AD-A046 919 AIRESEARCH MFG CO OF CALIFORNIA TORRANCE F/G 13/10
LARGE HYDROFOIL TRANSMISSION SYSTEM STUDY.(U)
OCT 77 N00014-76-C-0803
UNCLASSIFIED 77-14501 NL

| OF |
AD
A046919

END
DATE
FILMED
1 -78
DDC

AIRESEARCH MANUFACTURING COMPANY OF CALIFORNIA
A DIVISION OF THE GARRETT CORPORATION
2525 WEST 190TH STREET • TORRANCE, CALIFORNIA 90509
(213) 323-9500, 321-5000

(12)

GARRETT

AIRESEARCH MANUFACTURING COMPANY OF CALIFORNIA

(9) FINAL REPORT

(6) LARGE HYDROFOIL TRANSMISSION SYSTEM STUDY.

U. S. NAVY CONTRACT N00014-76-C-0803 new

(14) 77-14501 11 October 1977

(15) N00014-76-C-0803

Number of pages 28

Original date (11) 11 Oct [redacted] 77

(12) 31 p.

Prepared by Staff

Edited by Staff

Approved by John H. Dannan

John H. Dannan
Program Manager

Revision	Date	Pages Affected (Revised, Added, Eliminated)

ACCESSION for
NTIS White Section
DDC Buff Section
UNANNOUNCED
JUSTIFICATION Letter on file
BY
DISTRIBUTION/AVAILABILITY CODES
Dist. AVAIL. and/or SPECIAL
A

DDC
RECEIVED
NOV 16 1977
A

387 343

DISTRIBUTION STATEMENT A
Approved for public release;
Distribution Unlimited

FORM 23 77 2-71

FINAL REPORT

Large Hydrofoil Transmission System Study

This report presents the results of a study to determine the performance and physical characteristics of an ac electrical system intended for use as the propulsion system of large hydrofoils.

The work was performed under Contract N00014-76-C-0803 and is presented in two sections. Section I provides a technical description of the system in terms of performance, weight and component characteristics. Section II describes anticipated problems associated with development of the system and its components, and includes activities through design and fabrication, and qualification of an integrated system.

The material of Section I was provided to the Marine Projects Office of Grumman Aerospace Corp. for inclusion as part of a larger propulsion system study published as Grumman Report MAR 298-100-2, dated January 1977.

The material of Section II was provided to Grumman in June 1977 for inclusion in a development plan and report.

The technical data of Section I is based on the requirements and characteristics provided by Grumman. This includes characteristics of the propeller, foilborne and hullborne thrust and drag, installation geometry and weight data, range requirements, etc.

The work included in Section I was conducted under the basic contract and completed in September 1976. The work of Section II was completed under Mod. P0002 in June 1977.

Section I DESCRIPTION OF AC SYSTEM AND MAJOR COMPONENTS

1. SYSTEM DESCRIPTION

Two system configurations considered in this study are shown schematically by Figures 1 and 2. For reasons of performance and simplicity Configuration I is preferred. Therefore, the descriptive data given below is principally for this configuration.

1.1 Configuration I

As shown by the schematic of Figure 1, Configuration I consists of two direct-turbine-driven ac generators supplying electrical power to either foilborne or hullborne propeller induction drive motors. Conventional switchgear is used for connecting the generator to either the foil or hull drive motors. Each induction motor supplies power to a fixed pitch propeller via a planetary type gearbox. Speed and power output of each induction motor is controlled by fuel flow to the turbine.

Figure 1 shows the system connected for operation in both foilborne and hullborne modes. During takeoff and in foilborne mode, both turbine generator units supply electrical power to the foil propeller drive motors. At lower ship speeds in hullborne mode, one turbine is shut down and both hull prop drive motors connected, via the switchgear, to the on-line turbine generator unit. Harbor maneuvering and reversing is accomplished by plugging either or both hull drive motors. Auxiliary systems are utilized for lubrication and cooling of all components; all heat being rejected to sea water.

1.2 Configuration II

Configuration II shown by Figure 2 consists of independent foilborne and hullborne propulsion systems. For takeoff and foilborne operation, two direct LM2500 turbine-drive ac generators supply electrical power to the foil propeller induction motors. Operation in this mode is identical to Configuration I. In hullborne mode below 16 knots, two GTPF 990 turbines each direct drive an ac generator which supplies power to hull propeller drive motors. Below approximately 12 knots one GT990 is shut down and both hullborne propellers driven in parallel by the operating turbine-generator unit. Configuration II provides a trade off between greater system weight, against a lower hullborne fuel consumption rate obtained by operating smaller turbines in hullborne mode. This provides, potentially, a greater hullborne range.

2. DESCRIPTION OF MAJOR COMPONENTS

2.1 Main Generator

The main generator is a 3-phase, 4-pole, Y-connected synchronous machine of conventional construction to be direct driven by an LM2500 or similar gas turbine. Design, rating and installation data are given by Figure 3. Liquid cooling, described later, is utilized. Design details defining mounting, maintenance and access areas are unresolved due to incomplete interface data.

2.2 Foil Propeller Drive Motor and Gearbox

The foil propeller drive motor is a 3-phase, 4-pole induction machine. Rating and installation data are given by Figure 4. Figure 5 shows estimated performance of the motor at various ship operating conditions. The gearbox is a planetary type with rating data given by Figure 4.

In order to obtain highest efficiency, a low rotor resistance is used to yield minimum slip. The electrical parameters of the motor were selected to provide a breakdown torque that exceeds the rated torque limit of the turbine. This assures that operation at high values of slip will not occur. Special features required by the foil pod mounting and installation constraints are not defined due to incomplete interface data. The gearbox weight and dimensions are based on data provided by Grumman. The gear ratio of 6.72 was derived by motor-propeller matching as described below.

2.3 Hull Propeller Drive Motor and Gearbox

The hull propeller drive motor and gearbox is similar to the foil propeller drive unit except for power rating and speed. Rating and installation data are given by Figure 6. Performance estimates at specific ship operating conditions are given by Figure 7.

2.4 Switchgear and Cabling Components

Data defining the switchgear and distribution system are given by Figure 8. The switchgear units are catalogue items as noted. Enclosures, with dimensions and weights are also given by the figure. The cable lengths are derived from drawings provided by Grumman. Terminations, flexible connections, etc., require additional interface data before details can be made. Weight estimates of the switchgear and cabling components as used in the performance calculations are noted by Figure 8.

2.5 Auxiliary Cooling and Lubrication Systems

Functional schematics of the generator and motor cooling and lubrication systems are given by Figure 9. Representative weight and installation data for various components are given by Figure 10. Heat exchangers were assumed to be of titanium to minize weight. The various systems, shown by Figure 9, have been integrated and simplified for installation in the ship as described earlier.

2.6 LM2500 Gas Turbine

The power, speed, SFC characteristics and engine limits are reproduced by Figure 11, which shows operating lines of the ac system in both hullborne and foilborne modes.

2.7 Propeller Data

Data defining foilborne and hullborne propellers is given by Figure 12. Fixed-pitch propeller characteristics are used in both modes.

2.8 Major Components, Configuration II

As stated in para 1.2, the foilborne systems for Configurations I and II are identical. The hullborne propeller, drive motor, and gearbox are also identical. The following components are required to complete the hullborne system:

(a) GTPF 990 gas turbine. Weight is 5500 lbs including gearbox which provides 3600 rpm output. SFC characteristics are reproduced in Figure 13.

(b) The turbine exhaust and inlet installations, and wash system are the same as those given for the base system provided by Grumman.

(c) A generator, to be direct driven by the GTPF 990 turbine, electrically matching the hull propeller drive motor. This would be a 3-phase, 4-pole machine of 1.65 kv, 4 kVA rating. Weight was estimated at 3600 pounds including structure and enclosure.

(d) Switchgear and cabling required for generator isolation and cross connection. Weight is given by Figure 8.

3. WEIGHT

A weight breakdown for Group 2 components is given by Figure 14 for Configurations I and II. Data for the base system is also given. Weights for the ac drive systems are based on component data given in paragraph 2. An estimating margin of 6 percent and a design margin of 15 percent are applied to the calculated weights. The group 2 total weights, with these margins, are used for all range calculations.

4. PERFORMANCE

4.1 Configuration I

Figure 15 indicates power flow data for Configuration I. In foilborne mode, the system was matched to obtain a highest ship speed by utilizing the maximum power available from the gas turbine noted earlier on Figure 11. This occurs at the turbine limits of 3600 rpm and a T54 of 1425°F, which provides the 50-knot foilborne cruise condition shown on Figure 11. Operation of the system at other foilborne conditions occurs along the operating line down to approximately 30 knots. Operation of the system at 25 percent excess thrust at 30 knots for takeoff, and 10 percent excess thrust at 40 knots for acceleration, is also depicted.

At lower speeds, in hullborne mode, either foil or hull propeller drive can be used. Operating lines for both are given by Figure 11. The hullborne operating line is based on "foils up" drag data only. Range calculations given below are based on the 40-knot and 45-knot foilborne cruise points and on the 15-knot hullborne operating point.

4.2 Configuration II

Figure 16 shows power flow data for operation in foilborne and hullborne modes. Foilborne operation is identical to that of Configuration I. In the hullborne mode the GTPF 990 turbines are utilized to drive the Troost propeller drive motors. The operating line of the GTPF 990 gas turbine is given by Figure 13.

4.3 Range Estimates

Figure 17 gives three range and endurance predications including:

Case a: 40-knot cruise

Case b: 15-knot cruise

Case c: 45-knot cruise (62 percent total time)

30-knot takeoff (2 percent total time)

Idle main turbines (37 percent total time)

Range predictions are based on a constant initial ship's weight of 1278 long tons and a base fuel weight of 400.1 long tons. Adjustments in fuel weight are made to accommodate changes in the ac propulsion system weight from the base system weight. Details of these calculations are given by Figure 17, using weight data with the 15-percent design margin, from Figure 14.

5. DEVELOPMENT STATUS

The ac propulsion system described herein is based on design, manufacturing and operating concepts that are in use in other well developed ship and land based systems. Therefore, no new development problems or development risk are believed introduced by the system for this hydrofoil application.

Additional system design and analysis needs to be conducted to evaluate higher operating frequencies with the objective of reducing electrical machinery weight and size from that given earlier. Environmental factors, EMI, structural requirements etc. unique to hydrofoil application should be further evaluated to determine the impact of these requirements on each system component. Ship maneuvering requirements need further study to verify that satisfactory thrust reveals, response times etc., of the system can be done using a fixed pitch propeller with motor plugging.

The performance and weight estimates of the motor and generator components were made utilizing standard computer programs. As these programs have been in continuous use in the design of other machines, It is believed that the performance weight and dimensions as given in previous paragraphs are accurate. Within the limited scope of Phase I, detailed stress and thermal analyses were omitted. However, magnetic and insulating materials properties, peripheral speeds, current and flux densities etc. are consistent with accepted design practice. Further analysis is required to determine the plugging operation of the hullborne motors during reversal, in that transient currents, heating, etc., requires further analysis to verify cooling requirements.

The planetary type gearbox units, used in both the foil and hull motor pods, will require development. As noted earlier, the size and weight used in the data given above was based on data provided by Grumman. Comparable data for planetary gear units developed under Navy/Marad sponsorship was obtained earlier from Curtiss Wright. Under this program considerable development data was obtained, including endurance at power levels of 40 KHP and output speeds in the range required by the hydrofoil.

The switchgear was selected from vendor industrial catalogue data as described earlier. Transient analyses should be conducted, however, simulating ship maneuvers to verify the selected switchgear. Special enclosures are required for mounting and shielding to obtain least weight. Weight and size reductions may be possible by use of special development switchgear. This was not investigated during Phase I. The use of tube-type conductors for connecting the various generators and motors was assumed. No attempt was made to determine installation or structural requirements and constraints. Also, swivel connections needed at the foil motor retraction pivot were not designed. A nominal weight allowance was made for these items in the data given earlier. This will be a development item, but is not felt to be significant.

As noted above, weights of heat exchangers were based on the use of titanium for tubes and headers. Titanium reduced system weight by approximately seven tons. Experience with titanium units in Naval vessels is not known. However, in power system service 31 plants have condensers fully tubed with titanium for both fresh and seawater. Twenty other plants have condenser partially tubed with titanium also in fresh and sea water. All of these condenser units are considerably larger that the exchangers required for the hydrofoil. Development titanium units for hydrofoil use does not appear to be a difficult extension of this power plant technology.

Section II AC SYSTEM, TECHNOLOGY STATUS AND DEVELOPMENT PLAN

1. SUMMARY, SYSTEM DESCRIPTION

The ac system consists of two direct-turbine-driven generators supplying electrical power to either foilborne or hullborne propeller induction drive motors. Conventional switchgear is used for connecting the generator to either the foil or hull drive motors. Each induction motor supplies power to a fixed pitch propeller via a planetary type gearbox. Speed and power output of each induction motor is controlled by fuel flow to the turbine and excitation of the gearbox.

During takeoff and in foilborne mode, both turbine generator units supply electrical power to the foil propeller drive motors. At lower ship speeds in hullborne mode, one turbine is shut down and both hullborne drive motors connected, via the switchgear, to the on-line turbine generator unit. Harbor maneuvering and reversing is accomplished by "plugging" either, or both, hull drive motors. Auxiliary systems are utilized for lubrication and cooling of all components; all heat being rejected to sea water.

The principal components of the system, which comprise the major development effort discussed below are:

Generators (2)

Foil motor (2)

Foil gearbox (2)

Hull motor (2)

Hull gearbox (2)

Switchgear

Transmission line subsystem

Cooling and lubrication subsystem for each machine

Control system

The gas turbines, propeller, propeller shafting, and pods are assumed GFE.

2. PROGRAM PLAN, SUMMARY CONTENT

The plan for development of the ac propulsion system encompasses three major phases:

(a) An initial or preliminary design phase needed to define final system performance, ship interfaces, environmental factors, control modes, etc. A system specification would be completed, defining detailed component design requirements. A time period of approximately 9 months will be required for this effort. The system development phase which follows, cannot be initiated until this system definition is completed.

(b) A second and principal phase, Component Fabrication and Test, during which all component shop drawings are completed, and all parts fabricated. Tests of each component, for mechanical and/or electrical integrity, will complete this phase.

(c) A third phase during which the components are assembled into a simulated System Test. Performance tests, control tests, and endurance tests will be conducted to best simulate system requirements.

The Development Plan discussed below is concerned with the second and third phases above i.e., Component Fabrication and Test and System Test Phases. Schedules and milestones for each of the phases is given in Figures 18 and 19.

2.1 Component Development

Development of each component of the system noted above will require technical and schedule content as described in the following paragraphs.

2.1.1 Main Generators

The main generators are 3-phase, Y-connected synchronous machines with liquid (oil) cooling of the stator and rotor members. A summary of the machine design parameters taken are:

Rating	16.3 Mva
Voltage	2 kv L-L
Poles	4
Overall diameter	46 in.
Length	50 in.
Weight	16,500 lb
Speed	2871 (3600 max) rpm
Current densities	5 ka/sq in.
Tip speed, nom.	350 ft/sec
max.	430 ft/sec

These parameters can be satisfied by a machine of conventional construction in terms of magnetic materials of the rotor and stator, electrical insulation, bearing speeds and loads, etc. Liquid cooling of the stator and rotor, adapted from similar machines, will be utilized. No new or unique development problems are introduced into the design of this component, and detailed design, tooling and fabrication of the machine can proceed as shown by the schedule of Figure 18.

The detailed design and supporting electrical mechanical and thermal analyses will be initiated at program startup. The details will be based on the preliminary design and component specification generated in the previous Preliminary Design Phase, as noted on Figure 18. Shop details will be started in the fourth month for identifying long lead time materials and/or parts. The generator design will be frozen at the seventh month, premitting all shop details to be completed by the twelfth month. All principal interfaces should be frozen by the seventh month, including those to the gas turbine deck structure, cooling system, and main electrical buss. Fabrication of most generator parts will be completed in eighteen months, permitting some assembly operations to be initiated. Final assembly, and initiation of a generator test, will occur at the eighteenth month. Testing is expected to require approximately four months as shown by Figure 18. In order to minimize facility requirements (i.e. generator drive source), electrical testing will be limited to full speed, open circuit, full voltage tests, and short circuit current full speed tests. Otherwise testing will cover the full speed range from zero, through design point, to overspeed. Approximately 200 running hours would be completed in this period.

2.1.2 Foilborne and Hullborne Propeller Drive Motors

Both machines are 3-phase, Y-connected induction machines using oil cooling of rotor and stator. Design parameters of each machine are:

	Foil Motor	Hull Motor
Rating, MVA	16.5	3.4
Volts kv L-L	2	1.6
Poles	4	4
Overall dia., in.	45	36
Overall length, in.	60	38
Weight, lb	14,200	6000
Speed, rpm	2864	2400
Current densities	6 ka	6 ka
Tip speed, nom ft/sec	374	240
max ft/sec	450	300

Detailed electrical and mechanical design, materials, thermal distribution, and so on, will be similar. Therefore, the development plan for each machine will be essentially identical for the current study. Figure 18 shows the plan for component fabrication and test.

The schedule and milestone plan for the two motors generally follows that for the main generator shown above.

2.1.3 Foil and Hull Motor Gearboxes

The planetary-type gearbox drives between the foil and hull drive motors and respective propellers have the following design parameters:

	Foil Gearbox	Hull Gearbox
Rating, hp	25000	5000
Input speed, rpm	3600	2300
Ratio	6.72	7.90
Outside dia., in.	34	30
Length, in.	36	34
Weight, lb.	4300	3000

These designs were reviewed by Curtiss-Wright, which has conducted extended development of planetary-type marine gearbox units (up to 50000-hp rating) for the Navy and Marad. The gearbox lengths and diameters specified above will be increased to accommodate 2-stage reduction for better design proportions. The data necessary to design the gearbox units for optimum gear proportions--allowable stress, materials, manufacturing techniques, and so on--is available at Curtiss-Wright, provider of the development plan shown in Figure 18. Approximately 500 hours at rated torque and speed will be completed under this plan.

2.1.4 Cooling and Lubrication Subsystem

Cooling and lubrication of the generator motor and gearbox units are required. A common cooling and lubricating subsystem is used with each unit. All heat is rejected to seawater through a common loop. Heat exchanger weights were based on the use of titanium for tubes and headers.

The cooling system has the greatest number of ship interfaces, and it requires intricate routing of fluid lines throughout the hull and foils. Therefore, a careful definition of all interfaces is required prior to final design freeze and part fabrication.

Testing during the component fabrication phase will be limited to checkout and short-time performance/mechanical integrity tests of critical components, such as pumps. Assembly of components into a final cooling system will be deferred to the system test.

2.1.5 Controls, Switchgear, Power Transmission

Component fabrication and test will track the schedule shown in Figure 18. Testing will be limited to checkout or simulation-type tests of individual components before assembly into a final system configuration. Since most components are either catalog items (e.g., switchgear), or can be tested via system simulators (controls), this procedure is considered acceptable.

Completion of the system simulation is necessary before the controls and switchgear components can be frozen and specifications defined. The milestones specified in Figure 18 must be met early in the program to accommodate the long leadtime required for fabrication and test of the control and switchgear components.

2.2 System Test

A schedule and milestone plan for a system test is shown in Figure 19. The system test involves assembly of one propulsion side (that is, one-half a ship system) into a test facility duplicating the general configuration of the final installation. Propeller absorption of power will be simulated by a dynamometer. As shown in Figure 19, initial planning and facility preparation should be started prior to completion of the component phase.

The system test objective is to verify overall system performance, simulate and verify control operation, and determine the performance levels and operational capabilities of such subsystems as cooling, monitoring, and instrumentation.

After completion of the initial checkout and verification tests, endurance and reliability tests will be started. It is expected that about 1000 hours of cumulative timing experience will be obtained on critical generator, motor, and gearbox components, as indicated in Figure 19.

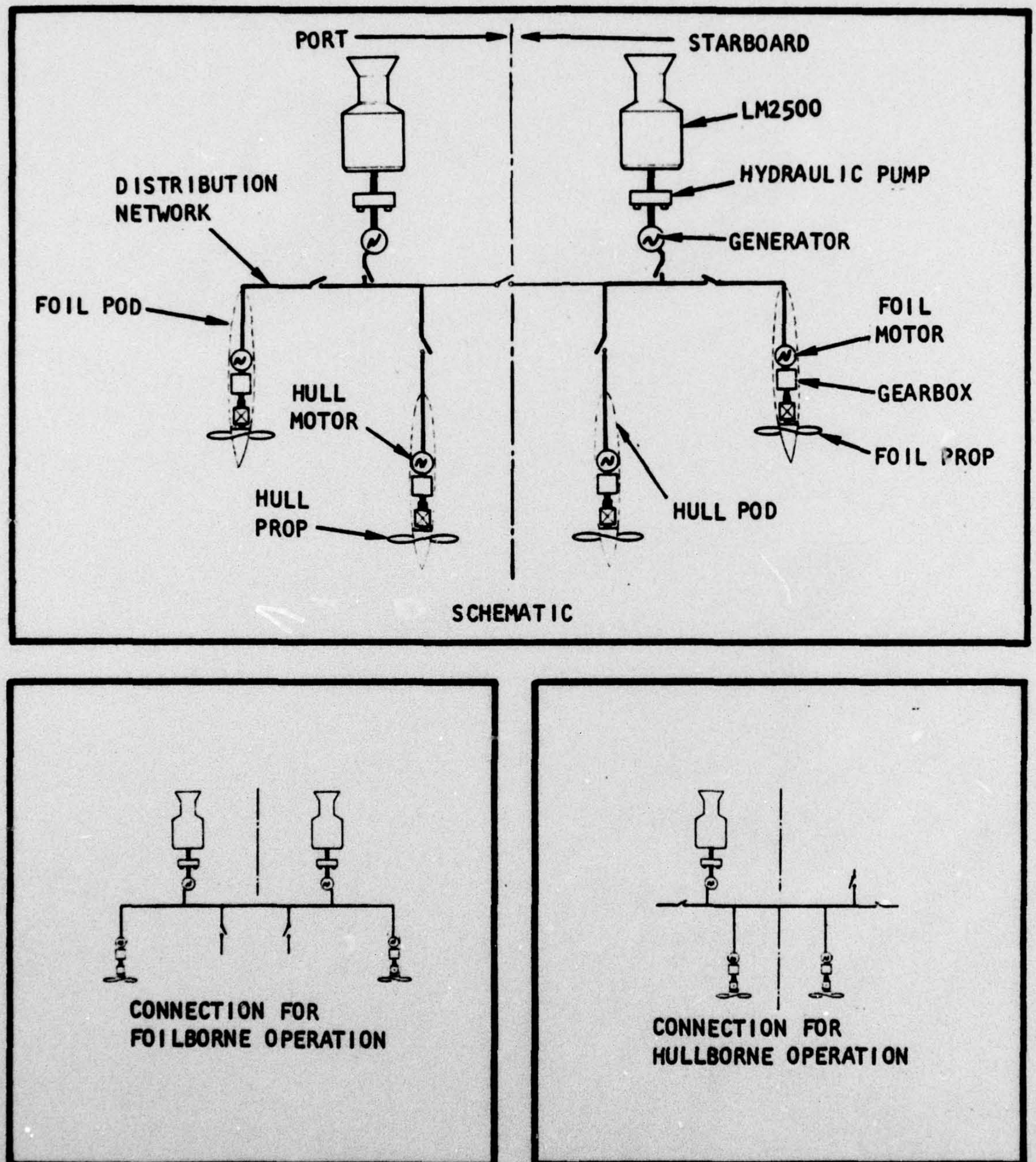


Figure 1. Schematic & Connection Diagram, Configuration I

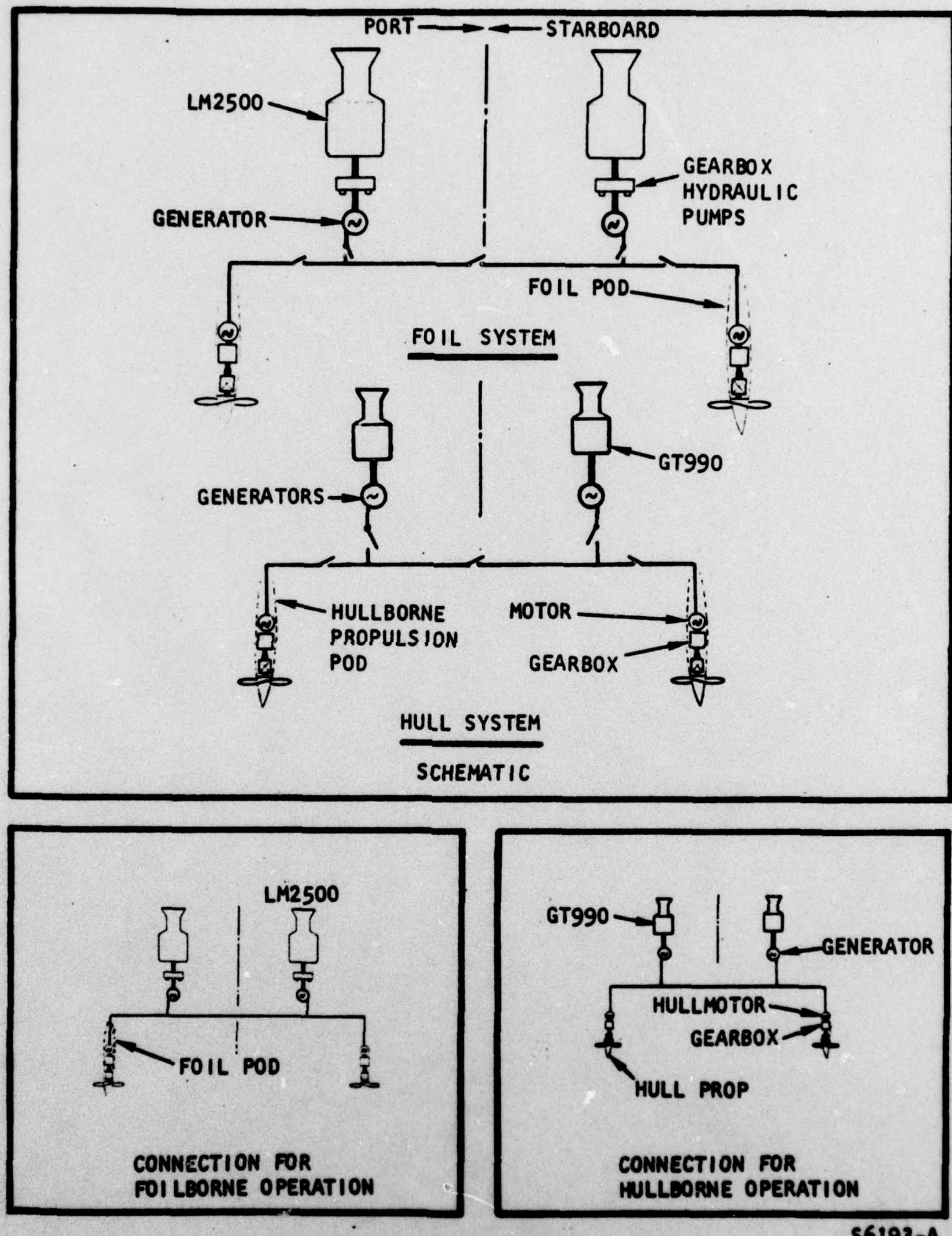


Figure 2. Schematic & Connection Diagram, Configuration II

Rating	KVA	16,250
Power, output	KW	15,275
Power factor, lag		.94
Voltage L-N/L-L		1136/1968
Current	amps	4768
Speed	RPM	2871
Poles		4
Frequency	Hz	95.7
Efficiency		.965
Rotor peripheral speed, peak	ft/sec	430
Rotor moment of inertia	in./lb sec^2	1431
Current density stator, max	$amps/in.^2$	5223
Current density rotor, max	$amps/in.^2$	6508
Stator bore diameter	in.	28.4
Stator outside diameter	in.	42.53
Overall outside diameter	in.	46.0
Gap length	in.	0.3
Active magnetic length	in.	32.3
Overall length (incl structure and excitation)	in.	66
Electromagnetic weight	lb	12,234
Total weight	lb	16,500

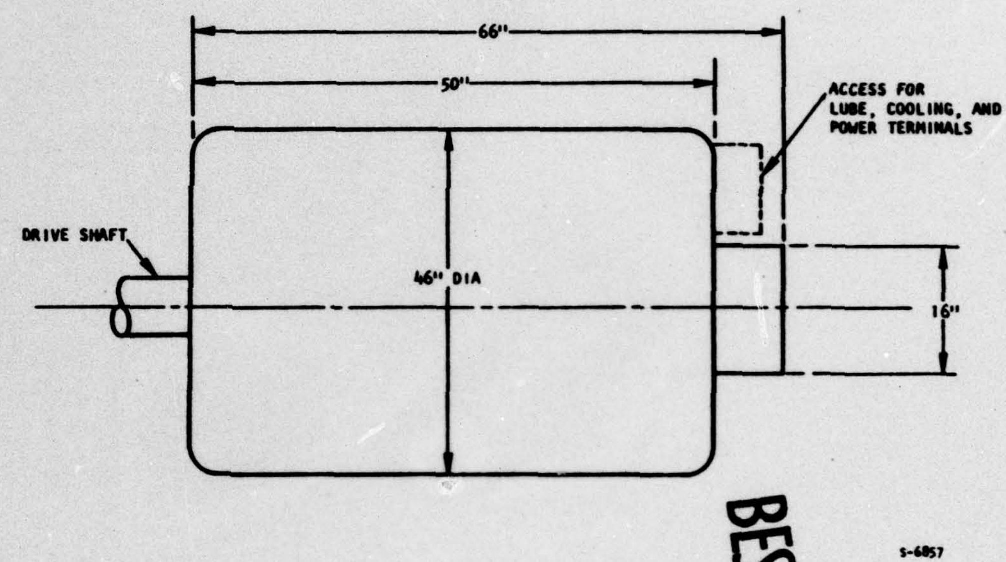


Figure 3. Rating and Installation Data, 16-MVA Main Generator

Motor

Rating, input	KVA	16,500
Power, output	HP	20,400
Power factor, lag		.94
Voltage L-N/L-L	amps	1150/2000
Current	amps	4720
Slip		.00294
Speed	RPM	2864
Poles		4
Frequency	Hz	95.7
Efficiency		.978
Rotor peripheral speed	ft/sec	450
Rotor moment of inertia	in.-lb-sec^2	1846
Current density stator, max	amps/in.^{2}	6937
Current density rotor, max	amps/in.^{2}	3761
Stator bore diameter	in.	30
Stator outside diameter	in.	41
Overall outside diameter	in.	45
Gap length	in.	.15
Active magnetic length	in.	36
Overal length	in.	63
Electromagnetic weight	lb	10,850
Total weight	lb	14,200

Gearbox

Gear ratio		6.72
Outside diameter	in.	46
Length	in.	34
Weight	lb	4300
Efficiency		.98
Power	HP	25,000
Input speed	RPM	3593

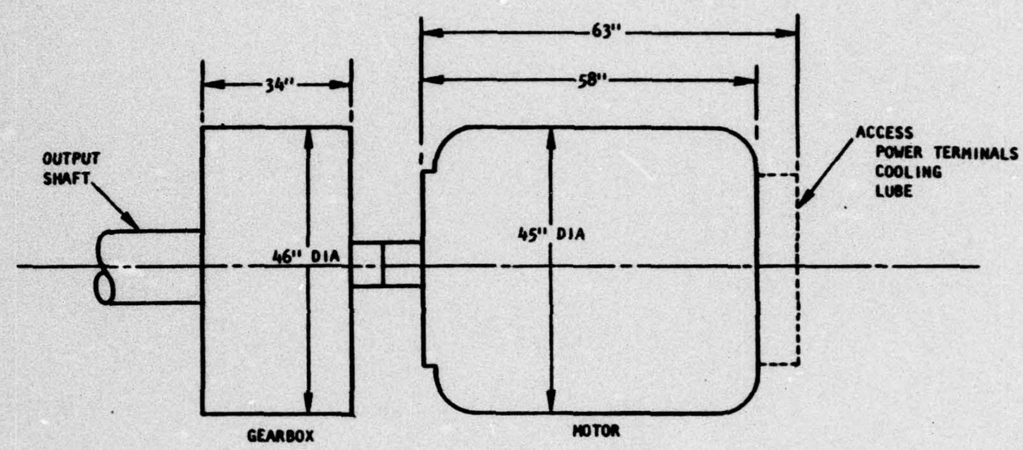


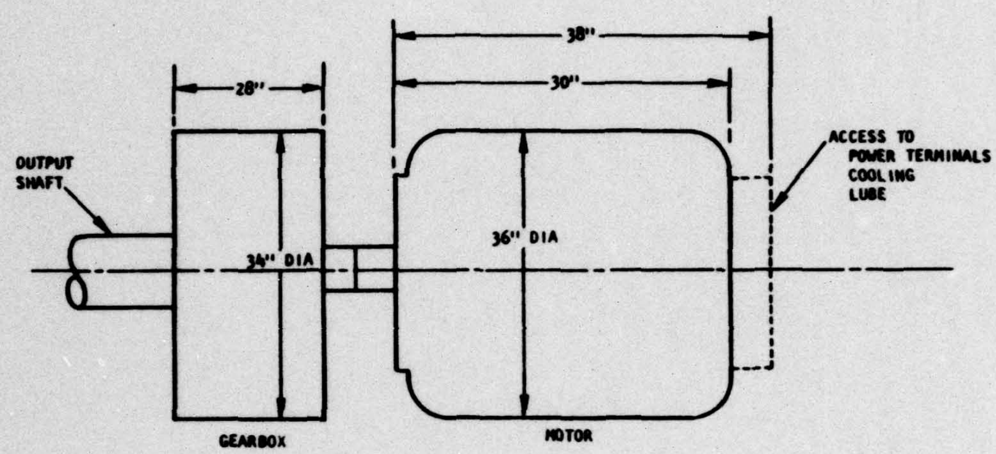
Figure 4. Rating and Installation Data, Foil Propeller Drive Motor & Gearbox

		Foilborne Cruise						Hullborne	
		50 Kts	45 Kts	40 Kts	30 Kts	30 Kts T = 1.25D	45 Kts T = 1.10D	16 Kts	8 Kts
Motor output	HP	23,980	19,132	15,306	14,796	20,408	22,040	5102	1020
Frequency	Hz	120	108	96.5	82.0	90.7	115.6	48	25
Voltage L-L	Volts	2470	2227	1964	1687	1863	2376	987	513
Primary current	Amps	4478	3931	3549	4021	5121	4337	2338	968
Primary current density	$Amp/in.^2$	6581	5777	5216	5910	7526	6374	3436	1423
Secondary current	rms amps	4404	3860	3483	3951	5045	4264	2272	868
Secondary current density	$Amps/in.^2$	3580	3138	2832	3212	4101	3467	1847	705
Slip	Per unit	.0018	.0017	.0017	.0023	.0027	.0018	.0022	.0016
Speed	RPM	3597	3244	2891	2455	2713	3462	1438	745
Power factor	Per unit	.94	.95	.95	.95	.95	.94	.95	.88
Efficiency (elect.)		.984	.984	.984	.982	.980	.982	.982	.982

Figure 5. Estimated Performance, Foil Propeller Drive Motor

Drive Motor		
Rating, input	KVA	3371
Power, output	HP	4020
Power factor, lag		.89
Voltage L-N/L-L		950/1645
Current	amps	1183
Slip		.0036
Speed	RPM	2392
Poles		4
Frequency	Hz	80.0
Efficiency		.97
Rotor peripheral speed	ft/sec	240
Current density stator	$amp/in.^2$	5790
Current density rotor	$amp/in.^2$	2319
Stator bore diameter	in.	23.5
Stator outside diameter	in.	33
Gap length	in.	.25
Active magnetic length	in.	23.0
Overall length	in.	38
Overal stator O.D.	in.	36.0
Electromagnetic weight	lb	4500
Overall weight	lb	6000

GEARBOX		
Gear ratio		7.90
Outside diameter	in.	34
Length	in.	28
Weight	lb	3000
Efficiency		.98
Power	HP	5000
Input speed	RPM	2300

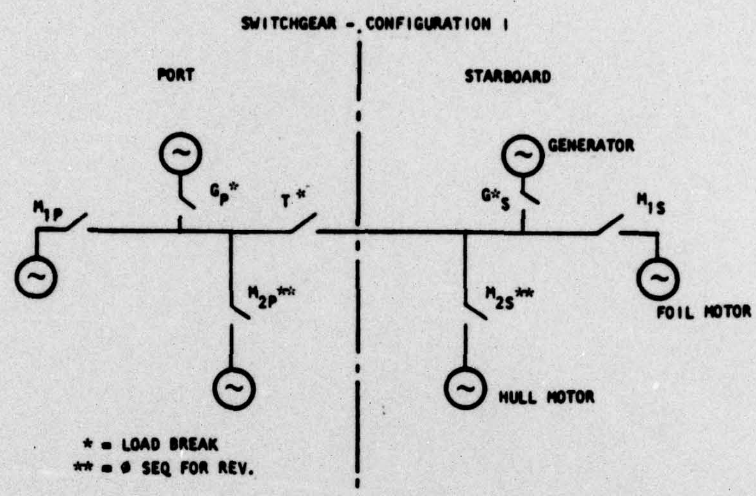


BEST AVAILABLE COPY

Figure 6. Rating and Installation Data, Hull Propeller Drive Motor & Gearbox

		Hullborne Cruise		
		16 Kts	15 Kts	10 Kts
Motor output	HP	5000	3590	1025
Speed, synchronous	RPM	2537	2299	1586
Frequency	Hz	84.61	76.64	52.8
Voltage L-L	Volts	1739	1576	1086
Primary current	Amps	1482	1276	547
Primary current density	$Amps/in.^2$	7265	6254	2681
Secondary current	Amps	1353	1148	416
Secondary current density	$Amps/in.^2$	3386	2873	1041
Slip	Per unit	.0041	.003	.002
Speed	RPM	2528	2291	1580
Power factor, lagging	Per unit	.88	.87	.87
Efficiency	Percent	.969	.969	.966

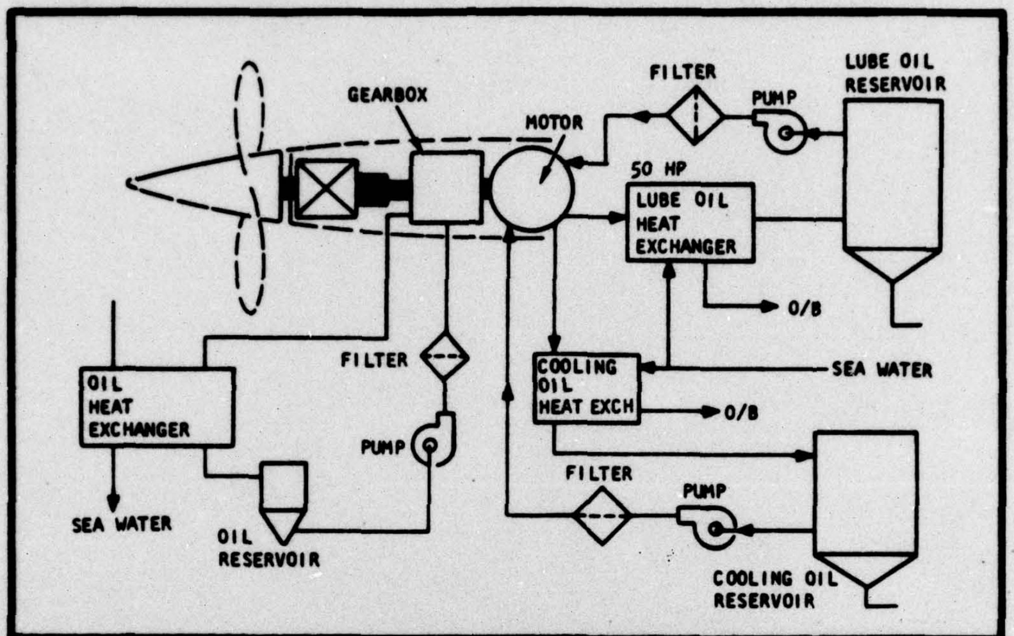
Figure 7. Estimated Performance, Hull Propeller Drive Motor



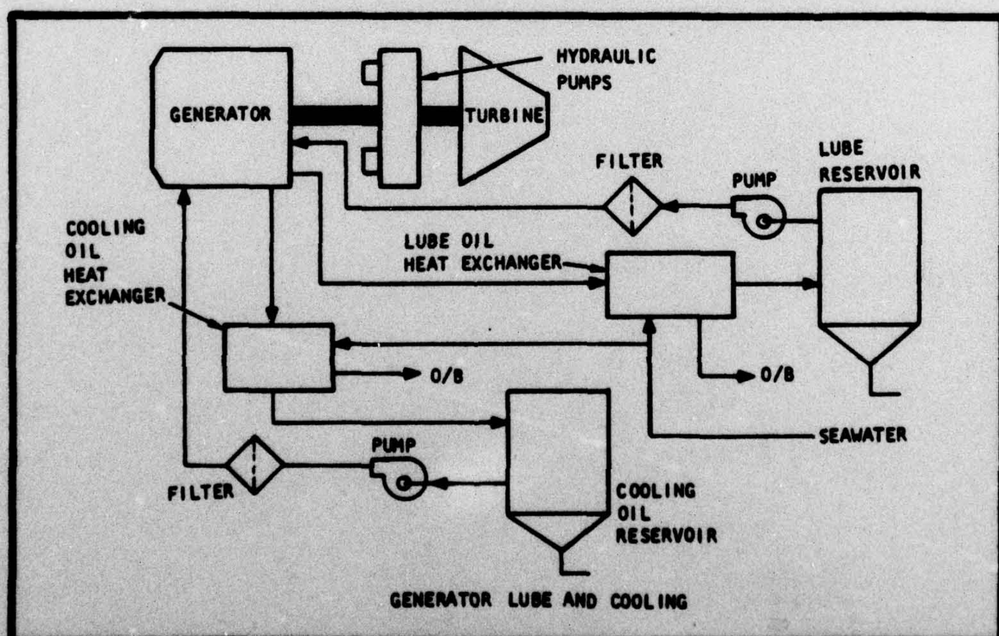
	Current				Volts L-L	Frequency Hz	Condition
	G_S and G_P	M_{1S} AND M_{1P}	T	M_{2S} and M_{2P}			
Foilborne System							
50 kts	4500	4500	0	-	2470	120	Maximum speed
40 kts	3550	3500	0	-	1970	96.5	Cruise, foilborne
30 kts	5121	5121	-	-	1863	90.5	Take-off
15	4860	2340.	2340	-	1000	48	Hullborne, 1 GT oper.
Hulborne System							
15 kts	2550	-	1275	1275	1575	76.5	Cruise, 1 GT oper.

Location	Mfg.	Unit Weight, lb	Weight/Ship (Long Tons)
G_S, G_P, M_{1S}, M_{1P}	ITE 5HK-350 Air brk 4.16 kv, 3 ka	1400	2.50
Enclosure	112"W x 72"H x 48"D	2000	0.89
Cabling	420 ft x 5 lb/ft		1.00
	Foilborne total/ship =		4.39
M_{2S}, M_{2P}, T	ITE 5HK-150 Air brk 4.16 kv, 1.2 ka	600	0.80
Enclosure	Incl above	600	0.27
Cabling	120 ft x 5 lb/ft		0.27
	Hullborne total/ship =		1.34

Figure 8. Rating and Installation Data, Switchgear and Cabling Components



LUBE AND COOLING
(FOIL AND HULL DRIVE MOTORS)



LUBE AND COOLING
(MAIN GENERATORS)

Figure 9. Schematic, Cooling & Lubrication Systems

	Per 1/2 System			Weight per 1/2 System				Envelope		
								Heat Exchangers		Tankage
	Heat Loss H.P.	Flow gpm	Pump Power gpm	Pumps and Plumbing lbs	Heat Exchangers and Tank lbs	Fluid lbs	Total	Dia X L (inches)	(cu ft)	Dia X L (inches)
Generator										
Cooling system	700	165	20	800	1800	1000	3600	10 x 114	5.2	20 x 36
Lubrication system	100	25	5					19 x 120	19.8	12 x 15
Foil POD Motor										
Cooling system	450	125	20	800	1100	1000	2900	10 x 114	5.2	20 x 36
Lubrication system	100	25	5					16 x 140	16.3	12 x 15
Foil POD gearbox										
Cooling and lubrication	500	125	20	300	900	500	1700	16 x 150	18	20 x 36
FOIL SYSTEM TOTAL 8200										
Hull motor										
Cooling system	120	25	10	500	900	700	2100	10 x 61	2.8	12 x 15
Lubrication system	50	10	5					10 x 130	5.9	12 x 15
Hull gearbox										
Cooling and lubrication	100	30	5	300	900	500	1800	10 x 114	5.2	12 x 15

Hull System Total 3900

Figure 10. Weight and Installation Data, Cooling and Lubrication Systems

BEST AVAILABLE COPY

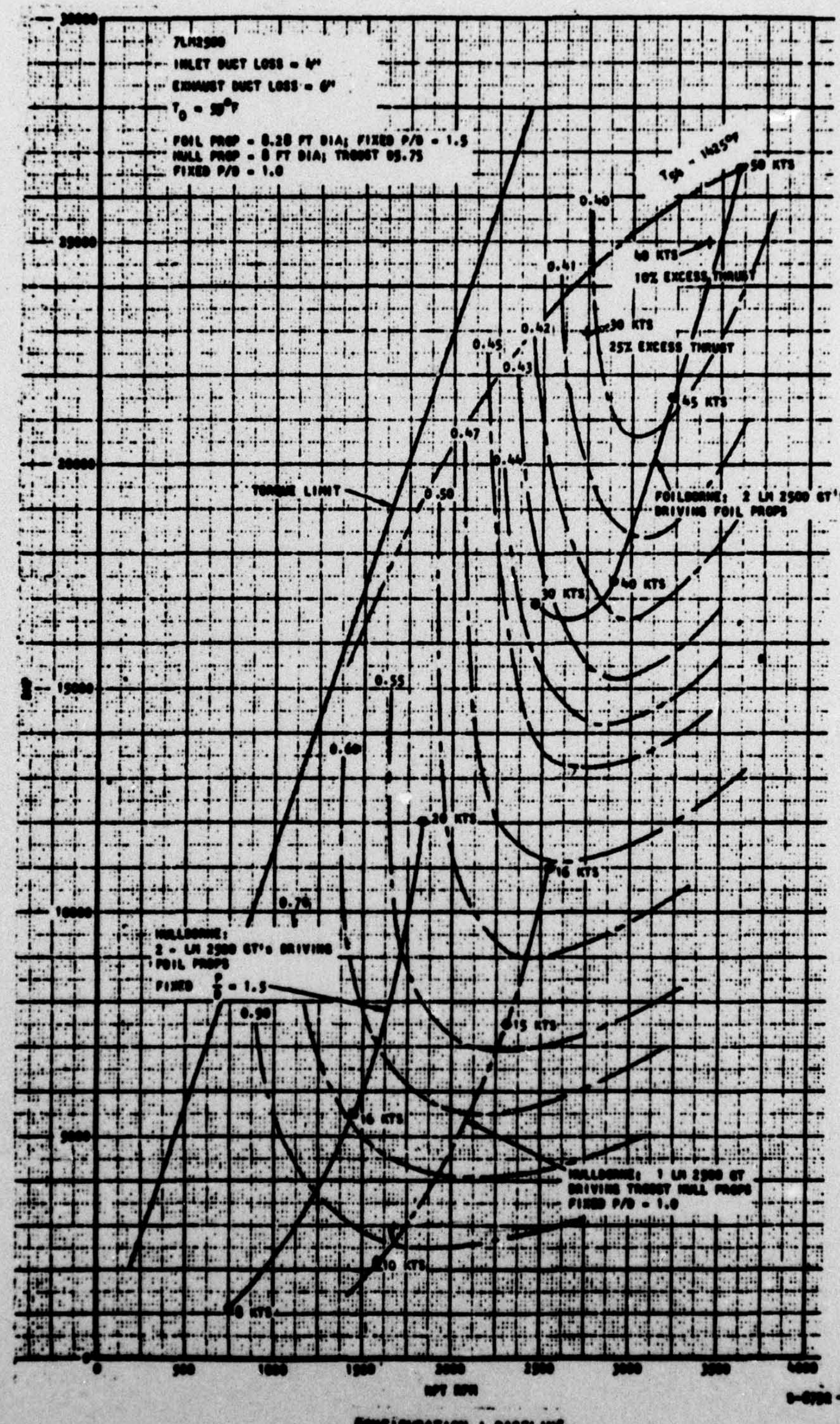


Figure 11. LM 2500 Matching Data, Hullborne and Foilborne Operation

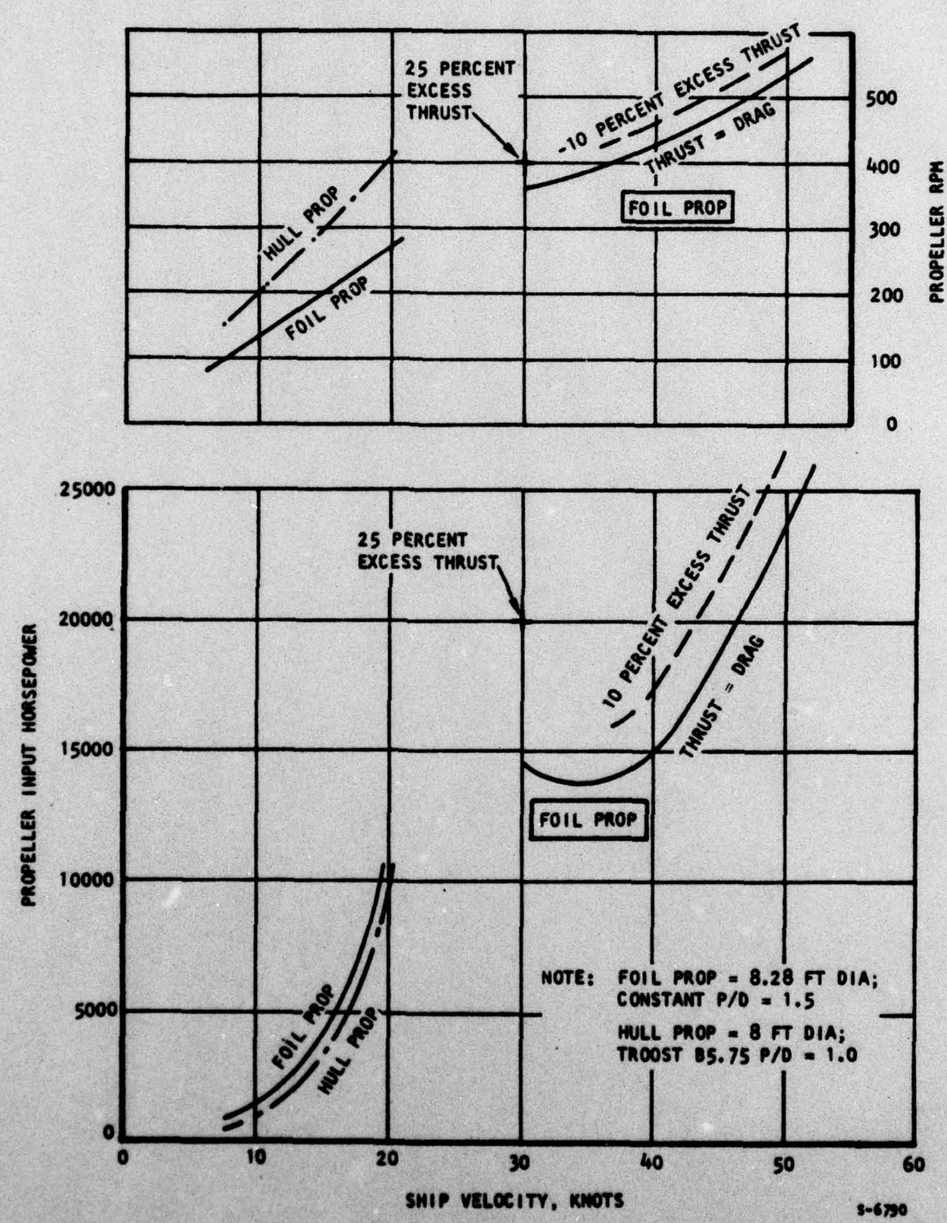


Figure 12. Propeller Data

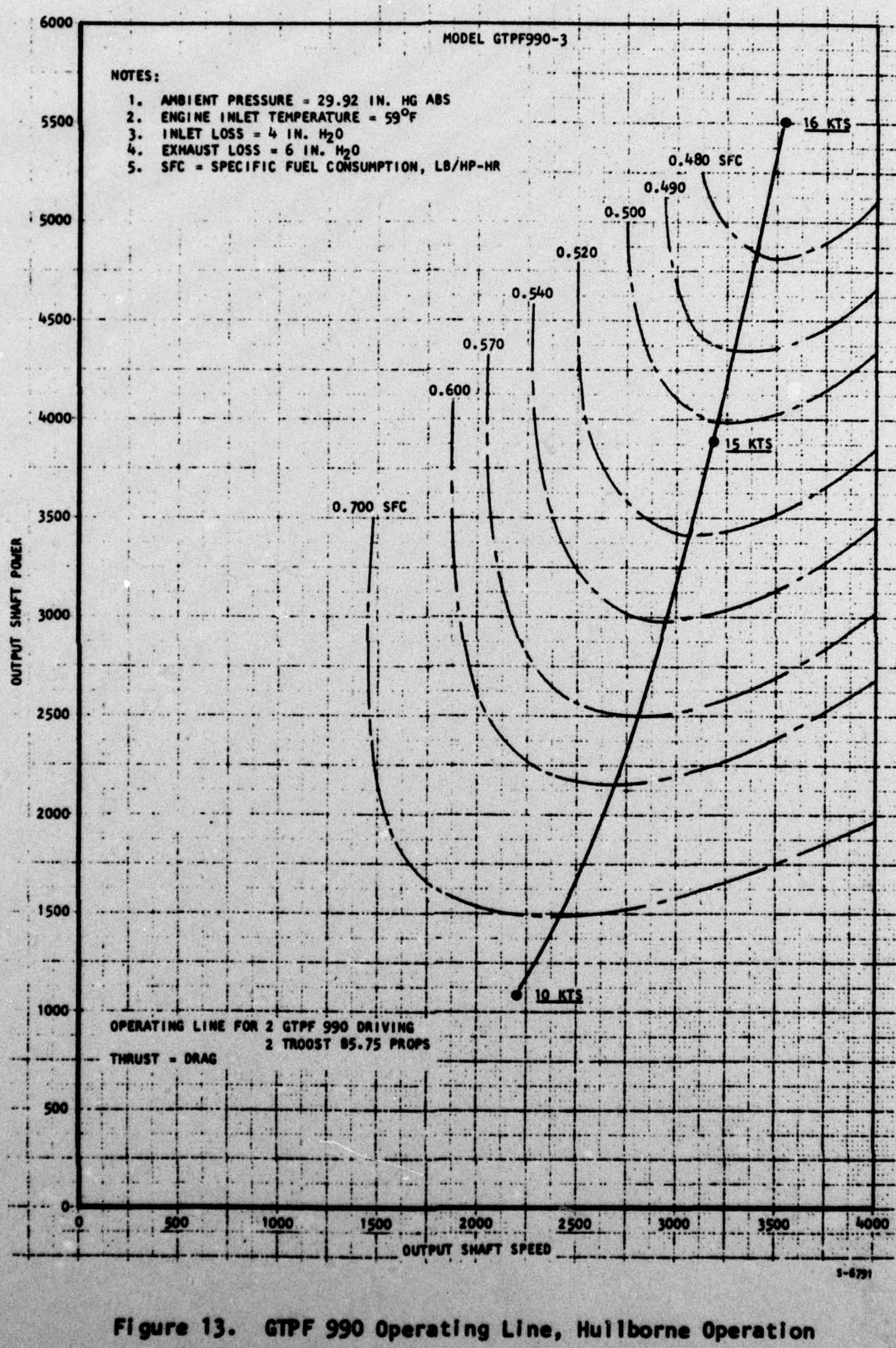


Figure 13. GTPF 990 Operating Line, Hullborne Operation

BEST AVAILABLE COPY

	Base System	Configuration I	Configuration II
	Long Tons Per Ship (Note 1)	Long Tons Per Ship	Long Tons Per Ship
1. Foilborne Propulsion			
Engine and acc.	14.286	14.286	14.286
Output shaft	1.205	Not used	Not used
Disconnect CPLG	.402	Not used	Not used
Upper GBX	3.576	Not used	Not used
Vertical shafts	2.661	Not used	Not used
Lower GBX	3.335	Not used	Not used
Planetary	3.661	Not used	Not used
Prop cartridge	1.652	1.652	1.652
Propeller	2.857	2.857	2.857
Generator		14.73	14.73
Foil prop motor		12.68	12.68
Foil prop gearbox		3.75	3.75
Switch gear and cabling		4.39	4.39
Cooling and lube systems		7.32	7.32
Fluid inv.		1.0	1.0
Total	33.635	62.67	62.67
2. Auxiliaries			
Exh. instl.	3.237	3.237	3.237
Air inlet and shrouds	.719	.719	.719
Wash system	.201	.201	.201
Gearbox L.O.	3.750	Not used	Not used
Instrm and control	.290	.290	.290
Circ. and cooling water	1.571	1.571	1.571
L.O. system	1.951	Not used	Not used
Total	11.719	6.02	6.02
3. Hullborne Propulsion			
TF 35 or GT PF 990	1.11 (TF35)	Not used	4.91 (990)
Exh. instl.	1.08	Not used	1.08
Air inlet	.09	Not used	.09
Wash system	.07	Not used	.07
Gearbox	4.47	Not used	Not used
Gearbox L.O.	.53	Not used	Not used
Prop shafting	1.97	1.97	1.97
Prop pitch control	.73	Not used	Not used
Prop shaft seals	.35	Not used	Not used
Propellers	2.68	2.68	2.68
Instr. and control	.13	.13	.13
Generator			3.21
Hull prop motor		6.07	6.07
Hull prop gearbox		4.00	4.00
Switchgear and cabling		1.34	2.76
Cooling and lube systems		3.39	5.60
Total	13.210	19.58	32.57
Total 1, 2, 3	58.564	88.27	101.26
Est. margin (6%)	3.436	5.28	6.06
Design margin (15%)	9.0	14.0	16.0
Total Group 2	71.000	107.55	123.3

Note: (1) Base weights derived from NavSec Report 6114-75-20 via Grumman Letter Report 298-100-1, dated 30 Jan. 1976.

Figure 14. Weight Breakdown

	Foilborne: Thrust = Drag				Foilborne: 25 % Excess Thrust	Foilborne: 10 % Excess Thrust	Hullborne: Foil Props 2-LM 2500 GT's Thrust = Drag			Hullborne: Transit Hull Prop 1-LM 2500 GT Thrust = Drag		
Ship speed, knots	50	45	40	30	30	45	20	16	8	16	15	10
Drag, lb	203000	185000	160000	200000	200000	185000						
Thrust, lb	203000	185000	160000	200000	250000	203500						
Prop in power, hp	23500	18750	15000	14500	20000	21600	11000	5000	1000	4942	3500	1000
Prop speed, rpm	530	478	426	362	400	510	270	212	110	320	290	200
Gearbox eff.	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.975	0.975	0.975
Motor output power, hp	23980	19132	15306	14796	20408	22040	11224	5102	1020	5069	3589	1025
Motor eff.	0.97	0.97	0.97	0.97	0.97	0.97	0.97	0.97	0.97	0.96	0.965	0.965
Motor input power, hp	24722	19724	15779	15254	21039	22722	11571	5260	1052	5280	3716	1062
Motor speed, rpm	3593	3240	2888	2454	2712	3458	1830	1437	745	2528	2291	1580
Transmission line eff.	0.995	0.995	0.995	0.995	0.995	0.995	0.995	0.995	0.995	0.995	0.995	0.995
Generator output power, hp	24846	19823	15858	15330	21445	22836	11629	5286	1057	10614	7468	2134
Generator eff.	0.965	0.965	0.965	0.965	0.965	0.965	0.965	0.965	0.965	0.965	0.965	0.965
Generator input power, hp	25747	20439	16351	15886	21912	24000	12051	5477	1095	11000	7468	2211
Generator speed, rpm	3600	3247	2895	2461	2722	3467	1835	1442	748	2530	2300	1587
Hydraulic power, hp	1000	1000	1000	1000	1000	1000	-	-	-	-	-	-
Gas turbine power, hp	26747	21439	17351	16886	22912	25000	12051	5477	1095	11000	7468	2211
Gas turbine speed (= N_{Gen}), rpm	3600	3247	2895	2461	2722	3467	1835	1442	748	2528	2300	1587
SFC	0.40	0.40	0.417	0.435	.46	.40	0.52	0.69	0.90	0.47	0.54	>0.90

NOTES: 1. Foil pod motor 1 G/R = 6.72
2. Hull pod motor 2 G/R = 7.90

S-6207

Figure 15. Power Flow Data, Configuration I

BEST AVAILABLE COPY

	Foilborne						Hullborne					
	Thrust = Drag				25 % Excess Thrust	10 % Excess Thrust	Foil Props 2-LM 2500 GT's Thrust = Drag			Troost Hull Prop 2-GTPF 990 Thrust = Drag		
Ship speed, knots	50	45	40	30	30	45	20	16	8	16	15	10
Drag, lb	205000	185000	160000	200000	200000	185000						
Thrust, lb	205000	185000	160000	200000	250000	203500						
Prop in power, hp	23500	18750	15000	14500	20000	21600	11000	5000	1000	4942	3500	1000
Prop speed, rpm	530	478	426	362	400	510	270	212	110	320	290	200
Gearbox eff.	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.972	0.975	0.975
Motor output power, hp	23980	19132	15306	14796	20408	22040	11224	5102	1020	5069	3590	1025
Motor eff.	0.97	0.97	0.97	0.97	0.97	0.97	0.97	0.97	0.97	0.96	0.96	0.965
Motor input power, hp	24722	19724	15779	15254	21039	22724	11571	5260	1052	5280	3740	1064
Motor speed, rpm	3883	3240	2880	2454	2712	3458	1830	1437	745	3520	3190	2200
Transmission line eff.	0.995	0.995	0.995	0.995	0.995	0.995	0.995	0.995	0.995	0.995	0.995	0.995
Generator output power, hp	24846	19823	15858	15330	21445	22836	11629	5286	1057	5307	3759	1067
Generator eff.	0.965	0.965	0.965	0.965	0.965	0.965	0.965	0.965	0.965	0.965	0.965	0.965
Generator input power, hp	25747	20439	16351	15806	21912	24000	12051	5477	1095	5500	3895	1072
Generator speed, rpm	3600	3247	2895	2461	2722	3467	1835	1442	748	3530	3200	2210
Hydraulic power, hp	1000	1000	1000	1000	1000	1000	-	-	-	-	-	-
Gas turbine power, hp	26747	21439	17351	16806	22912	25000	12051	5477	1095	5500	3895	1072
Gas turbine speed (= N_{Gen}), rpm	3600	3247	2895	2461	2722	3467	1835	1442	748	3530	3200	2210
SFC	0.40	0.40	0.417	0.435	-	-	0.52	0.69	0.90	0.48	0.503	0.75

NOTES: 1. Foil pod motor G/R = 6.72
2. Hull pod motor G/R = 11.0

S-6208

Figure 16. Power Flow Data, Configuration II

BEST AVAILABLE COPY

	Base System (Note 1)	Configuration I	Configuration II
Group 2 weight (Note 6) L. tons	71.0	107.6	123.3
Group 3 weight (Note 1) L. tons	46.0	46.0	46.0
Total; Group 2 + Group 3 L. tons	117	153.6	169.3
Increase over base system L. tons	-0-	+ 36.6	+ 52.3
Base fuel weight L. tons	400.1	400.1	400.1
∓ Wt inc. over base weight L. tons	-0-	- 36.6	- 52.3
Available mission fuel L. tons		363.5	347.8
Shipboard electrical power (Note 2) kw	576	576	576
Fuel rate (Note 3) lb/hr	442	442	442
Case a: 40 knot cruise (Note 4)			
Gas turbine propulsion shp		17351 X 2	17351 X 2
SFC #/HP HR		.417	.417
Propulsion fuel rate lb/hr		14470	14470
Total fuel rate (Note 5) lb/hr		14912	14912
Endurance hrs		54.6	52.2
Range Naut. miles		2184	2089
Case b: 15 knot cruise (Note 4)			
Gas turbine propulsion shp		7468	3895 X 2
SFC		.54	.503
Propulsion fuel rate lb/hr		4032	3918
Total fuel rate (Note 5)		4474	4360
Endurance Hrs		182	179
Range Naut. miles		2730	2680
Case c: (Note 4)			
45 knot shp		21439 X 2	
SFC		.40	
fuel rate lb/hr		17151	
30 knot T.O. SHP		22912 X 2	Same as Configuration I
SFC		.40	
fuel rate lb/hr		18329	
Idle fuel rate lb/hr		1000 X 2	
Endurance hrs		67.86	
Range Naut. miles		1914	

Notes:

(1) Derived from NavSec Report 6114-75-20, via Grumman Ltr Report 298-100-1 Dated January 30, 1976

(2) Per GAC Ltr MAR GEN 800.125-76, 2 June 1976; Attach. 3, Item e

(3) Assumed SFC = .55 and generator eff = .96

(4) Per Para. 7 of GAC Ltr 298-100-1 Dated 30 January 1976

(5) Propulsion fuel rate (lb/hr) plus electrical power fuel rate (lb/hr)

(6) All weights include margins

Figure 17. Range and Endurance Estimates, Base, Configuration I, and Configuration II Systems

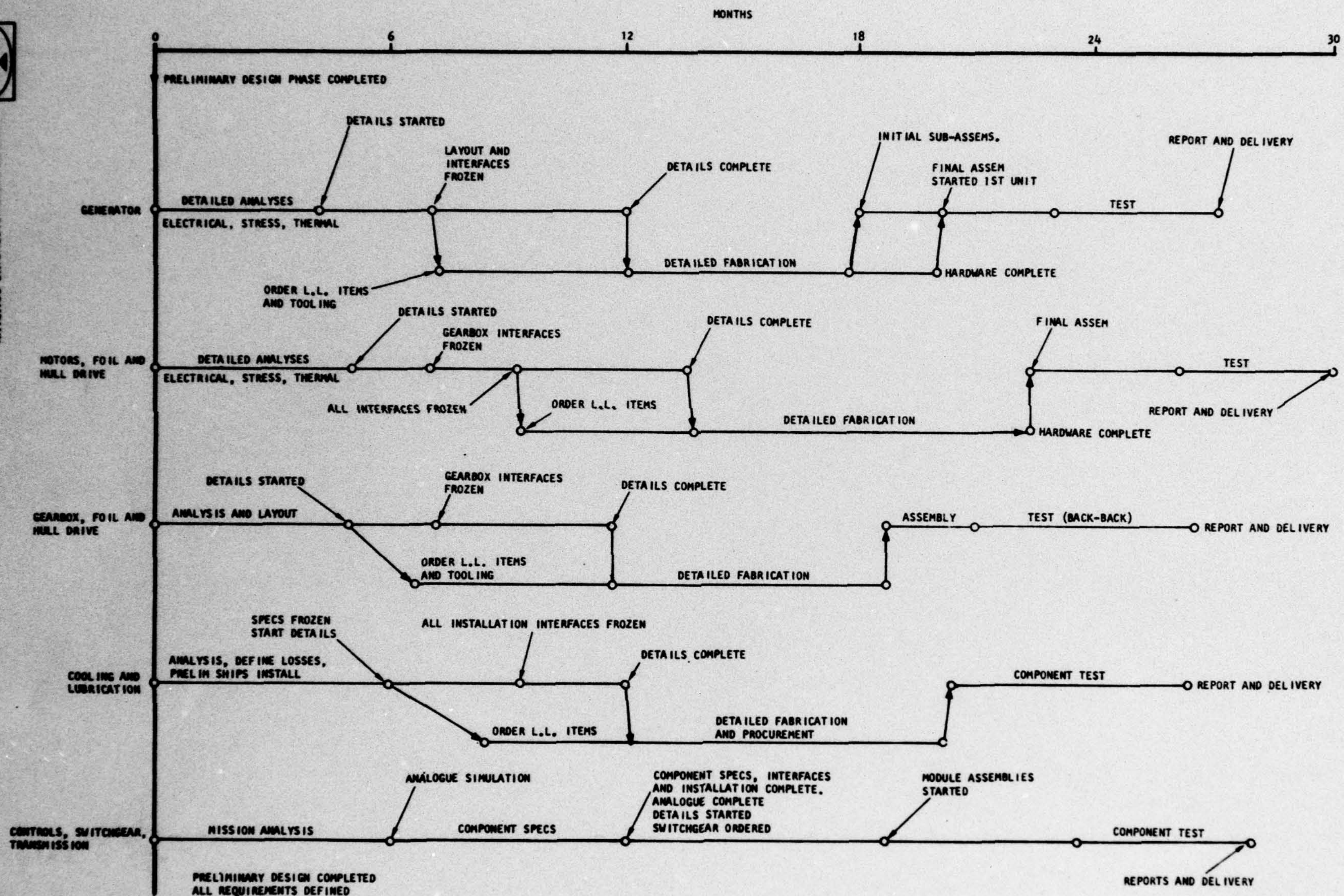


Figure 18. Component Fabrication and Test, Ac-Ac System

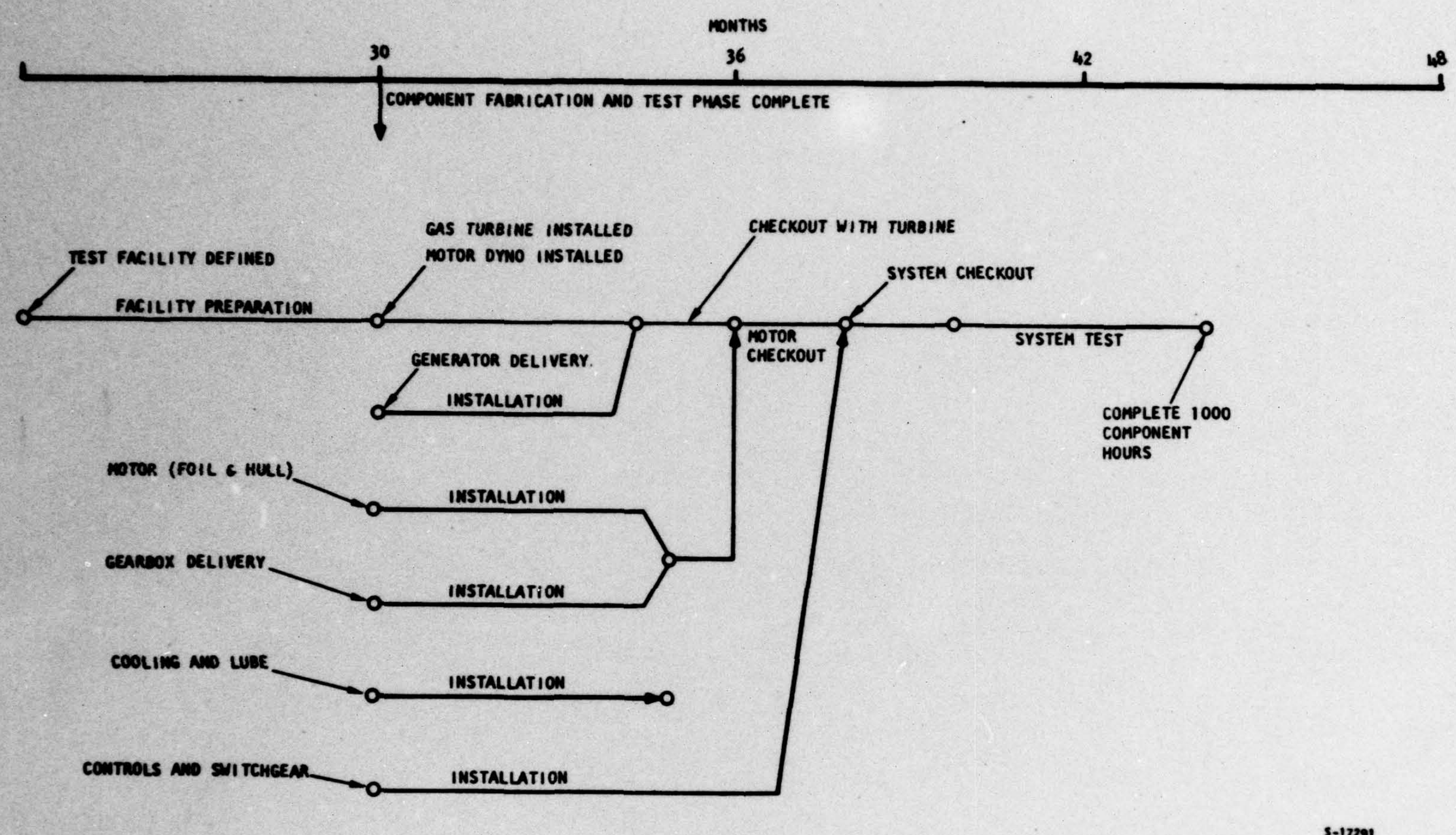


Figure 19. System Installation and Test, Ac-Ac System