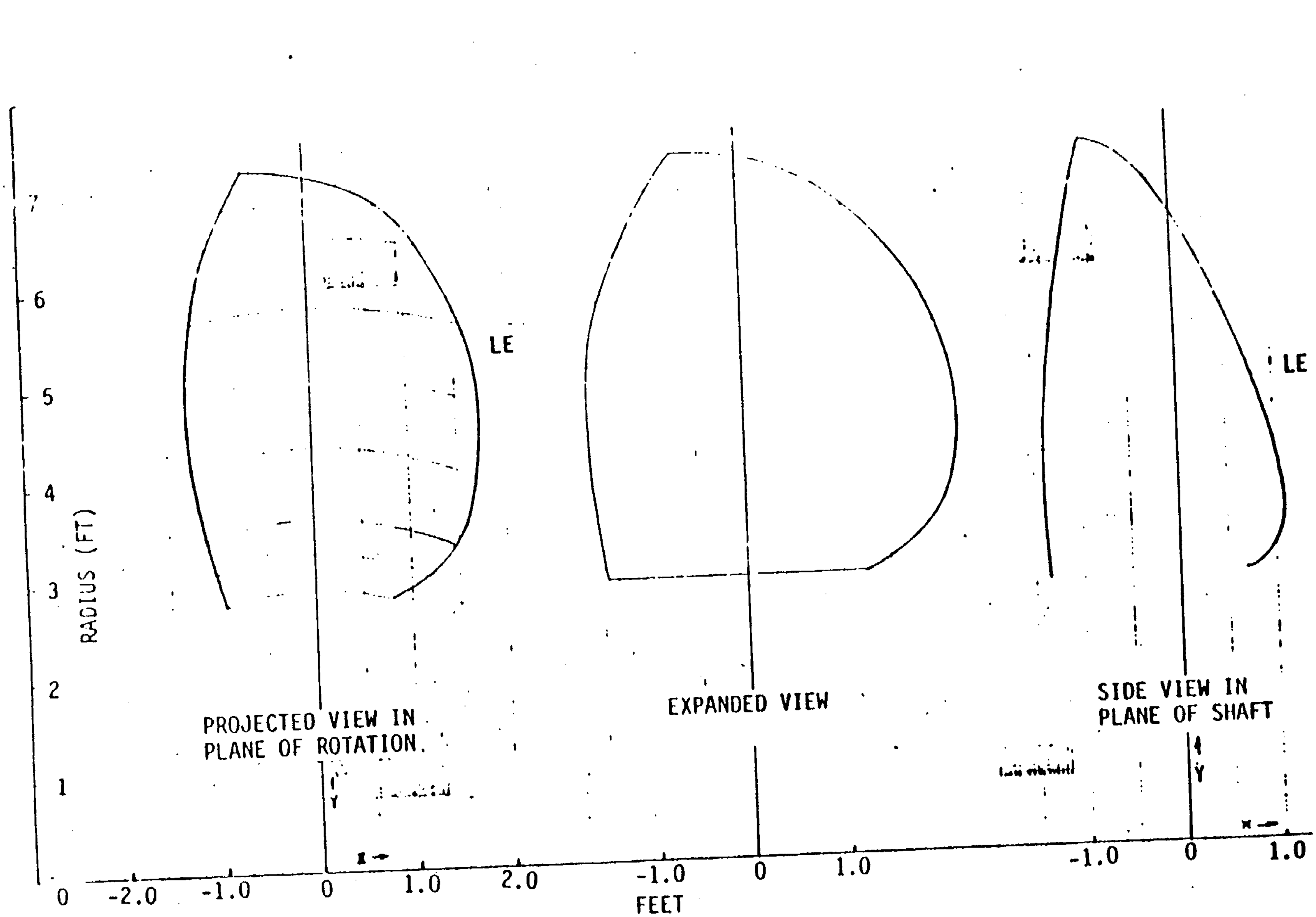

Figure 2-4 MDS 1500 PROPELLER

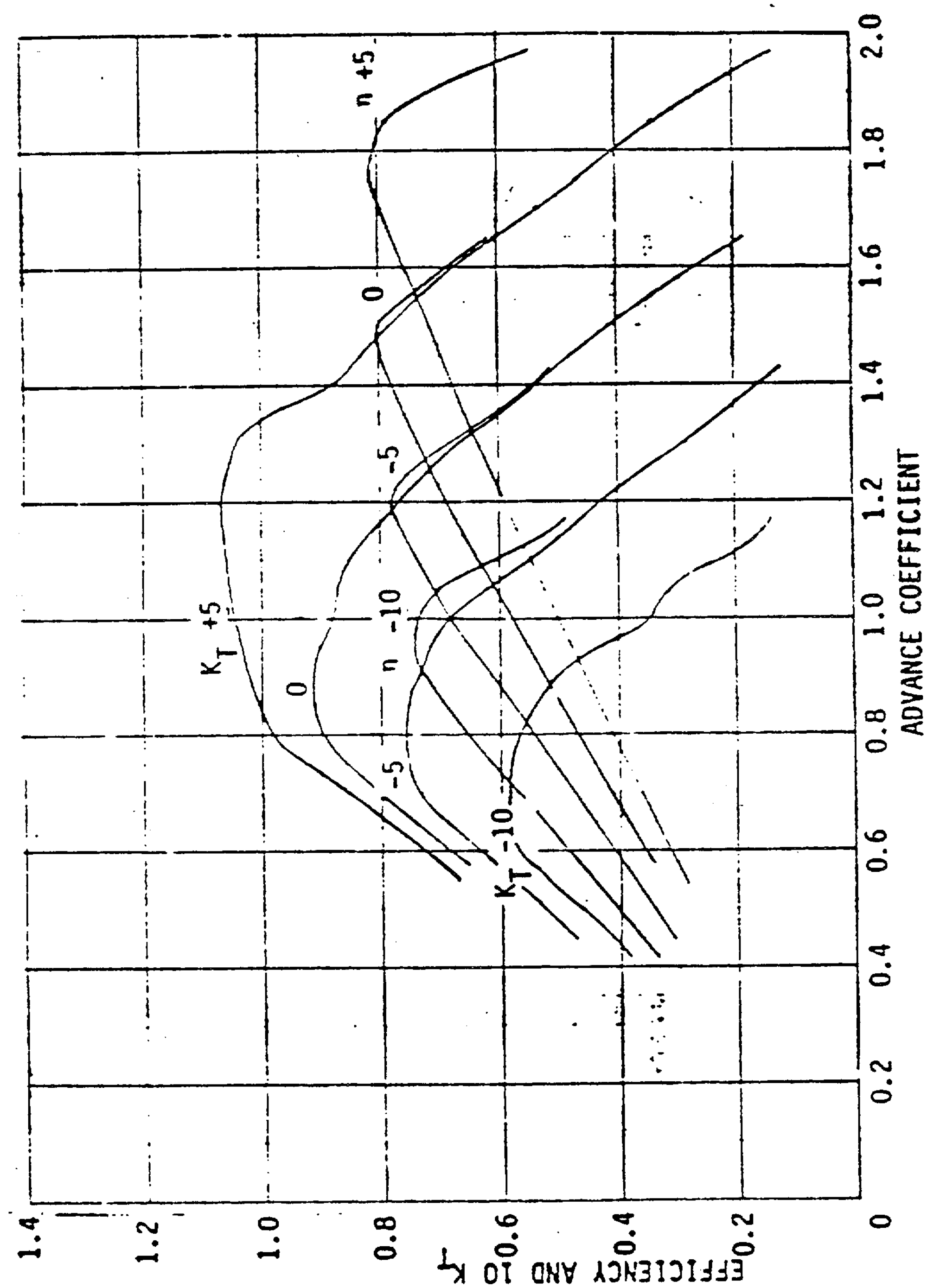

Figure 2-5 MDC 1500 PROPELLER (50 PERCENT SUBMERGED)

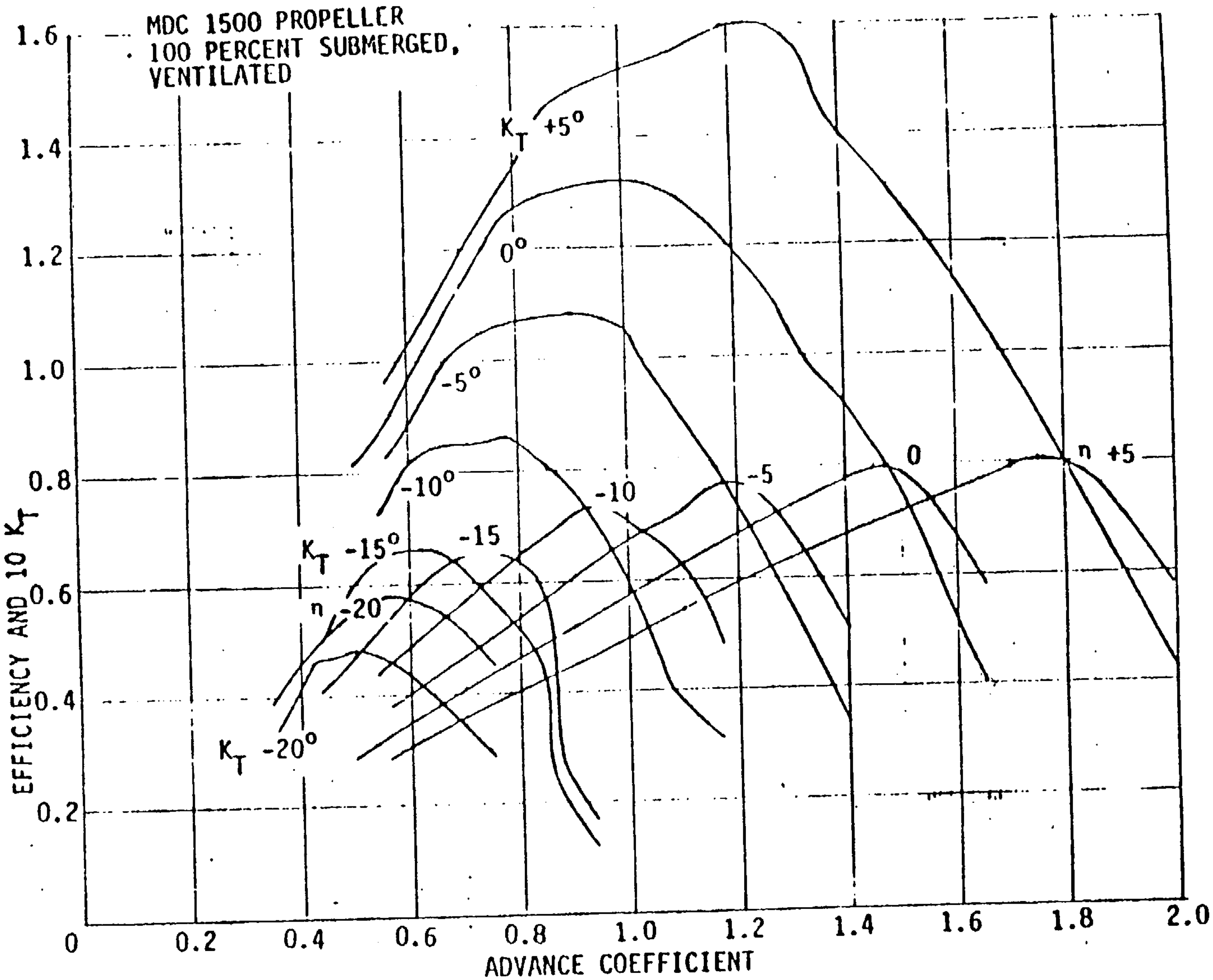

Figure 2-6 MDC 1500 PROPELLER (100 PERCENT SUBMERGED, VENTILATED)

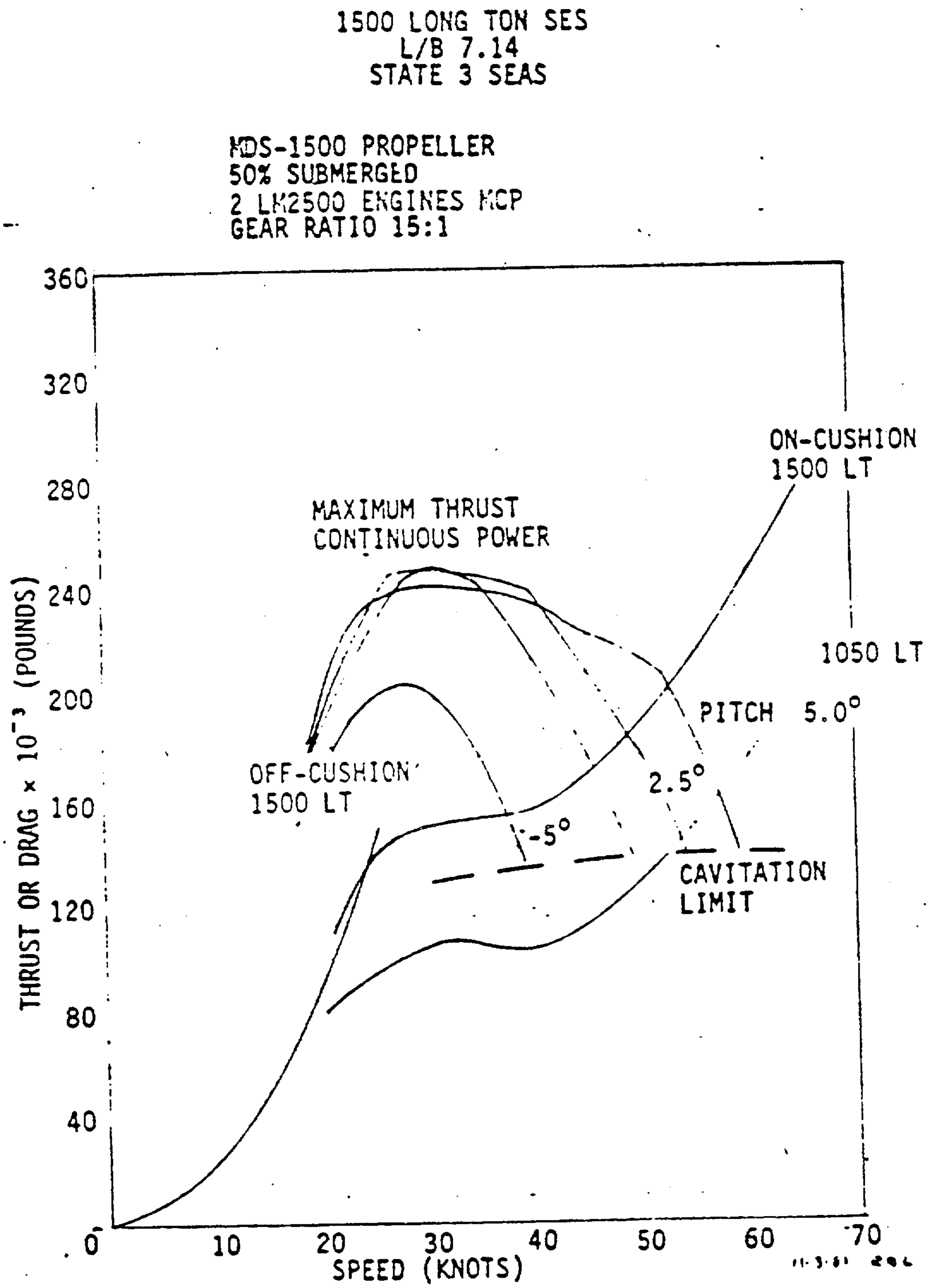

Figure 2-7 MAXIMUM THRUST ON CUSHION - LM2500 ENGINES, MCP

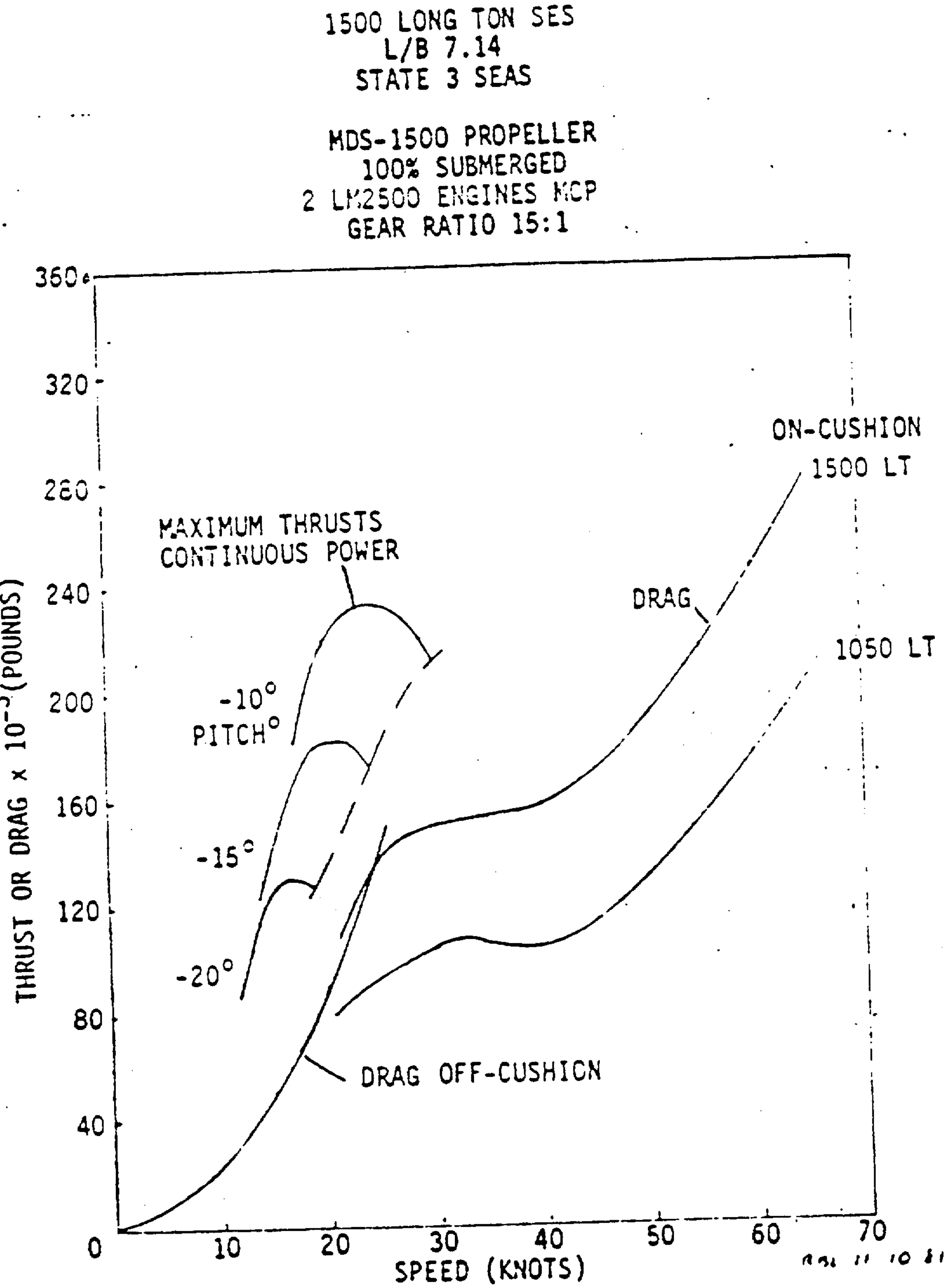

Figure 2-8 MAXIMUM THRUST OFF CUSHION - LM2500 ENGINES, MCP

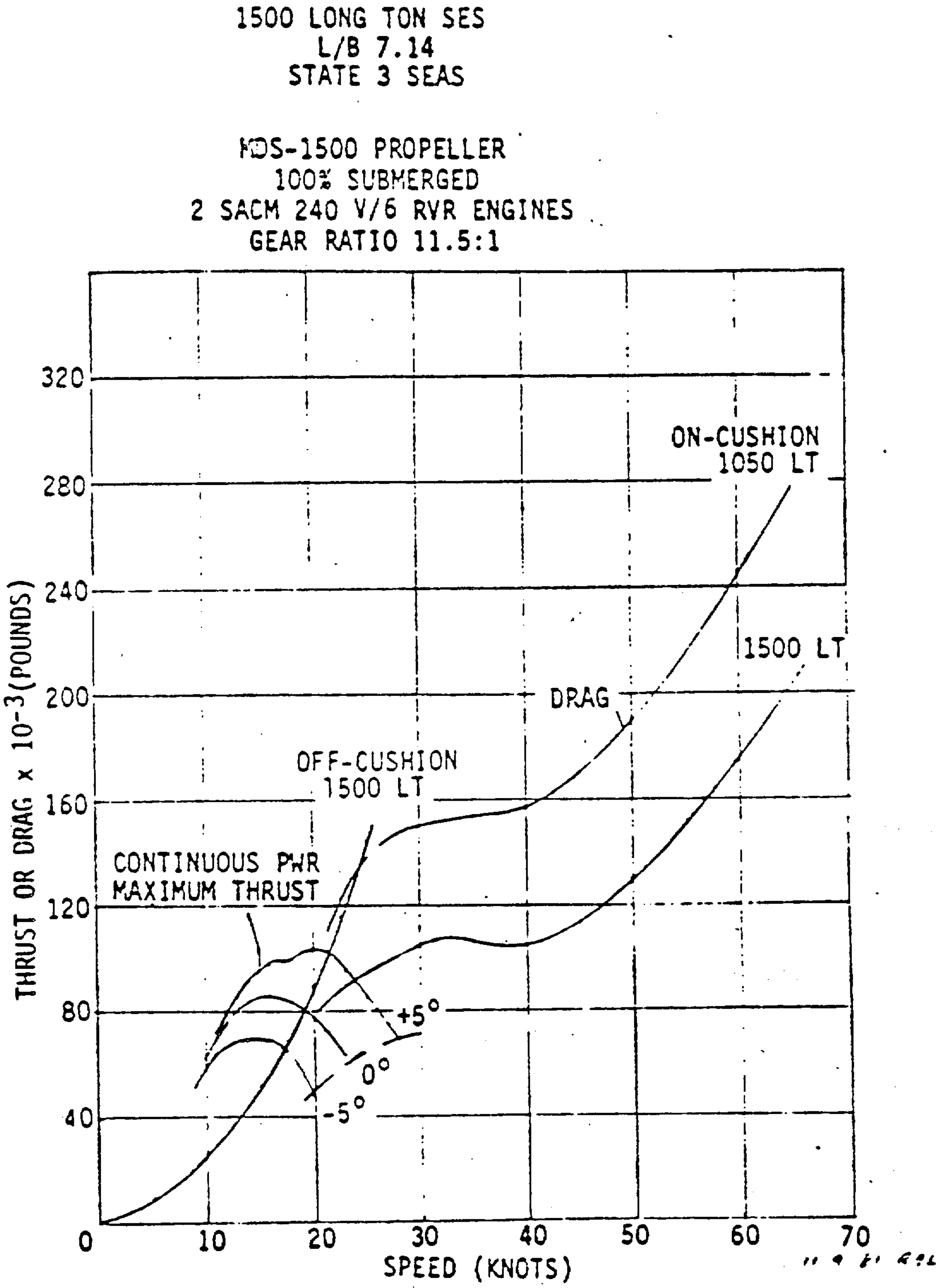

Figure 2-9 MAXIMUM THRUST OFF CUSHION - SACM ENGINES

TABLE 2-I

NAVY REQUIREMENTS FOR MDS 1500 PROPELLERS

Two supercavitating controllable pitch

Two General Electric LM2500 gas turbines (baseline)

Two CODOG diesel engines for off cushion (alternate)

Gear reduction ratios to be selected

Sidehull width at transom and chine, 14.5 feet

8-degree shaft inclination

DESIGN POINTS

On Cushion - 45 knots in sea state 3 at FLD, 1500 LT, 50 percent submergence

Off Cushion - 20 knots in sea state 3 at FLD, 1500 LT, 100 percent submergence

OFF-DESIGN POINT

On Cushion - Maximum knots in sea state 3 with partial load of 1050 LT

DRAG

170,000 lb at 45 knots, sea state 3, 1500 LT, on cushion

90,000 lb at 20 knots, sea state 3, 1500 LT, off cushion

LM2500 ENGINE RATINGS

27,000 maximum intermittent power, 3600 rpm

24,000 maximum continuous power, 3600 rpm

DIESEL ENGINE RATINGS

Engine to be selected from proven models.

TABLE 2-11

SECTION OFFSETS AND PLANFORM DIMENSIONS FOR MDS 1500 PROPELLER

SUPERCAVITATING PROPELLER DESIGN INPUT SUMMARY

DESIGN PROGRAM CONTROL SPECIFICATIONS -
7. CURVED BEAM STRUCTURAL ANALYSIS INCLUDED DURING DESIGN ITERATIONS
9. SECTION OFFSETS TABULATED

DSGNMOC15 0001 CHORD LIM. 2 NO INTERFERENCE IN EXPANDED OUTLINE

THRUST	86500.00	MAX.THRST	92000.00	SHAFT SUBM	0.	DIAMETER	14.50
REVS/SEC	4.00	VELOCITY	76.00	CAV.PRES.	2116.00	NO.BLADES	6.00
HUB RAD.	0.	HUB LENGTH	0.	HUB SURF.	0.	HUB SHAPE	0.
HUB CDC	0.	PALM DIAM.	1.80	METAL DENS	8.59	MAX.RPS	4.50
STRESS	18000.00	L.E.STRESS	0.80	ANNEX THIK	0.	UNDERCUT	0.80
PROP.EAR	0.50	BLADE CHAR	0.70	BLADE XBAR	0.65		
TIP SKEW	15.00	SKEW TANG.	-20.00	SKEW EXPON	3.00		
TIP RAKE	0.	RAKE TANG.	5.00	RAKE EXPON	0.		

SPANWISE CHARACTERISTICS OF BLADE

RADIAL STATION	CT(R) (SPECIFIED)	ESTIMATED ETAC(R)	ANNEX/ HYD.CHORD	SECTION CL-DELTA	ESTIMATED CINC.FACTOR	NORMAL CHORDS	NORMAL ANNEXES
1.000	0.0043	0.8000	0.	0.300	0.001	0.	0.
0.950	0.7612	0.8000	0.	0.300	0.200	0.	0.
0.900	1.0000	0.8000	0.	0.300	0.300	0.	0.
0.800	0.9915	0.8000	0.	0.300	0.400	0.	0.
0.700	0.9612	0.8000	0.	0.300	0.550	0.	0.
0.600	0.8011	0.8000	0.	0.300	0.700	0.	0.
0.500	0.5385	0.8000	0.	0.300	0.800	0.	0.
0.450	0.4391	0.8000	0.	0.300	0.900	0.	0.
0.400	0.3360	0.8000	0.	0.300	1.000	0.	0.

TABLE 2-11 (Cont)

BELL AEROSPACE TEXTRON　　　PROPELLER DESIGN　0001

SUMMARY OF CALCULATED PROPELLER CHARACTERISTICS

GEOMETRIC	OPERATIONAL	PERFORMANCE INDICES (BASED ON FULL DIAM.)	
HUB RAD.RATIO= 0.4000	J (TIP) = 1.310	CT = 0.14545	DIAMETER = 14.50800
NUMBER BLADES= 6.0000	J (.7R) = 1.872	CP = 0.20225	VELOCITY = 76.000
EX.AREA RATIO= 0.5000	LAMBDA(.7R)= 0.642	KF = 0.06178	CAV. PRES. = 2116.00
TIP SKEW =-15.0000	BETAI(.7R) =29.431	KQ = 0.01792	SUBM = 0.50000
HYDR.TIP RAKE= 0.	PITCH(.7R) =21.915	ETA = 0.71915	DELT. PITCH = 0.
SUBM/DIAM = 0.5000	SIG.CAV.7R = 0.000	THRST= 0.86856 LBS-5	RPS = 4.00000
BLADE WEIGHT = 3.1760 LBS-3	SIG.CAV.HUB= 0.000	POWER= 0.16689 HP-5	

BLADE SECTION CHARACTERISTICS

N.D.RAD	C(HYD) FT.	C(ANNEX) FT.	CL	CD	CD-CAV	ETA	ETAI	ETAB	ETAC	'IDEAL' CT	ACTUAL CT
1.000	0.	0.	0.	0.	0.	0.8248	1.0273	0.9761	0.8225	0.	0.00094
0.950	1.756	0.	0.1291	0.0141	0.01002	0.7996	1.0549	0.9716	0.8225	0.169	0.16645
0.900	2.451	0.	0.1290	0.0153	0.01135	0.7722	1.0728	0.8879	0.8107	0.222	0.21867
0.800	3.293	0.	0.1076	0.0128	0.00894	0.7804	1.0758	0.8750	0.8290	0.271	0.21681
0.700	3.735	0.	0.1047	0.0125	0.00860	0.7831	1.0609	0.8797	0.8390	0.217	0.21019
0.600	3.862	0.	0.0953	0.0116	0.00771	0.7890	1.0447	0.8914	0.8473	0.181	0.17518
0.500	3.632	0.	0.0813	0.0126	0.00870	0.7551	1.0331	0.9054	0.8073	0.124	0.11775
0.450	3.315	0.	0.0811	0.0149	0.01098	0.7119	1.0265	0.9108	0.7615	0.102	0.09602
0.400	2.704	0.	0.0924	0.0223	0.01825	0.6201	1.0198	0.9162	0.6636	0.000	0.07347

DIM.RAD.	FT.	DELTA 1ST ORD	KAPPA 1ST ORD	TAU	BEND.STRES PSI	LE STRES PSI	SECT.AREA SQ.FT.	ZBAR	SIGC	BETAI	BETAO	PITCH FT.
1.00	7.25		0.	0.	0.	0.	0.	0.	0.000	22.05880	22.495	18.06
0.950	6.89	1.396	0.0893	0.0137	0.	14518.	0.14	0.00028	0.000	22.58703	25.432	20.58
0.900	6.52	1.404	0.0898	0.0130	2544.	14425.	0.27	0.00027	0.000	23.36665	27.579	21.41
0.800	5.80	1.166	0.0746	0.0111	5965.	14366.	0.41	0.00019	0.000	25.92367	30.002	21.73
0.700	5.07	1.136	0.0726	0.0091	11592.	14459.	0.48	0.00017	0.000	29.43146	34.500	21.92
0.600	4.35	1.035	0.0662	0.0110	18049.	9712.	0.51	0.00017	0.000	33.79387	38.506	21.75
0.500	3.63	0.884	0.0565	0.0251	17756.	2482.	0.64	0.00031	0.000	39.03846	43.056	21.28
0.450	3.26	0.882	0.0564	0.0354	17638.	1285.	0.67	0.00049	0.000	42.17469	45.916	21.17
0.400	2.90	1.004	0.0642	0.0553	17657.	593.	0.64	0.00102	0.000	45.31093	48.839	20.84

N.D.RAD	DELTA GEOM	KAPPA(I) GEOM	U1 FPS	U' FPS	U2 FPS	OMEGA1 RAD/SEC	OMEGA' RAD/SEC	OMEGA2 RAD/SEC	W1 FPS	W' FPS	W2 FPS
1.000	0.	0.	73.944	75.638	77.333	25.146	25.122	0.047	182.3111	182.0638	181.8165
0.950	2.491	0.1191	72.059	77.338	82.617	25.158	24.850	0.617	173.2761	171.1772	169.0783
0.900	3.006	0.1330	70.844	78.266	85.689	25.160	24.652	1.014	164.1678	160.0795	157.5913
0.800	2.912	0.1232	70.644	78.518	86.391	25.142	24.444	1.396	145.8247	141.0048	137.7849
0.700	2.982	0.1272	71.643	78.660	85.678	25.127	24.277	1.699	127.5201	123.2344	118.9487
0.600	2.676	0.1182	72.751	78.437	84.122	25.114	24.153	1.921	109.2476	105.0832	100.9187
0.500	2.133	0.0992	73.566	77.834	82.101	25.102	24.074	2.056	90.9963	87.2758	83.5554
0.450	2.000	0.0961	74.042	77.640	81.218	25.094	24.003	2.182	81.8702	78.3192	74.7683
0.400	2.051	0.1033	74.517	77.446	80.375	25.086	23.931	2.309	72.7441	69.3626	65.9812

TABLE 2-II (Cont)

BELL AEROSPACE TEXTRON
SECTION OFFSETS FOR PROPELLER DESIGN 0001

1.000 RADIAL STATION
L.E.RADIUS = 0.

Y/C	Y	T-CAV	T-FACE
0.	0.	0.	0.
0.	0.	0.	0.
0.	0.	0.	0.
0.	0.	0.	0.
0.	0.	0.	0.
0.	0.	0.	0.
0.	0.	0.	0.
0.	0.	0.	0.
0.	0.	0.	0.
0.	0.	0.	0.
0.	0.	0.	0.
0.	0.	0.	0.
0.	0.	0.	0.
0.	0.	0.	0.
0.	0.	0.	0.
0.	0.	0.	0.
0.	0.	0.	0.
0.	0.	0.	0.
0.	0.	0.	0.
0.	0.	0.	0.
0.	0.	0.	0.
0.	0.	0.	0.

0.950 RADIAL STATION
L.E.RADIUS = 0.0001660

Y/C	Y	T-CAV	T-FACE
0.	0.	0.	0.
0.05	0.0878	0.0099	-0.0045
0.10	0.1756	0.0152	-0.0072
0.15	0.2634	0.0196	-0.0101
0.20	0.3513	0.0234	-0.0131
0.25	0.4391	0.0268	-0.0163
0.30	0.5269	0.0300	-0.0198
0.35	0.6147	0.0330	-0.0235
0.40	0.7025	0.0359	-0.0273
0.45	0.7903	0.0385	-0.0315
0.50	0.8781	0.0411	-0.0358
0.55	0.9659	0.0436	-0.0404
0.60	1.0538	0.0459	-0.0452
0.65	1.1416	0.0482	-0.0503
0.70	1.2294	0.0504	-0.0558
0.75	1.3172	0.0526	-0.0615
0.80	1.4050	0.0547	-0.0677
0.85	1.4928	0.0567	-0.0743
0.90	1.5806	0.0587	-0.0815
0.95	1.6684	0.0607	-0.0897
1.00	1.7563	0.0626	-0.1002
1.00	1.7563	0.	0.

0.900 RADIAL STATION
L.E.RADIUS = 0.0002061

Y/C	Y	T-CAV	T-FACE
0.	0.	0.	0.
0.05	0.1225	0.0135	-0.0053
0.10	0.2451	0.0208	-0.0087
0.15	0.3676	0.0268	-0.0124
0.20	0.4902	0.0321	-0.0165
0.25	0.6127	0.0368	-0.0209
0.30	0.7352	0.0412	-0.0256
0.35	0.8578	0.0454	-0.0308
0.40	0.9803	0.0492	-0.0363
0.45	1.1028	0.0529	-0.0421
0.50	1.2254	0.0565	-0.0483
0.55	1.3479	0.0599	-0.0549
0.60	1.4705	0.0632	-0.0620
0.65	1.5930	0.0663	-0.0694
0.70	1.7155	0.0694	-0.0773
0.75	1.8381	0.0724	-0.0858
0.80	1.9606	0.0752	-0.0949
0.85	2.0831	0.0781	-0.1047
0.90	2.2057	0.0808	-0.1155
0.95	2.3282	0.0835	-0.1278
1.00	2.4508	0.0861	-0.1437
1.00	2.4508	0.	0.

0.800 RADIAL STATION
L.E.RADIUS = 0.0002019

Y/C	Y	T-CAV	T-FACE
0.	0.	0.	0.
0.05	0.1647	0.0152	-0.0056
0.10	0.3293	0.0235	-0.0091
0.15	0.4940	0.0302	-0.0131
0.20	0.6586	0.0362	-0.0176
0.25	0.8233	0.0415	-0.0225
0.30	0.9880	0.0465	-0.0279
0.35	1.1526	0.0511	-0.0338
0.40	1.3173	0.0555	-0.0401
0.45	1.4820	0.0596	-0.0469
0.50	1.6466	0.0636	-0.0541
0.55	1.8113	0.0674	-0.0619
0.60	1.9759	0.0711	-0.0701
0.65	2.1406	0.0747	-0.0789
0.70	2.3053	0.0781	-0.0883
0.75	2.4699	0.0815	-0.0984
0.80	2.6346	0.0847	-0.1092
0.85	2.7993	0.0879	-0.1210
0.90	2.9639	0.0910	-0.1339
0.95	3.1286	0.0940	-0.1487
1.00	3.2932	0.0970	-0.1681
1.00	3.2932	0.	0.

TABLE 2-II (Cont)

BELL AEROSPACE TEXTRON

SECTION OFFSETS FOR PROPELLER DESIGN 0001

0.700 RADIAL STATION

L.E.RADIUS = 0.0001560

Y/C	Y	T-CAV	T-FACE
0.	0.	0.	0.
0.05	0.1867	0.0157	-0.0044
0.10	0.3735	0.0244	-0.0075
0.15	0.5602	0.0315	-0.0114
0.20	0.7470	0.0377	-0.0159
0.25	0.9337	0.0434	-0.0210
0.30	1.1205	0.0486	-0.0267
0.35	1.3072	0.0535	-0.0329
0.40	1.4940	0.0582	-0.0398
0.45	1.6807	0.0626	-0.0471
0.50	1.8675	0.0668	-0.0551
0.55	2.0542	0.0708	-0.0636
0.60	2.2410	0.0747	-0.0728
0.65	2.4277	0.0785	-0.0826
0.70	2.6145	0.0822	-0.0931
0.75	2.8012	0.0857	-0.1044
0.80	2.9880	0.0892	-0.1166
0.85	3.1747	0.0925	-0.1300
0.90	3.3615	0.0958	-0.1447
0.95	3.5482	0.0990	-0.1616
1.00	3.7350	0.1022	-0.1838
1.00	3.7350	0.	0.

0.600 RADIAL STATION

L.E.RADIUS = 0.0002325

Y/C	Y	T-CAV	T-FACE
0.	0.	0.	0.
0.05	0.1931	0.0166	-0.0063
0.10	0.3862	0.0256	-0.0101
0.15	0.5793	0.0328	-0.0144
0.20	0.7724	0.0392	-0.0192
0.25	0.9655	0.0450	-0.0246
0.30	1.1586	0.0503	-0.0305
0.35	1.3517	0.0553	-0.0368
0.40	1.5448	0.0600	-0.0437
0.45	1.7378	0.0644	-0.0511
0.50	1.9309	0.0687	-0.0590
0.55	2.1240	0.0728	-0.0675
0.60	2.3171	0.0767	-0.0765
0.65	2.5102	0.0805	-0.0862
0.70	2.7033	0.0842	-0.0965
0.75	2.8964	0.0878	-0.1076
0.80	3.0895	0.0913	-0.1195
0.85	3.2826	0.0947	-0.1325
0.90	3.4757	0.0980	-0.1469
0.95	3.6688	0.1013	-0.1632
1.00	3.8619	0.1044	-0.1121
1.00	3.8619	0.	0.

0.500 RADIAL STATION

L.E.RADIUS = 0.0011406

Y/C	Y	T-CAV	T-FACE
0.	0.	0.	0.
0.05	0.1816	0.0236	-0.0179
0.10	0.3632	0.0349	-0.0263
0.15	0.5448	0.0440	-0.0338
0.20	0.7265	0.0519	-0.0411
0.25	0.9081	0.0589	-0.0484
0.30	1.0897	0.0654	-0.0559
0.35	1.2713	0.0714	-0.0635
0.40	1.4529	0.0770	-0.0713
0.45	1.6345	0.0823	-0.0794
0.50	1.8161	0.0874	-0.0878
0.55	1.9977	0.0923	-0.0965
0.60	2.1794	0.0970	-0.1056
0.65	2.3610	0.1015	-0.1151
0.70	2.5426	0.1058	-0.1250
0.75	2.7242	0.1100	-0.1355
0.80	2.9058	0.1141	-0.1466
0.85	3.0874	0.1181	-0.1585
0.90	3.2690	0.1220	-0.1714
0.95	3.4507	0.1258	-0.1859
1.00	3.6323	0.1295	-0.2044
1.00	3.6323	0.	0.

0.450 RADIAL STATION

L.E.RADIUS = 0.0020742

Y/C	Y	T-CAV	T-FACE
0.	0.	0.	0.
0.05	0.1658	0.0276	-0.0241
0.10	0.3315	0.0405	-0.0350
0.15	0.4973	0.0508	-0.0444
0.20	0.6630	0.0596	-0.0531
0.25	0.8288	0.0674	-0.0616
0.30	0.9945	0.0746	-0.0700
0.35	1.1603	0.0813	-0.0784
0.40	1.3260	0.0875	-0.0869
0.45	1.4918	0.0934	-0.0955
0.50	1.6576	0.0991	-0.1044
0.55	1.8233	0.1045	-0.1134
0.60	1.9891	0.1096	-0.1228
0.65	2.1548	0.1146	-0.1324
0.70	2.3206	0.1194	-0.1424
0.75	2.4863	0.1240	-0.1528
0.80	2.6521	0.1286	-0.1638
0.85	2.8178	0.1329	-0.1754
0.90	2.9836	0.1372	-0.1879
0.95	3.1493	0.1414	-0.2018
1.00	3.3151	0.1456	-0.2191
1.00	3.3151	0.	0.

TABLE 2-II (Cont)

BELL AEROSPACE TEXTRON
SECTION OFFSETS FOR PROPELLER DESIGN 0001

0.400 RADIAL STATION
L.E.RADIUS = 0.0041367

Y/C	Y	T-CAV	T-FACE
0.	0.	0.	0.
0.05	0.1352	0.0329	-0.0317
0.10	0.2704	0.0479	-0.0458
0.15	0.4057	0.0597	-0.0574
0.20	0.5409	0.0698	-0.0680
0.25	0.6761	0.0789	-0.0780
0.30	0.8113	0.0871	-0.0878
0.35	0.9466	0.0947	-0.0973
0.40	1.0818	0.1019	-0.1068
0.45	1.2170	0.1086	-0.1163
0.50	1.3522	0.1150	-0.1259
0.55	1.4875	0.1211	-0.1356
0.60	1.6227	0.1270	-0.1454
0.65	1.7579	0.1326	-0.1555
0.70	1.8931	0.1381	-0.1658
0.75	2.0284	0.1434	-0.1764
0.80	2.1636	0.1485	-0.1875
0.85	2.2988	0.1534	-0.1971
0.90	2.4340	0.1583	-0.2114
0.95	2.5693	0.1630	-0.2249
1.00	2.7045	0.1676	-0.2414
1.00	2.7045	0.	0.

TABLE 2-II (Cont)

BELL AEROSPACE TEXTRON

PLANFORM OUTLINE FOR PROPELLER 0001
CARTESIAN COORDINATES

SKEW LINE X	SKEW LINE Y	SKEW LINE Z	LEADING EDGE X	LEADING EDGE Y	LEADING EDGE Z	TRAILING EDGE X	TRAILING EDGE Y	TRAILING EDGE Z
-0.8963	7.2224	-0.6319	-0.8963	7.2224	-0.6319	-0.8963	7.2224	-0.6319
-1.0107	6.8341	-0.8560	-0.2565	6.8491	0.7265	-1.0107	6.8341	-0.8560
-1.1101	6.4435	-1.0280	0.0246	6.4257	1.1341	-1.1101	6.4435	-1.0280
-1.2509	5.6664	-1.2376	0.4354	5.5857	1.5620	-1.2509	5.6664	-1.2376
-1.3483	4.9054	-1.3011	0.7672	4.7721	1.7271	-1.3483	4.9054	-1.3011
-1.3929	4.1652	-1.2544	1.0114	4.0029	1.7028	-1.3929	4.1652	-1.2544
-1.3886	3.4451	-1.1277	1.0912	3.3161	1.4643	-1.3886	3.4451	-1.1277
-1.3809	3.0915	-1.0424	1.0004	3.0277	1.2153	-1.3809	3.0915	-1.0424
-1.3561	2.7413	-0.9461	0.6801	2.7859	0.8056	-1.3561	2.7413	-0.9461

TABLE 2-II (Cont)

BELL AEROSPACE TEXTRON
SECTION PRESSURE COEFFICIENTS FOR PROPELLER 0001

Y/C	0.000	0.050	0.100	0.150	0.200	0.250	0.300	0.350	0.400	0.450	0.500
R/RAD											
1.000	1.000	0.179	0.160	0.150	0.141	0.137	0.133	0.129	0.126	0.123	0.120
0.950	1.000	0.180	0.161	0.151	0.143	0.138	0.134	0.130	0.126	0.123	0.121
0.900	1.000	0.181	0.162	0.151	0.144	0.139	0.134	0.130	0.127	0.124	0.121
0.800	1.000	0.150	0.134	0.126	0.120	0.115	0.112	0.108	0.106	0.103	0.101
0.700	1.000	0.147	0.131	0.123	0.117	0.112	0.109	0.106	0.103	0.100	0.098
0.600	1.000	0.133	0.119	0.112	0.108	0.102	0.099	0.096	0.094	0.091	0.089
0.500	1.000	0.114	0.102	0.095	0.091	0.087	0.085	0.082	0.080	0.078	0.076
0.450	1.000	0.114	0.102	0.095	0.091	0.087	0.084	0.082	0.080	0.078	0.076
0.400	1.000	0.129	0.116	0.108	0.103	0.099	0.096	0.093	0.091	0.089	0.087

Y/C	0.550	0.600	0.650	0.700	0.750	0.800	0.850	0.900	0.950	1.000	1.050
R/RAD											
1.000	0.117	0.115	0.113	0.110	0.108	0.105	0.103	0.100	0.097	0.089	0.
0.950	0.118	0.116	0.113	0.111	0.108	0.106	0.103	0.101	0.097	0.089	0.
0.900	0.119	0.116	0.114	0.111	0.109	0.107	0.104	0.101	0.098	0.090	0.
0.800	0.099	0.097	0.095	0.093	0.091	0.089	0.086	0.084	0.081	0.075	0.
0.700	0.096	0.094	0.092	0.090	0.088	0.086	0.084	0.082	0.079	0.073	0.
0.600	0.087	0.086	0.084	0.082	0.080	0.079	0.077	0.075	0.072	0.066	0.
0.500	0.075	0.073	0.072	0.070	0.069	0.067	0.066	0.064	0.061	0.057	0.
0.450	0.075	0.073	0.072	0.070	0.069	0.067	0.065	0.064	0.061	0.056	0.
0.400	0.085	0.083	0.081	0.080	0.078	0.076	0.074	0.072	0.070	0.064	0.

TABLE 2-11 (Cont)

BELL AEROSPACE TEXTRON
SECTION PRESSURES (PSF/1000.) FOR PROPELLER 0001

Y/C R/RAD	0.000	0.050	0.100	0.150	0.200	0.250	0.300	0.350	0.400	0.450	0.500
1.000	38.600	6.912	6.177	5.780	5.507	5.298	5.127	4.981	4.853	4.737	4.631
0.950	35.073	6.316	5.645	5.281	5.012	4.841	4.685	4.551	4.434	4.329	4.231
0.900	31.819	5.762	5.149	4.818	4.590	4.416	4.274	4.152	4.045	3.949	3.860
0.800	26.132	3.937	3.514	3.287	3.132	3.017	2.916	2.833	2.760	2.695	2.634
0.700	21.266	3.116	2.785	2.605	2.482	2.388	2.311	2.245	2.188	2.135	2.087
0.600	17.114	2.284	2.042	1.910	1.820	1.751	1.694	1.646	1.604	1.566	1.530
0.500	13.606	1.551	1.386	1.297	1.236	1.189	1.150	1.118	1.089	1.063	1.039
0.450	12.096	1.377	1.231	1.151	1.097	1.055	1.021	0.992	0.967	0.944	0.922
0.400	10.676	1.382	1.235	1.156	1.101	1.059	1.025	0.996	0.971	0.947	0.926

Y/C R/RAD	0.550	0.600	0.650	0.700	0.750	0.800	0.850	0.900	0.950	1.000	1.050
1.000	4.531	4.436	4.344	4.254	4.163	4.070	3.971	3.862	3.729	3.427	0.
0.950	4.140	4.054	3.969	3.887	3.804	3.719	3.629	3.529	3.407	3.132	0.
0.900	3.777	3.698	3.621	3.546	3.470	3.393	3.311	3.220	3.108	2.857	0.
0.800	2.577	2.523	2.471	2.419	2.368	2.315	2.259	2.197	2.121	1.949	0.
0.700	2.042	2.000	1.958	1.917	1.876	1.835	1.790	1.741	1.681	1.545	0.
0.600	1.497	1.466	1.436	1.406	1.376	1.345	1.312	1.276	1.232	1.133	0.
0.500	1.017	0.996	0.975	0.955	0.934	0.913	0.891	0.867	0.837	0.769	0.
0.450	0.903	0.884	0.865	0.847	0.829	0.811	0.791	0.769	0.743	0.683	0.
0.400	0.906	0.887	0.869	0.851	0.833	0.814	0.794	0.772	0.746	0.685	0.

TABLE 2-III

POWER AND PROPELLER PERFORMANCE ON DRAG CURVE AT 1500 TONS

VK - speed, knots
VM - speed, miles per hour
DRAG - pounds
HP - engine power required

EN - propeller rpm
RPMENG - engine rpm
SIGMA - cavitation number
CT/J**2 - thrust parameter K_T/J^2

ETAZRO - propeller efficiency
ETAD - propulsion efficiency with a 4% loss
JT - propeller advance coefficient
HPENG - horsepower per engine

PITCH - propeller blade pitch
SUB - propeller submergence

POWER REQUIREMENTS FOR 275.4 FT. BOAT OF 1500.0 TONS

PROP. DIA = 14.500
PITCH/DIA = -10.000 TO +5°
GEAR RATIO = 15.000
PROPELLER(S) = RDC-1500 100 % SUBMERGENCE { 50 % SUBMERGENCE 2 LM 2500 MCP (1500 LT)

VK	VM	DRAG	H.P.	EN	RPMENG	SIGMA	CT/J**2	ETAZRO	ETAD	JT	HPENG	PITCH	SUB
2.5	2.88	4000.00	82.03	34.43	549.44	115.141	0.279	0.390	0.374	0.477	41.0	-10.0	100.0
5.0	5.76	8500.00	215.14	49.33	739.88	28.790	0.148	0.632	0.607	0.708	107.4	-12.5	
7.5	8.44	15000.00	824.85	62.65	939.72	12.796	0.116	0.684	0.658	0.834	242.4	-10.0	
10.0	11.51	24500.00	1119.24	81.24	1218.50	7.198	0.107	0.700	0.672	0.860	557.4		
12.5	14.39	35500.00	1996.15	98.98	1484.43	4.606	0.099	0.711	0.683	0.882	990.1		
15.0	17.27	51000.00	3439.90	118.49	1780.29	3.199	0.099	0.711	0.683	0.883	1719.9		
17.5	20.15	69000.00	5424.21	138.22	2073.24	2.350	0.098	0.712	0.684	0.885	2712.1		
20.0	23.03	90000.00	8083.94	157.90	2368.45	1.799	0.098	0.712	0.684	0.885	4042.0		
22.5	25.91	115000.00	11639.17	178.15	2672.19	1.422	0.099	0.711	0.683	0.882	5819.6		100.0
24.0	27.64	134000.00	14532.02	191.49	2872.34	1.250	0.102	0.708	0.680	0.874	7266.0		50.0
25.0	28.79	138000.00	17547.26	226.92	3403.78	1.152	0.096	0.629	0.604	0.770	8773.4		
27.0	31.09	145500.00	19174.46	235.99	3539.86	0.907	0.087	0.655	0.629	0.799	9587.3	-10.0	
29.0	33.39	149500.00	20734.41	227.49	3412.32	0.856	0.078	0.669	0.642	0.891	10347.2	- 7.5	
31.0	35.70	151000.00	21544.45	233.66	3504.84	0.749	0.069	0.695	0.667	0.927	10771.2	- 7.5	
35.0	40.30	153500.00	24007.35	232.40	3486.00	0.588	0.055	0.716	0.687	1.052	12003.7	- 5.0	
38.5	44.33	155600.00	26524.37	229.24	3438.52	0.486	0.046	0.723	0.694	1.173	13263.2	- 2.5	
40.0	46.06	157000.00	27477.27	234.36	3515.41	0.450	0.043	0.731	0.702	1.192	13738.6		
41.0	47.21	159000.00	28385.08	238.29	3574.37	0.428	0.041	0.735	0.705	1.202	14192.5	- 2.5	
45.0	51.82	170000.00	33017.82	238.72	3580.81	0.355	0.037	0.741	0.711	1.317	16500.9	0.0	
50.0	57.57	190000.00	42243.18	231.02	3465.30	0.288	0.033	0.719	0.691	1.512	21121.6	5.0	
55.0	63.33	215000.00	51862.91	249.86	3747.908	0.230	0.031	0.729	0.700	1.538	25931.58		
60.0	69.09	245500.00	64077.19	269.89	4048.208	0.200	0.030	0.735	0.706	1.553	32038.68		
65.0	74.85	278500.00	78198.37	289.96	4349.448	0.170	0.029	0.740	0.711	1.566	39099.20	5.0	50.0

*EXCEEDS LIMIT

TABLE 2-IV

POWER AND PROPELLER PERFORMANCE ON DRAG CURVE AT 1050 TONS

3600.,24000.

POWER REQUIREMENTS FOR 275.4 FT. BOAT OF 1050.0 TONS

PROP. DIA = 14.500
PITCH/DIA = -10.000 TO +7.5°
GEAR RATIO = 15.000
PROPELLER(S) = HDC-1500 50 % SUBMERGENCE 2 LM 2500 MCP

VK	VM	DRAG	H.P.	EN	RPMENG	SIGMA	CT/J**2	ETAZRO	ETAD	JT	HPENG	PITCH	SUB
22.5	25.91	87500.00	9103.13	187.26	2800.97	1.422	0.075	0.692	0.664	0.839	4551.6	-10.0	50.
25.0	28.79	95000.00	10408.26	199.68	2995.15	1.152	0.066	0.716	0.687	0.875	5304.1	-10.0	50.
27.5	31.67	99500.00	12139.24	196.98	2954.44	0.952	0.057	0.721	0.692	0.975	6069.4	-7.5	50.
30.0	34.54	104500.00	13687.75	207.99	3119.88	0.800	0.051	0.733	0.703	1.008	6843.9	-7.5	50.
32.0	36.85	107000.00	14835.27	202.86	3042.95	0.703	0.046	0.738	0.709	1.102	7417.6	-5.0	50.
33.0	38.00	107500.00	15293.41	206.84	3102.55	0.661	0.041	0.742	0.712	1.115	7646.7	-5.0	50.
35.0	40.30	106000.00	15924.00	199.49	2992.41	0.588	0.038	0.745	0.715	1.224	7962.0	-2.5	50.
39.0	44.91	101000.00	16765.49	198.16	2972.43	0.473	0.030	0.766	0.736	1.375	8382.7	0.0	50.
41.0	47.21	105500.00	17901.44	204.78	3071.69	0.428	0.027	0.773	0.742	1.399	8950.7	0.0	50.
42.5	48.94	108000.00	19177.62	197.04	2955.54	0.398	0.026	0.766	0.735	1.507	9588.8	2.5	50.
45.0	51.82	113500.00	21148.82	205.95	3089.21	0.355	0.024	0.772	0.742	1.527	10574.4	2.5	50.
50.0	57.57	130000.00	26865.57	212.34	3185.17	0.288	0.023	0.774	0.743	1.645	13432.8	5.0	50.
55.0	63.33	151000.00	34085.75	231.91	3478.70	0.238	0.022	0.779	0.748	1.657	17042.9	5.0	50.
60.0	69.09	177000.00	43739.58	238.22	3573.24	0.200	0.021	0.777	0.746	1.740	21869.8	7.5	50.
66.0	76.00	210500.00	57017.34	261.27	3919.098	0.165	0.021	0.779	0.748	1.765	28508.78	7.5	50.

*EXCEEDS LIMITS

TABLE 2-V

POWER AND PROPELLER PERFORMANCE ON DRAG CURVE WITH DIESEL POWER, OFF-CUSHION

POWER REQUIREMENTS FOR 278.4-FT BOAT OF 1800.0 TONS

PROP. DIA = 14.500

GEAR RATIO = 11.500

PROPELLER(S) = MDC-1500 100 X SUBMERGENCE (2) SACM240V16RVR ENGINES

VK	VN	DRAG	H.P.	EN	RPMENG	SIGMA	CT/J**2	ETAZRO	ETAD	JT	HCENG	PITCH	SUB
2.5	2.88	4000.00	92.73	40.28	463.25	115.141	0.279	0.345	0.331	0.434	44.9	-12.5	100.
5.0	5.76	8500.00	212.48	53.20	611.82	28.790	0.148	0.440	0.414	0.457	104.2	-15.0	100.
7.5	8.64	15000.00	524.88	62.45	720.43	12.796	0.116	0.606	0.458	0.836	262.4	-10.0	100.
10.0	11.51	24500.00	1119.26	81.24	934.24	7.198	0.107	0.700	0.472	0.540	539.4	-10.0	100.
12.5	14.39	35500.00	1994.15	98.98	1138.22	4.606	0.099	0.711	0.481	0.882	978.1	-10.0	100.
15.0	17.27	51000.00	3502.29	110.53	1271.05	3.199	0.099	0.699	0.471	0.948	1751.1	- 7.5	100.
17.5	20.15	69000.00	5901.72	114.16	1312.90	2.350	0.098	0.666	0.439	1.071	2900.9	- 2.5	100.
20.0	23.03	90000.00	9088.64	116.61	1341.06	1.799	0.098	0.633	0.408	1.198	4344.3	+ 2.5	100
22.5	25.91	115000.00	13091.23	131.66	1514.058	1.422	0.099	0.632	0.407	1.194	6345.68	+ 2.5	100
24.0	27.64	134000.00	16385.86	141.80	1630.718	1.250	0.102	0.628	0.403	1.182	8192.98	+ 2.5	100
25.0	28.79	138000.00	17352.12	144.77	1664.868	1.152	0.096	0.636	0.410	1.206	8674.18	+ 2.5	100

* EXCEEDS LIMITS

SECTION 3

CONCLUSIONS

3. CONCLUSIONS

An efficient 14.5-foot diameter propeller has been designed for the IDS 1500-ton ship.

Alternatives of one gas turbine per propeller, or one gas turbine and one diesel each, have significant advantages, dependent upon the use of the vessel. A demonstrator SES with only gas turbines would greatly simplify the propulsion machinery. However, the range at off-cushion speeds would be much greater with diesel power and CODOG reduction gears.

3.1 Recommendations

Continue the propeller design effort to define the propeller hub and interfaces between the propeller and the hull. The design must satisfy both performance and structural considerations.

Make the proposed improvements in the SCRP computer program, so that the experience gained in the present project will be readily available for the design of new supercavitating propellers.

APPENDIX A

PRIOR REPORTS

Report 7593-933046, *Monthly Letter Status Report No 46, Selected Problems in SES Technology*, December 1980.

Report 7593-902007, *Propeller Design for Medium Displacement Combatant Surface Effect Ship Powered by LM2500 Engine*, May 1981.

TN/SES TECH/017, *Propellers for Medium Displacement Combatant SES*, July 1981.

TN/SES TECH/019, *Medium Displacement Combatant Surface Effect Ship Propulsion Efficiency vs. Forward Speed*, September 1981.

TN/SES TECH/020, *Performance of Scaled SES-100B Propeller for the Medium Displacement Combatant SES*, September 1981.

APPENDIX I

SULZER-ESCHER WYSS REPORT

MTG Marinetechnik GmbH

SURFACE EFFECT SHIP (SES) 1500

Enclosures to Report No.:

170/00/0010-02

PROPELLER DESIGN

Wandsbeker Königstraße 62 · 2000 Hamburg 70 · Telefon (040) 6 58 10

SULZER-ESCHER WYSS Gesellschaft mit beschränkter Haftung RAVENSBURG

SULZER ESCHER WYSS

MfG Order No. 1346/01 + SEWR No.1290016 Page 1
Propeller Design for SES 1500 - First Stage 31 January 1986

1. Introduction

For a SES with 1500 lt displacement a propeller was to be designed as an alternative to the design of ref. (1).

The requirements for this alternative propeller are the same as for the original one, however, the approach was different since the alternative propeller design was based on model test results. These propeller characterics are those of a model propeller which has been developed by SEWR for an another SES and has been tested extensively in a large cavitation tunnel with a free water surface.

For details of the propeller (z = 7) see " Particulars for Blade Drawing ".

Like the propeller of ref. (1) the SEWR propeller is ventilated in the cushionborn mode, however, contrary to the former one the SEWR propeller is submerged 75 %.

In the hullborn mode the propeller is fully submersed and fully wetted.

2. Design Envelope

The design envelope is taken from fig. 2-1 of ref. (1), presented in metric units in fig. 1 of this report. The curves show the thrust requirement for several modes and sea states and the NAVY Requirements of table 2-1 of ref. (1), page 28.

3. Selection of Propeller Diameter

The propeller diameter has been selected by means of the fig. 2 which presents the thrust loading of the propeller as a function of the vehicle speed. This selection of the propeller diameter is governed by the maximum thrust loading which occurs between 10 knots and abt. 30 knots depending on the operation mode.

According to the propeller characteristics the propeller diameter should not be less then 3.00 m which is also acceptable with respect to the specific mechanical loading of the propeller hub. A propeller diameter in excess of 3.0 m does not offer a better performance.

4. Performance Prediction

In fig. 3 and 4 the results of the performance calculation have been compiled. Fig. 3 is an possible RPM-Power relationship which matches the power ...

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SULZER ESCHER WYSS

0 B 95/ 0 5 8 8

displacement at sea state 3 as well as for the 1500 lt displacement at the same sea sate and also for this displacement at sea state 6 (curve 1).

From fig. 4 can be seen that in the light condition (1050 lt) the pitch has to be increased above 30 knots in order to follow the RPM-Power schedule (1). This figures also shows that the power absorption of the propeller would be little lower when operating the propeller at 1500 lt at a higher pitch and a lower shaft speed.

At 20 knots hullborn when fully wetted the propeller has to be operated at a substantial lower speed than when fully ventilated, however the power absorbtion is much smaller in the former case.

5. Conclusion

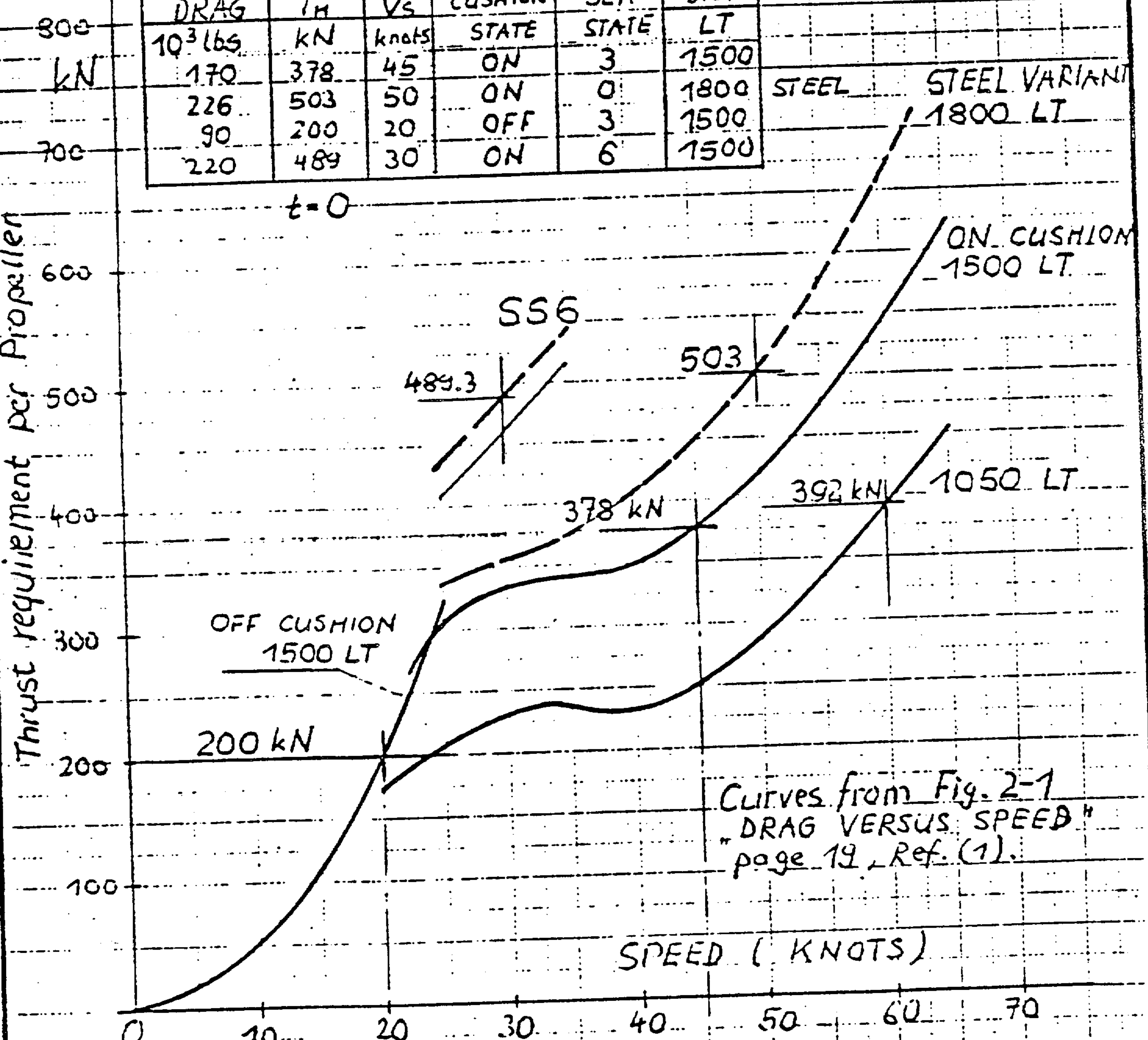
With the selected diameter the propeller satisfies the requirements. The forthcoming model tests with the NSRDC-Model no. 4281 (z = 8) will show whether an further improvement of the performance can be expected when utilising an much smaller submergence.

Reference : Report 7593-950002 , Nov. 30,1981
by Bell Aerospace Textron.

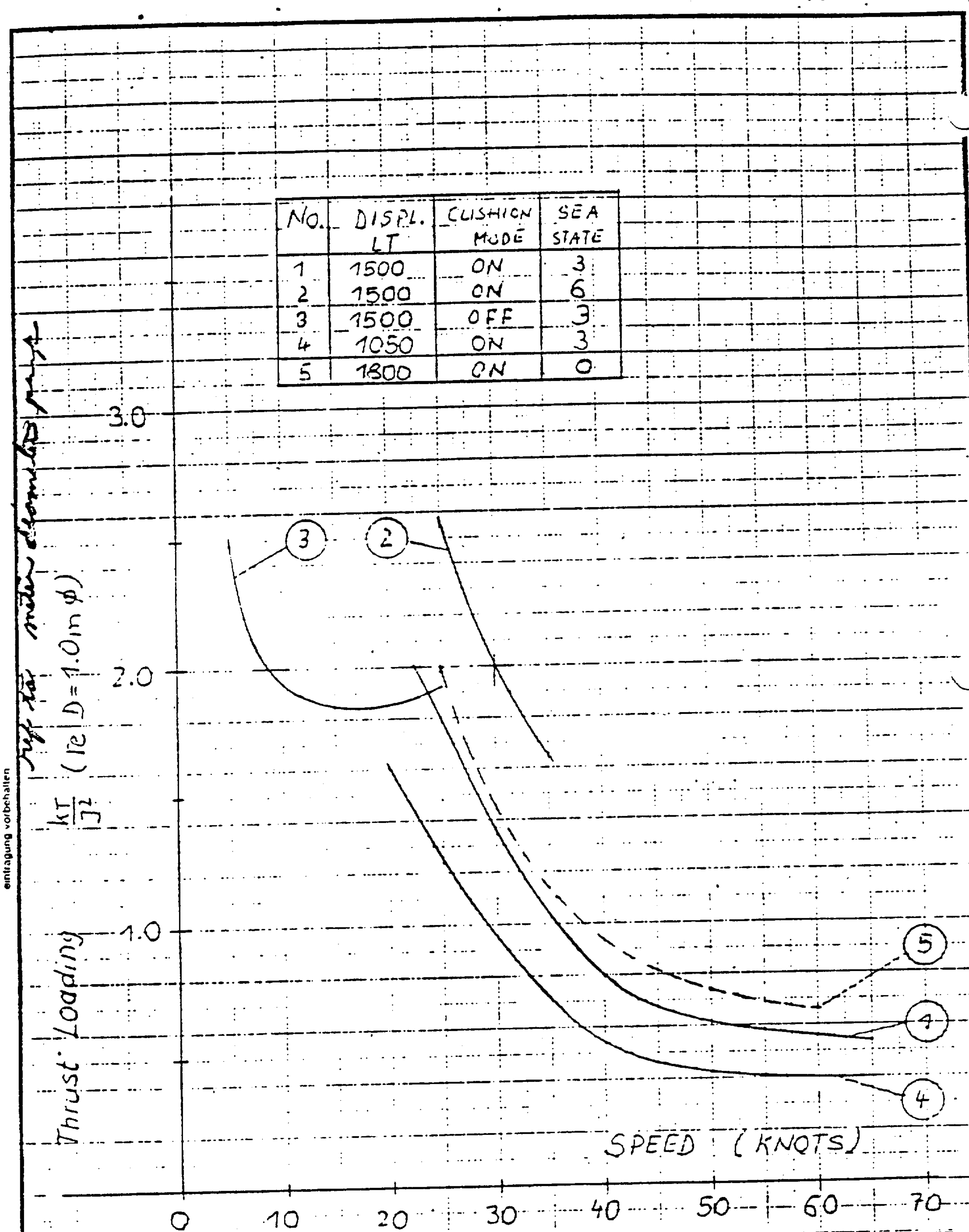
NAVY Requirements for MDS 1500

From Table 2-I, page 28, Ref. (1):

DRAG 10^3 lbs	T_H kN	V_S knots	CUSHION STATE	SEA STATE	DISP. LT
170	378	45	ON	3	1500
226	503	50	ON	0	1800
90	200	20	OFF	3	1500
220	489	30	ON	6	1500

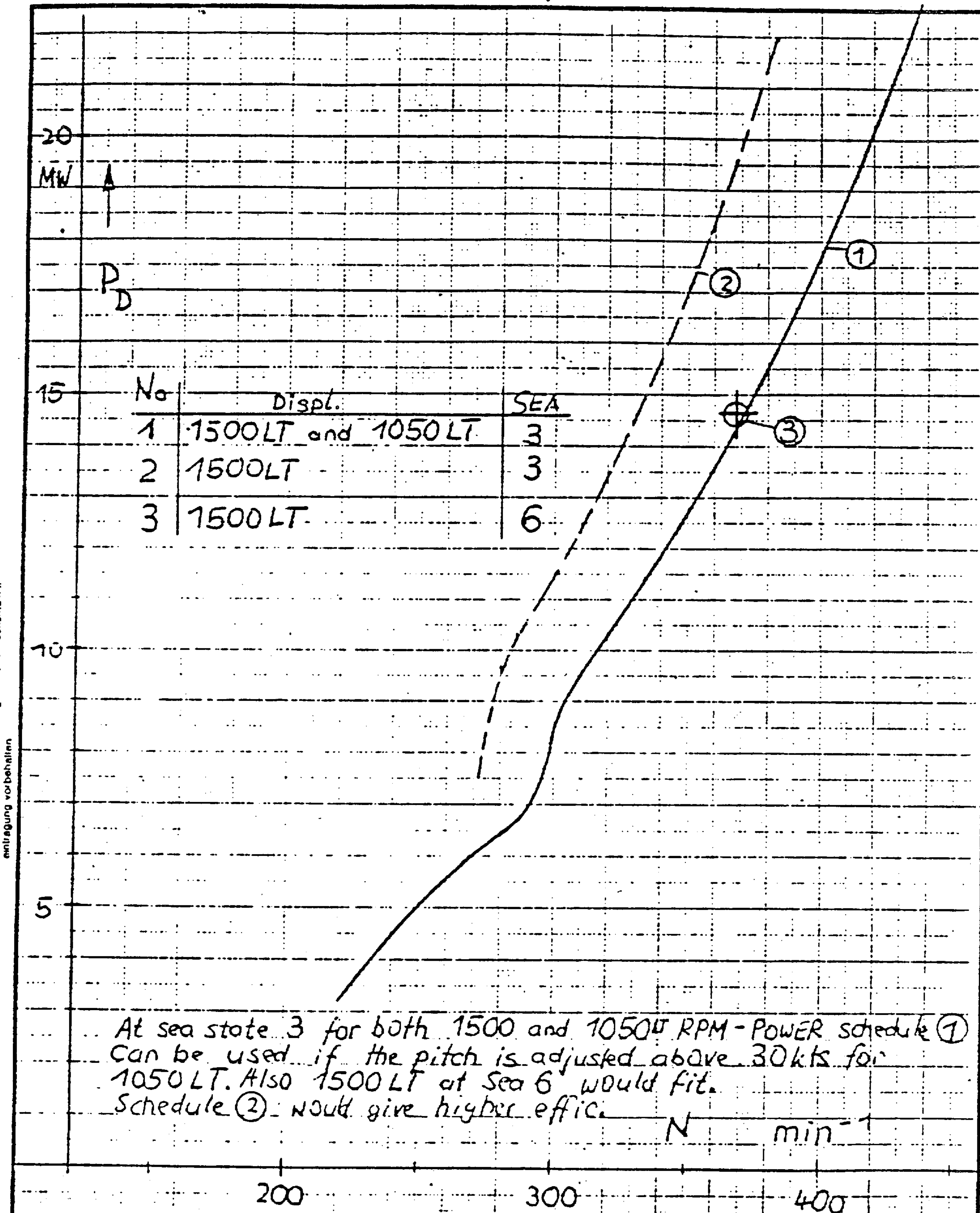


Entstand aus	Ersetzt durch	Ersatz für	Orig. Maßstab
Bezeichnung der Gruppe	Benennung		Gez. 30.12.85
Auftrags-Nr. 12 90016	DESIGN ENVELOPE		Gepr.
Stichwort SES 1500			



No.	DISPL. LT	CUSHION MODE	SEA STATE
1	1500	ON	3
2	1500	ON	6
3	1500	OFF	3
4	1050	ON	3
5	1800	ON	0

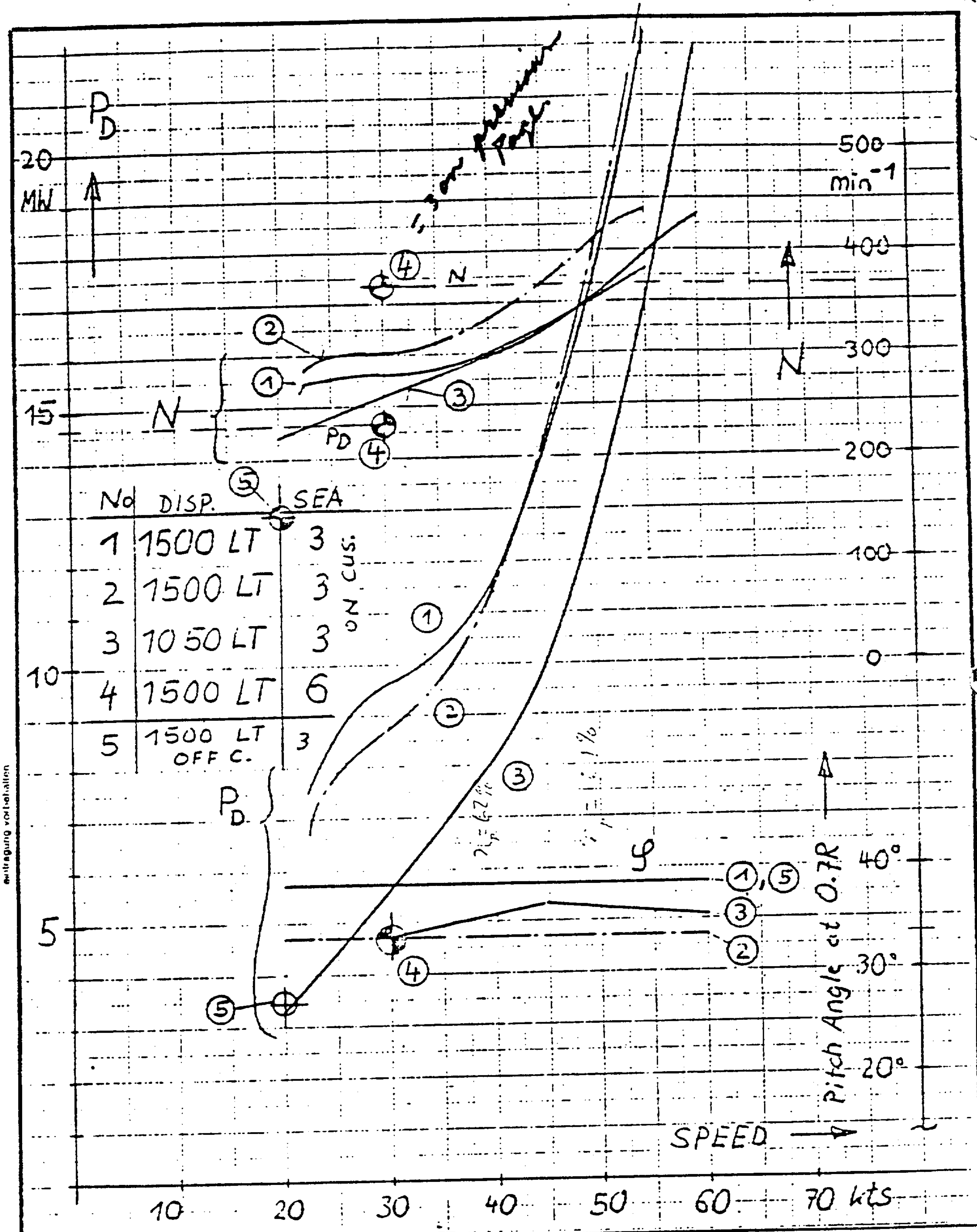
Entstand aus	Ersetzt durch	Ersatz für	Orig. Maßstab
Bezeichnung der Gruppe	Benennung	Gez.	30.12.85
Auftrags-Nr 1290016	Thrust Loading of Propeller	Gepr.	
Sachwort SES 1500			



No	Displ.	SEA
1	1500 LT and 1050 LT	3
2	1500 LT	3
3	1500 LT	6

At sea state 3 for both 1500 and 1050 LT RPM-POWER schedule ① can be used if the pitch is adjusted above 30 kts for 1050 LT. Also 1500 LT at Sea 6 would fit. Schedule ② would give higher effic.

Entstand aus	Ersetzt durch	Ersatz für	Orig. Maßstab	
Bezeichnung der Gruppe	Benennung		Gez.	31.1.86 / [illegible]
Auftrags-Nr 1290016	RPM-POWER SCHEDULE		Gepr.	
Sachwort SES 1500				



No	DISP.	SEA
1	1500 LT	3
2	1500 LT	3
3	1050 LT	3
4	1500 LT	6
5	1500 LT OFF C.	3

ON CUS.

Entstand aus	Ersetzt durch	Ersatz für	Orig. Maßstab
Bezeichnung der Gruppe	Benennung	Gez.	31.1.86 Widmer
Auftrags-Nr 1290016	PERFORMANCE DATA	Gepr	
Stichwort SES 1500			

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SULZER ESCHER WYSS

ANGABEN FUER DIE FLUEGELZEICHNUNG PARTICULARS FOR BLADE DRAWING

DURCHMESSER...................DIAMETER...........	MM	3000.0
MITTL.NENN-STEIGUNG...............MEAN NOMINAL PITCH.	MM	4340.
NENN-STEIGUNGSVERHAELTNIS.........NOMINAL PITCH RATIO	--	1.447
FLAECHENVERHAELTNIS...............BLADE AREA RATIO...	--	0.667
FLUEGELZAHL.......................NUMBER OF BLADES...	--	7
DREHRICHTUNG......................DIRECTION OF ROTATION		L + R
WERKSTOFF.........................MATERIAL		
ZUGFESTIGKEIT.....................TENSILE STRENGTH...	N/MM2	780.
STRECKGRENZE......................YIELD STRENGTH.....	N/MM2	540.
DEHNUNG...........................ELONGATION.........	%	15.
GEWICHTE..........................WEIGHTS :		
1 FLUEGEL MIT TELLER..............1 BLADE WITH PALM	KG	259.
(TELLER..........................PALM...............	KG	76.0)
(NABE............................HUB................	KG	4100.)
PROPELLER.........................PROPELLER..........	KG	5915.
MASSENTRAEGHEITSMOMENT............INERTIA MOMENT		
1 FLUEGEL OHNE TELLER.............1 BLADE WITHOUT PALM	KGM2	149.9
(NABE............................HUB................	KGM2	450.0)
(PROPELLER TROCKEN................PROPELLER DRY......	KGM2	1499.2)
PROPELLER EINSCHLIESSLICH.......PROPELLER WITH MITSCHWINGENDER WASSERMASSE.....ENTRAINED WATER		
IN NULLSCHUBSTELLUNG.............ZERO THRUST POSITION	KGM2	1537.8
BEI PFAHLZUGBEDINGUNG............AT BOLLARD CONDITION	KGM2	
IN ENTWURFS-STELLUNG.............IN DESIGN POSITION		

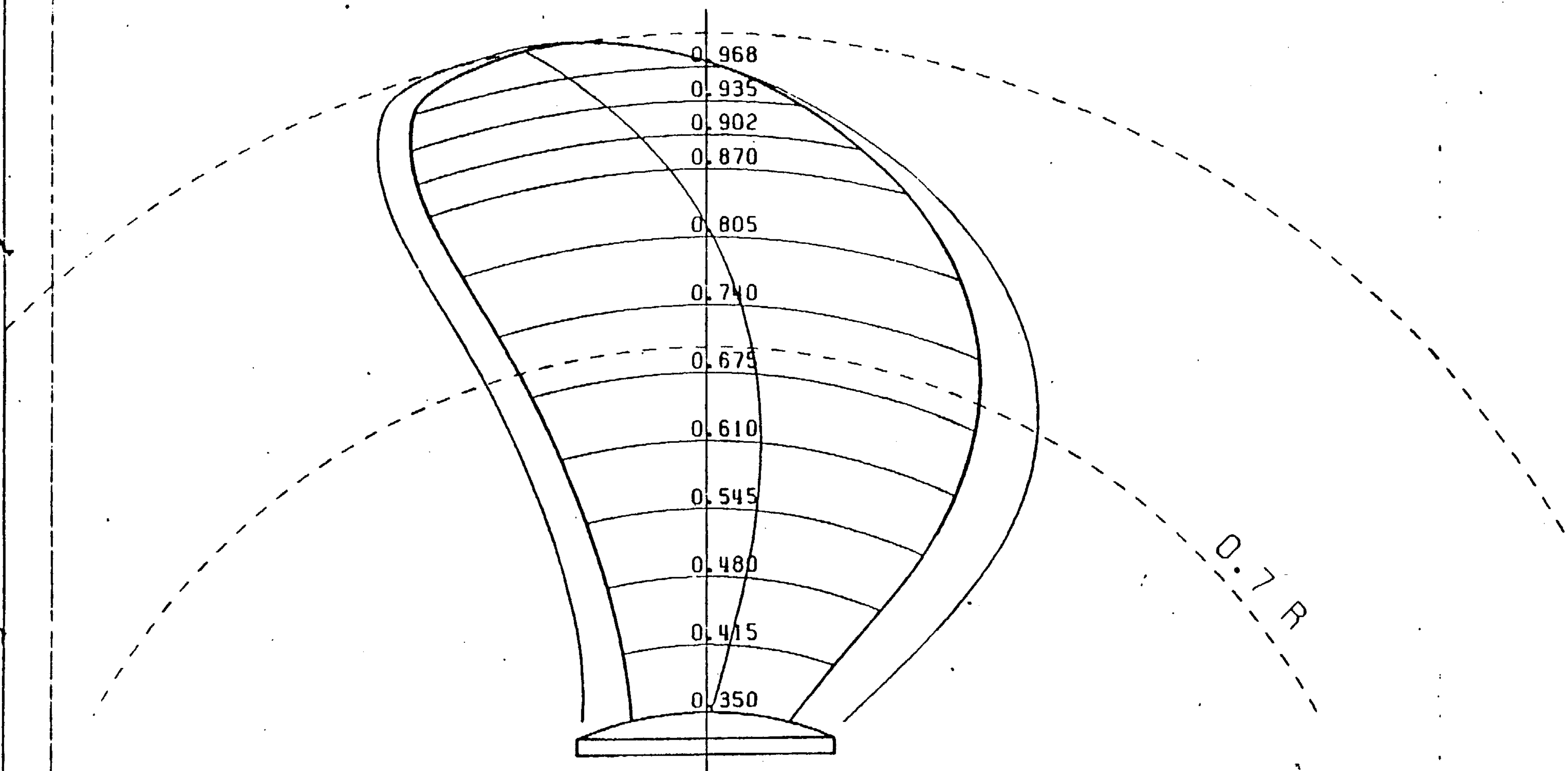
HERSTELLUNGSTOLERANZEN............MANUFACTURING TOLERANCES ISO 484/1 CLASS S

KLASSIFIKATION....CLASSIFICATION NONE

EISKLASSE..............ICE CLASS NONE

WERFT.................SHIP YARD MTG MARINETECHNIK GMBH HAMBURG

BAU - NR...............YARD - NO. 1346 / 01



CPP FOR SES 1500

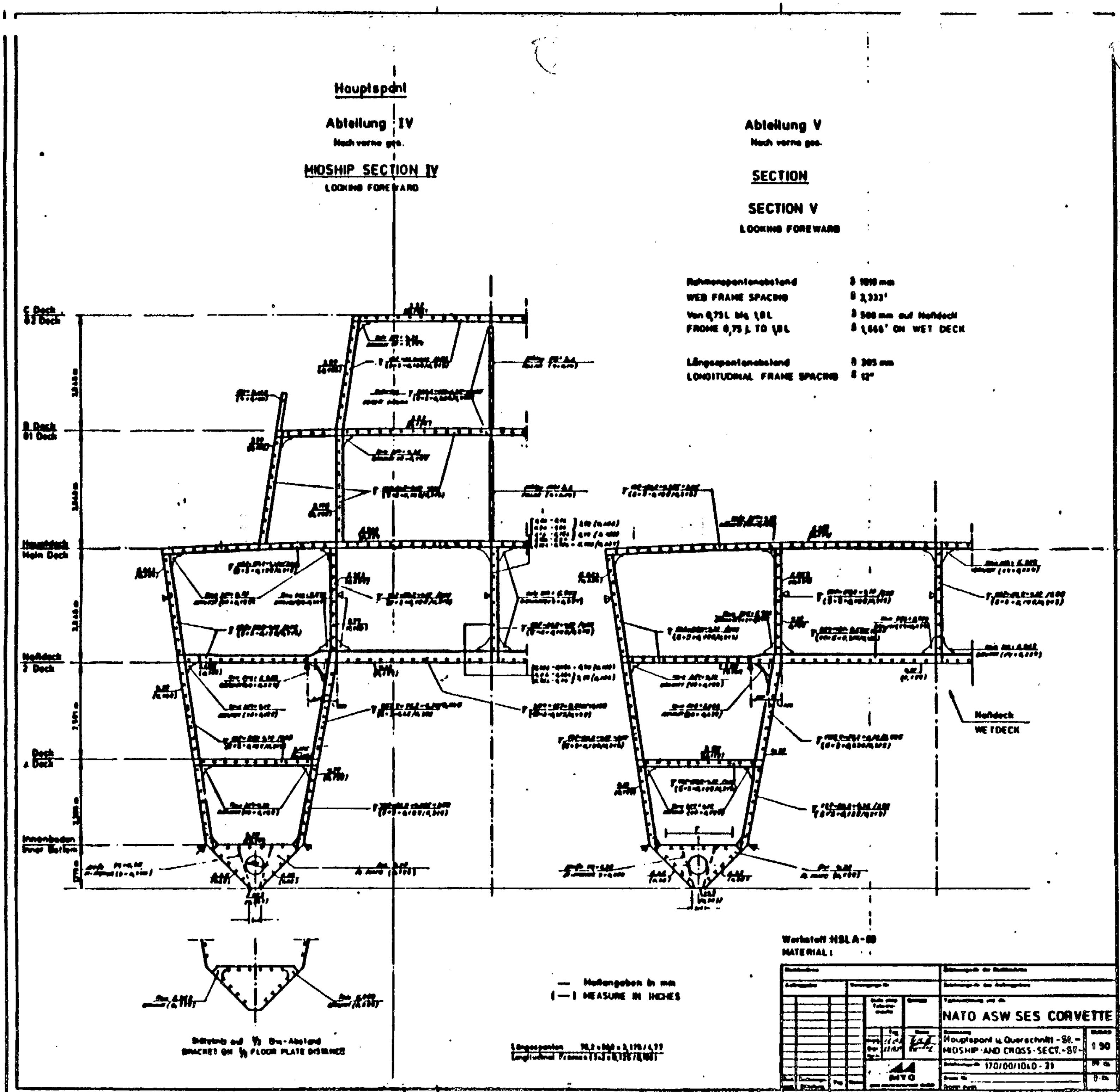
SES 1500 NO FILLET
1290016
30-JAN-86
18:00:00

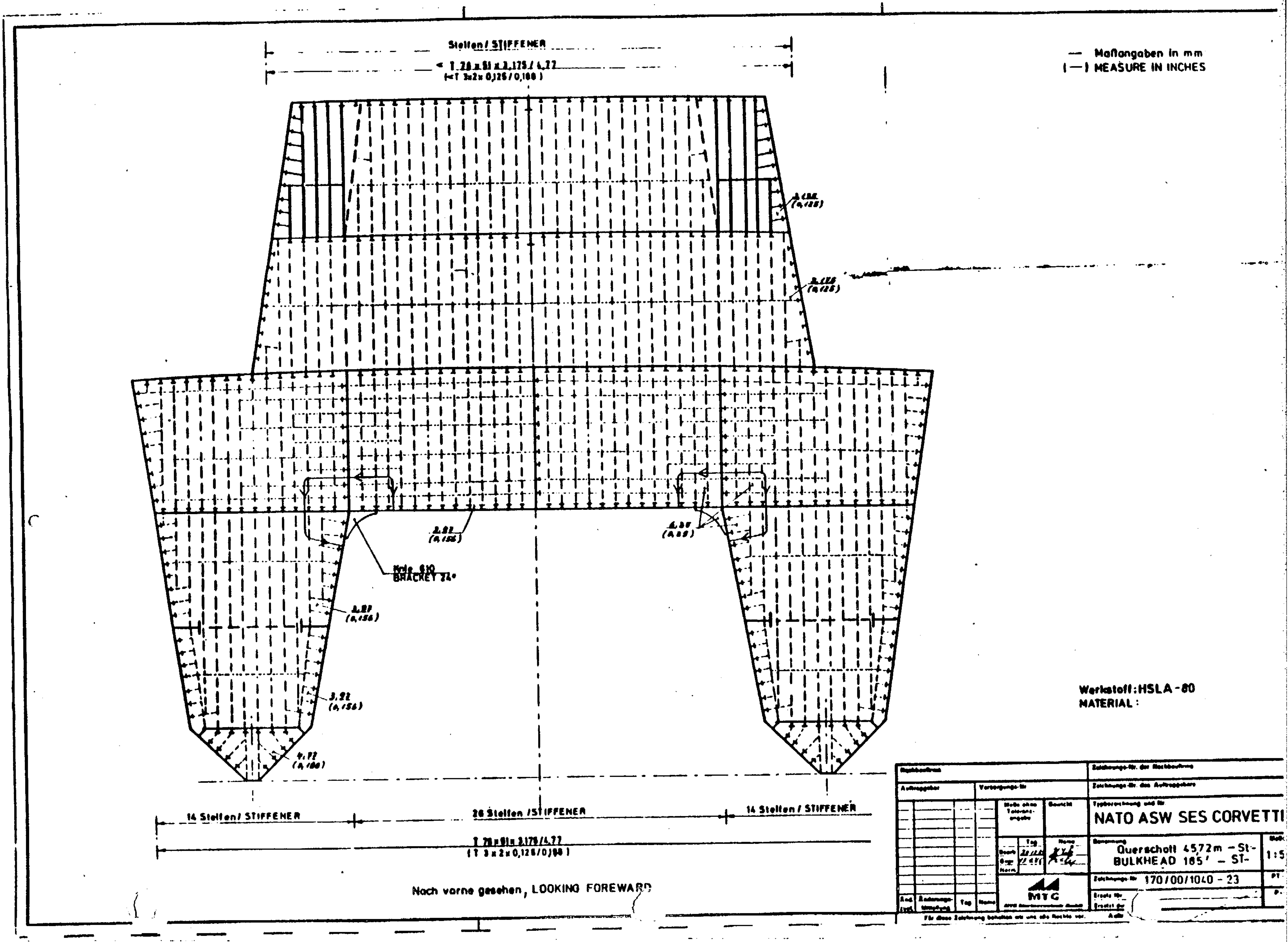
1:7.00

VP 823-4 F.MILONER 30-JAN-86

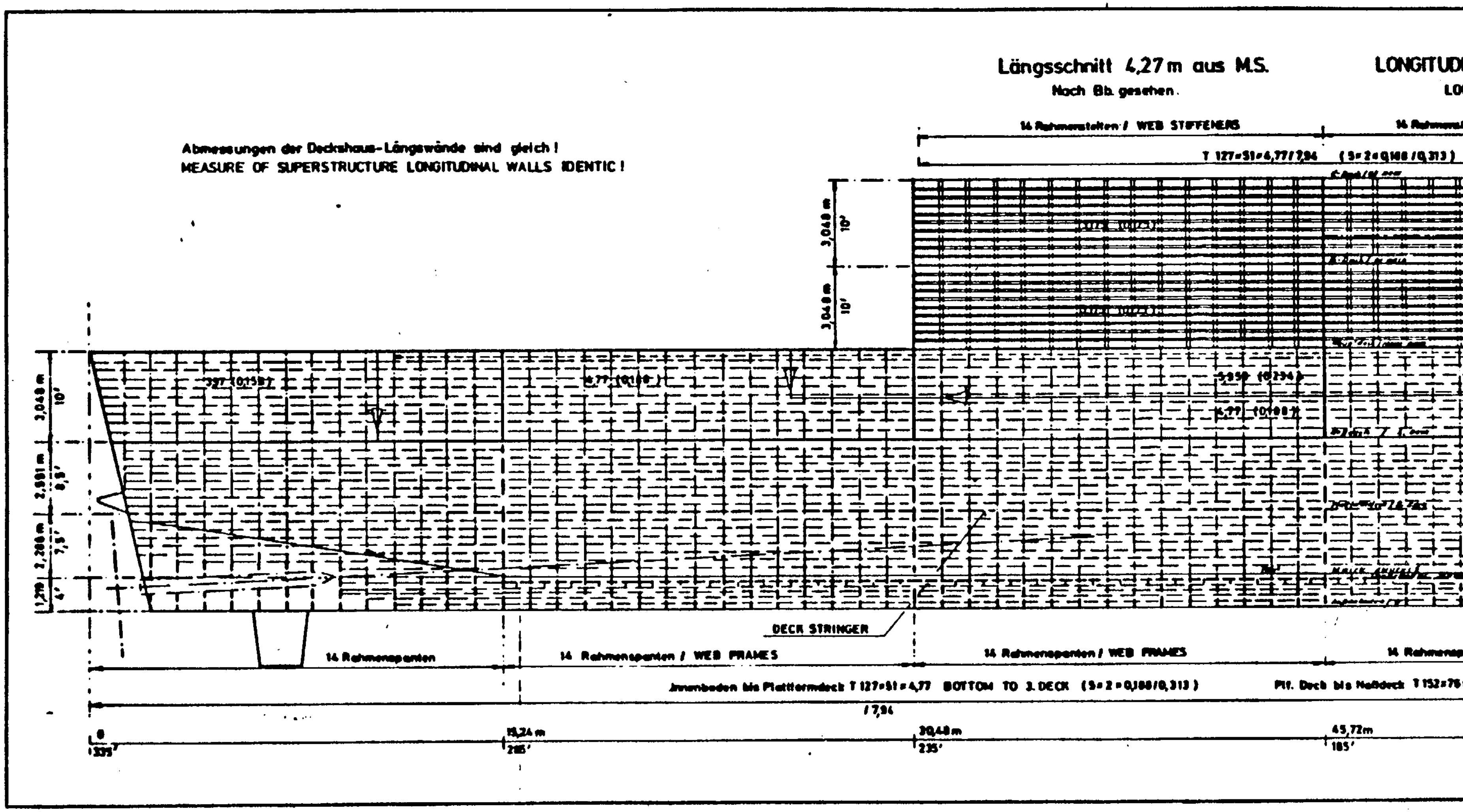
APPENDIX J

STRUCTURAL DRAWINGS

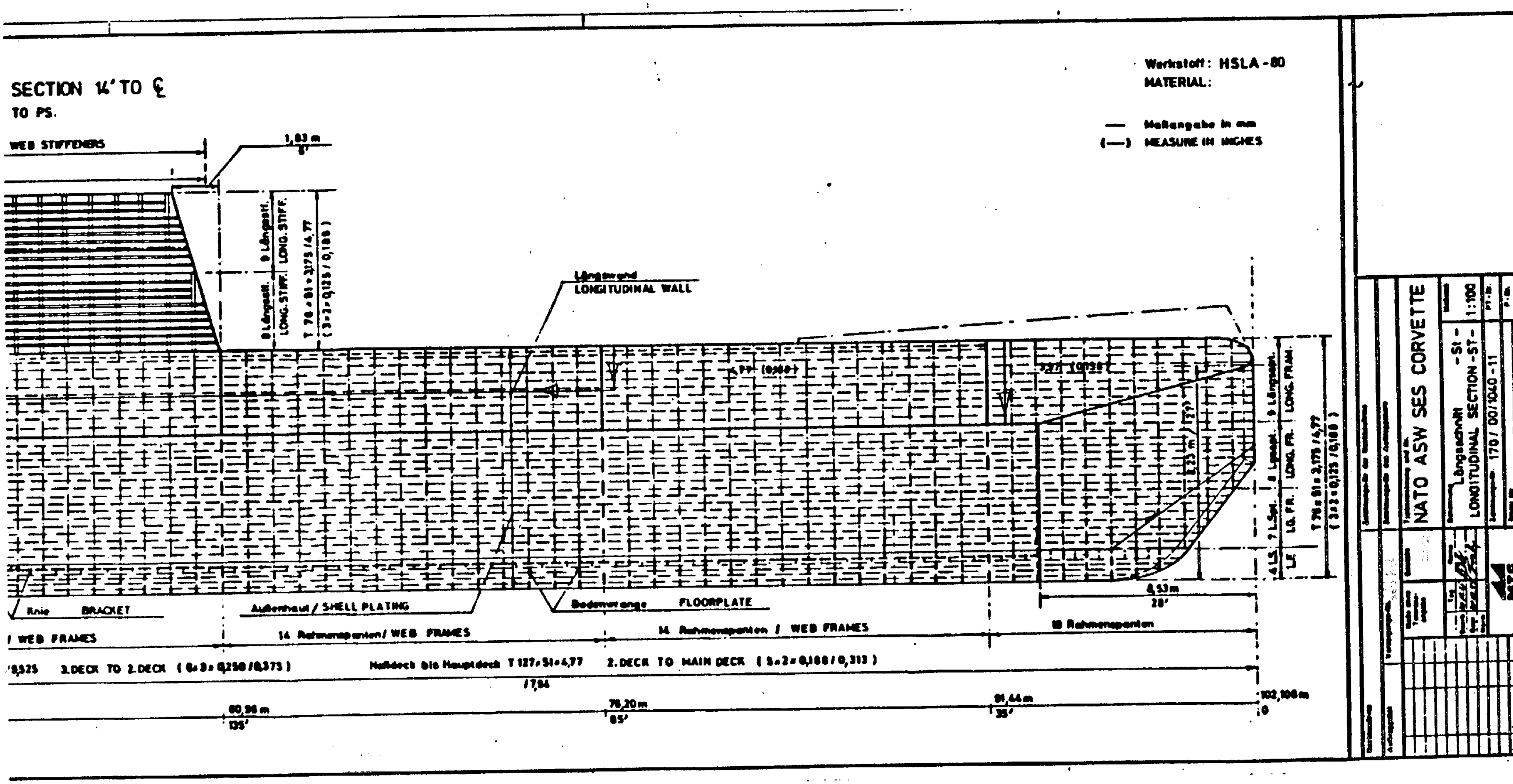

Hauptspant
Abteilung IV
Nach vorne ges.
MIDSHIP SECTION IV
LOOKING FOREWARD
Abteilung V
Nach vorne ges.
SECTION
SECTION V
LOOKING FOREWARD
Rahmenspantenabstand
WEB FRAME SPACING
Von 0,75 L bis 1,0 L
FROME 0,75 L TO 1,0 L
Längsspantenabstand
LONGITUDINAL FRAME SPACING
C Deck
B Deck
Hauptdeck
Main Deck
Naßdeck
2 Deck
Deck
4 Deck
Innenboden
Inner Bottom
Naßdeck
WETDECK
Bödenblech auf 1/2 Bo.-Abstand
BRACKET ON 1/2 FLOOR PLATE DISTANCE
Maßangaben in mm
MEASURE IN INCHES
Werkstoff: HSLA-80
MATERIAL:
NATO ASW SES CORVETTE
Hauptspant u. Querschnitt - St.
MIDSHIP AND CROSS-SECT. - ST
170/00/1040 - 21
1:50



Steifen / STIFFENER
< T 78 x 91 x 3,175 / 4,77
(< T 3x2x 0,125 / 0,188)
— Maßangaben in mm
(—) MEASURE IN INCHES
3,22
(0,156)
Knie 610
BRACKET 24"
4,77
(0,188)
Werkstoff: HSLA - 80
MATERIAL:
14 Steifen / STIFFENER
26 Steifen / STIFFENER
14 Steifen / STIFFENER
T 78 x 91 x 3,175 / 4,77
(T 3 x 2 x 0,125 / 0,188)
Nach vorne gesehen, LOOKING FOREWARD
NATO ASW SES CORVETTE
Querschott 45,72m - St-
BULKHEAD 165' - ST-
1:5
170 / 00 / 1040 - 23
MTG

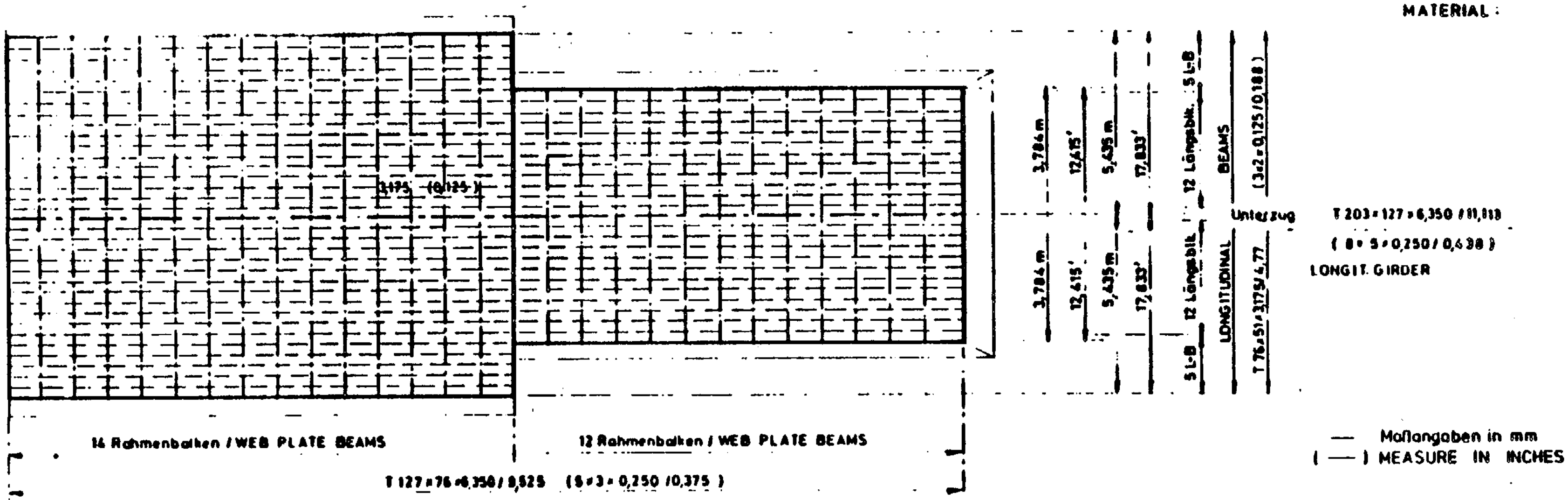


Längsschnitt 4,27 m aus M.S.
Nach Bb. gesehen.
LONGITUDIN
Abmessungen der Deckshaus-Längswände sind gleich!
MEASURE OF SUPERSTRUCTURE LONGITUDINAL WALLS IDENTIC!
14 Rahmensteifen / WEB STIFFENERS
T 127×51×4,77/7,94
3,048 m
10'
2,591 m
8,5'
2,286 m
7,5'
4'
DECK STRINGER
14 Rahmenspanten
14 Rahmenspanten / WEB FRAMES
Innenboden bis Plattformdeck T 127×51×4,77 BOTTOM TO 3. DECK
7,94
0
15,24 m
30,48 m
45,72m
185'


SECTION 14' TO ℄
TO PS.
Werkstoff: HSLA-80
MATERIAL:
Maßangabe in mm
(----) MEASURE IN INCHES
WEB STIFFENERS
1,83 m
6'
Längswand
LONGITUDINAL WALL
Knie BRACKET
Außenhaut / SHELL PLATING
Bodenwrange FLOORPLATE
WEB FRAMES
14 Rahmenspanten / WEB FRAMES
14 Rahmenspanten / WEB FRAMES
10 Rahmenspanten
3.DECK TO 2.DECK
2.DECK TO MAIN DECK
8,53 m
28'
60,96 m
135'
76,20 m
85'
91,44 m
35'
102,108 m
0
NATO ASW SES CORVETTE
Längsschnitt -St-
LONGITUDINAL SECTION -ST-
1:100
170/00/1040-11

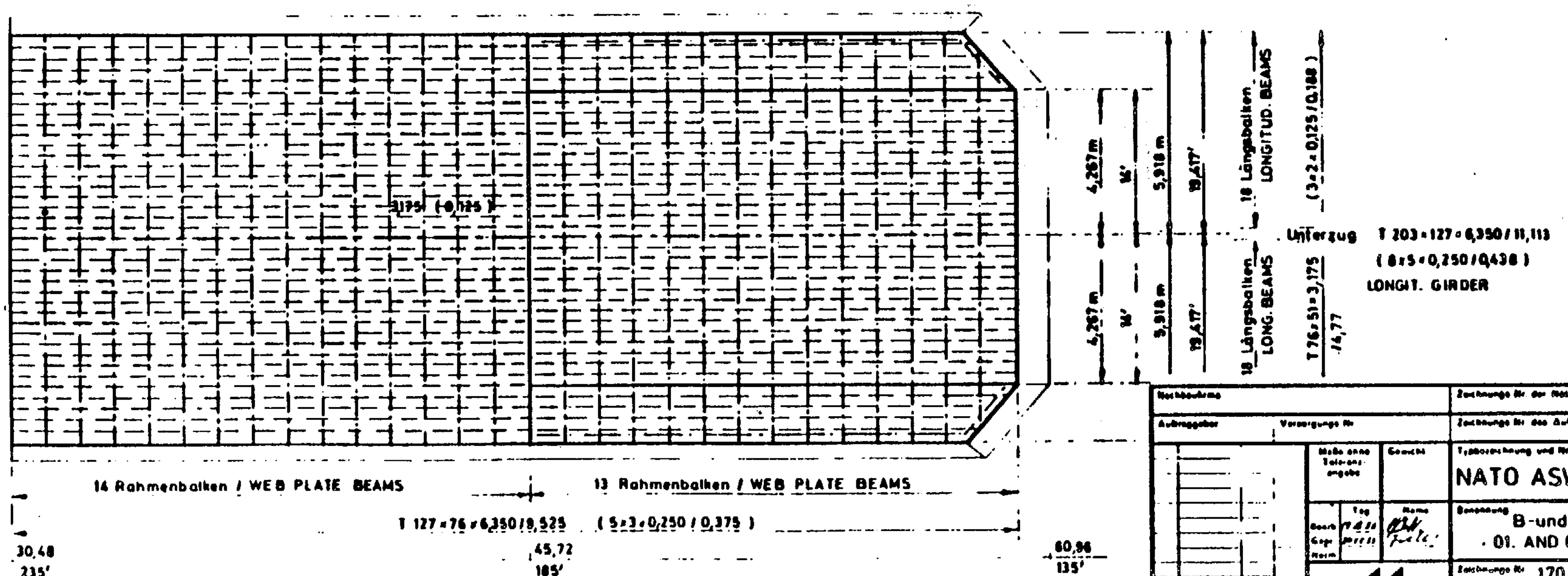
C-Deck / 02.DECK

Werkstoff : HSLA-80
MATERIAL :

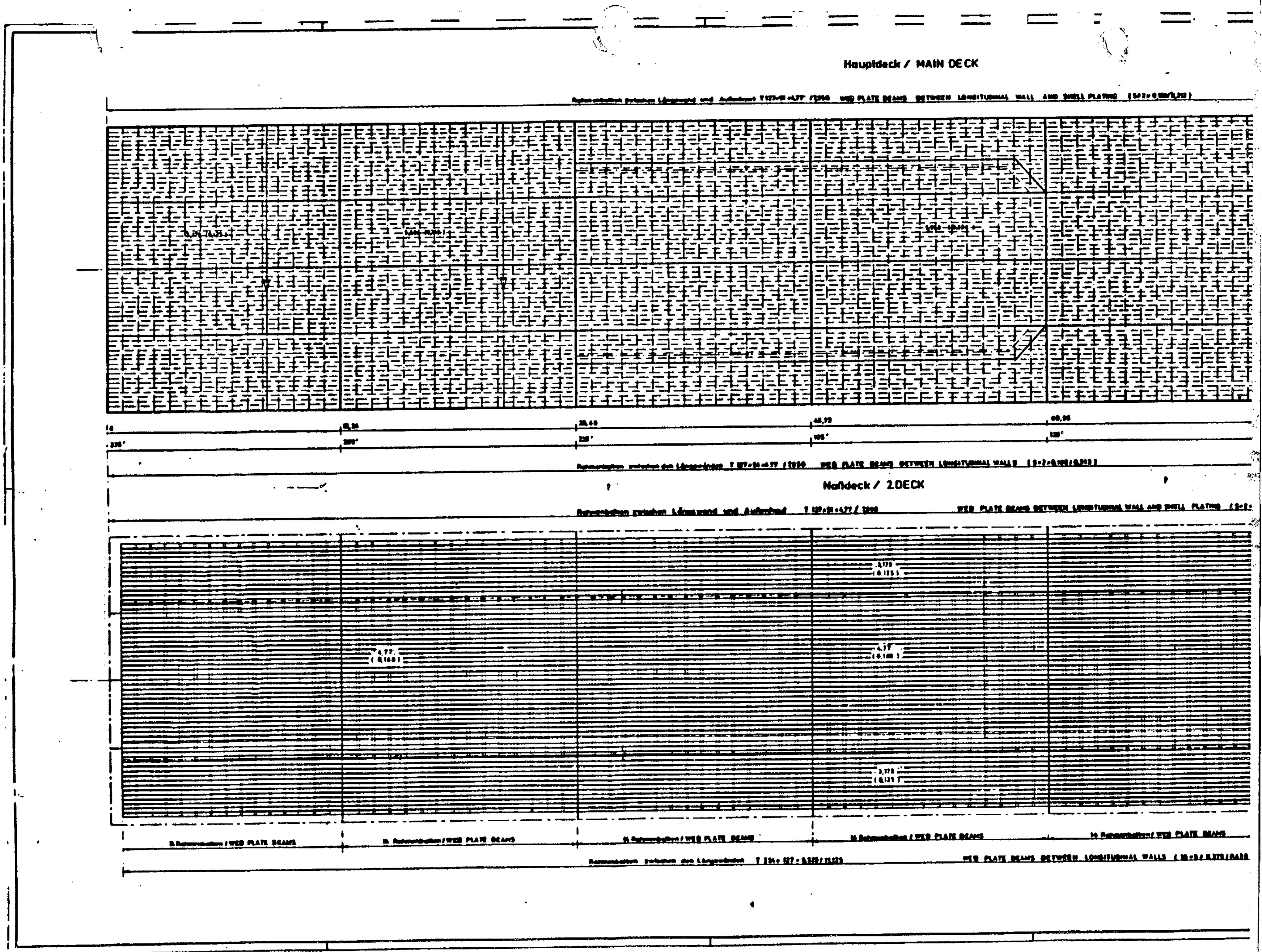


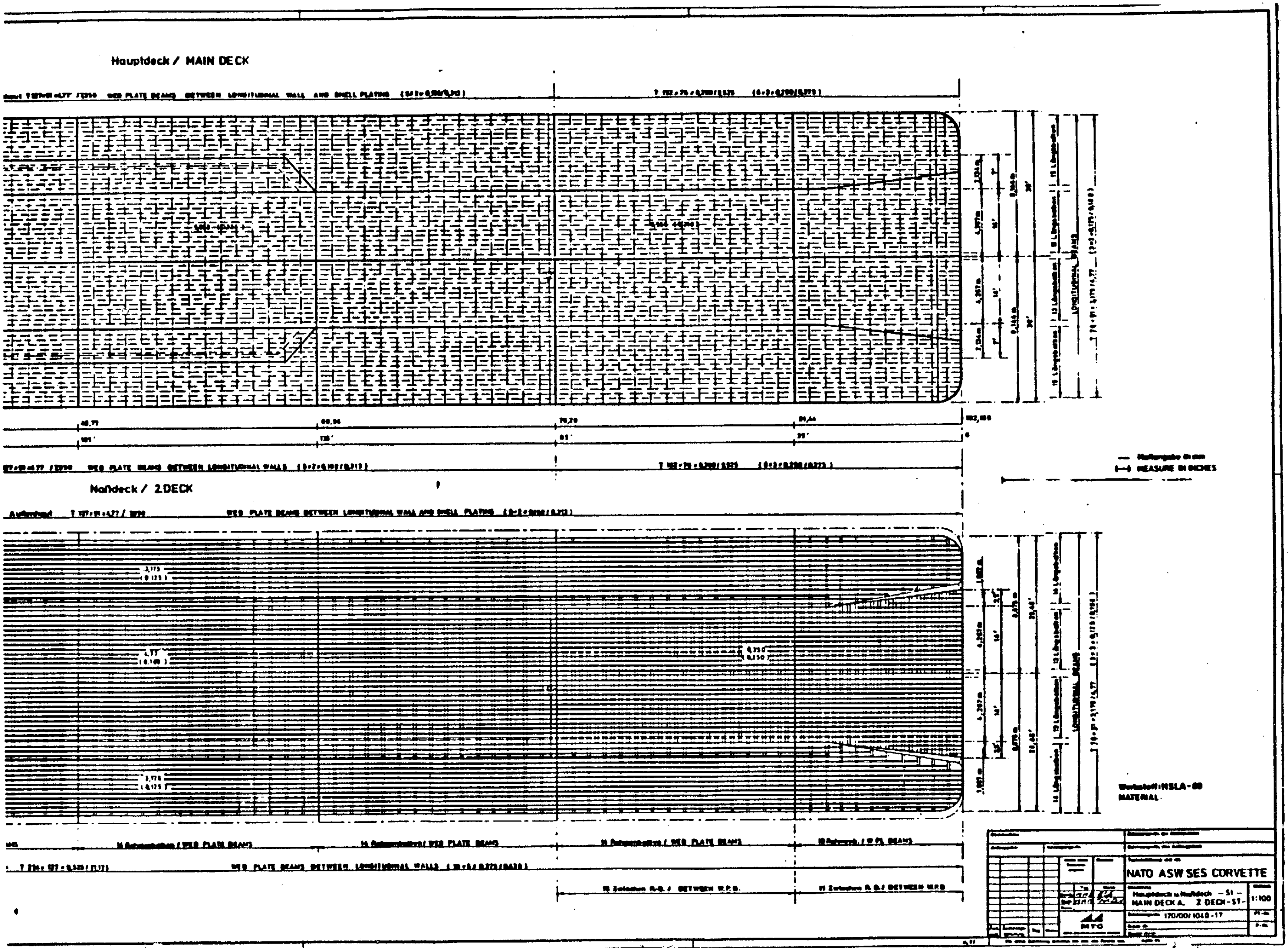
— Maßangaben in mm
(—) MEASURE IN INCHES

B-Deck / 01.DECK

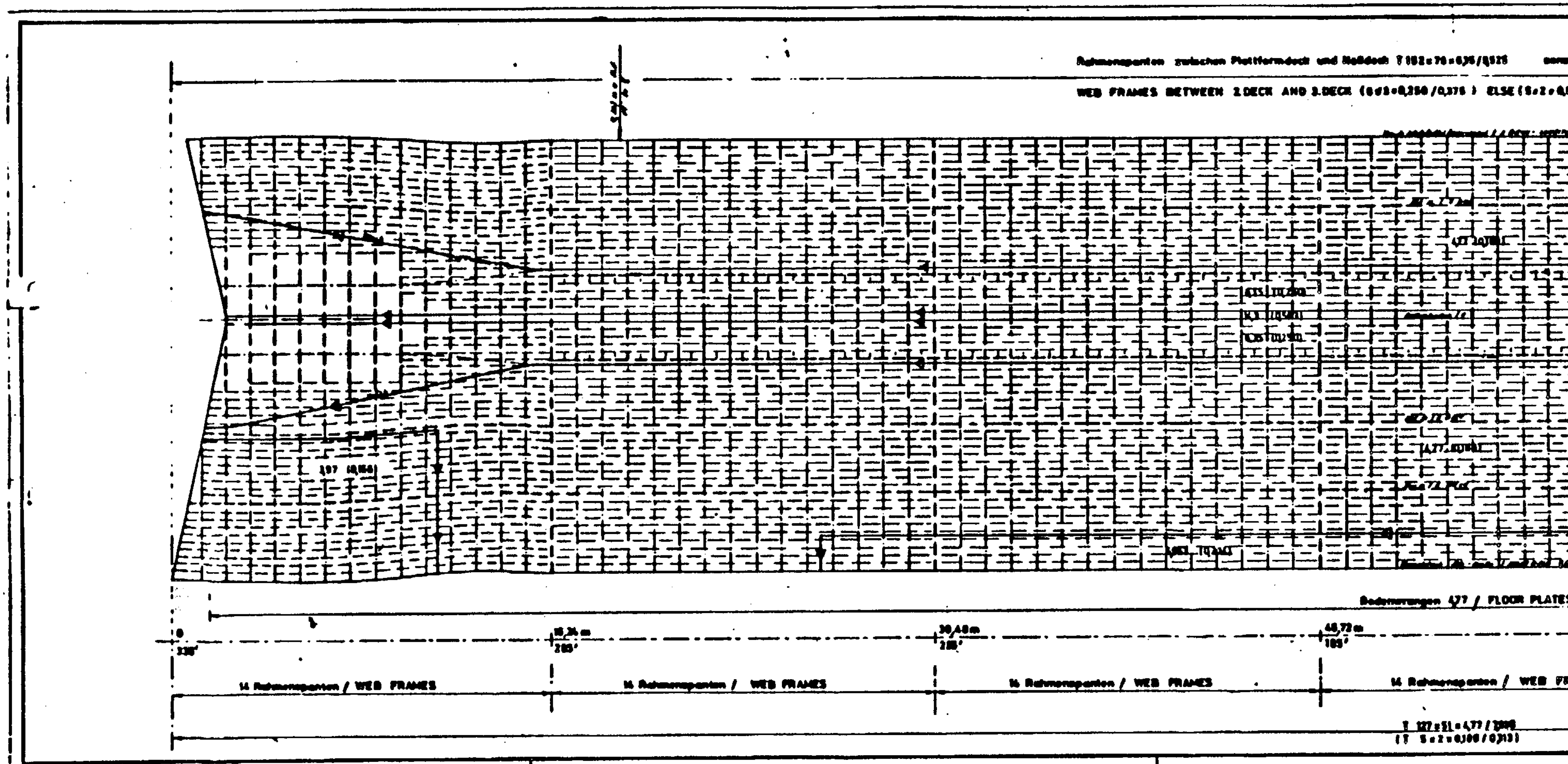


Zeichnungs-Nr. der Nachbaufirma	
Zeichnungs-Nr. des Auftraggebers	
Typbezeichnung und Nr.	NATO ASW SES CORVETTE
Benennung	B-und C-Deck – St – / 01. AND 02. DECK – ST –
Maßstab	1:100
Zeichnungs-Nr.	170/00/1040-19

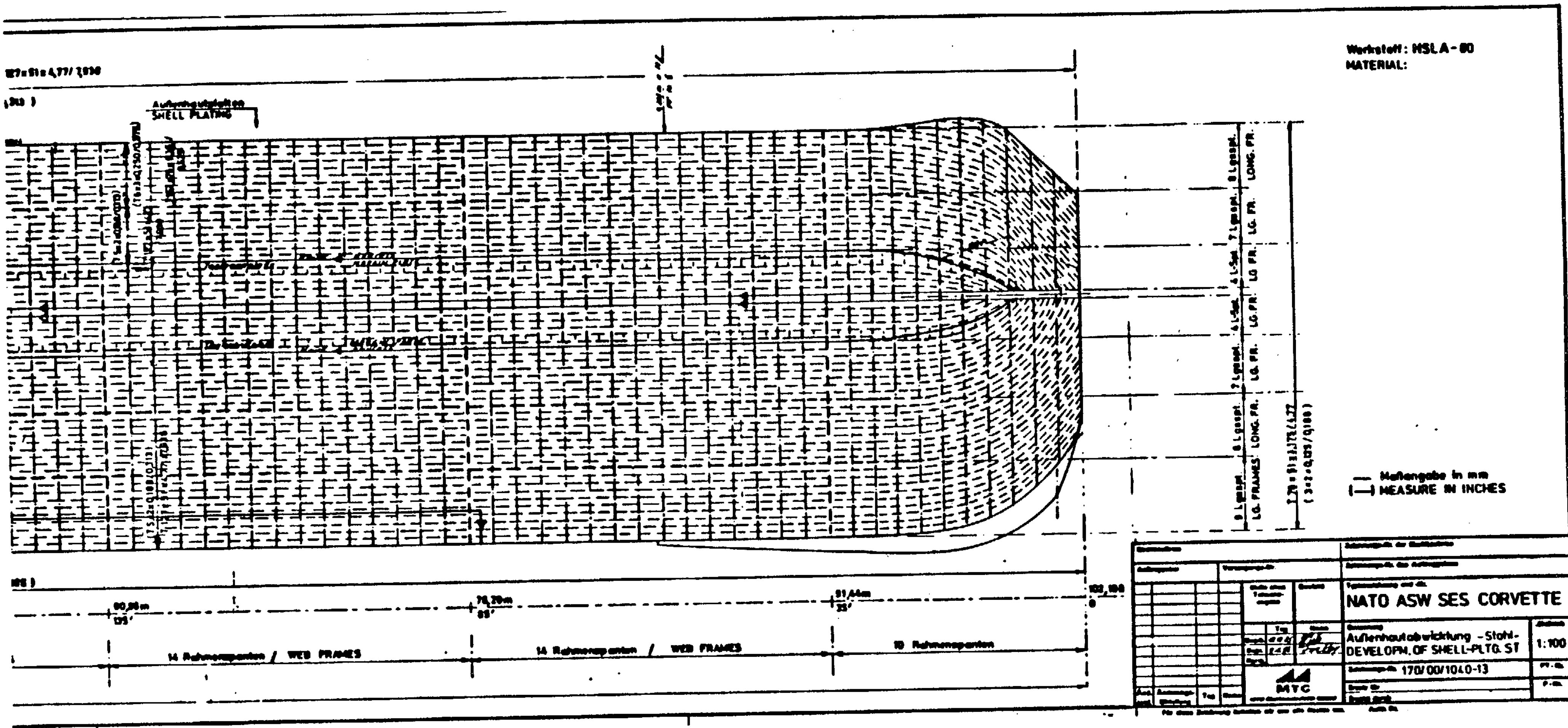

Hauptdeck / MAIN DECK
WEB PLATE BEAMS BETWEEN LONGITUDINAL WALL AND SHELL PLATING
WEB PLATE BEAMS BETWEEN LONGITUDINAL WALLS
Naßdeck / 2.DECK
WEB PLATE BEAMS BETWEEN LONGITUDINAL WALL AND SHELL PLATING
WEB PLATE BEAMS
WEB PLATE BEAMS BETWEEN LONGITUDINAL WALLS



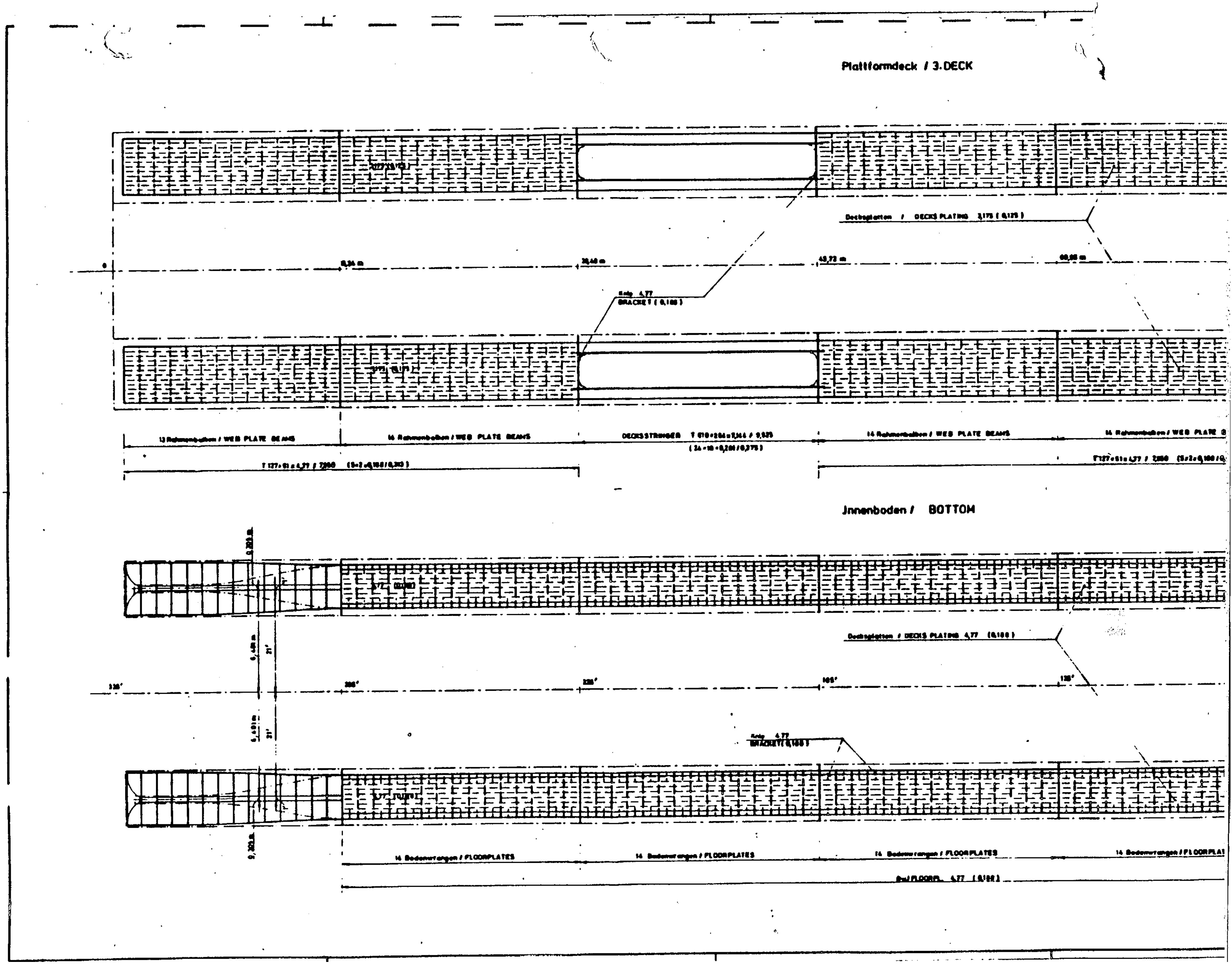
Hauptdeck / MAIN DECK
WEB PLATE BEAMS BETWEEN LONGITUDINAL WALL AND SHELL PLATING
WEB PLATE BEAMS BETWEEN LONGITUDINAL WALLS
Naßdeck / 2.DECK
WEB PLATE BEAMS BETWEEN LONGITUDINAL WALL AND SHELL PLATING
MEASURE IN INCHES
Werkstoff: HSLA-80
MATERIAL
WEB PLATE BEAMS
WEB PLATE BEAMS BETWEEN LONGITUDINAL WALLS
NATO ASW SES CORVETTE
MAIN DECK A. 2 DECK-ST-
1:100
170/00/1040-17



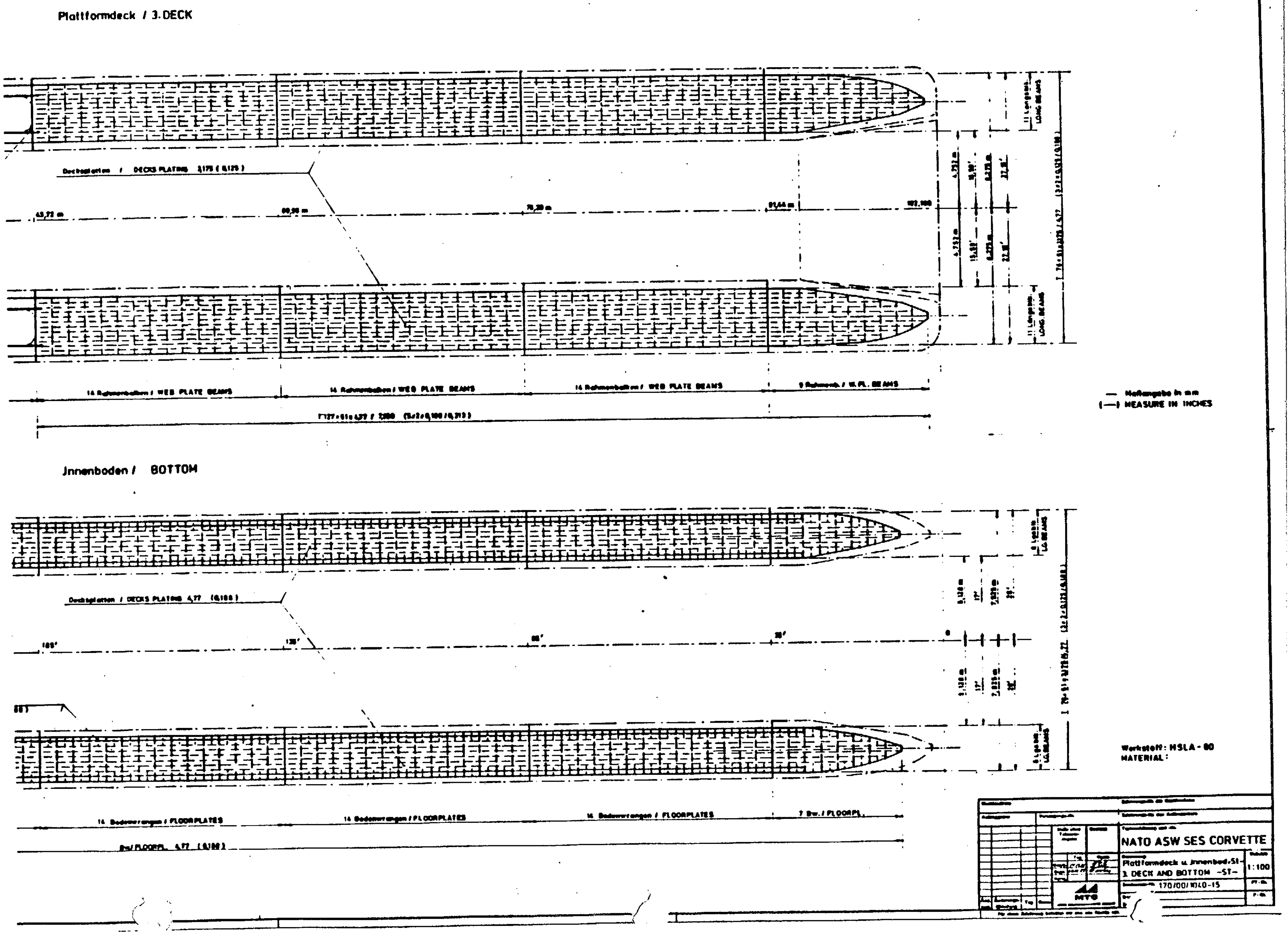
WEB FRAMES BETWEEN 2.DECK AND 3.DECK
Bodenwrangen 477 / FLOOR PLATES
0
10,36 m
30,48 m
48,72 m
14 Rahmenspanten / WEB FRAMES
16 Rahmenspanten / WEB FRAMES
16 Rahmenspanten / WEB FRAMES
14 Rahmenspanten / WEB FR



Werkstoff: HSLA-80
MATERIAL:
Außenhautplatten
SHELL PLATING
Maßangabe in mm
MEASURE IN INCHES
14 Rahmenspanten / WEB FRAMES
14 Rahmenspanten / WEB FRAMES
10 Rahmenspanten
NATO ASW SES CORVETTE
Außenhautabwicklung -Stahl-
DEVELOPM. OF SHELL-PLTG. ST
1:100
170/00/1040-13
MTC



Plattformdeck / 3.DECK
Decksplatten / DECKS PLATING 3,175 (0,125)
8,36 m
30,40 m
45,72 m
60,96 m
BRACKET (0,188)
13 Rahmenbalken / WEB PLATE BEAMS
14 Rahmenbalken / WEB PLATE BEAMS
DECKSSTRINGER
14 Rahmenbalken / WEB PLATE BEAMS
Innenboden / BOTTOM
Decksplatten / DECKS PLATING 4,77 (0,188)
14 Bodenwrangen / FLOORPLATES
14 Bodenwrangen / FLOORPLATES
14 Bodenwrangen / FLOORPLATES



Plattformdeck / 3.DECK
Deckplatten / DECKS PLATING
14 Rahmenbalken / WEB PLATE BEAMS
LONG BEAMS
Maßangabe in mm
MEASURE IN INCHES
Innenboden / BOTTOM
Deckplatten / DECKS PLATING 4,77
14 Bodenwrangen / FLOORPLATES
Werkstoff: HSLA-80
MATERIAL:
NATO ASW SES CORVETTE
Plattformdeck u. Innenboden -St-
3. DECK AND BOTTOM -ST-
1:100
170/00/1040-15
MTG