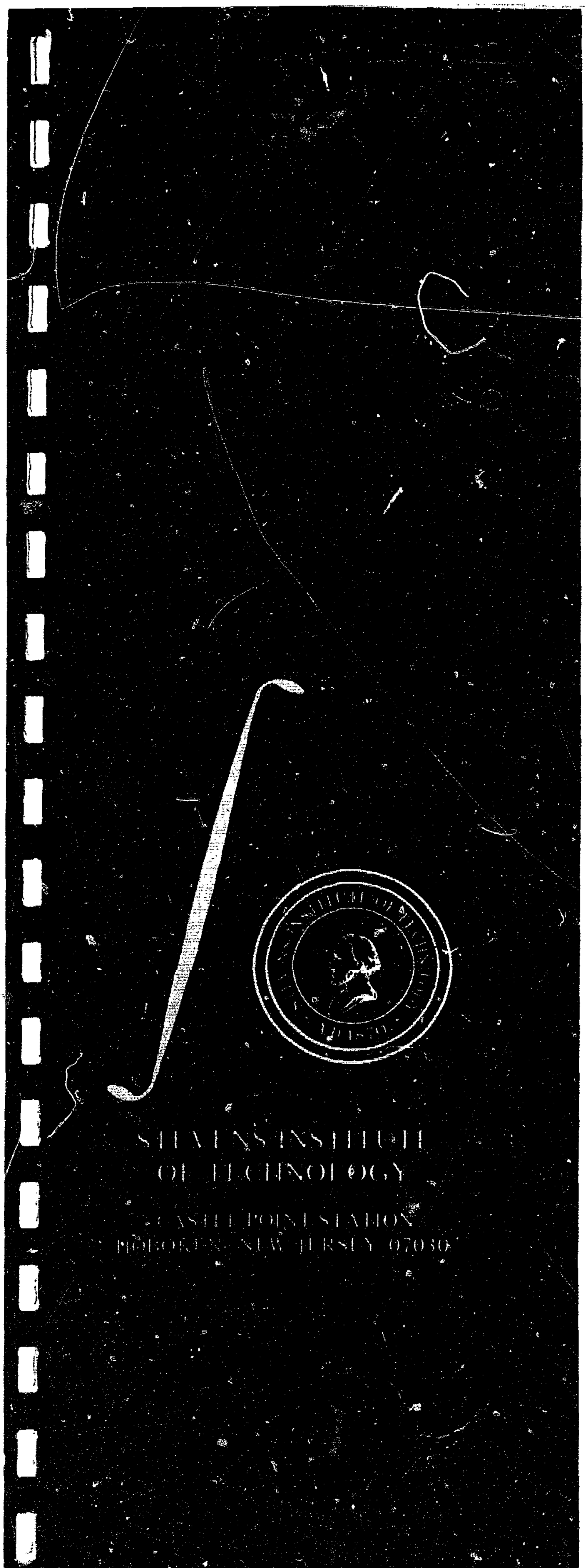
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FINAL REPORT
ON
DESIGN AND CONSTRUCTION
OF
1/3-SCALE MANNED MODEL
OF
SKI-CAT HIGH-SPEED CATAMARAN
(U)

by

Daniel Savitsky
John K. Roper
John A. Mercier

[redacted]

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Report SIT-DL-74-1699

March 1974

FINAL REPORT ON DESIGN AND CONSTRUCTION OF 1/3-SCALE MANNED MODEL OF SKI-CAT HIGH-SPEED CATAMARAN (U)

by

Daniel Savitsky
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Prepared for

Naval Ship Systems Command
Washington, D.C. 20360
Under Contract N00014-67-A-0202-0031, Mod. 3
(DL Projects 4050/146 & 4051/147)

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INTRODUCTION

Background

(U) In past years there have been few significant hydrodynamic improvements made in the design of planing or high-speed displacement hulls.

(U) Planing hulls have a basic conflict between efficiency and seakeeping ability. The low loadings, high aspect ratio, low deadrise and high trim desirable for maximum lift-drag ratio are in direct opposition to the high loadings, low trim, low aspect ratio, and high deadrise required for minimum accelerations and motion in rough water. From an arrangement standpoint, usable hull volume is limited by severe rotational accelerations to those spaces near the longitudinal center of gravity and, thus, result in crowded areas. Further, the lift-drag ratio of planing hulls with straight buttock lines in the planing area is not much greater than 6.0 for speeds in excess of 50 knots.

(U) High-speed displacement hull forms, governed by the trade-off between wavemaking and frictional resistance, tend to have high length-beam ratios and low beam-draft ratios and, for high-speed operation, become impractically large when compared with normal small boat design practice. While these characteristics result in smooth- and rough-water performance which are better than that of planing hulls, they produce arrangement problems which are compounded by precarious transverse stability and large overall lengths.

(U) Under Contract N00014-67-A-0202-0031, the Davidson Laboratory, Stevens Institute of Technology, carried out a systematic series of model tests of a unique hydrodynamic system composed of high length-beam ratio catamaran hulls with a canard system of submerged main hydrofoil combined with either small forward planing skis or surface-piercing ventilated hydrofoils. The smooth- and rough-water characteristics of these configurations were found to be superior to both the planing and high-speed displacement hulls at speeds up to 60 knots.

(U) On the basis of measurements and observations of these tests, a l/3-

scale manned model was designed and built by John K. Roper Associates, working under a subcontract from and in close coordination with Davidson Laboratory.

Design Features

(U) The novel features of this hydrodynamic support system will be described briefly here: a more complete exposition of principles and evolution of design details is given by Savitsky[1] in the report on model tests carried out.

[redacted] The manned model represents a l/j-scale model of the prototype. Principal characteristics of both are tabulated below:

TABLE 1

PRINCIPAL CHARACTERISTICS OF SKI-CAT HIGH-SPEED CATAMARAN

	Prototype	Manned Model
Scale	3	1
Displacement, lb	135,000	5,040
Length Overall	80'	26'-8''
Beam (Maximum), ft	36	12
Burst Speed, kt	60	34.6
Cruise Speed, kt	40	23
Take-off Speed, kt	20	11.5

(U) Figure 1 shows the general arrangement, outboard profile, and deck plan of the manned model. It is seen that the craft is composed of high length-beam ratio twin hulls with a submerged high aspect ratio main hydrofoil just aft of the LCG, hydroskis which stand-off below the bow of each hull, and submerged damping plates attached to the transom of each hull which also serve as ventilation plates over the propeller. At high speed, with the hull unported, the load distribution is 90% on the main foil, 6%

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[1] Superior numbers in text matter refer to similarly numbered references listed at the end of this report.

on the damping plates and 4% on the hydroskis (for the design LCG condition). The foil submergence subsequent to hull unporting is one chord. An important feature is that there is no active control system in the design, Flaps on the main foil and hydroskis are manually positioned for load variations and for selected operating speeds.

(U) The design philosophy embodied in the hydrodynamic configuration is as follows: The high length-beam ratio hulls have a high beam loading ($C_\Delta = 1.5$) and, at maximum speed, are designed to run at zero trim. As shown in Reference 2, this combination of large C_Δ and low trim angle results in extremely low "g" loadings when running in waves. Thus, hull clearance can be reduced (relative to conventional hydrofoil hulls) and the resulting hull impact with waves are tolerably small. This leads to reduced strut length with a considerable saving in structural weight, hydrodynamic drag, and simplicity in propulsive system.

(U) The catamaran hulls and connecting bridge structure are fabricated of 3/16-inch marine plywood on spruce framing. The connection between the hulls and the center bridge is effected by sixteen 1/4-inch diam tie-rods, which affords convenient disassembly and transportability. A general arrangement and inboard profile, indicating some framing details of the hulls and bridge is given in Figure 2.

(U) The forward lifting surface, a low aspect ratio planing surface, was selected because of reliability of flow separation at low speed and because of its low lift rate ($dC_L/d\alpha$) compared to surface-piercing fully-ventilated hydrofoils. Early flow separation assures a stabilized flow over most of the speed range while a low lift rate results in small impact loads in waves, The submerged aft plate has a lift rate approximately twice that of the hydroski and thus provides the required pitch damping without being exposed to wave impact loads. Pitch stability and control are provided by the combined pitch restoring moment and damping action of the hydroskis and damping plates. Heave stability is provided primarily by the natural reduction in lift on the main hydrofoil as it approaches the free surface and by the natural increase in lift as its submergence increases. Because of the small clearance between hull and foils, the hull itself will provide for pitch and heave stability if the craft motions exceed the hull clearance, Thus, the proposed hydrofoil system is inherently self-stabilizing and does not require any active control system. This was verified in the smooth- and rough-water model tests conducted at the Davidson Laboratory.[1]

[redacted] The main foil is a constant chord 6% thick ogive section with a design lift coefficient $C_L=0.115$ at burst speed. An ogive section is selected because of simplicity in construction and, consequently, low cost. In the 1/3-scale manned model, the scaled burst speed will be 34.6 knots so that the foil system will certainly be non-cavitating. Hence, tests of this manned model will provide data only on such important hydrodynamic characteristics as stability, control, seakeeping, and power requirements of a non-cavitating system, but will not deal with inception of cavitation, or its effect on performance.

(U) The hydrofoils, struts, and damping plates are of machined and welded aluminum.

(U) The craft will be propelled by two left-handed, fixed pitch, propellers mounted on an inclined shaft and driven by two Volvo-type BB170A 182 cu in, 6-cylinder gasoline engines, each rated at 170 HP at 5000 engine rpm. Reverse-reduction gears having a ratio of 1.52:1 are installed.

(U) Steering of the vessel is currently performed by a pair of rudders hung by pintles and gudgeons on the hull transoms, controlled by flexible push-pull roads actuated by a steering wheel in the cockpit. In spite of modifications to improve mechanical effectiveness of the actuating gear, the steering performance of the craft with rudders alone is not good: a combination of rudder and throttle control produces a great improvement in performance. Differential main foil flap adjustment is useful during turns while flying so that the craft leans into the turns. Further modifications of the craft and steering system to effect improvements in turning performance are now being considered.

(U) A summary of the measured weights and longitudinal centers of gravity of the components of the craft is listed in the table on the following page of this report.

TABLE 2

WEIGHT SUMMARY

Component	Weight	Forward Transom	Longitudinal Moment
Port Hull Assembly	1710#	10.63'	18177 ft-lbs.
Starboard Hull Assembly	1710	10.57	18075
Center Section Assembly	660	10.57	6976
Hydrofoil	200	9.70	1940
Propellers	22	0	0
Light Ship	4302#	10.5'	45168
Complement	330	10.0	3300
Fuel	168	- 0.67	- 111
Water	40	10.0	400
Base	4840#	10.07	48757
Ballast (Nom.)	200	8.67	1734
Full Load Displacement	5040#	10.02'	50491 fr-lbs.

(U) The entire craft can be readily disassembled, mounted aboard a specially-designed Transport and Launching Trailer which has been supplied along with a small van suitable for towing the trailer and carrying support equipment for the manned model.

(U) More complete information on arrangements, and structural and installation details, are contained in the drawings for the 1/3-scale Manned Model of Ski-Cat High-Speed Catamaran. A list of these drawings is given in Table 3 on the following page of this report.

(U) Further details, including vehicle characteristics, foil system characteristics, subsystem characteristics, equipment list, structural analyses, measured weights, hydrostatics, estimated drag, estimated thrust, and performance summary are included in the Design Notebook appended to this report.

TABLE 3

DRAWING LIST

Title of Drawing	Drawing No.
General Arrangement Outboard Profile and Deck Plan	202-00.1 (Design Evaluation)
General Arrangement, Inboard Profile	202-00.2 (Design Evaluation)
Hull Lines	202-01.1 (Design Evaluation)
Structural Arrangement	202-01.2 (Design Evaluation) (2 sheets)
Frames and Bulkheads	202-01.3 (Design Evaluation)
Machinery Installarion and Details	202-02.1 (installation)
Piping Systems-Diagrammatic	202-05.1 (Maintenance)
Main Foil and Controls	202-08.1 (Design Evaluation)
Aft Foil and Controls	202-08.2 (Design Evaluation)
Ski Details	202-08.3 (Design Evaluation)
Transport & Launching Trailer	202-09.1

Progress

Some key steps in the conduct of work on this project may be cited:

1) Initiation of design work on 1/3-scale manned model (also Contract date for Modification 1 of Contract N00014-67-A-0202-0031
1 December 1973

2) Initiation of manned model construction
16 March 1973

3) Launching of manned model, and first flight trials
24 July 1973

4) Extended Builder's Trials (carried out under Modification 2 of contract)
31 July to 3 August 1973

5) Delivery of manned model to NSRDC, Annapolis, reassembly and flight trials
September 1973

(U) Further evaluations of this manned model, including performance trials, will be carried out by NSRDC. Davidson Laboratory will act in an advisory capacity for these tests.

PERFORMANCE

Extended Builder's Trials

(U) Extended builder's trials, prior to final delivery of the manned model to NSRDC at Annapolis, were carried out to evaluate proper ski and foil-flap settings for operation at various speeds, displacements and LCG's and proper rudder and foil flap settings for turning maneuvers. The principal dimensions of the test craft are shown in Figure 3. Motion picture records were also made of some aspects of the tests. These tests were authorized as an extension in scope of contract under Mod 3 of Contract N00014-67-A-0202-0031.

Speed Trials

(U) Effect of Displacement: Tests were carried out to determine the effect on speed capability as a function of increased displacements. for various main foil flap settings the speed and engine RPM's were measured for several throttle settings. The Bliss (catalog Fig. 850) pitot-log which is mounted beneath the trailing edge of the starboard ski, and the readout dial gauge were calibrated by comparing dial readings with timed speeds for traversing a distance between two buoys whose spacing was measured with surveying equipment. The timed speed was found to be about 0.98 times the pitot-log indicated speed.

(U) Results for the design displacement, 5040 lbs (139,600-lb full scale) and, two greater loads, 5540 lbs (153,470-lb full scale) and 6040 lbs 167,320-lb full scale) are presented in Table 3 and Figures 4 and 5. Propeller RPM's and hull trims are shown as a function of measured speed in Figure 4, while the estimated drag curve (calculations are presented in the "Estimated Drag" Section of the design notebook) is compared with the estimated propeller thrust (from the section, "Estimated Thrust and Torque," of the design notebook) in Figure 5. The thrust estimates are based on measured speed and RPM and take into account in an approximate manner the effects of cavitation and shaft inclination.

(U) The scatter of the derived thrust estimates shown in Figure 5 is excessive and clearly indicates that one or another of the measurements are in error. By inspection of the propeller thrust map, Figure 1-2 of the design notebook, an estimate of the effect of erroneous RPM or speed measurements can be obtained. For instance, consider data points from Test 1, Run 3, with 5-deg main foil incidence:

(From Table 3, Test 1)

Run NO.	Speed kts	RPM Port	RPM Stbd	Est Thrust Port	Est Thrust Stbd
3-a	22.6	2240	1970	750	270
3-b	23.4	2240	1970	650	250

The effect of speed on estimated thrust may be derived from these sets of observations where with similar RPM readings slightly different speeds were indicated. The ratio $(\Delta T/T_{ave})_{est}/(\Delta V/V_{ave})_{est}$, which is a measure of sensitivity of the thrust estimate to the speed measurement is 4.1 for the port propeller and 2.2 for the starboard propeller. Similarly, the sensitivity of the thrust estimate to the RPM measurement can be given in terms of a ratio $(\Delta T/T_{ave})_{est}/\Delta N/N_{ave})_{est}$, which gives values 7.3 for the first set of observations and 6.9 for the second set of observations. Thus, a 1% error in observed speed can produce a 2 to 4% error in estimated thrust while a 1% error in observed RPM can produce a 7% error in estimated thrust. The particular numerical values obtained for the sensitivity factors depend, of course, on both RPM and speed and, in general, would be derived from the propeller thrust maps (cf., Figure 1-2) in each particular case.

(U) The importance of accurate measurements of speed and RPM is clear and highly accurate measurements, including at least propeller torque, must be made during the comprehensive trials. It is also clear that the data obtained during these extended builder's trials are not sufficiently accurate to permit reliable and accurate estimates of thrust and other performance parameters to be derived. (The RPM measurements are especially suspect, since they imply an unreasonably large thrust differential.) Nonetheless, the data on speed and RPM achieved are roughly correct and indicate the satisfactory capability of the manned model to achieve high speeds with engine capability to spare. Another significant observation which can be made from these tests is that a rather long approach run (500 to 1000 yds is suggested) should be made to assure that the craft has achieved steady speed prior to recording data.

(U) The effect of increasing displacement on performance is mainly a consequence of increased lift coefficient on the foil while flying: 1) The take-off speed is slightly increased, with some added wetness, 2) for these preliminary tests, a somewhat greater tendency to intermittent loss of lift, evidently due to ventilation of the main foil (this tendency has been greatly reduced by blocking the air path down the strut fairing which encases the flap push-rod, as described later under "corrective actions"), 3) for a full-scale craft, cavitation inception might occur at a slightly lower speed due to the high lift coefficient and, 4) in the absence of cavitation or ventilation, the speed-power relation in the flying mode of operation which, for ski-cat, is primarily a consequence of skin-friction, is quite insensitive to changes in displacement. if the design displacement were changed, the main foil design characteristics would, of course, be adjusted and the relatively minor changes in performance mentioned above would be appreciably ameliorated. A more definitive evaluation of increased displacement will be made following the Annapolis tests.

(U) Effect of LCG: Additional tests were carried out at the medium displacement of 5540 lb. to assess the effects of variations of LCG position on speed performance. The ballast weights (five one-hundred-pound bags of cement) were shifted, first aft by the greatest amount possible, producing a 0.75-ft. change in LCG position, then forward by a similar amount. Again, runs were made at various main foil flap settings and speed and engine RPM indications recorded for several throttle settings. For the forward LCG condition, it proved to be quite difficult to keep the ski-tips out of the water with the standard ski incidence of 3.6-deg. relative to the hull and the operation was, consequently, quite wet. In an attempt to remedy this, it was decided to adjust the aft ski-control-rod, increasing the ski-incidence to 7.6 degrees. There was little difficulty then in keeping the ski-tips planing, but the spray generated was nonetheless much greater than for the normal of aft LCG location.

(U) Results of these trials are presented in Table 4 and in Figure 6, which is similar to Figure 4. Estimated thrust values are not tabulated because of their relatively low accuracy.

(U) Effect of Ski-Height: One group of tests were made at a displacement of 5240 lb (145,160-lb full scale) to evaluate the effect of increased clearance between ski and hull. The skis were adjusted an additional 3.75" downward with the standard 3.6-deg incidence. in operation, the hull-water clearance was favorably modified, bringing the main foils slightly closer to the water surface. Flying performance was generally satisfactory except that occasional intermittent loss of main foil lift occurred, perhaps due to air-drawing down the strut fairing encasing the flap push-rod, and the craft would come down from flying to planing mode for a brief time with attendant spray-generation from the ski-control-rods.

(U) Trials results for this case are given in Table 5 and in Figure 7.

Turning Trials

(U) Turning trials were carried out at a displacement of 5240 lb (145,160-lb full scale) with the design LCG location, 10-ft forward of the center of gravity.

(U) The measurements technique was admittedly crude: 1) the craft was driven up to speed along a straight path and the steady speed recorded, 2) a turn was initiated by rudders and differential main foil flaps, 3) the time for successive 30-deg heading changes (obtained from the compass) to occur was measured with a stop-watch and recorded. The radius of the turning circle was obtained from the relation:

$$2\pi \times \text{Radius} \times \frac{30\text{ deg}}{360\text{ deg}} = \text{Speed} \times \text{Time for 30-deg Heading Change}$$

Results for turns executed with rudder and flaps only are recorded in Table 6. Some additional trials were run in which differential engine RPM was used: a) at low speed (estimated to he 6 MPH) with one engine off, b) flying, with 5-deg main foil flap angle, at about 28 MPH with the maximum differential engine thrust for which the pilot could maintain flying equilibrium together with maximum rudder action, and c) using ahead thrust on one propeller and astern thrust on the other, the craft can be turned quite expeditiously in its *own* length. Results for the additional tests with differential thrust are tabulated in Table 7. At high speed the turning circle radius appears to be reduced by about 25% by using differential propeller thrust as well as rudder.

(U) The large turning circles for this 30-ft LOA craft are associated with two factors: a) the craft has exceptional directional stability, afforded by the large profile area of the aft strut, which acts as propeller shaft bearing support and cooling water intake, and b) the unbalanced rudder could not be turned through large angles at high speeds because of inadequate mechanical advantage in the linkage system. When this difficulty was first observed, the foot pedal linkage system was modified and the increased mechanical advantage afforded resulted in a useful improvement in turning performance: this revised system was used for the tests reported in Tables 6 and 7. The maximum rudder angle was still limited by the pilot's strength to about 5 to 10 degrees. The rudder angle for the tests reported was not accurately measured, but based on observed foot-pedal deflections, was in this range, i.e., 5 to 10 degrees.

[redacted] Published data on turning performance of high-speed craft is sparse. Sugai[2] has reported results of research on maneuverability of a slender, twin-screw, twin-rudder, hard-chine boat model which show that turning diameters are greater for high speeds (Froude Numbers based on length up to 1.0). For rudder angles of 15-deg turning diameters in excess of 10 times the length are found, even with quite large rudders. The present craft, however, with Froude Number of 1.6 at 30 knots, requires a turning diameter of 30 to 40 lengths with the (small) maximum rudder angle. It is expected that a further rudder modification, preferably replacing the present unbalanced rudders with balanced ones, will substantially improve the turning capability. Further, the prototype design need not have the same profile characteristics as the manned model, viz., the cooling water intakes, which make the aft strut large, could be eliminated with air-cooled gas turbine engines.

Motion Pictures

(U) During the course of the extended builder's trials, motion pictures were taken of selected runs. Table 8 lists titles for the various scenes in the edited version of motion picture which was submitted to NSRDC on 15 January 1974.[3]

EQUIPMENT DEFICIENCIES, ANALYSES AND CORRECTIVE ACTION

Propeller Pitch

(U) During the builder's trials, a loud noise and service vibration was observed to occur in the starboard engine compartment on at least three occasions, which caused the pilot to immediately shut down operation. These occurrences were invariably associated with very high speeds, i.e., engine rpm's above about 4200.

(U) The most likely explanation of this behavior is considered to be the existence of some form of critical {resonant) vibration of the engine and shafting, most likely a lateral (whirling) mode. The noise was so intense that it was deemed to be excessively dangerous to risk extensive exploratory operation in the vicinity of this speed which might lead to a more conclusive diagnosis. Instead, the propellers were re-pitched (pitch increased) and a "full cup" blade modification incorporated, to increase the propeller torque and thrust for a given rpm. In this way the engine and propeller shaft rpm's can be kept below the dangerous initial speed while still absorbing and delivering adequate power, even though the engine's full power rating applies at the appreciably higher value of 5000 rpm.

(U) The details of the original and modified pitch propellers are described in the "Estimated Thrust and Torque" Section of the Design Notebook.

Main Foil Ventilation

(U) During the builder's trials occasional instances of precipitous, intermittent, loss of lift on either one side of the main foil or both sides occurred, which resulted in the bow skis plowing in and substantial spray and wetness on deck and in the cockpit. This behavior was generally (but not always) quickly corrected by a slight change in speed, foil flap setting, or engine rpm's. It was diagnosed as probably due to ventilation over part of the main foil by air flowing down through the flap push-rod enclosure of the inboard struts (see Figure 2).

(U) This air-drawing was corrected by blocking rhe path of air with a sponge-rubber pad inserted in the push-rod enclosure near the bottom of the strut. The flap adjustment push-rod slides easily in this pad and the water-soaked sponge effectively prevents air-drawing.

REFERENCES

1. Savitsky, D. and Roper, J.K., "Hydrodynamic Development of a High-Speed Hydrofoil Catamaran (U)," Davidson Laboratory, Stevens institute of Technology, Report SIT-K-73-1671, December 1973.

2. Sugai, K., "On the Maneuverability of the High-Speed Boat," Japanese Transportation Technical Research Institute, Tokyo, Vol.12, No.11, 20 March 1963 (Bureau of Ships Translation No.868).

3. **Letter, dated** 15 January 1974, J. Mercier (DL) to G. Springston (NSRDC) conveying one copy 16mm motion pictures of "A **One-Third Scale Manned** Model of Ski-Cat, High-Speed Hydrofoil Catamaran."

TABLE 3

RESULTS OF EXTENOED BUILDER'S TRIALS
SPEED TRIALS AT THREE DISPLACEMENTS

RUN	MAIN FOIL FLAP deg	SPEED kts	TRIM deg	PROPELLCR RPM'S Port	Stbd	Ave.	ESTIMATED THRUST* Port lb	Stbd lb	Total lb
TEST 1: Displ = 5040 lbs, LCG = 10-ft forward transom									
1	15	13.9	1.5	1580	1710	1645	-	-	-
	15	15.6	1.5	,710	1840	,775	-		
	15	16.5	1.5	1840	1840	,840	700	700	1400
2	10	19.1	1.0	1840	1840	,840	470	470	940
3	5	22.6	1.0	2240	,970	2105	750	270	,020
	5	23.4	1.0	2240	1970	2105	650	250	900
	5							276	552
	5	25.2 24.3	1.0 10	2105	2105	2105 2105	276 263	263	526
4	0	26.9	2.0	2500	2105	2300	755	200	955
	0	31.3	1.5	2630	2630	2630	480	480	960
	0	33.0	1.0	2760	2700	2730	530	470	,000
	0	33.0	1.0	2760	2760	2760	530	530	1 060
TEST 2: Displ = 5540 lbs, LCG = 10 ft-forward transom									
14	15	15.6	2.5	1645	1840	1740	500	750	1250
	15	16.9	2.0	,840	,775	,810	650	560	1210
	15	20.8	1.0	1840	2105	1970	370	740	1110
10	10	16.5	3.0	1645	1775	1710	400	570	970
11	10	18.7	2.25	1775	1940	1860	420	640	,060
	10	23.4	1.0	2040	2170	2105	390	570	960
9	5	21.7	2.0	2040	2170	2105	520	700	1220
8	5	23.9	1.5	2070	2240	2155	380	680	1060
15	5	23.5	2.0	,975	2170	2070	280	530	810
	5	24.3	2.0	1975	2300	2140	250	700	950
	5	25.2	1.0	2170	2300	2235	350	590	920
7	5	28.2	1.0	2300	2470	2385	320	560	880
13	0	27.8	2.5	2370	2565	2470	460	780	1240
12	0	28.7	1.75	2435	2565	2500	470	700	1170

[Cont'd]

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*Notes : 1) Based on measured rpm and speed and Design Notebook Fig.I-2.

2) The estimated thrusts are considered to be of questionable reliability and accuracy, probably because measurements of rpm and speed are not sufficiently accurate.

TABLE 3 (Cont'd)

RUN	MAIN FOIL FLAP deg	SPEED kts	TRIM deg	PROPELLER RPM'S Port	Stbd	Ave.	ESTIMATED THRUST* Port lb	Stbd lb	Total lb
TEST 3: Displ = 6040 lbs, LCG = 10 ft forward transom									
18	15	16.5	2.25	1840	1645	1740	670	430	1100
16	10	22.1	2.0	2105	1975	2040	580	400	980
	10	24.3	2.0	2240	2105	2170	590	380	970
20	5	23.5	2.0	2240	2170	2205	650	540	1190
	5	26.9 27.4	1.75 1.5	2370 2370	2105 2300	2235 2335	540 450	390 160	700 840
17	5	26.9	1.0	2435	2240	2335	660	350	1010
19	0	26.5	2.5	2435	2235	2335	600	300	900
	0	27.8	2.0	2565	2300	2430	780	360	1140

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*Notes :
1) Based on measured rpm and speed and Design Notebook Fig. 1-2.
2) The estimated thrusts are considered to be of questionable reliability and accuracy, probably because measurements of rpm and speed are not sufficiently accurate.

TABLE 4

RESULTS OF EXTENDED BUILDER'S TRIALS
SPEED TRIALS AT TWO ADDITIONAL LCG'S

RUN	MAIN FOIL FLAP deg	SPEED kts	TRIM deg	PROPELLER RPM'S Port lb	Stbd lb	Ave. lb
TEST 4:	Displ = 5540 lb, LCG = 9.25-ft forward transom					
23	15	19.5	1.5	1910	1840	1875
	15	20.4	1.5	1975	1840	1910
21	10	21.7	1.75	2040	1840	1940
	5	21.3	2.0	2040	1875	1960
22	5	23.5	2.0	2105	2105	2105
	5	26.1		2235	2105	2170
	5	26.5	1.75	2300	2170	2235
25	5	26.5	1.5	2300	2170	2235
		27.4		2435	2235	2335
		28.2		2435	2235	2335
24	0	28.2	2.0	2500	2370	2435
		29.5		2565	2435	2500
TEST 5:	Displ = 5540 lb, LCG = 10.75-ft forward transom					
25	10	24.3		2235	2105	2170
	10	26.1	1.0	2300	2170	2235
	10	27.8		2370	2300	2335
26	5	26.5	1.5	2300	2235	2270
	5	27.8		2370	2270	2320
	5	28.2		2500	2235	2370
TEST 6:	Displ = 5540 Ib, LCG = 10.75-ft forward of transom Ski Incidence = 7.64 degrees					
29	15	13.0	3.0	1710	1580	1645
	15	16.5	2.0	1840	1775	1810
	15	17.4	2.0	1975	-	-
	15	18.2	2.0	1975	1710	1845
27	10	21.7	1.5	2040	1975	2010
	10	23.9	1.0	2170	2105	2140
	la	25.2		2300	2105	2205

[Cont'd]

TABLE 4 (Cont'd)

RUN	MAIN FOIL FLAP deg	SPEED kts	TRIM deg	PROPELLER RPM'S Port lb.	Stbd lb	Ave. lb
TEST 6 Cont'd:						
31	5	.4	2.0	2300	2040	2170
	5	26.5	2.0	2435	2235	2335
28	5	25.6	1.5	2300	2235	2270
	5	29.5	1.25	2500	2370	2435
30	0	28.2	2.0	2500	2370	2435
	0	29.5	1.75	2630	2500	2565
	0	30.0	1.75	2630	2570	2603

TABLE 5

RESULTS OF EXTENDED BUILDER'S TRIALS
SPEED TRIALS WITH MODIFIED SKI-ELEVATION

RUN	MAIN FOIL FLAP	SPEED	TRIM	PROPELLER RPM'S		
	deg	krs	deg	Port lb	Stbd lb	Ave ~~lb~~
TEST 9:	Displ = 5240 lb, LCG = 10-ft forward transom Skis lowered 3.75 inches					
43	10	20.0	1.75	1910	1840	1875
44	10	22.6	2.0	2040	1975	2010
41	5	26.9	2.0	2300	2170	2235
42	5	27.4	1.5	2370	2300	2335
39	5	27.8	1.0	2370	2170	2270
40	5	27.8	1.5	2435	2105	2270
45	0	29.5		2630	2435	2535

TABLE 6

RESULTS OF EXTENDED BUILDER'S TRIALS
TURNING TRIALS WITH RUDDER AND DIFFERENTIAL FLAP ONLY

Table 7: Displ = 5240 lb, LCG = 10 ft forward of transom

RUN	MAIN FOIL FLAP deg	SPEED kts	PROPELLER RPM'S Port lb	Stbd lb	Ave. lb	RUDDER	TIME FOR 30° CHANGE IN HEADING sec	RADIUS OF TURNING CIRCLE ft
32		≈5	1120	1180	1150	max port	20.3	280
			1120	1180	1150	max stbd	19.2	270
33	10	19.5	1975	1775	1875	max stbd	11.6	730
	10	19.5	1975	1775	1875	max port	9.4	590
	10	20.4	2040	1840	1940	max port	9.4	620
34	5	25.2	2300	2105	2200	max port	5.2	420
	5	25.2	2300	2105	2200	max port	5.2	420
	5	25.2	2300	2105	2200	max port	5.8	470
	5	25.2	2300	2105	2200	max port	6.2	500
35	5	25.2	2300	2040	2170	max stbd	9.0	730
36	0	26.9	2500	2240	2370	max stbd	5.8	500
	0	26.9	2500	2240	2370	max port	6.8	590
	0	26.9	2500	2240	2370	max port	7.2	620
	0	26.9	2500	2240	2370	max port	7.0	610

TABLE 7

RESULTS OF EXTENDED BUILDER'S TRIALS TURNING TRIALS WITH RUDDER DIFFERENTIAL FLAP AND DIFFERENTIAL ENGINE RPM

Test 8: Displ = 5240 lb, LCG = 10-ft forward of transom

RUN	MAIN FOIL FLAP deg	SPEED kts	PROPELLER RPM'S Port lb	Stbd lb	Ave. lb	RUDDER	TIME FOR 30° CHANGE IN HEADING sec	RADIUS OF TURNING CIRCLE ft
37	-	≈ 5	0	1640	820	Centered	10.6	180
			0	1640	820	Centered	11.2	190
			0	1640	820	Max stbd	6.1	100
			0	1640	820	Max stbd	6.7	110
38	5	24.3	Not Recorded			Max port	3.0	240
			Not Recorded			Max port	5.4	420
			Not Recorded			Max port	3.2	250
			Not Recorded			Max stbd	4.2	330
			Not Recorded			Max stbd	5.8	460

TABLE 8

TITLES OF MOTION PICTURE RECORDS
OF A
ONE-THIRD SCALE MANNED MODEL
OF SKI CAT, HIGH-SPEED HYDROFOIL CATAMARAN
FOR
NAVAL SHIP SYSTEMS COMMAND
CONTRACT N00014-67-A-0202-0031
JULY-AUGUST 1973

BUILDER'S TRIALS
AT LAKE NUBANUSIT
NEAR HANCOCK, N.H.

MANNED MODEL ON TRANSPORT
AND LAUNCHING TRAILER
PRIOR TO LAUNCHING

LAUNCHING OPERATIONS
24 JULY 1973
MODEL THEN TOWED TO MOORING
FOR FURTHER OUTFITTING

LOW-SPEED TURNS AND TAKE-OFF

SPEEDS FROM 19 TO 35 MPH
DISPL = 5540 LBS

TAKE-OFF AND FLY-BY
DISPL = 6040 LBS

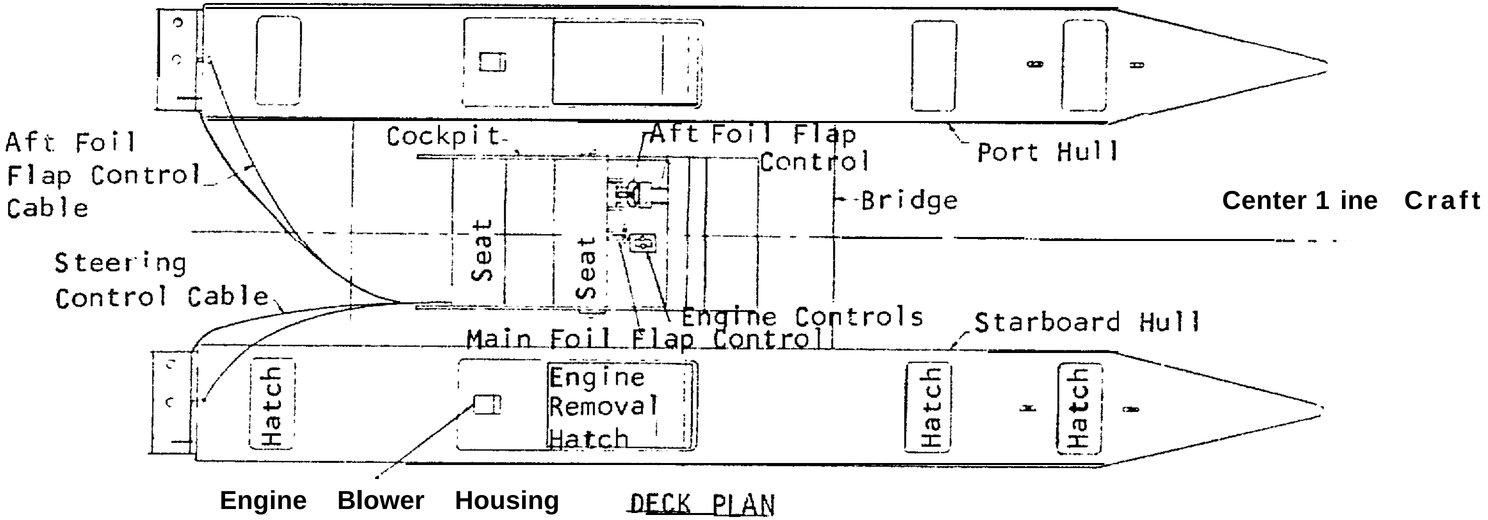
TURNING PERFORMANCE
DISPL = 5240 LBS

BOW SKIS LOWERED 3.75-IN
TO INCREASE HULL-WATER CLEARANCE
DISPL = 5240 LBS

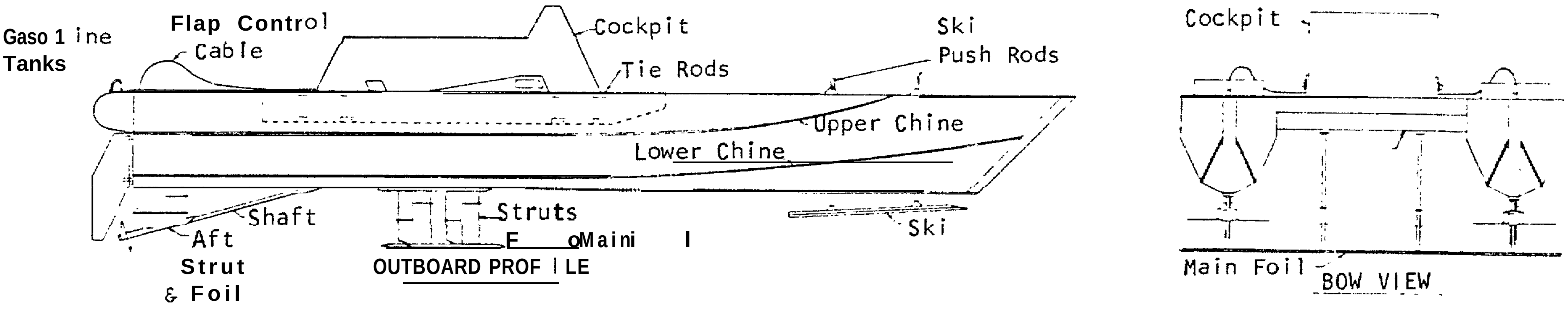
PILOT-INDUCED "GALLOPING"
DEMONSTRATES CRAFT'S RUGGEDNESS
AND MILD IMPACT BEHAVIOR

THE END

DAVIDSON LABORATORY FILM NO.78



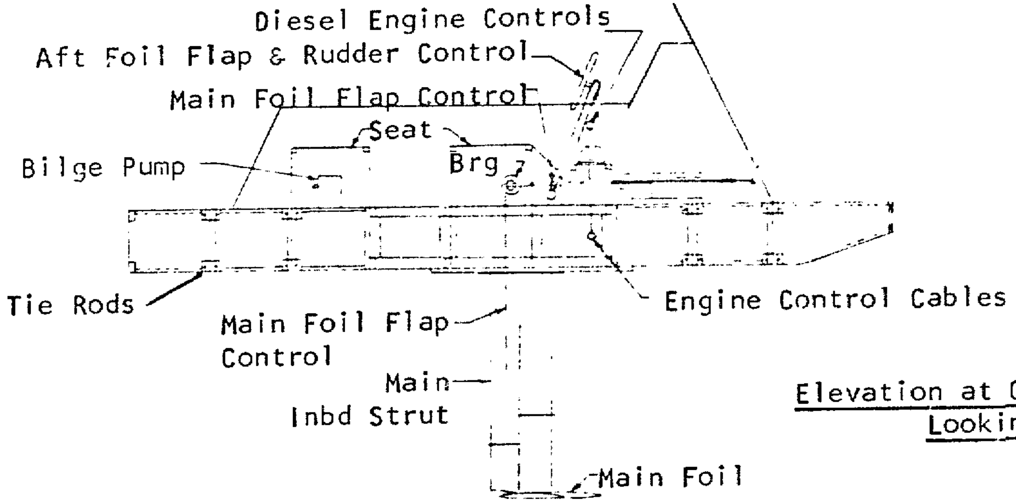
DECK PLAN



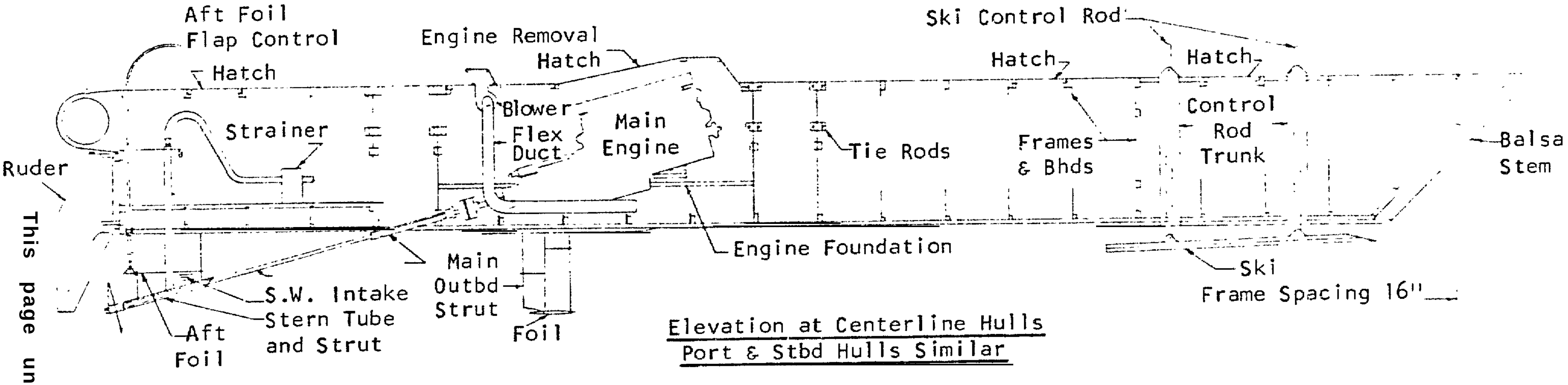
OUTBOARD PROFILE

BOW VIEW

FIGURE 1. GENERAL ARRANGEMENT, OUTBOARD PROFILE AND DECK PLAN OF SKI-CAT HIGH-SPEED CATAMARAN
(1/3-Scale Manned Model)
L_{PP} = 26'-8", LOA = 30'-8" Max Beam = 12'



Elevation at Centerline Bridge
Looking to Port



Elevation at Centerline Hulls
Port & Stbd Hulls Similar

FIGURE 2. GENERAL ARRANGEMENT AND INBOARD PROFILE OF SKI-CAT HIGH-SPEED CATAMARAN
(1/3-Scale Manned Model)
L_{pp} = 26'-8", LOA = 30'-8", Max Beam = 12'

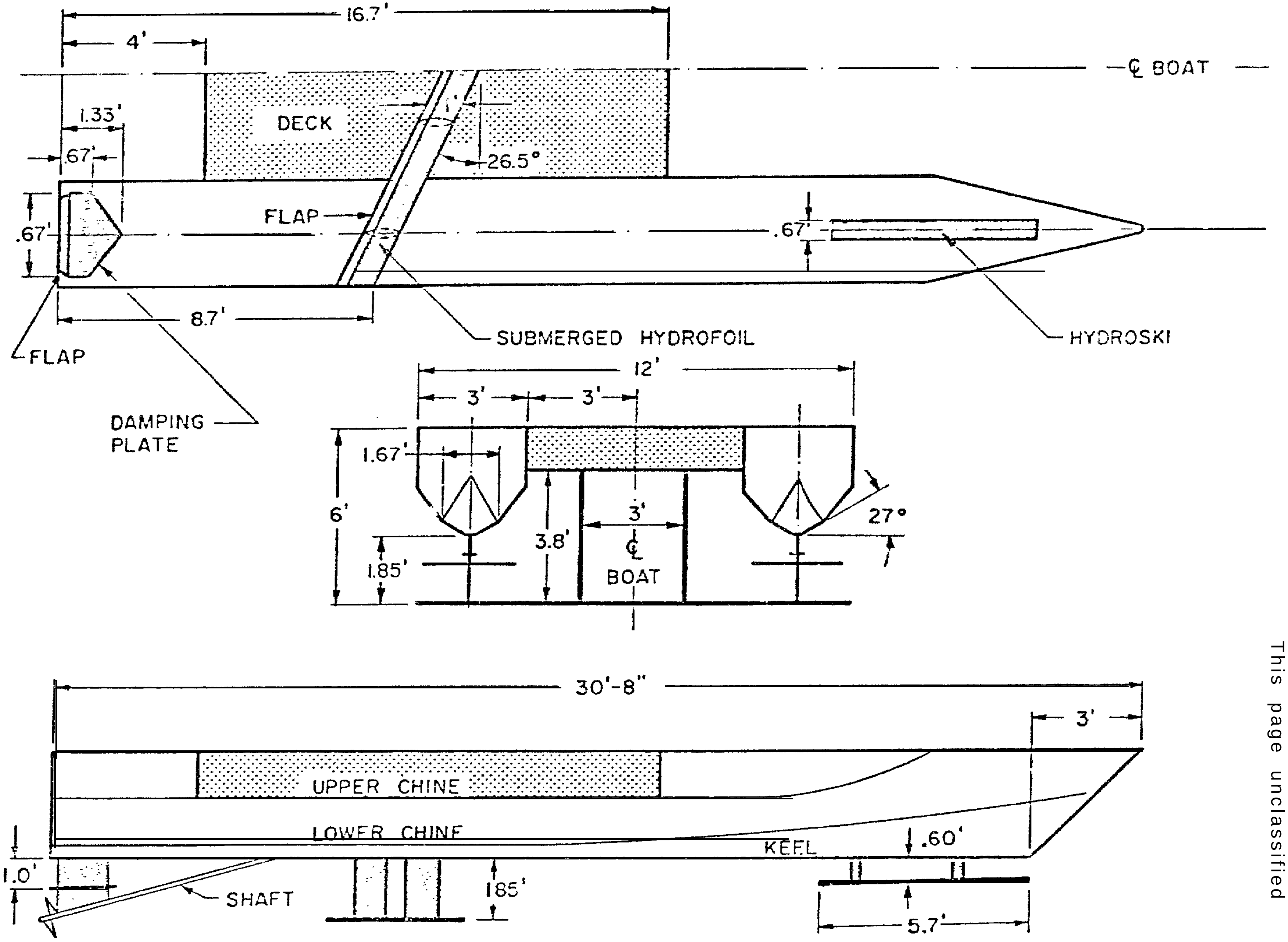


FIGURE 3. HYDROFOIL–SKI-CAT WITH SYMMETRIC HULLS
5,040 lb CRAFT

R-1699

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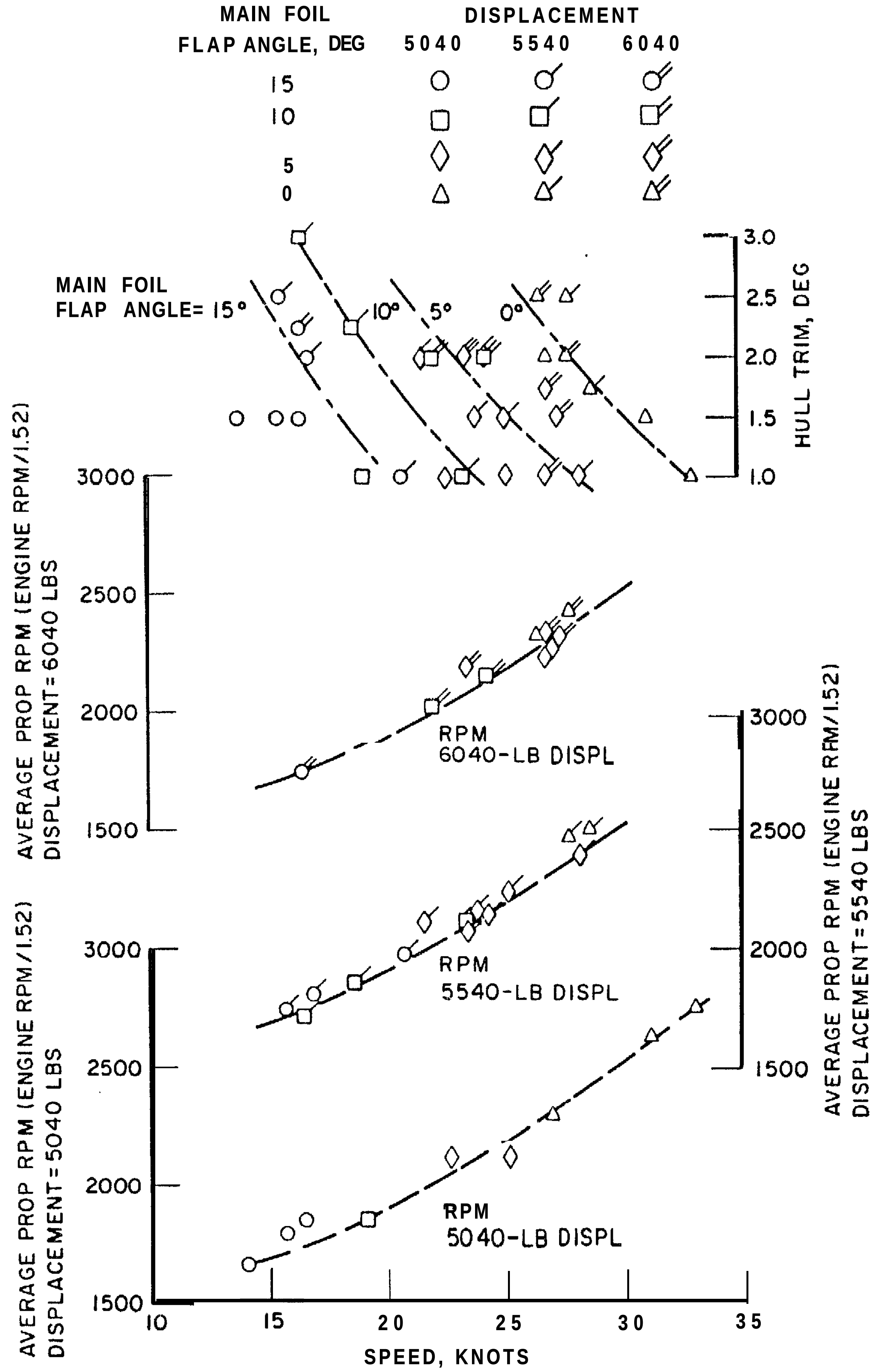

FIG.4. RPM AND TRIM VERSUS SPEED FOR VARIOUS DISPLACEMENTS, NORMAL LCG (10.0 FT FORWARD OF TRANSOM

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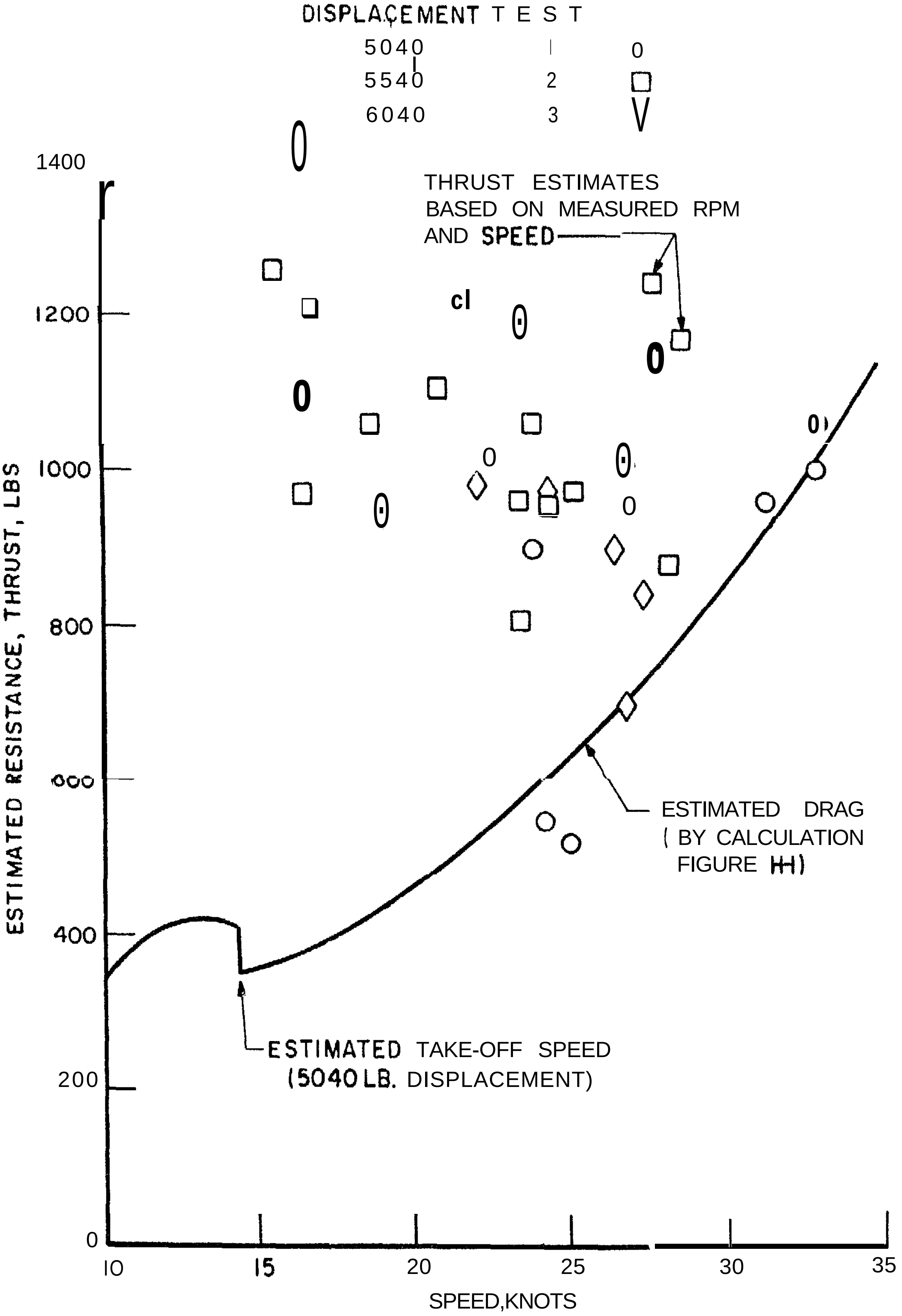

FIG. 5. COMPARISON OF ESTIMATED DRAG (FROM DESIGN NOTEBOOK, FIG. A31 WITH ESTIMATED PROPELLER THRUST BASED ON MEASURED SPEED AND RPM AND DESIGN NOTEBOOK FIG.I-2

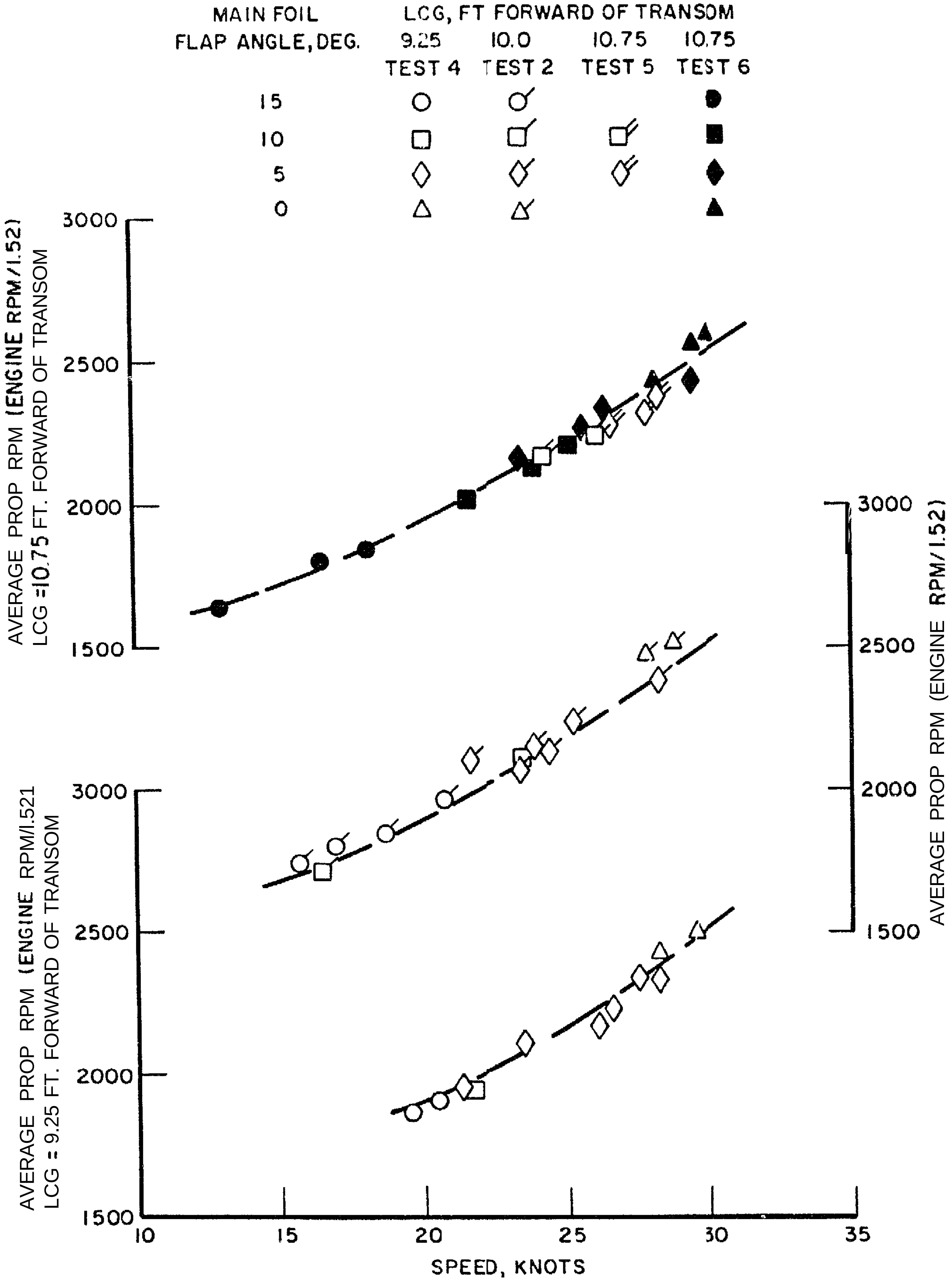

FIG.6. RPM VERSUS SPEED FOR VARIOUS LCG POSITIONS MIDDLE DISPLACEMENT = 5540 LBS

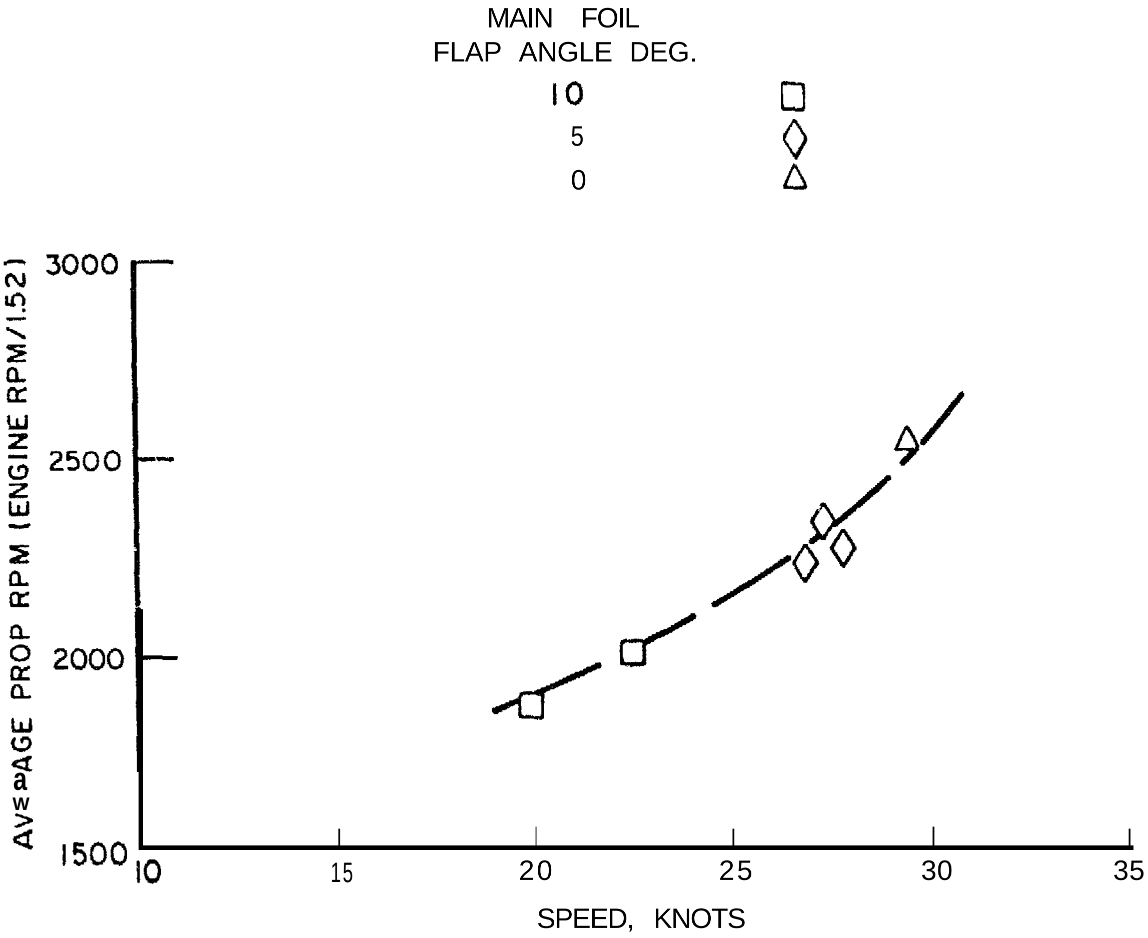

FIG. 7. RPM VERSUS SPEED, NORMAL LCG, 5240 LB DISPLACEMENT, SKIS LOWERED 3.75 IN.

APPENDIX

DESIGN NOTEBOOK

A. Vehicle Characteristics

B. Hull Characteristics

C. Foil System Characteristics

D. Equipment List

E. Structural Analyses

F. Measured Weights

G. Hydrostatics

H. Estimated Drag

I. Estimated Thrust and Torque

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A-1

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VEHICLE CHARACTERISTICS

This page unclassified

MODEL CHARACTERISTICS

$\lambda = 3$

$\Delta = \frac{136,000}{(3)^3} = 5040\#$

$L_K = \frac{80}{3} = 26'-8''$

$B = \frac{36}{3} = 12'$

$V_{BURST} = \frac{60}{\sqrt{3}} = 34.6$ KNOTS $\qquad L/D = 4.5$ EST.

$V_{CRUISE} = \frac{40}{\sqrt{3}} = 23$ KNOTS

$V_{TO} = \frac{20}{\sqrt{3}} = 11.5$ KNOTS

$L/D_{BURST} = 4.5$ EST

$T = \frac{5040}{4.5} = 1120\#$

$P.C. = .5$ EST

$HP = \frac{(1120)(34.6)}{(326)(.5)} = 238$

USE 2 VOLVO BB170A, 170 HP @ 5000 RPM

TARGET WEIGHTS

HULL	GROUP 1	1750
FOIL SYSTEM	" 3	350
MACHINERY	" 2,3	1800
OUTFIT	" 4,5,6	200
LIGHT WEIGHT		4100
CREW		330
		4430
USEFUL LOAD (PAYLOAD + FUEL)		610
		5040#

HULL CHARACTERISTICS

HULL LOADING

$$C_\Delta = \frac{\Delta}{w B^3}$$

$$\Delta = \frac{5040}{2} = 2520^{\#}/\text{HULL}$$

$$w = 64$$

$$B = 20'' = 1.67'$$

$$C_\Delta = \frac{2520}{(64)(1.67)^3} = 8.5$$

$$K = \frac{C_\Delta}{\left(\frac{L}{B}\right)^2}$$

(PARKINSON)

$$L = 320'' = 26.67'$$

$$\frac{L}{B} = \frac{320}{20} = 16$$

$$K = \frac{8.5}{(16)^2} = .0332$$

$$\frac{L}{\nabla^{1/3}} = \frac{26.67}{\left(\frac{2520}{64}\right)^{1/3}} = 7.86$$

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C-1

FOIL SYSTEM CHARACTERISTICS

NOMINAL WEIGHT DISTRIBUTION

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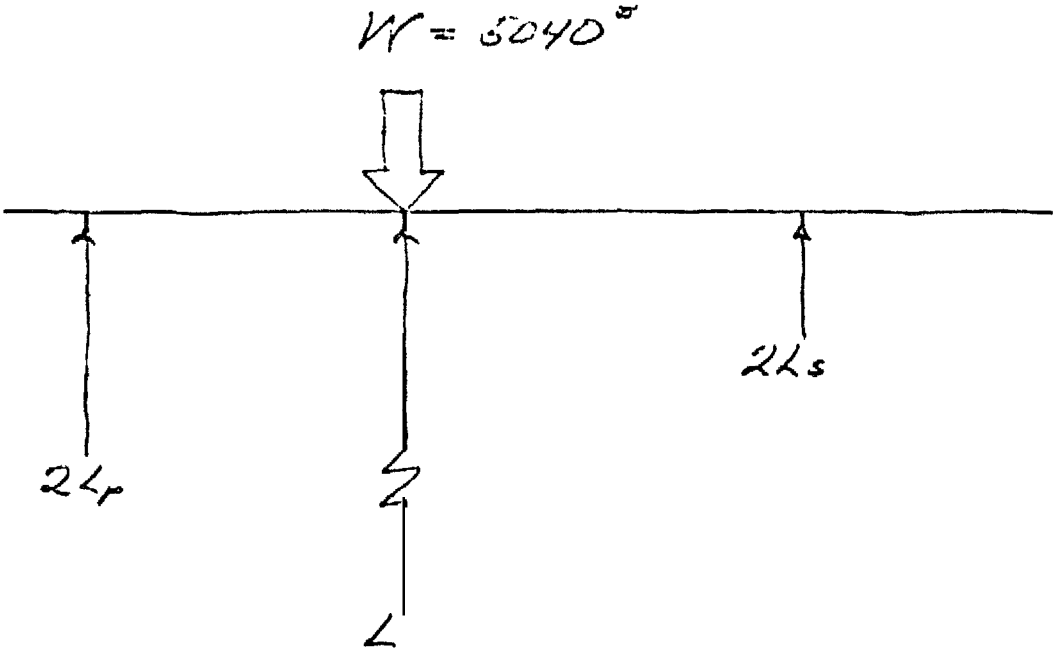

$V = 34.6$ KNOTS (BURST SPEED)

$L_F = .90W = 4536^{\#}$

$2L_p = .06W = 302^{\#}$ $\quad L_p = 151^{\#}$

$2L_s = .04W = 202^{\#}$ $\quad L_s = 101^{\#}$

$V = 23.1$ KNOTS (CRUISE SPEED)

$2L_p = (.06)(5040)\left(\frac{23.1}{34.6}\right)^2 = 134.4^{\#}$, $L_p = 67.2^{\#}$

$2L_s = (.04)(5040)\left(\frac{23.1}{34.6}\right)^2 = 89.6^{\#}$ $\quad L_s = 44.8^{\#}$

$L_F = 5040 - (134.4 - 89.6) = 4816^{\#}$

$V = 14.4$ KNOTS (MINIMUM FLYING SPEED)

$2L_p = (.06)(5040)\left(\frac{14.4}{34.6}\right)^2 = 52.5^{\#}$ $\quad L_p = 26.25^{\#}$

$2L_s = (.04)(5040)\left(\frac{14.4}{34.6}\right)^2 = 35.0^{\#}$ $\quad L_s = 17.5^{\#}$

$L_F = 5040 - (52.5 + 35) = 4952.5^{\#}$

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SKI LIFT - CHARACTERISTICS

ALL SPEEDS

$(C_\ell = \text{CONSTANT})$

b = SKI WIDTH = 8" = .67'

$$C_{\ell_{REQ}} = \frac{L_S}{q\,b^2} = \frac{101}{(3420)(.67)^2} = .066$$

$\tau = 4^\circ$

$$C_\ell = .012\,\tau^{1.1}\,\lambda^{1/2}$$

$$\lambda = \left[\frac{C_\ell}{.012\,\tau^{1.1}}\right]^{1/2} = \left[\frac{.066}{.012\,(4)^{1.1}}\right]^{1/2} = 1.20$$

$\ell = \lambda b = (1.20)(.67) = .80' = 9.6"$

$S = b\ell = (.67)(.80) = .54\ \text{FT}^2$

PLAN LIFT CHARACTERISTICS

ALL SPEEDS (CL = CONSTANT)

b = SPAN = 32" = 2.67'

$\bar{c}$ = AVG. CHORD = $\frac{6+18}{2} = 12" = 1'$

S_P = PLANFORM AREA = $(2.67)(1) = 2.67$ FT^2

DEPTH / CHORD RATIO = $\frac{4}{12} = .33$

ASPECT RATIO = $\frac{2.67}{1} = 2.67$

$K_2 = .73$ (TN 4168)

$K_3 = .72$

.52

$$\frac{dC_L}{d\alpha} = \left(\frac{2\pi}{57.3}\right) K_2 K_3 \left(\frac{A}{A+2K_2+1}\right) = \left(\frac{2\pi}{57.3}\right)(.73)(.72)\left(\frac{2.67}{2.67+1.46+1}\right) = .0302 \text{ /DEG. } \alpha$$

FLAP CHORD RATIO = $\frac{4}{12} = .33$

FLAP SPAN RATIO = 1

$(\alpha_\delta)_{C_L} = .62$ (TN 3911)

$K_c = 1.12$

$K_B = 1$

$$\frac{dC_L}{d\delta} = \left(\frac{dC_L}{d\alpha}\right)(\alpha_\delta)_{C_L}(K_c)(K_B) = (.0302)(.62)(1.12)(1) = .021 \text{ /DEG. } \delta$$

$$C_{L_{REQ}} = \frac{L_P}{q\, S_P} = \frac{151}{(3420)(2.67)} = .0165$$

$\alpha = 0$

$$\delta = \frac{.0165}{.021} = .79^\circ$$

FOIL LIFT CHARACTERISTICS

GENERAL

DEPTH/CHORD RATIO $= \frac{14}{12} = 1.167$

ASPECT RATIO $= \frac{12}{1} = 12$

$K_2 = .965$ (TN 4168)

$K_3 = .895$

$$\frac{dC_l}{d\alpha} = \left(\frac{2\pi}{57.3}\right) K_2 K_3 \left(\frac{A}{A + 2K_2 + 1}\right) = \left(\frac{2\pi}{57.3}\right)(.965)(.895)\left(\frac{12}{12 + 1.93 + 1}\right) = .0767 \text{ /DEG. } \alpha$$

FLAP CHORD RATIO = .25

FLAP SPAN RATIO = 1

$(\alpha_\delta)_{C_L} = .47$ (TN 3911)

$K_C = 1.065$

$K_B = 1$

$$\frac{dC_l}{d\delta} = \left(\frac{dC_l}{d\alpha}\right)(\alpha_\delta)_{C_L} K_C K_B = (.0767)(.47)(1.065)(1) = .0384 \text{ /DEG } \delta$$

$$\alpha_0 = -104 \left[\frac{(t/c)_{TOP} - (t/c)_{BOTTOM}}{2}\right] = -104\left[\frac{.05 - .025}{2}\right] = -1.30^\circ$$ (SOTTORF)

$V = 34.6$ KNOTS (BURST SPEED)

$$C_l = \frac{L_F}{q S_F} = \frac{4536}{(3420)(12)} = .11$$

$$\alpha = -1.30 + \frac{.11}{.0767} = .13^\circ$$

$V = 23.1$ KNOTS (CRUISE SPEED)

$$C_l = \frac{4917}{(1530)(12)} = .268$$

$$\alpha = .13^\circ$$

$$\delta = \frac{.268 - .11}{.0384} = 4.11^\circ$$

FOIL LIFT CHARACTERISTICS

V = 14.4 KNOTS (MINIMUM FLYING SPEED)

$$C_l = \frac{4952}{(592)(12)} = .697$$

$$\alpha = .13^\circ$$

$$\delta = \frac{.697 - .11}{.0384} = 15.3^\circ$$

CAVITATION CHECK

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FOIL

$$V_c = \left[\frac{K - (.6)(L_F/S_F)}{2.54\,(t/c)}\right]^{1/2} \frac{1}{\cos\psi}$$

$K = (14.7)(144) + (1.167)(64) = 2191$ PSF

$L_F = (.9)(5040) = 4536$ #

$S_F = 12\ \text{FT}^2$

$\psi = 26.5°$ $\cos\psi = .895$

$t/c = .075/.895 = .0838$ (.05 TOP, .025 BOTTOM)

$$V_c = \left[\frac{2191 - (.6)(4536/12)}{(2.54)(.0838)}\right]^{1/2}\left(\frac{1}{.895}\right) = 107.35\ \text{FT/SEC}$$

$$V_{K_c} = \frac{107.35}{1.69} = 63.52\ \text{KNOTS}$$

STRUT

$$V_c = \left[\frac{K}{2.54(t/c)}\right]^{1/2}$$

$K = (14.7)(144) = 2117$ PSF

$t/c = .10$

$$V_c = \left[\frac{2117}{2.54(.10)}\right]^{1/2} = 91.29\ \text{FT/SEC}$$

$$V_{K_c} = \frac{91.29}{1.69} = 54.02\ \text{KNOTS}$$

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CAVITATION CHECK

STRUT-FOIL INTERSECTION

$$V_c = \left[\frac{K}{C_{P_{FOIL}} + C_{P_{STRUT}}}\right]^{1/2}$$

$$K = (14.7)(144) + (1.167)(64) = 2191 \text{ psf}$$

$$C_{P_{FOIL}} = 2.54\, t/c + .6\, C_l$$

$$t/c = .075$$

$$C_l = .11$$

$$= 2.54(.075) + .6(.11) = .2565$$

$$C_{P_{STRUT}} = 2.54\, t/c$$

$$t/c = .10$$

$$= 2.54(.1) = .254$$

$$V_c = \left[\frac{2191}{.2565 + .254}\right]^{1/2} = 65.51 \text{ FT/SEC}$$

$$V_{K_c} = \frac{65.51}{1.69} = 38.76 \text{ KNOTS}$$

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FOIL FLAP LOADS

GENERAL

$$H = C_H \, q \, S_F \, c_F$$

$$S_F = (6)(.25) = 1.5 \text{ FT}^2$$

$$c_F = 3'' = .25'$$

$$C_H = \left(\frac{dC_H}{dC_\ell}\right) C_\ell + \left(\frac{dC_H}{d\delta}\right) \delta$$

$$\left(\frac{dC_H}{dC_\ell}\right) = .095$$

$$\left(\frac{dC_H}{d\delta}\right) = .0105$$

$$C_H = .095\, C_\ell + .0105\, \delta$$

BURST SPEED (34.6 KNOTS)

$$C_H = .095\, C_\ell + .0105\, \delta = (.095)(.11) + (.0105)(0) = .01045$$

$$H = (.01045)(3420)(1.5)(.25) = 13.40 \text{ FT}^{\#}$$

a = MOMENT ARM = 1.5" = .125'

P = PUSHROD LOAD = $\frac{H}{a} = \frac{13.40}{.125} = 107^{\#}$

CRUISE SPEED (23.1 KNOTS)

$$C_H = .095\, C_\ell + .0105\, \delta = (.095)(.266) + (.0105)(4.11) = .069$$

$$H = (.069)(1530)(1.5)(.25) = 39.6 \text{ FT}^{\#}$$

$$P = \frac{39.6}{.125} = 316.7^{\#}$$

~~MINIMUM FLYING SPEED~~ (14.4 KNOTS)

$$C_H = .095\, C_\ell + .0105\, \delta = (.095)(.69) + (.0105)(15.3) = .2269$$

$$H = (.2269)(592)(1.5)(.25) = 50.4 \text{ FT}^{\#}$$

$$P = \frac{50.4}{.125} = 403^{\#}$$

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EQUIPMENT LIST

PROPULSION EQUIPMENT

ENGINES

VOLVO PENTA BB170A WITH FOLLOWING EQUIPMENT 2
1.52:1 REVERSE - REDUCTION GEAR
12V, 38A. ALTERNATOR RECTIFIER
INSTRUMENT PANEL
SINGLE LEVER CONTROL WITH CABLES (22')
PROPELLER SHAFT COUPLING (1⅛" SHAFT DIAM.)

TORQUE METER COUPLINGS

FEDERAL MODEL 43A 4
4" FLANGE, 1" SHAFT DIAM.

PROPELLER SHAFTS.

1⅛" DIAM., 96⅝" LONG, ¼" KEYWAY 2
WITH NUTS & KEYS & PINS.
17-4 PH STAINLESS

PROPELLERS

COLUMBIAN BRONZE, MAKO 2
13½" DIAM. X 16" PITCH, L.H.
1⅛" SHAFT DIAM.

PROPELLER SHAFT BEARINGS

BW BYPLEX - "BLUEFISH" 4
1⅛" SHAFT DIAM

PROPELLER SHAFT SEALS

O-RINGS
PARCO PRP 568-216 COMPOUND 4200-70 12

SHAFT LOG HOSE & CLAMPS

1⅞" I.D. HOSE 1'
BLISS FIG. QS 200 - M36S CLAMPS 8

Propulsion Equipment

Shaft Seal Supply Hose & Clamps

1/4" I.D. HOSE	10'
BLISS FIG. QS 200 - M36S CLAMPS	4

Fuel System Equipment

Valves:

Smith Valve Corp. 316T - 3/8" female pipe thread Stainless, Ball Valve	2

Hose Fittings:

Parker 20120-6-6	2

Hose & Clamps

Parker SS25-6 hose	40'
Breeze Ind. QS200-M6S clamps	2

COOLING SYSTEM EQUIPMENT

STRAINER

GROOD SA-250 3/4 IPS	2

HOSE & CLAMPS

BLISS FIG. 1328, 1" I.D. TUBING	40'
BLISS FIG. QS200-M12S CLAMPS	10

EXHAUST EQUIPMENT

HOSE & CLAMPS

3" I.D. HOSE	20'
BIGGS FIG. QS200 - M48S CLAMPS	8

BILGE EQUIPMENT

BILGE PUMP (POWER)

BLISS FIG. 36960-0000

HOSE + CLAMPS

BLISS FIG. 1378, 3/4" I.D. TUBING	40'
BLISS FIG. QS200-M12S CLAMPS	2

BILGE PUMP SWITCH

BLISS FIG. 1152 M

BILGE PUMP (MANUAL)

BLISS FIG. 2658

VENTILATION EQUIPMENT

BLOWERS

BLISS FIG. 35115-0020 2
105 CFM, 3" DIAM.

VENT HOSE

BLISS FIG. 2201, 3" DIAM, 10' LENGTHS

BLOWER SWITCH

BLISS FIG. 1152M 1

ELECTRICAL EQUIPMENT

Batteries

Sears 28W96482N 12V. 70A.H	24.95	2

Battery Cables

Sears 28W 71808 4 AWG, 58" long.	3.59	4

CONTROL EQUIPMENT

STEERING CABLES

MORSE "RED JAKET" 64-BC-348 CABLE	2

TRIM CABLES

MORSE "RED JAKET" 63-BC-396	2

CABLE CLAMPS & SHIMS

MORSE A37885	4

BALL JOINTS

MORSE A 38491	2

CLEVISES

MORSE A29132	2
MORSE A42034	2

NAVIGATION EQUIPMENT

LIGHTS	
BLISS FIG. 1941 (BOW)	1
" " 1940 (SIDE)	1 PAIR
" " 1942 (STERN)	1
SPEEDOMETER	
BLISS FIG. 850	1
COMPASS	
BLISS FIG. 66-W	1
BELL	
BLISS FIG. 1953	1
HORN	
BLISS FIG. FFD-7	1
CLINOMETER	
BLISS FIG. 2056C	1

OUTFIT

ANCHOR & CHAIN

BLISS FIG. 1164 (5# DANFORTH HI-TENSILE ANCHOR)	1
BLISS FIG. 931 (1/4" CHAIN)	10'

ANCHOR LINE

BLISS FIG. 1147 (5/16" NYLON)	200'

MOORING LINES

BLISS FIG. 1762 (5/16" POLYPROPELENE)	100'

CLEATS

BLISS FIG. HA-330	4

LIFE VESTS

BLISS FIG. AK-1	2

CUSHIONS

BLISS FIG. 282	2

FIRE EXTINGUISHERS

BLISS FIG. 310R (4# DRY CHEMICAL)	2

FENDERS

BLISS FIG. 2489 (5"x20")	2

BOAT HOOK

BLISS FIG BH 101	1

STRUCTURAL ANALYSES

STRESS CRITERIA

TYPE STRESS	PROPORTIONAL LIMIT	
	MAHOGANY	SPRUCE
FLEXURAL ∥ GRAIN	7960	6700
BEARING ∥ "	6600	5610
BEARING ⊥ "	1100	710
SHEAR ∥ OR ⊥ "	1230	1150
SHEAR ROLLING	369	

REFERENCE:

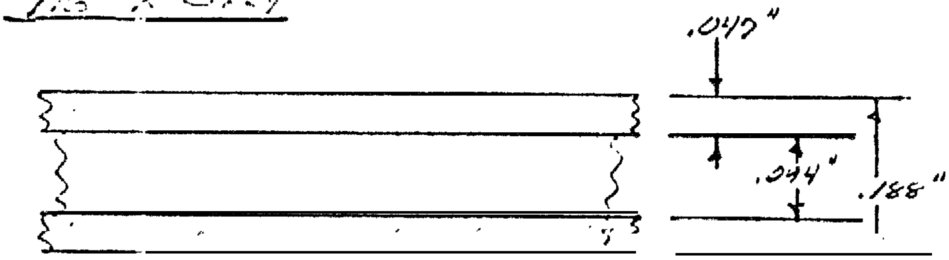
BAUMEISTER & MARKS, "STANDARD HANDBOOK FOR MECHANICAL ENGINEERS" SEVENTH EDITION, McGRAW-HILL.

NOTE:

FLEXURAL STRENGTH OF MAHOGANY PLYWOOD WAS VERIFIED BY TEST.

PLYWOOD SECTION PROPERTIES

3/16" X 3 PLY



$t_{\parallel}$ FACE GRAIN $= 2(.047) = .094"$

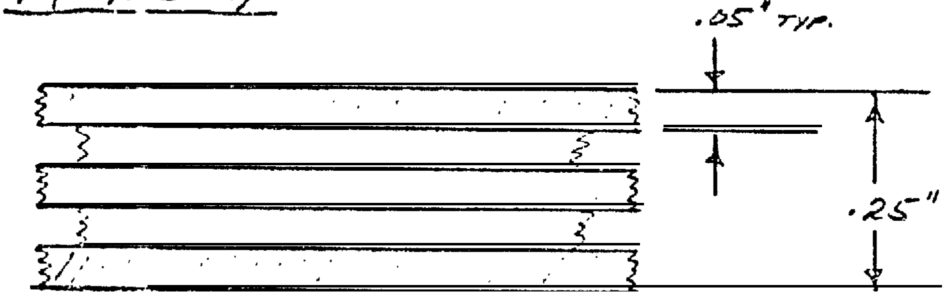
$I_{\parallel}$ " " $= 2(.047+\frac{.047}{2})^2(.047)(1) = .000468$ IN^4/IN WIDTH

$Z_{\parallel}$ " " $= \frac{.000468}{.094} = .00498$ IN^3/IN WIDTH

$t_{\perp}$ FACE GRAIN $= .094"$

$Z_{\perp}$ " " $= \frac{(1)(.094)^2}{6} = .00147$ IN^3/IN WIDTH

1/4" X 5 PLY



$t_{\parallel}$ FACE GRAIN $= 3(.05) = .15"$

$I_{\parallel}$ " " $= 2(.025+.05+.025)^2(.05)(1) + \frac{(1)(.05)^3}{12} = .00101$ IN^4/IN WIDTH

$Z_{\parallel}$ " " $= \frac{.00101}{.125} = .00808$ IN^3/IN WIDTH

$t_{\perp}$ " " $= 2(.05) = .10"$

$I_{\perp}$ " " $= 2(.025+.025)^2(.05)(1) = .00025$ IN^4/IN WIDTH

$Z_{\perp}$ " " $= \frac{.00025}{.15} = .00167$ IN^3/IN WIDTH

HULL BOTTOM PLATING

DESIGN LOADING

z = MAXIMUM ALTITUDE = 1.33'

$\dot{z}$ = SINK RATE (FREE FALL FROM MAX. ALT.) = $\sqrt{2gz} = \sqrt{(2)(32.2)(1.33)} = 9.27$ FT/

β = HULL DEADRISE = 26.5°

V_p = PROPAGATION VELOCITY OF STAGNATION LINE $= \left(\frac{\pi}{2}\right)\frac{\dot{z}}{\tan\beta} = \left(\frac{\pi}{2}\right)\left(\frac{9.27}{.5}\right) = 29.1$ FT/SEC

p_p = STAGNATION PRESSURE $= \left(\frac{\rho}{2}\right)(V_p)^2 = \left(\frac{2}{2}\right)(29.1)^2 = 846$ psf $= 5.88$ psi

STRESS CHECK

l = SPAN = 2.5"

w = UNIT WIDTH = 1"

M = BENDING MOMENT IN PLATING $= \frac{p l^2 w}{12} = \frac{(5.88)(2.5)^2(1)}{12} = 3.06$ IN#/IN WIDTH

t = PLATING THICKNESS = 3/16" (M.P. FACE GRAIN LONG.)

$Z_\perp$ = SECTION MODULUS OF PLATING = .00147 IN³/IN WIDTH

s = BENDING STRESS IN PLATING $= \frac{M}{Z} = \frac{3.06}{.00147} = 2082$ psi (7960)

HULL BOTTOM LONGITUDINALS

DESIGN LOADING

p = PLATING DESIGN PRESSURE = 5.88 psi

k = REDUCTION FACTOR = .6

p_L = LONGITUDINAL DESIGN PRESSURE = $k\,p$ = $(.6)(5.88) = 3.53$ psi

STRESS CHECK

l = SPAN = 15.75"

b = PANEL WIDTH = 3.5"

M = BENDING MOMENT IN LONGITUDINAL = $\frac{p\,l^2 b}{12} = \frac{(3.53)(15.75)^2(3.5)}{12} = 255$ in#

Z = SECTION MODULUS OF LONGITUDINAL = $\frac{(1)(1)^2}{6} = .167$ in^3

s = BENDING STRESS IN LONGITUDINAL = $\frac{M}{Z} = \frac{255}{.167} = 1530$ psi (6700)

HULL BOTTOM FRAMES

DESIGN LOADING

p = PLATING DESIGN PRESSURE = 5.88 psi

k = REDUCTION FACTOR = .6

p_L = FRAME DESIGN PRESSURE = $(k)p = (.6)(5.88) = 3.53$ psi

STRESS CHECK

l = SPAN = 10"

b = PANEL WIDTH = 16"

M = BENDING MOMENT IN FRAME $= \frac{p_L l^2 b}{12} = \frac{(3.53)(10)^2(16)}{12} = 470$ IN#

t = EFFECTIVE THICKNESS OF FRAME = .10" (1/4" M.P. FACE GRAIN VERT.)

d = DEPTH OF FRAME = 5"

Z = SECTION MODULUS OF FRAME $= \frac{t d^2}{6} = \frac{(.10)(5)^2}{6} = .417$ IN^3

s = BENDING STRESS IN FRAME $= \frac{M}{Z} = \frac{470}{.417} = 1128$ psi (7960)

HULL BOTTOM FRAMES (FOIL FOUNDATION)

DESIGN LOAD

$P = (1.5)\left(\frac{5000}{4}\right) = 1875^{\#}$ (ASSUMES LOAD ON 1 FRAME)

STRESS CHECK

l = SPAN = 14"

M = BENDING MOMENT IN FRAME = $\frac{Pl}{8} = \frac{(1875)(14)}{8} = 3280$ IN-#

t = EFFECTIVE THICKNESS OF FRAME = $2(.15) + .10 = .40$"

d = DEPTH OF FRAME = 4"

Z = SECTION MODULUS OF FRAME = $\frac{td^2}{6} = \frac{(.40)(4)^2}{6} = 1.07$ IN^3

s = BENDING STRESS IN FRAME = $\frac{M}{Z} = \frac{3280}{1.07} = 3075$ psi (7960)

KEEL (FOIL FOUNDATION)

DESIGN LOADS

$P = (1.5)\left(\frac{5000}{4}\right) = 1875^{\#}$

STRESS CHECK

l = SPAN = 16"

M = BENDING MOMENT IN KEEL = $\frac{Pl}{8} = \frac{(1875)(16)}{8} = 3750$ in#

t = THICKNESS OF KEEL = $2(1) + .188 = 2.188$"

w = WIDTH OF KEEL = 4"

Z = SECTION MODULUS OF KEEL = $\frac{wt^2}{6} = \frac{(4)(2.188)^2}{6} = 3.19$ in^3

σ = BENDING STRESS IN KEEL = $\frac{M}{Z} = \frac{3750}{3.19} = 1175$ psi (6700)

HULL SIDE PLATING

DESIGN LOADING

$p = (2 + \frac{29}{12})(\frac{64}{144}) = 1.97$ psi (2' S.W. OVER DECK)

STRESS CHECK

l = SPAN = 4"

w = UNIT WIDTH = 1"

M = BENDING MOMENT IN PLATING = $\frac{p l^2 w}{12} = \frac{(1.97)(4)^2(1)}{12} = 2.62$ IN#/IN WIDTH

t = PLATING THICKNESS = 3/16" (M.P. FACE GRAIN LONG.)

Z = SECTION MODULUS OF PLATING = .00147 IN³/IN WIDTH

s = BENDING STRESS IN PLATING = $\frac{M}{Z} = \frac{2.62}{.00147} = 1782$ psi (2960)

HULL SIDE LONGITUDINAL

DESIGN LOADING

$p = \left(2 + \frac{26.5}{12}\right)\left(\frac{64}{144}\right) = 1.87$ psi

STRESS CHECK

ℓ = SPAN = 15.75"

b = PANEL WIDTH = 5"

M = BENDING MOMENT IN LONGITUDINAL = $\frac{p \ell^2 b}{12} = \frac{(1.87)(15.75)^2(5)}{12}$ = 193 IN#

Z = SECTION MODULUS OF LONGITUDINAL = $\frac{(1)(1)^2}{6}$ = .167 IN^3

s = BENDING STRESS IN LONGITUDINAL = $\frac{M}{Z} = \frac{193}{.167}$ = 1160 psi (6700)

KNUCKLE PLATING

DESIGN LOADING

$p = \left(2 + \frac{8}{12}\right)\left(\frac{64}{144}\right) = 1.19$ psi

STRESS CHECK

l = SPAN = 6"

w = UNIT WIDTH = 1"

M = BENDING MOMENT IN PLATING = $\frac{p l^2 w}{12} = \frac{(1.19)(6)^2(1)}{12}$ = 3.57 IN#/IN WIDTH

t = PLATING THICKNESS = 3/16" (M.P. FACE GRAIN LONG.)

Z = SECTION MODULUS OF PLATING = .00147 IN^3/IN WIDTH

s = BENDING STRESS IN PLATING = $\frac{M}{Z} = \frac{3.57}{.00147}$ = 2429 psi (2960)

KNUCKLE LONGITUDINAL

DESIGN LOADING

$p = \left(2 + \frac{8}{12}\right)\left(\frac{64}{144}\right) = 1.19$ psi

STRESS CHECK

l = SPAN = 15.75"

b = PANEL WITH = 7

M = BENDING MOMENT IN LONGITUDINAL = $\frac{pl^2b}{12} = \frac{(1.19)(15.75)^2(7)}{12} = 172$ in#

Z = SECTION MODULUS OF LONGITUDINAL = $\frac{(1)(1)^2}{6} = .167$ in^3

s = BENDING STRESS IN LONGITUDINAL = $\frac{M}{Z} = \frac{172}{.167} = 1030$ psi (6700)

HULL SIDE FRAME

DESIGN LOADING

$$p = \left(2 + \frac{16}{12}\right)\left(\frac{64}{144}\right) = 1.48 \text{ psi}$$

STRESS CHECK

ℓ = SPAN = 19"

b = PANEL WIDTH = 16"

M = BENDING MOMENT IN FRAME = $p\dfrac{\ell^2 b}{12} = \dfrac{(1.48)(19)^2(16)}{12}$ = 712 in#

t = EFFECTIVE THICKNESS OF FRAME = .15" (1/4" M.P. FACE GRAIN VERT.)

d = DEPTH OF FRAME = 4"

z = SECTION MODULUS OF FRAME = $\dfrac{td^2}{6} = \dfrac{(.15)(4)^2}{6}$ = .40 in^3

s = BENDING STRESS IN FRAME = $\dfrac{M}{z} = \dfrac{712}{.4}$ = 1781 psi (2960)

DECK PLATING

DESIGN LOADING

$p = (2)\left(\frac{64}{144}\right) = .89$ psi (2' S.W. OVER DECK)

STRESS CHECK

l = SPAN = 14.25"

w = UNIT WIDTH = 1"

M = BENDING MOMENT IN PLATING = $\frac{p\,l^2 w}{12} = \frac{(.89)(14.25)^2(1)}{12}$ = 16.14 IN#/IN WIDTH

t = PLATING THICKNESS = 3/16" (M.P. FACE GRAIN LONG.)

Z = SECTION MODULUS OF PLATING = .000468 IN^3/IN WIDTH

f = BENDING STRESS IN PLATING = $\frac{M}{Z} = \frac{16.14}{.000468}$ = 3448 psi (2960)

DECK FRAMES

DESIGN LOADING

p = PLATING DESIGN PRESSURE = .89 psi

STRESS CHECK

l = SPAN = 20"

b = PANEL WIDTH = 16"

M = BENDING MOMENT IN FRAME = $\frac{p l^2 b}{12} = \frac{(.89)20)^2(16)}{12}$ = 474 in#

t = EFFECTIVE THICKNESS OF FRAME = .10" (1/4" MP. FACE GRAIN VERT.)

d = DEPTH OF FRAME = 4"

Z = SECTION MODULUS OF FRAME = $\frac{t d^2}{6} = \frac{(.10)(4)^2}{6}$ = .267 in^3

s = BENDING STRESS IN FRAME = $\frac{M}{Z} = \frac{474}{.267}$ = 1778 psi (2960)

BULKHEAD PLATING

DESIGN LOADING

$p = \left(\frac{17+8}{12}\right)\left(\frac{64}{144}\right) = .925$ psi

STRESS CHECK

ℓ = SPAN = 16"

w = UNIT WIDTH = 1"

M = BENDING MOMENT IN PLATE = $\frac{p\ell^2 w}{12} = \frac{(.925)(16)^2(1)}{12}$ = 19.7 IN# / IN WIDT

Z = SECTION MODULUS OF PLATE = .00808 IN³/IN WIDTH (1/4" M.P. FACE GRAIN

s = BENDING STRESS IN PLATE = $\frac{M}{Z} = \frac{19.7}{.00808}$ = 2438 psi (2960)

ENGINE GIRDER

DESIGN LOAD

P = MAX. ENGINE MOUNT LOAD $= (1.5)\left(\frac{640}{3}\right) = 320^{\#}$

STRESS CHECK

ℓ = SPAN = $14''$

M = BENDING MOMENT IN GIRDER $= \frac{P\ell}{8} = \frac{(320)(14)}{8} = 560 \text{ in}^{\#}$

Z = SECTION MODULUS OF GIRDER $= \frac{(2)(1)^2}{6}(.5) = .167$ (1" M.P. FACE GRAIN LON

s = BENDING STRESS IN GIRDER $= \frac{M}{Z} = \frac{560}{.167} = 3353$ psi (7960)

HULL GIRDER

MOMENT OF INERTIA (HORIZONTAL BENDING)

ITEM	DIMENSIONS	AREA	LEVER	MOMENT	LEVER	MOMENT OF INERTIA	h	$\frac{Ah^2}{12}$
KEEL	(1) 5.5" × 1"	5.50	17.5	96.20	17.5	1680		
BOTTOM PL	(2) 9 × .094"	1.69	16	27.04	16	433	4	2
BOTTOM LONGS.	(2) 1" × 1"	2.00	16	32.00	16	512		
CHINES	(2) 1" × 1.5"	3.00	13.5	40.50	13.5	547		
SIDE PL	(2) 18" × .094"	3.38	6	20.28	6	122	16	72
SIDE LONGS.	(4) 1" × 1"	4.00	6	24.00	6	144		
KNUCKLES	(2) 1" × 1.75"	3.50	−2	−7.00	−2	14		
KNUCKLE PL	(2) 16" × .094"	3.01	−10	−30.10	−10	301	16	64
KNUCKLE LONGS.	(2) 1" × 1"	2.00	−9.5	−19.00	−9.5	180.5		
GUNWALES	(2) 2" × 1"	4.00	−17	−68.00	−17	1155		
DECK PL	(1) 36" × .094"	3.38	−18	−60.84	−18	1095		
		35.46		55.08		6184		138

I_{18} = MOMENT OF INERTIA ABOUT 18" WL = 6184 + 138 = 6322 IN^4

d = NEUTRAL AXIS BELOW 18" W.L. = $\frac{55.08}{35.46}$ = 1.55" (16.45" WL)

I_0 = MOMENT OF INERTIA ABOUT NEUTRAL AXIS = $I_{18} - Ad^2 = 6322 - (35.46)(1.55)^2 =$ 6237 IN^4

MAXIMUM BENDING MOMENT $\left(\frac{W}{4} \times \frac{l}{2}\right)$

$$M = \left(\frac{W}{4}\right)\left(\frac{l}{2}\right) = \left(\frac{5000}{4}\right)\left(\frac{320}{2}\right) = 200{,}000 \text{ IN\#}$$

STRESS CHECK

$$s = \frac{Mc}{I} = \frac{(200{,}000)(18+1.55)}{6237} = 627 \text{ psi}$$ (DECK)

(7960)
(6700)

HULL GIRDER

MOMENT OF INERTIA (LATERAL BENDING)

ITEM	DIMENSIONS	AREA	LEVEL	MOMENT	LEVEL	MOMENT OF INERTIA	h	$\frac{Ah^2}{12}$
KEEL	(1) 5.5" X 1"	5.50	0	0	0	0	5.5	14
BOTTOM PL	(2) 9" X .094"	1.69	6	10.14	6	60.84	8	9
BOTTOM LONGS	(2) 1" X 1"	2.00	6	12.00	6	72.00		
CHINES	(2) 1" X 1.5"	3.00	9.5	28.50	9.5	270.50		
SIDE PL	(2) 16" X .094"	3.38	14	47.32	14	662.48	8	18
SIDE LONGS	(4) 1" X 1"	4.00	14	56.00	14	794.00		
KNUCKLES	(2) 1" X 1.75"	3.50	17.5	61.20	17.5	1070.00		
KNUCKLE PL	(2) 16" X .094"	3.01	18	54.18	18	975.24		
KNUCKLE LONGS	(2) 1" X 1"	2.00	17.5	35.00	17.5	612.50		
GUNWALES	(2) 2" X 1"	4.00	17.5	70.00	17.5	1225.00		
DECK	(1) 36" X .094"	3.38	0	0	0	0	36	365
		35.46		374.34		5742.56		406

I = MOMENT OF INERTIA ABOUT ℄ = 5743 + 406 = 6149 IN^4

MAXIMUM BENDING MOMENT

$$M = \left(\frac{W}{4}\right)\left(\frac{L}{2}\right) = \left(\frac{5000}{4}\right)\left(\frac{320}{2}\right) = 200{,}000 \text{ IN}^{\#}$$

STRESS CHECK

$$f = \frac{Mc}{I} = \frac{(200{,}000)(18)}{6149} = 585 \text{ psi}$$

(7960)
(6700)

HULL - BRIDGE JOINT

DESIGN LOAD (FIX 1 HULL, CANTILEVER ½ GROSS WT. AT ℄ OF OTHER HULL)

W = GROSS WT. = 5000#

ℓ = EFFECTIVE MOMENT ARM = $(6 + \frac{3}{2})12$ = 90"

n = NUMBER OF EFFECTIVE ENDS = 4

M = BENDING MOMENT IN BHD. = $\frac{\left(\frac{W}{2}\right)\ell}{n} = \left(\frac{5000}{2}\right)\left(\frac{90}{4}\right)$ = 56250 in#

STRESS CHECK

h = VERT. DISTANCE BETWEEN TIE RODS = 10"

T = TENSION IN TIE ROD = $\frac{M}{2h} = \frac{56250}{2(10)}$ = 2812#

d = TIE ROD DIAM. = .25"

A_T = TENSILE AREA IN TIE ROD = $(.766)(.25)^2$ = .049 in²

s_T = TENSILE STRESS IN TIE ROD = $\frac{T}{A_T} = \frac{2812}{.049}$ = 57 300 psi

C = COMPRESSION IN BHD. FLANGE = 2T = 2(2812) = 5625#

A_c = COMPRESSIVE AREA IN BHD. FLANGE = 2(4) = 8 in²

s_c = COMPRESSIVE STRESS IN BHD FLANGE = $\frac{C}{A_c} = \frac{5625}{8}$ = 703 psi (5610)

A_B = BEARING AREA AT SHELL = 2(6) = 12 in²

s_B = BEARING STRESS IN SHELL = $\frac{C}{A_B} = \frac{5625}{12}$ = 469 psi (1100)

A_R = ROLLING SHEAR AREA IN BHD WEB = (2)(36)(2) = 144 in²

s_R = ROLLING SHEAR STRESS IN BHD WEB = $\frac{C}{A_R} = \frac{5625}{144}$ = 39 psi (360)

A_S = DIRECT SHEAR AREA IN BHD WEB = (2)(36)(.25) = 18 in²

s_S = DIRECT SHEAR STRESS IN BHD WEB = $\frac{C}{A_S} = \frac{5625}{18}$ = 313 psi ([illegible])

Bridge Torque Box

Design Moment

$$M = \left(\frac{W}{4}\right)\left(\frac{l}{2}\right) = \left(\frac{5000}{4}\right)\left(\frac{320}{2}\right) = 200,000 \text{ in}\#$$

Shear Check

l = [illegible] = 144"

d = BRIDGE DEPTH = 12"

t = BRIDGE PLATING THICKNESS = .188"

τ = SHEAR STRESS IN PLATING $= \dfrac{M}{2 l d t} = \dfrac{200,000}{2(144)(12)(.188)} = 308$ psi (

HYDROFOIL

DESIGN LOADING

p_0 = 1g LOADING = $\frac{4526}{12}$ = 376 psf = 2.62 psi

k = LOAD FACTOR 1.5

p = DESIGN LOADING = $p_0 k$ = (2.62)(1.5) = 3.93 psi

STRESS CHECK (INBD.)

l = SPAN = 36"

c = CHORD = 12" , t = THICKNESS = .9"

M = BENDING MOMENT IN FOIL = $\frac{p l^2 c}{12} = \frac{(3.93)(36)^2(12)}{12}$ = 5099 IN#

Z = SECTION MODULUS OF FOIL = $.08 t^2 c = (.08)(.9)^2(12)$ = .78 IN³

s = BENDING STRESS IN FOIL = $\frac{M}{Z}$ $\frac{5099}{.78}$ = 6530 psi

STRESS CHECK (OUTBD.)

l = DISTANCE TO CENTER OF PRESSURE (.9)(9) 8.1

c = CHORD = 12"

b = SPAN = 18"

M = BENDING MOMENT IN FOIL = $p\,l\,b\,c$ = (3.93)(8.1)(18)(12) = 6576 IN#

Z = SECTION MODULUS OF FOIL = .78 IN³

s = BENDING STRESS IN FOIL = $\frac{M}{Z} = \frac{6576}{.78}$ = 8515 psi

STRUT

DESIGN LOADING

Δ = GROSS WEIGHT = 5000#

k = LOAD FACTOR = .33

n = NUMBER OF EFFECTIVE STRUTS = 2

S = SIDE FORCE PER STRUT = $\frac{\Delta k}{n} = \frac{(5000)(.33)}{2}$ = 833#

STRESS CHECK

l = STRUT LENGTH ≈ 20", c = CHORD = 12", t = THICKNESS = 1.2"

M = BENDING MOMENT IN STRUT = $lS = 20(833)$ = 16660 in#

Z = SECTION MODULUS OF STRUT = $.08\,t^2c = .08(1.2)^2(12)$ = 1.38 in^3

σ = BENDING STRESS IN STRUT = $\frac{M}{Z} = \frac{16660}{1.38}$ = 12100 psi

PUSHRODS

DESIGN LOAD

P = PUSHROD DESIGN LOAD = 403#

SAFE BUCKLING LOAD

$$B = \frac{\pi^2 EI}{\ell^2}$$

$E = 30 \times 10^6$

$I = .007$ (9/16" DIAM. ROD)

$\ell = 53"$

$$B = \frac{\pi^2 (30 \times 10^6)(.005)}{(53)^2} = 528^{\#}$$

PLATE

DESIGN LOADING

p_0 = 1g LOADING = $\frac{151}{2.67}$ = 56.6 = .393 psi

k = LOAD FACTOR = 2

p = DESIGN LOADING = (.393)(2) = .786 psi

STRESS CHECK

l = DISTANCE TO CENTER OF PRESSURE = (.9)(8) = 7.2"

$\bar{c}$ = AVG CHORD = 12"   (ROOT CHORD = 18")

b = SEMI SPAN = 16"

M = BENDING MOMENT IN FOIL = $plbc$ = (.786)(7.2)(16)(12) = 1087 in#

Z = SECTION MODULUS OF PLATE = $\frac{(18)(.25)^2}{6}$ = .1875 in³

σ = BENDING STRESS IN PLATE = $\frac{M}{Z}$ = $\frac{1087}{.1875}$ = 5797 psi

SKI

DESIGN LOADING

p_o = 1g LOADING $\frac{171}{(8)(16)}$ = 1.32 psi

k = LOAD FACTOR = 2

p = DESIGN LOADING = $p_o k = (1.32)(2) = 2.64$ psi

STRESS CHECK

ℓ = SPAN = 32"

b = SKI CHORD = 8"

M = BENDING MOMENT IN SKI = $p \frac{\ell^2 b}{8} = \frac{(2.64)(32)^2(8)}{8} = 2703$ in#

t = SKI THICKNESS = 2"

Z = SECTION MODULUS OF SKI = $\frac{(8)(2)^2}{6} = 5.33$ in^3

σ - BENDING STRESS IN SKI = $\frac{M}{Z} = \frac{2703}{5.33} = 507$ psi (6700)

MEASURED WEIGHTS

Description	Wt.	Trans.	Long. Mom.
Port Hull Assembly	1710	10.63	18177
Stbd. Hull Assembly	1710	10.63	[illegible]
Center Section Assembly	660	10.57	6976
Hydrofoil	200	9.70	1940
Prop. Unit	22	0	0
Light Ship	4302#	10.5'	45126
Complement	330	10	3300
Fuel	138	-.80	-111
Water	40	10	400
Base	4810#	10.07	48257
Ballast (Nom.)	200	8.67	1734
Full Load Disp.	5010#	10.02'	50491

MOMENTS & WEIGHTS

PORT HULL ASSEMBLY

WT AT BHD #9 = 980 - 10 = 970#

WT AT BHD #16 = 750 - 10 = 740#

1710#

$$LCG = \frac{(970)(20-9)(16/12) + (740)(20-16)(16/12)}{1710} = 10.63' \text{ FWD. TRANSOM}$$

STBD. HULL ASSEMBLY

WT AT BHD #9 = 970 - 10 = 960#

WT AT BHD #16 = 760 - 10 = 750#

1710#

$$LCG = \frac{(960)(20-9)(16/12) + (750)(20-16)(16/12)}{1710} = 10.57' \text{ FWD. TRANSOM}$$

CENTER SECTION ASSEMBLY

WT AT BHD #9 = 380 - 10 = 370#

WT AT BHD #16 = 300 - 10 = 290#

660#

$$LCG = \frac{(370)(20-9)(16/12) + (290)(20-16)(16/12)}{660} = 10.57' \text{ FWD. TRANSOM}$$

HYDROFOIL

WT = 200#

LCG = 9.7' FWD. TRANSOM

PROPELLERS

WT = 2(11) = 22#

LCG = 0' FWD. TRANSOM

HYDROSTATICS

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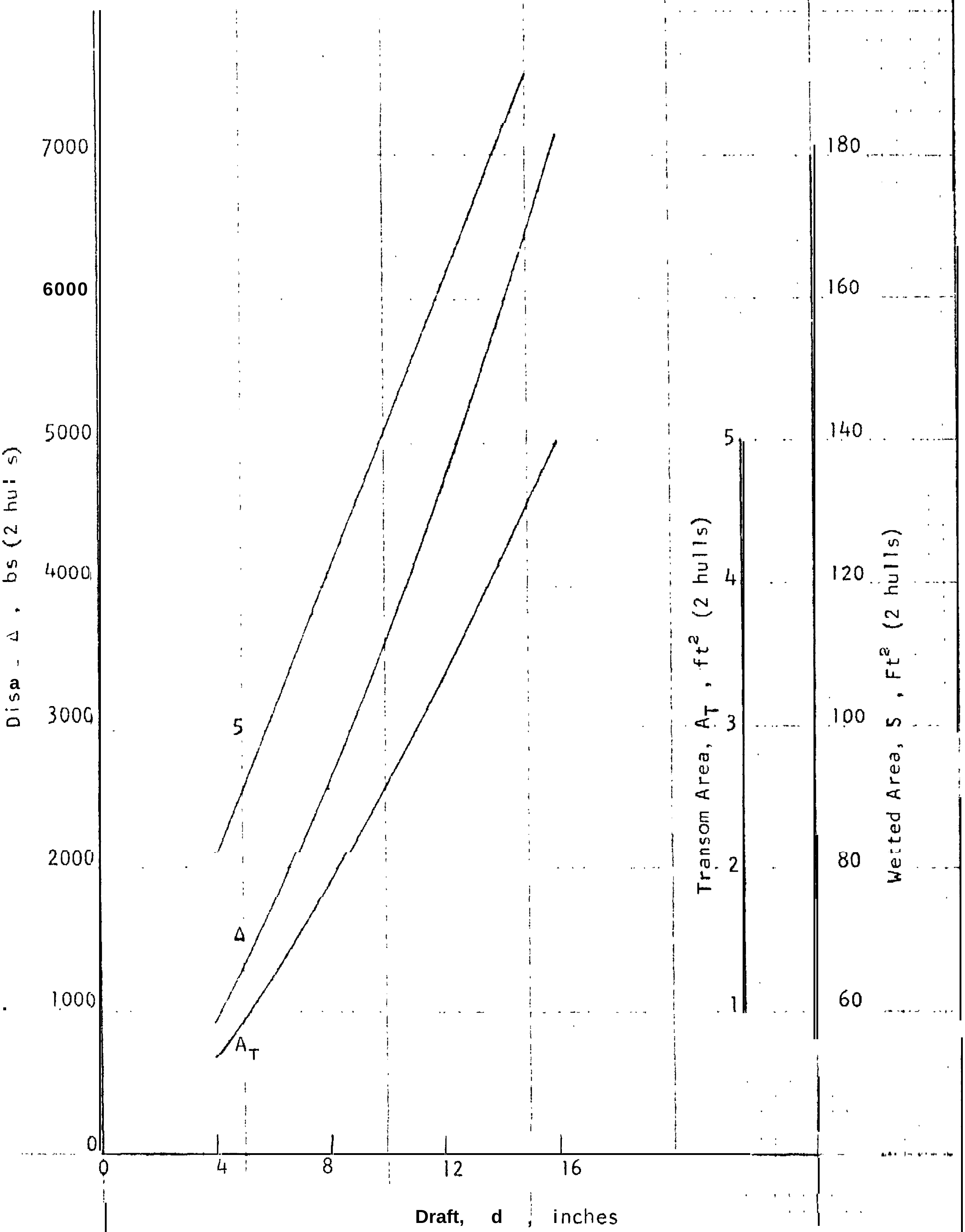

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FIGURE G-1. HYDROSTATIC CHARACTERISTICS

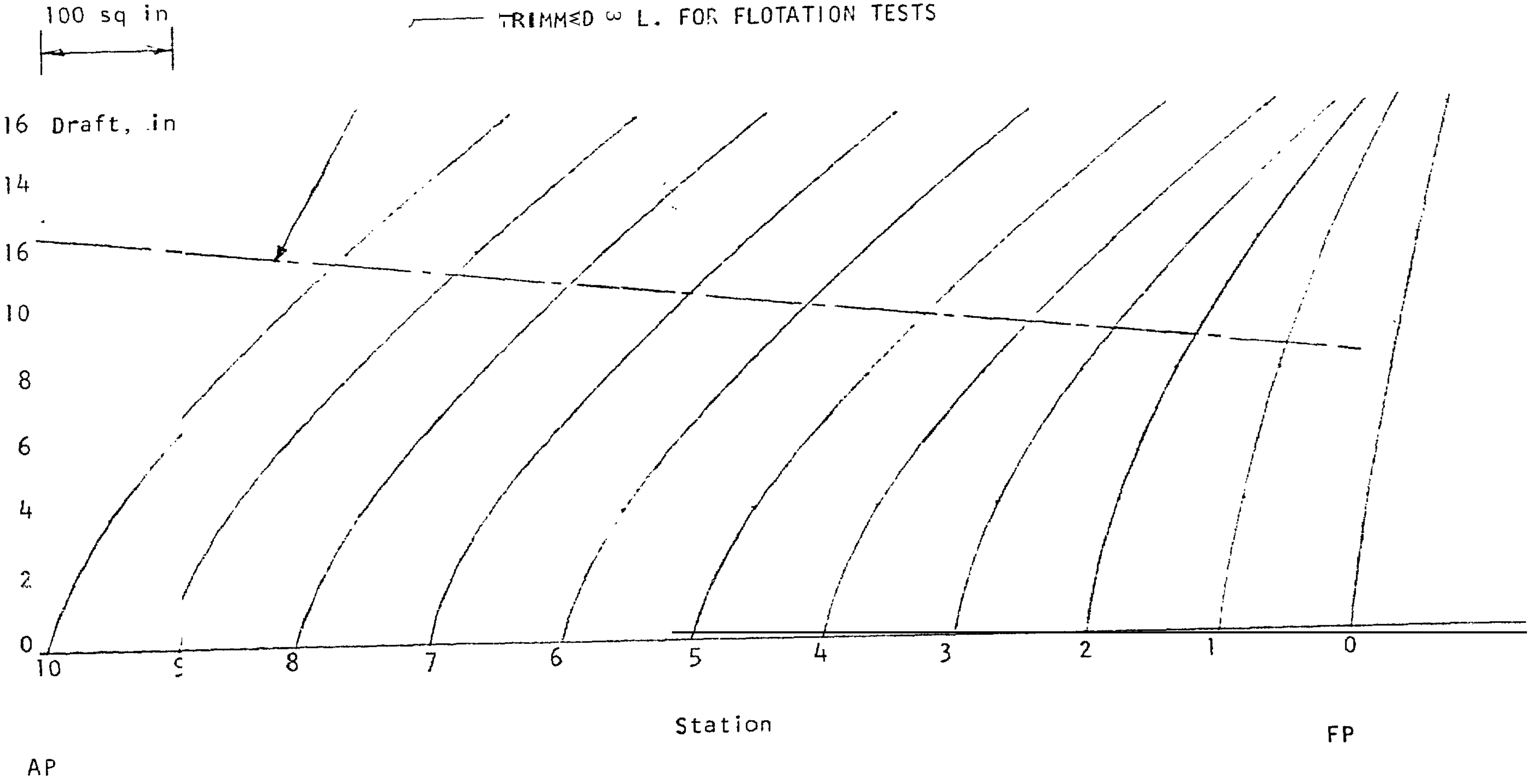

FIGURE G-2. BONJEAN'S CURVES FOR ONE HULL OF SKI-CAT 1/3-SCALE MANNED MODEL

SECTION PROPERTIES

STATION 0

$$A_4 = 2\left(\frac{1.6+2.12}{2}\right)(4) = 14.88 \text{ in}^2 \qquad G_4 = 2(2+4) = 12$$

$$A_8 = 2\left(\frac{1.6+2.52}{2}\right)(8) = 32.96 \qquad G_8 = 2(2+8) = 20$$

$$A_{12} = 2\left(\frac{1.6+2.92}{2}\right)(12) = 54.24 \qquad G_{12} = 2(2+12) = 28$$

$$A_{16} = 2\left(\frac{1.6+3.32}{2}\right)(16) = 78.72 \qquad G_{16} = 2(2+16) = 36$$

STATION 1

$$A_4 = 2\left(\frac{2+3.12}{2}\right)(4) = 20.48 \qquad G_4 = 2(2+4.12) = 12.24$$

$$A_8 = 2\left(\frac{2+4.20}{2}\right)(8) = 49.60 \qquad G_8 = 2(2+8.16) = 20.32$$

$$A_{12} = 2\left(\frac{2+5.33}{2}\right)(12) = 87.96 \qquad G_{12} = 2(2+12.4) = 28.8$$

$$A_{16} = 2\left(\frac{2+5.60}{2}\right)(13.2) + 2\left(\frac{5.60+7.20}{2}\right)(2.8) = 136.16 \qquad G_{16} = 2(2+16.8) = 39.6$$

STATION 2

$$A_4 = 2\left(\frac{2+4.4}{2}\right)(4) = 25.60 \qquad G_4 = 2(2+4.6) = 13.2$$

$$A_8 = 2\left(\frac{2+6.8}{2}\right)(8) = 70.40 \qquad G_8 = 2(2+9.4) = 22.8$$

$$A_{12} = 2\left(\frac{2+7.6}{2}\right)(9.4) + 2\left(\frac{7.6+9.0}{2}\right)(2.6) = 133.40 \qquad G_{12} = 2(2+14) = 32$$

$$A_{16} = 2\left(\frac{2+7.6}{2}\right)(9.4) + 2\left(\frac{7.6+11.2}{2}\right)(6.6) = 214.32 \qquad G_{16} = 2(2+18) = 40$$

STATION 3

$$A_4 = 2\left(\frac{2+6.2}{2}\right)(4) = 32.80 \qquad G_4 = 2(2+5.8) = 15.6$$

$$A_8 = 2\left(\frac{2+9.0}{2}\right)(6.6) + 2\left(\frac{9+9.8}{2}\right)(1.4) = 98.92 \qquad G_8 = 2(2+11.2) = 26.4$$

$$A_{12} = 2\left(\frac{2+9.0}{2}\right)(6.6) + 2\left(\frac{9+12}{2}\right)(5.4) = 186.00 \qquad G_{12} = 2(2+15.8) = 35.6$$

$$A_{16} = 2\left(\frac{2+9.0}{2}\right)(6.6) + 2\left(\frac{9+14.4}{2}\right)(9.4) = 292.56 \qquad G_{16} = 2(2+20.2) = 44.4$$

SECTION PROPERTIES

STATION 4

$A_4 = 2\left(\frac{2+8.4}{2}\right)(4) = 41.6$

$A_8 = 2\left(\frac{2+9.8}{2}\right)(4.8) + 2\left(\frac{9.8+11.6}{2}\right)(3.2) = 125.12$

$A_{12} = 2\left(\frac{2+9.8}{2}\right)(4.8) + 2\left(\frac{9.8+13.6}{2}\right)(7.2) = 225.12$

$A_{16} = 2\left(\frac{2+9.8}{2}\right)(4.8) + 2\left(\frac{9.8+15.6}{2}\right)(11.2) = 341.12$

$G_4 = 2(2+7.6) = 19.2$

$G_8 = 2(2+12.8) = 29.6$

$G_{12} = 2(2+17.2) = 38.4$

$G_{16} = 2(2+21.6) = 47.2$

STATION 5-10

$A_4 = 2\left(\frac{2+10}{2}\right)(4) = 48$

$A_8 = 2\left(\frac{2+10}{2}\right)(4) + 2\left(\frac{10+12}{2}\right)(4) = 136$

$A_{12} = 2\left(\frac{2+10}{2}\right)(4) + 2\left(\frac{10+14}{2}\right)(8) = 240$

$A_{16} = 2\left(\frac{2+10}{2}\right)(4) + 2\left(\frac{10+16}{2}\right)(12) = 360$

$G_4 = 2(2+8.8) = 21.6$

$G_8 = 2(2+13.2) = 30.4$

$G_{12} = 2(2+17.6) = 39.2$

$G_{16} = 2(2+22) = 48$

HYDROSTATICS

4" WL

STA	A	T.M	f(V)	LEVER	f(MOM)	G	T.M.	f(S)
0	14.58	½	7.44	10	74.40	12.00	½	6.00
1	20.48	1	20.48	9	184.32	12.24	1	12.24
2	25.60	1	25.60	8	204.80	13.20	1	13.20
3	32.80	1	32.80	7	229.60	15.60	1	15.60
4	41.60	1	41.60	6	249.60	19.20	1	19.20
5	48.00	1	48.00	5	240.00	21.60	1	21.60
6	48.00	1	48.00	4	192.00	21.60	1	21.60
7	46.00	1	48.00	3	144.00	21.60	1	21.60
8	48.00	1	48.00	2	96.00	21.60	1	21.60
9	46.00	1	48.00	1	48.00	21.60	1	21.60
10	48.00	½	24.00	0	0	21.60	½	10.80
			391.92		1662.72			185.04

$$\Delta = 2\frac{(32)(391.92)}{(1728)}(64) = 930^{\#}$$ 1.33

$$LCB = \left(\frac{32}{12}\right)\left(\frac{1662.72}{391.92}\right) = 11.3' \text{ FWD. TRANS.}$$

$$S = 2\frac{(32)(185.04)}{(144)} = 82.2 \text{ FT}^2$$ .444

$$A_T = \frac{2(48)}{144} = .667 \text{ FT}^2$$

HYDROSTATICS

8" WL

Sta.	A	T.M.	f(∇)	Lever	f(mom.)	G	T.M.	f(S)
0	32.96	½	16.48	10	164.80	20.00	½	10.00
1	49.60	1	49.60	9	446.40	20.32	1	20.32
2	70.40	1	70.40	8	563.20	22.60	1	22.60
3	98.92	1	98.92	7	692.44	26.40	1	26.40
4	125.12	1	125.12	6	750.72	29.60	1	29.60
5	136.00	1	136.00	5	680.00	30.40	1	30.40
6	136.00	1	136.00	4	544.00	30.40	1	30.40
7	136.00	1	136.00	3	408.00	30.40	1	30.40
8	136.00	1	136.00	2	272.00	30.40	1	30.40
9	136.00	1	136.00	1	136.00	30.40	1	30.40
10	136.00	½	68.00	0	0	30.40	½	15.20
			1108.52		4657.56			276.32

$$\Delta = 2\frac{(32)(1108.52)}{(1728)}(64) = 2622^{\#}$$

$$LCB = \left(\frac{32}{12}\right)\left(\frac{4657.56}{1108.52}\right) = 11.2' \text{ FWD. TRANS.}$$

$$S = 2\frac{(32)(276.32)}{(144)} = 122.70 \text{ FT}^2$$

$$A_T = \frac{2(136)}{144} = 1.89 \text{ FT}^2$$

HYDROSTATICS

12" WL

STA	A	T.M.	f(V)	LINE	f(MOM.)	G	T.M.	f(S)
0	54.24	½	27.12	10	271.20	28.00	½	14.00
1	87.96	1	87.96	9	791.64	28.80	1	28.80
2	133.40	1	133.40	8	1067.20	32.00	1	32.00
3	186.00	1	186.00	7	1302.00	35.60	1	35.60
4	225.12	1	225.12	6	1350.72	38.40	1	38.40
5	240.00	1	240.00	5	1200.00	39.20	1	39.20
6	240.00	1	240.00	4	960.00	39.20	1	39.20
7	240.00	1	240.00	3	720.00	39.20	1	39.20
8	240.00	1	240.00	2	480.00	39.20	1	39.20
9	240.00	1	240.00	1	240.00	39.20	1	39.20
10	240.00	½	120.00	0	0	39.20	½	19.60
			1979.60		8382.76			364.40

$$\Delta = \frac{2(32)(1979.60)}{1728}(64) = 4700$$

$$LCB = \left(\frac{32}{12}\right)\left(\frac{8382.76}{1979.60}\right) = 11.3' \text{ FWD. TRANS.}$$

$$S = \frac{2(32)(364.40)}{(144)} = 162 \text{ FT}^2$$

$$A_T = \frac{2(240)}{144} = 3.33 \text{ FT}^2$$

HYDROSTATICS

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16" WL

STA.	A	T.M.	f(▽)	LEVER	f(MOM)	G	T.M.	f(S)
0	78.72	½	39.36	10	393.60	36.00	½	18.00
1	136.16	1	136.16	9	1225.44	39.60	1	39.60
2	214.32	1	214.32	8	1714.56	40.00	1	40.00
3	292.56	1	292.56	7	2047.92	44.40	1	44.40
4	341.12	1	341.12	6	2046.72	47.20	1	47.20
5	360.00	1	360.00	5	1800.00	48.00	1	48.00
6	360.00	1	360.00	4	1440.00	48.00	1	48.00
7	360.00	1	360.00	3	1080.00	48.00	1	48.00
8	360.00	1	360.00	2	720.00	48.00	1	48.00
9	360.00	1	360.00	1	360.00	48.00	1	48.00
10	360.00	½	180.00	0	0	48.00	½	24.00
			3003.52		12828.24			453.20

$$\Delta = 2\frac{(32)(3003.52)}{(1728)}(64) = 7110^{\#}$$

$$LCB = \left(\frac{32}{12}\right)\left(\frac{12828.24}{3003.52}\right) = 11.4' \text{ FWD TRANS.}$$

$$S = 2\frac{(32)(453.20)}{144} = 201 \text{ FT}^2$$

$$A_T = 2\frac{(36.00)}{144} = 5 \text{ FT}^2$$

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ESTIMATED DRAG

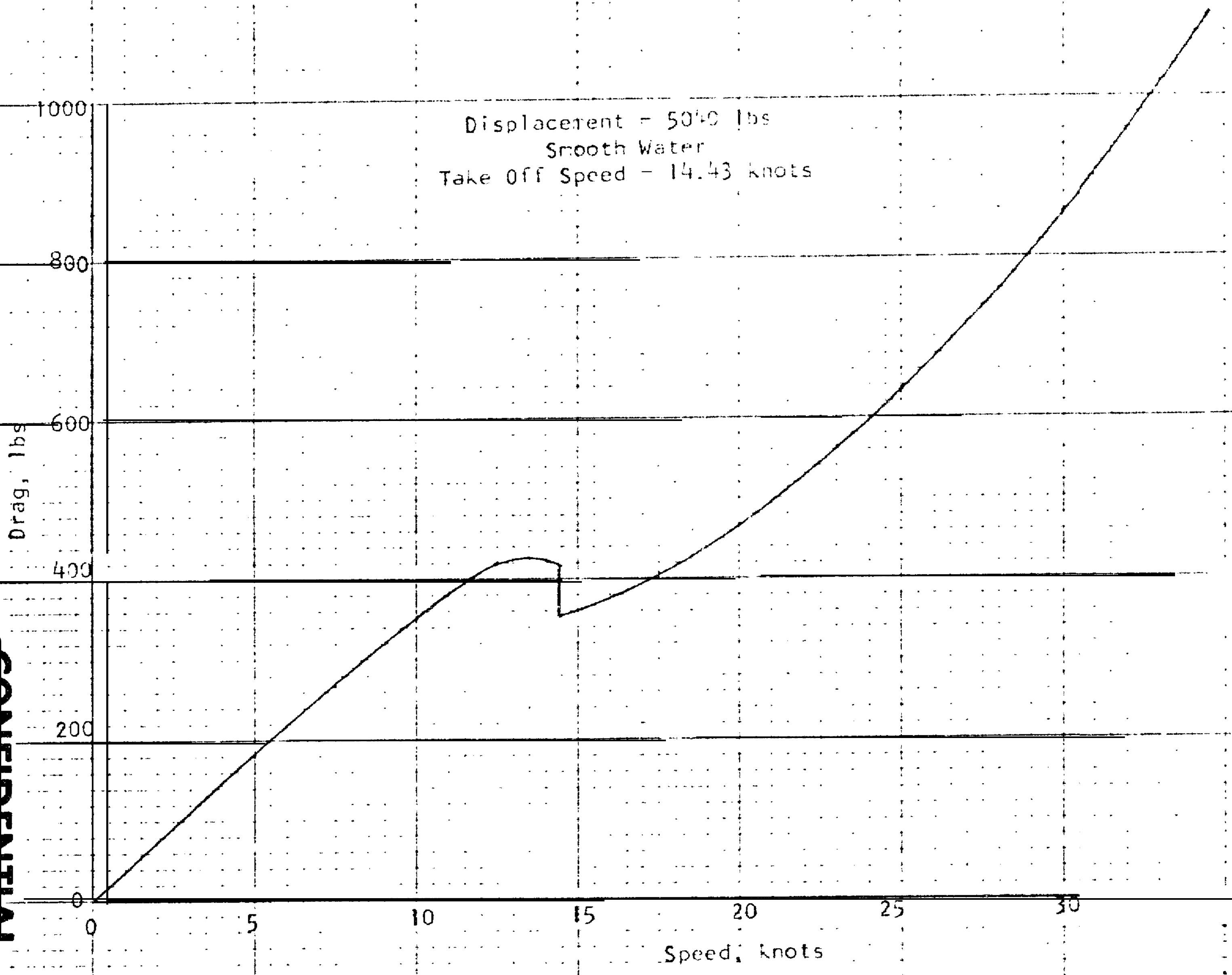

FIGURE H-2. DRAG CHARACTERISTICS

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Drag Summary

	Speed ~ Knots						
	5.77	8.66	11.55	14.43	14.43	23.09	34.64
Foil Assembly							
Foil Induced	20	46	81	127	137	57	20
Foil Profile	13	28	48	73	73	174	349
Strut Profile	8	16	27	42	29	69	148
Strut Spray	–	1	2	3	6	15	33
Interference	–	1	1	1	1	4	8
Fence Friction	2	4	6	9	7	17	35
Plate Assemblies							
Plate Induced	–	–	–	–	–	–	1
Plate Friction	5	12	20	30	30	71	151
Strut Profile	4	8	14	22	14	32	69
Strut Spray	–	–	–	–	7	18	41
Shaft	1	2	4	7	4	9	21
Shaft Spray	–	–	–	–	3	6	14
Tube	1	2	4	6	6	16	36
Rudders							
Rudder Friction	3	6	10	14	9	21	44
Rudder Spray	–	1	1	2	2	5	11
Rudder Cavity	15	15	15	15	7	7	7
Skis							
Ski Induced	–	1	2	3	3	6	14
Ski Friction	3	6	11	16	3	7	16
Hulls							
Hydro	142	152	147	33	–	–	–
Aero	2	4	8	13	13	33	73
	219	305	401	416	354	561	1111
	23.01	16.52	12.57	12.12	14.24	8.98	4.54

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INDUCED DRAG.

FOIL

V_k	V	q	C_l	S	L_f	AR	$\bar{c}$	h	$\frac{h}{\bar{c}}$	$\frac{C_l}{\alpha_i}$	α_i	D
5.77	9.76	95	.6936	12	791	12	1	1.67	1.67	27	.0257	20.33
8.66	14.64	211	.6936		1781						.0257	45.77
11.55	19.51	381	.6936		3171						.0257	81.49
14.43	24.39	595	.6936		4952						.0257	127.27
14.43	24.39	595	.6936	12	4952		1	1.167	1.167	25	.0277	137.17
23.09	39.03	1523	.2635		4816						.0105	50.57
34.64	58.54	3427	.1103		4536						.0044	19.96

PLATE

V_k	V	q	C_l	S	L_p	AR	$\bar{c}$	h	$\frac{h}{\bar{c}}$	$\frac{C_l}{\alpha_i}$	α_i	D_1	n	D
5.77	9.76	95	.0165	2.67	4	2.67	1	.83	.83	6.3	.0026	.01	2	.02
8.66	14.64	211	.0165		9						.0026	.02		.04
11.55	19.51	381	.0165		17						.0026	.04		.08
14.43	24.39	595	.0165		26						.0026	.07		.14
14.43	24.39	595	.0165	2.67	26			.33	.33	4.8	.0034	.09	2	.18
23.09	39.03	1523	.0165		67						.0034	.23		.46
34.64	58.54	3427	.0165		151						.0034	.51		1.02

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INDUCED DRAG

SKI

V_k	V	q	C_f	k	L_s	τ	$L\tau$	D_i	n	D
5.77	9.76	95	.066	.67	3	4	.0699	.21	2	.42
8.66	14.64	214	.066		6			.42		.84
11.55	19.51	381	.066		11			.77		1.54
14.43	24.39	595	.066		18			1.26		2.52
14.43	24.39	595	.066	.67	18			1.26	2	2.52
23.09	39.03	1523	.066		45			3.15		6.30
34.64	58.54	3427	.066		101			7.06		14.12

NOT PRECISE BUT NEGLIGIBLE

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Hull Drag

V_k	V	q	L_{tot}	Δ	d	S	A_r	l	R_e	C_f	C_F	D_F	D_r	D
5.77	9.76	95	805	4235	.942	154	3.05	26.67	2.09×10^7	.0026	.0031	49.74	91.94	141.68
8.66	14.61	214	1811	3229	.775	135	2.35		3.15	.00244	.00324	93.60	58.28	151.88
11.55	19.51	381	3227	1813	.525	105	1.30		4.20	.00233	.00313	125.22	21.84	147.06
14.43	24.39	595	5040	0	0	18	0		5.26	.00228	.00308	32.99	0	32.99

$$D_r = \left(\frac{d}{2}\right)(64)\,A_r = 32\,d\,A_r$$

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Parasitic Drag

Foil Profile Drag

$D = C_d q S$

$C_{d_0} = 2(C_f + .0008)(1.2\, t/c + 1)$

V_k	V	q	c	R_e	C_f	t/c	C_d	S	D
5.77	9.76	95	1	2.87×10^5	.0046	.075	.01177	12	13.42
8.66	14.64	214		1.18×10^6	.00425		.01101		28.27
11.55	19.51	381		1.57	.00402		.01051		48.05
14.43	24.39	595		1.97	.00387		.01618		72.69
14.43	24.39	595	1	1.97	.00387	.075	.01018	12	72.69
23.09	39.03	1523		3.15	.00356		.00950		173.62
34.64	58.54	3427		4.72	.00332		.00898		369.29

Strut Profile Drag

$D = C_d q S$

$C_{d_0} = 2(C_f + .0008)(1.2\, t/c + 1)$

V_k	V	q	c	R_e	C_f	t/c	C_d	S	D
5.77	9.76	95	1	2.87×10^5	.0046	.10	.01210	6.67	7.67
8.66	14.64	214		1.18×10^6	.00425		.01131		16.14
11.55	19.51	381		1.57	.00402		.01080		27.45
14.43	24.39	595		1.97	.00387		.01046		41.51
14.43	24.39	595	1	1.97	.00387	.10	.01046	4.67	29.06
23.09	39.03	1523		3.15	.00356		.00977		69.49
34.64	58.54	3427		4.72	.00332		.00923		147.72

Strut Spray Drag

$D = C_d q t^2 n$

$C_{d_0} = .24$

V_k	V	q	t	t^2	C_d	n	D
5.77	9.76	95	.10	.01	.24	2	.46
8.66	14.64	214					1.03
11.55	19.51	381					1.83
14.43	24.39	595					2.86
14.43	24.39	595	.10	.01	.24	4	5.71
23.09	39.03	1523					14.62
34.64	58.54	3427					32.90

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PARASITIC DRAG

STRUT - FOIL INTERFERENCE DRAG

$$D = C_d (t)^2 q n$$
$$C_d = (17)(t/c)^2 - .05$$

V_k	V	q	(t/c)	C_d	t	n	D
5.77	9.76	95	.0875	.0802	.0875	4	.23
8.66	14.64	214					.53
11.55	19.51	381					.94
14.43	24.39	595					1.46
14.43	24.39	595	.0875	.0802	.0875	4	1.46
23.09	39.03	1523					3.74
34.64	58.54	3427					8.42

FENCE FRICTION DRAG

$$D = C_d q S$$
$$C_d = 2(C_f + .0008)$$

V_k	V	q	l	R_e	C_f	C_d	S	D
5.77	9.76	95	1	7.87×10^5	.0046	.0108	1.67	1.71
8.66	14.64	214		1.18×10^6	.00425	.0101		3.61
11.55	19.51	381		1.57	.00402	.00964		6.13
14.43	24.39	595		1.97	.00387	.00934		9.28
14.43	24.39	595		1.97	.00387	.00934	1.25	6.95
23.09	39.03	1523		3.15	.00356	.00872		16.60
34.64	58.54	3427		4.72	.00332	.00824		35.30

PARASITIC DRAG

PLATE FRICTION DRAG

$$D = C_D q S$$
$$C_D = 2(C_f + .0008)$$

V_k	V	q	$\bar{c}$	R_e	C_f	C_D	S	D
5.77	9.76	95	1	7.87×10^5	.0046	.0108	5.33	5.47
8.66	14.64	214		1.18×10^6	.00425	.0101		11.52
11.55	19.51	381		1.57	.00402	.00964		19.58
14.43	24.39	595		1.97	.00387	.00934		29.62
14.43	24.39	595	1	1.97	.00387	.00934	5.33	29.62
23.09	39.03	1523		3.15	.00356	.00872		72.79
34.64	58.54	3427		4.72	.00332	.00824		150.51

STRUT PROFILE DRAG

$$D = C_D q S$$
$$C_D = 2(C_f + .0008)(1.2\,t/c + 1)$$

V_k	V	q	c	R_e	C_f	t/c	C_D	S	D
5.77	9.76	95	1.33	1.05×10^6	.00435	.1188	.01177	3.56	3.98
8.66	14.64	214		1.57	.00402		.01101		8.39
11.55	19.51	381		2.10	.00382		.01056		14.32
14.43	24.39	595		2.62	.00369		.01026		21.73
14.43	24.39	595	1.33	2.62	.00369		.01026	2.22	13.55
23.09	39.03	1523		4.20	.00339		.00957		32.36
34.64	58.54	3427		6.29	.00317		.00907		69.00

STRUT SPRAY DRAG

$$D = C_D t^2 q n$$
$$C_D = .24$$

V_k	V	q	t	C_D	n	D
5.77	9.76	95	.1583	.24	0	
8.66	14.64	214				
11.55	19.51	381				
14.43	24.39	595				
14.43	24.39	595	.1583	.24	2	7.16
23.09	39.03	1523				18.33
34.64	58.54	3427				41.24

Shaft Drag (cross flow)

$D = C_D\, q\, A$
$C_D = (1) \sin^3 \alpha$
$A = d\, l$

V_k	V	q	α	C_D	d	l	A	D
5.77	9.76	95	14.71	.0164	.0938	2.50	.2035	1.10
8.66	14.64	214						2.47
11.55	19.51	351						4.40
14.43	24.39	595						6.86
14.43	24.39	595	14.71	.0164	.0938	4.00	.3752	3.66
23.09	39.03	1523						9.37
34.64	58.54	3427						21.09

Shaft Spray Drag

$D = C_D\, q\, d^2 n$
$C_D = .24$

V_k	V	q	d	C_D	n	D
5.77	9.76	95	.0938	.24	0	0
8.66	14.64	214				0
11.55	19.51	381				0
14.43	24.39	595				0
14.43	24.39	595	.0938	.24	2	2.51
23.09	39.03	1523				6.43
34.64	58.54	3427				14.47

Tube Drag (cross flow)

$D = C_D\, q\, A$
$C_D = (1) \sin^3 \alpha$
$A = d\, l$

V_k	V	q	α	C_D	d	l	A	D
5.77	9.76	95	14.71	.0164	.1563	4.00	.6332	.99
8.66	14.64	214						2.22
11.55	19.51	381						3.96
14.43	24.39	595						6.18
14.43	24.39	595	14.71	.0164	.1563	4.00	.6332	6.18
23.09	39.03	1523						15.82
34.64	58.54	3427						35.59

Parasitic Drag

Rudder Friction Drag

$D = C_d q S$

$C_d = 2(C_f + .0005)$

V_K	V	q	$\bar{c}$	R_e	C_f	C_d	S	D
5.77	9.76	95	.75	5.90×10^5	.00465	.01136	2.50	2.70
8.66	14.64	214		8.85	.00449	.01058		5.66
11.55	19.51	381		1.18×10^6	.00425	.0101		9.62
14.43	24.39	595		1.48	.00407	.00974		14.49
14.43	24.39	595	625	1.23×10^6	.00421	.01002	1.46	8.70
23.09	39.03	1523		1.97	.00387	.00934		20.77
34.64	58.54	3427		2.95	.0036	.0088		44.03

Rudder Spray Drag

$D = C_d q t^2 n$

$C_d = .24$

V_K	V	q	t	C_d	n	D
5.77	9.76	95	.0833	.24	2	.32
8.66	14.64	214				.71
11.55	19.51	381				1.27
14.43	24.39	595				1.98
14.43	24.39	595	.0833	.24	2	1.98
23.09	39.03	1523				5.08
34.64	58.54	3427				11.42

Rudder Cavity Drag

$D = (64)\left(\frac{\ell}{2}\right)(\ell)(t)n$

V_K	ℓ	t	n	D
5.77	1.67	.0833	2	14.87
8.66				14.87
11.55				14.87
14.43				14.87
14.43	1.167	.0833	2	7.26
23.09				7.26
34.64				7.26

PARASITE DRAG

SKIN FRICTION DRAG

$$D = C_D q S$$
$$C_D = C_f + .0008$$

V_k	V	q	ℓ	R_e	C_f	C_D	S	D
5.77	9.76	95	5.5	4.33 × 10^6	.00337	.00417	2.37	2.92
8.66	14.64	214		6.49	.00315	.00395		6.23
11.55	19.51	381		8.65	.00299	.00379		10.64
14.43	24.39	595		1.08 × 10^7	.00288	.00368		16.14
14.43	24.39	595	.80	1.57 × 10^6	.00402	.00482	1.07	3.07
23.09	39.03	1523		2.52	.0037	.0045		7.33
34.64	58.54	3427		3.78	.00345	.00425		15.58

AERODYNAMIC DRAG

$$D = C_D q A$$
$$C_D = .5$$

V_k	V	q	C_D	A	D
5.77	9.76	.11	.50	36	1.98
8.66	14.64	.25			4.50
11.55	19.51	.45			8.10
14.43	24.39	.71			12.78
14.43	24.39	.71	.50	36	12.78
23.09	39.03	1.81			32.58
34.64	58.54	4.07			73.26

ESTIMATED THRUST AND TORQUE

PROPELLER CHARACTERISTICS

The propellers were modified subsequent to completing the builder's trials by increasing the pitch and bending the trailing edge down to form a "full cup" blade contour. The characteristics of the original and modified propeller are listed in the following table:

	Original (Columbian Bronze "Mako" Style)	Modified
Diameter, in	13½	13½
Pitch (effective)	16	18.9 (estimated)
P/D	1.2	1.4
Blade Area Ratio	0.77	0.77
Rotation	Left Hand	Left Hand
Material	Manganese Bronze	Many. Bronze

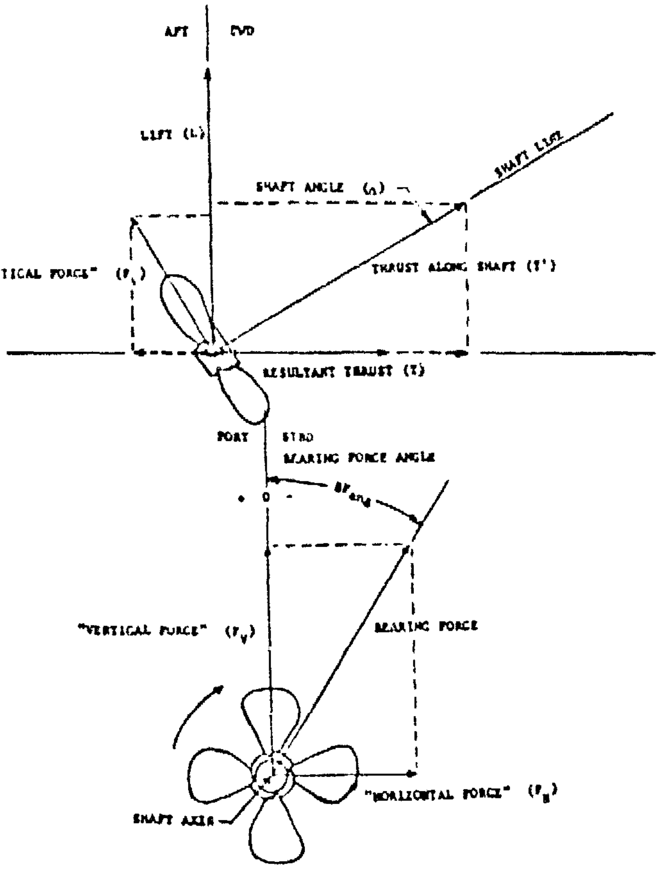
THRUST AND TORQUE ESTIMATES

Axial Flow

Estimates of thrust and torque for the two alternative versions of the propellers were made on the basis of data published by Gawn and Burrill, "Effect of Cavitation on the Performance of a Series of 16-in Model Propellers," Transactions, Institution of Naval Architects, 1957. "Maps" of propeller thrust and torque, as a function of propeller RPM and vessel speed for axial flow conditions taking account of the development of cavitation, are given in the accompanying Figures I-2 to I-5. Lines of constant advance coefficient, J = speed of advance/ (Diam x rps), are included in these figures.

Inclined Shaft Effects

Only a very few published investigations treat the effect of shaft inclination on the complete system of forces acting on marine propellers and even fewer include effects of cavitation, The only complete set of experimental investigations of propeller performance characteristics with inclined shaft and cavitation was recently reported by Peck and Moore to the Spring Meeting of the Society of Naval Architects and Marine Engineers in April 1973. This reference gives complete tabulated information for four commercial-type propellers, having four blades and differing pitch ratios. The force diagram in the sketch below indicates the method of resolving the force components and of presenting results:



Sketch I-1, From Peck and Moore Paper

Comparable results for three-bladed propellers (or, indeed, any other propellers) are not yet available. Consequently, for the purposes of the present investigations, an attempt will be made to generalize these results as much as possible for purposes of analysis of results of tests with the 1/3-scale model of SKI-CAT. Two kinds of analysis problems will be considered: (1) the case of the builder's trials, where vessel speed and propeller RPM are known and it is desired to estimate the propeller thrust for preliminary comparison with the predicted drag, and (2) the case of the comprehensive trials, where vessel speed, propeller RPM and shaft torque are measured and it is desired to derive the propeller thrust. These cases will be considered separately.

(1) Known Speed and RPM

In this case, one can obtain the expected thrust developed by the propellers, in axial flow, from the curves presented in the previous section, which include a dependency on cavitation index, To estimate the effects of shaft inclination on thrust developed, the data presented by Peck and Moore have been plotted in Figure 1-6 in the form of the ratio of the horizontal component of thrust at 15-deg shaft inclination to that at 0-deg inclination as a function of $J/\frac{P}{D}$ ($\approx$1-"slip") for one of the propellers tested. This generalized presentation shows that in the region $J/\frac{P}{D} \approx 0.85$, which is approximately the operating point for the ski-cat propellers, the axial-flow thrust should be modified by a factor which depends on the craft speed (cavitation index). Figure 1-7 shows the multiplying factor as a function of craft speed corresponding to $J/\frac{P}{D} \approx 0.85$ for three propellers : there are differences among the rzsults, but the trends are generally similar. The amount of scatter of the multiplying factor is rather greater than hoped for, but it appears preferable to apply the correction, especially at higher speed, instead of ignoring the effect of shaft inclination.

Other factors could affect the thrust developed by the propeller; for instance, a possibility of air-drawing down the inclined propeller shaft. It is not possible to account for factors such as these for the present analyses. However, the approximate analysis described above has been used to analyze the extended builder's trials results (presented in the text of this report).

(2) Measured Torque, RPM and Speed

For the comprehensive trials, torsion meters will be fitted in the propeller shaft, inboard of the stuffing box. With this measured data improved estimates of thrust can be obtained since both thrust and torque are composed of suitably resolved components of the blade element lift and drag.

The axial-flow thrust for a given torque, RPM and speed may be estimated by correcting the thrust obtained from Figure I-5 for the measured speed and RPM by the ratio of measured torque to the torque obtained from Figure I-4 for the same speed and RPM. This value should then be corrected further to approximately account for shaft inclination affects. The final estimate would be expressed as

$$T_{corr,incl} = T(V,RPM)_{axial} \cdot \left\{\frac{Q_{measured}}{Q(V,RPM)_{axial}}\right\} \cdot \left\{\frac{T(V,RPM)_{incl}}{T(V,RPM)_{axial}}\right\} \cdot \left\{\frac{Q(V,RPM)_{axial}}{Q(V,RPM)_{incl}}\right\}$$

or,

$$T_{corr,incl} = T(V,RPM)_{axial} \cdot \left\{\frac{Q_{measured}}{Q(V,RPM)_{axial}}\right\} \cdot \left\{\frac{TD/Q_{incl}}{TD/Q_{axial}}\right\}$$

where

$T(V,RPM)_{axial}$ is found in Figure I-4 (modified prop)

$Q(V,RPM)_{axial}$ is found in Figure I-5 (modified prop)

and the ratio $(TD/Q)_{incl}/(TD/Q)_{axial}$ must be estimated from the published data of Peck and Moore. Figure I-8 shows the effect of cavitation index and advance coefficient on this ratio for 15-deg shaft inclination for one of the propellers tested, Figure I-9 gives values of this ratio as a function of speed for three propellers, all at $J/\frac{P}{D} \approx 0.85$. It is suggested that these results be applied for analyses of comprehensive trials results.

ORIGINAL PROPELLER
(Builder's Trials)

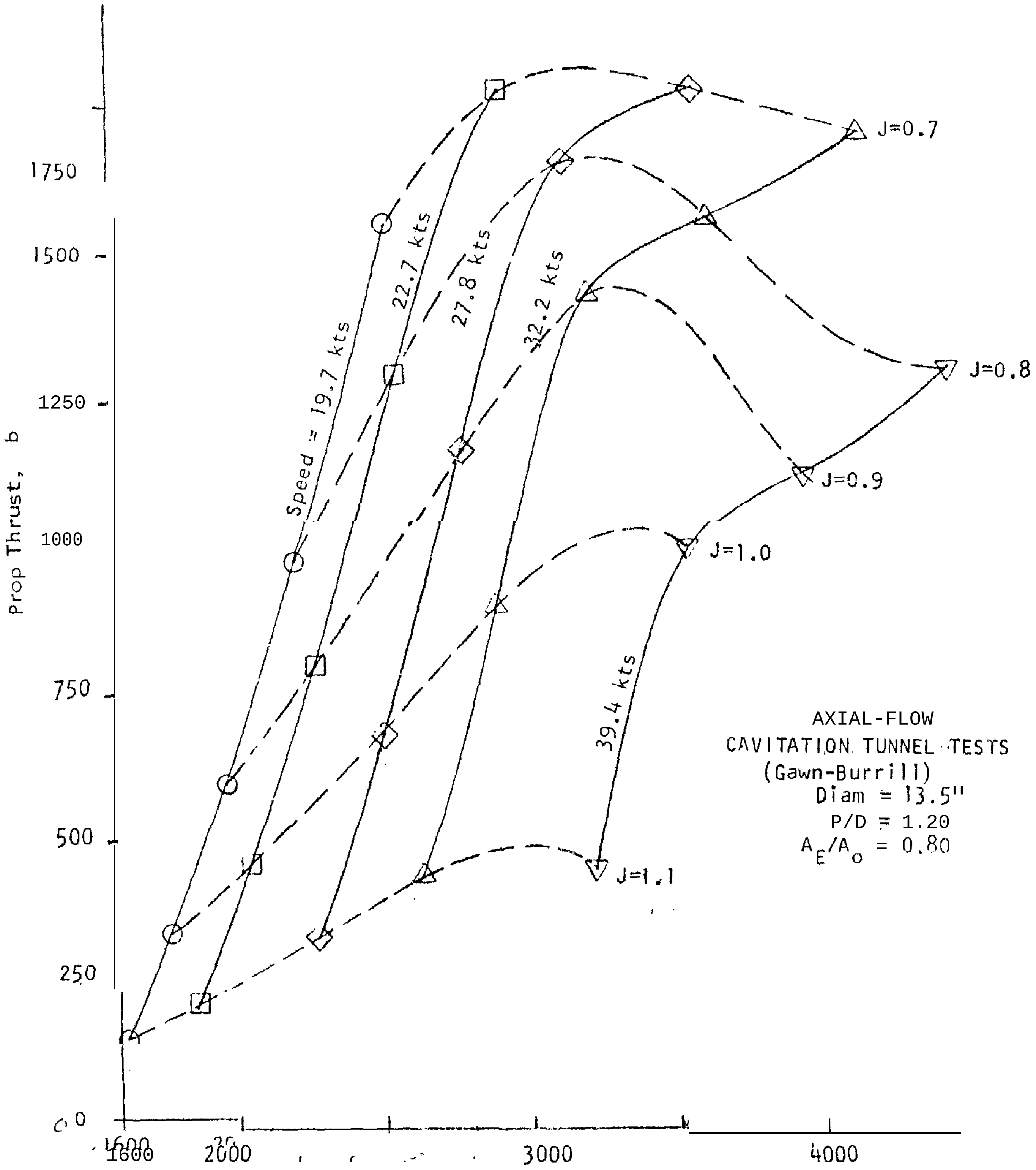


FIGURE 1-2. ORIGINAL PROPELLER
(BUILDER'S TRIALS)

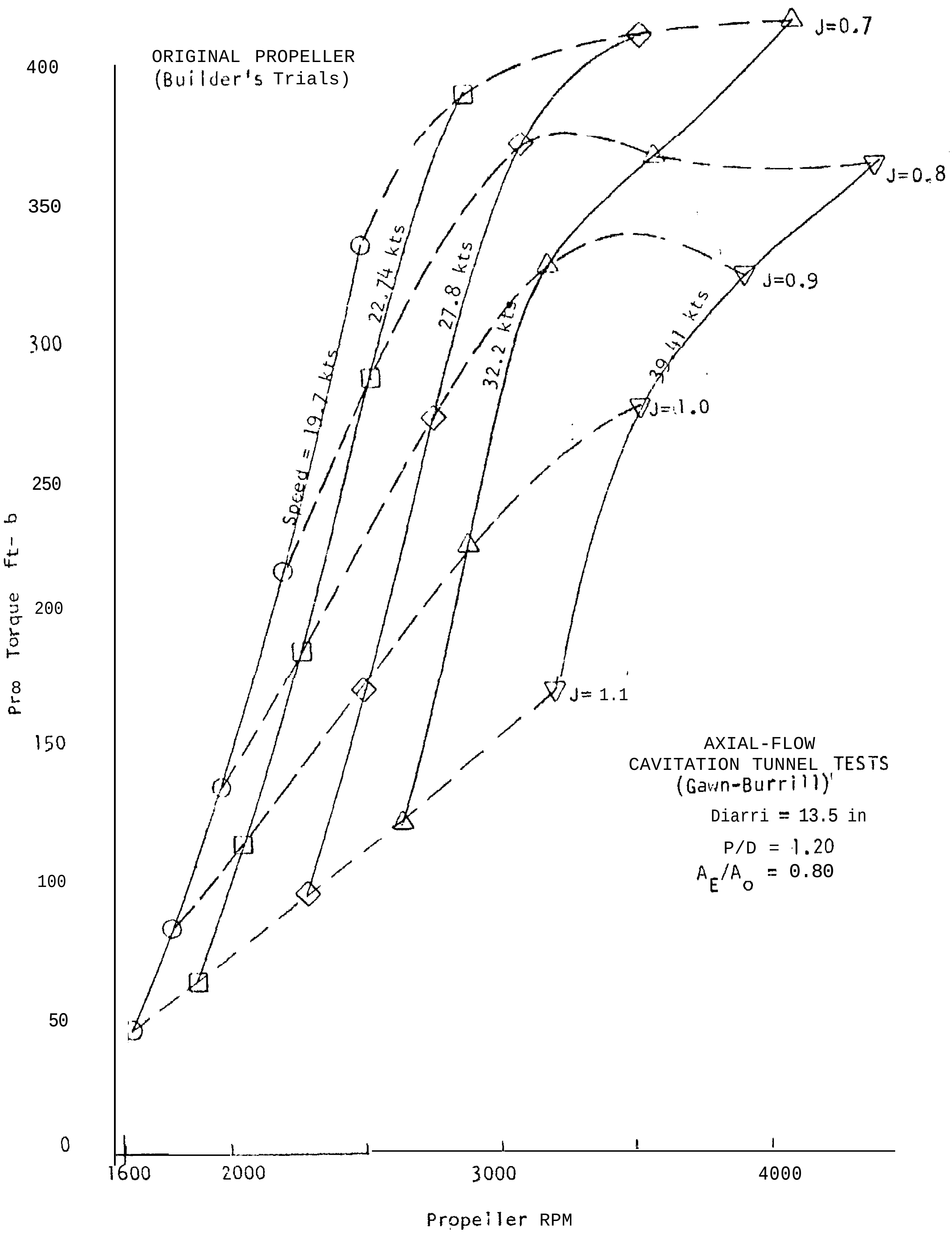


FIGURE 1-3. ORIGINAL PROPELLER
(BUILDER'S TRIALS)

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Modified Propeller
(Sept 1973)

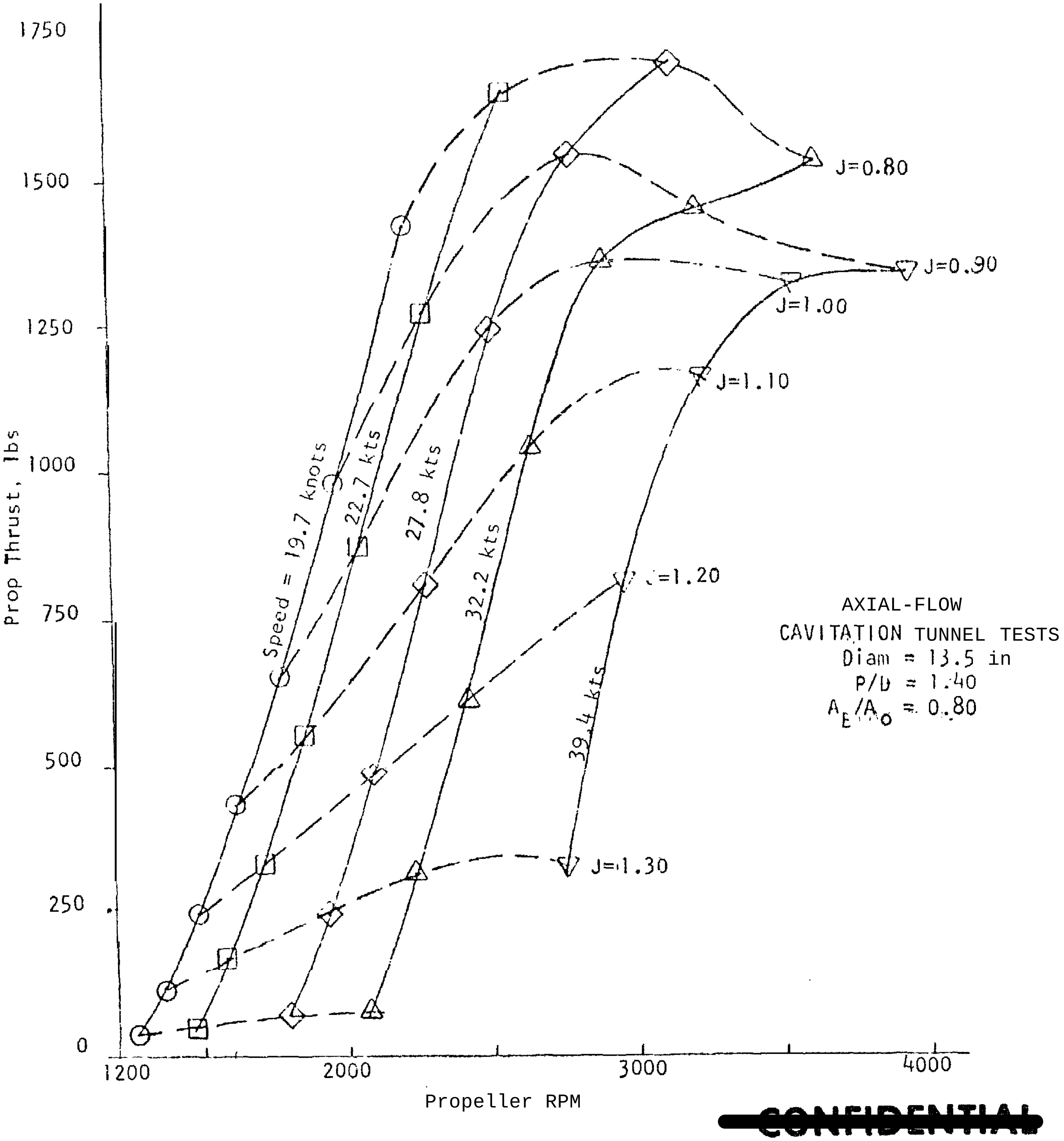

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FIGURE 1-4. MODIFIED PROPELLER (Sept 1973)

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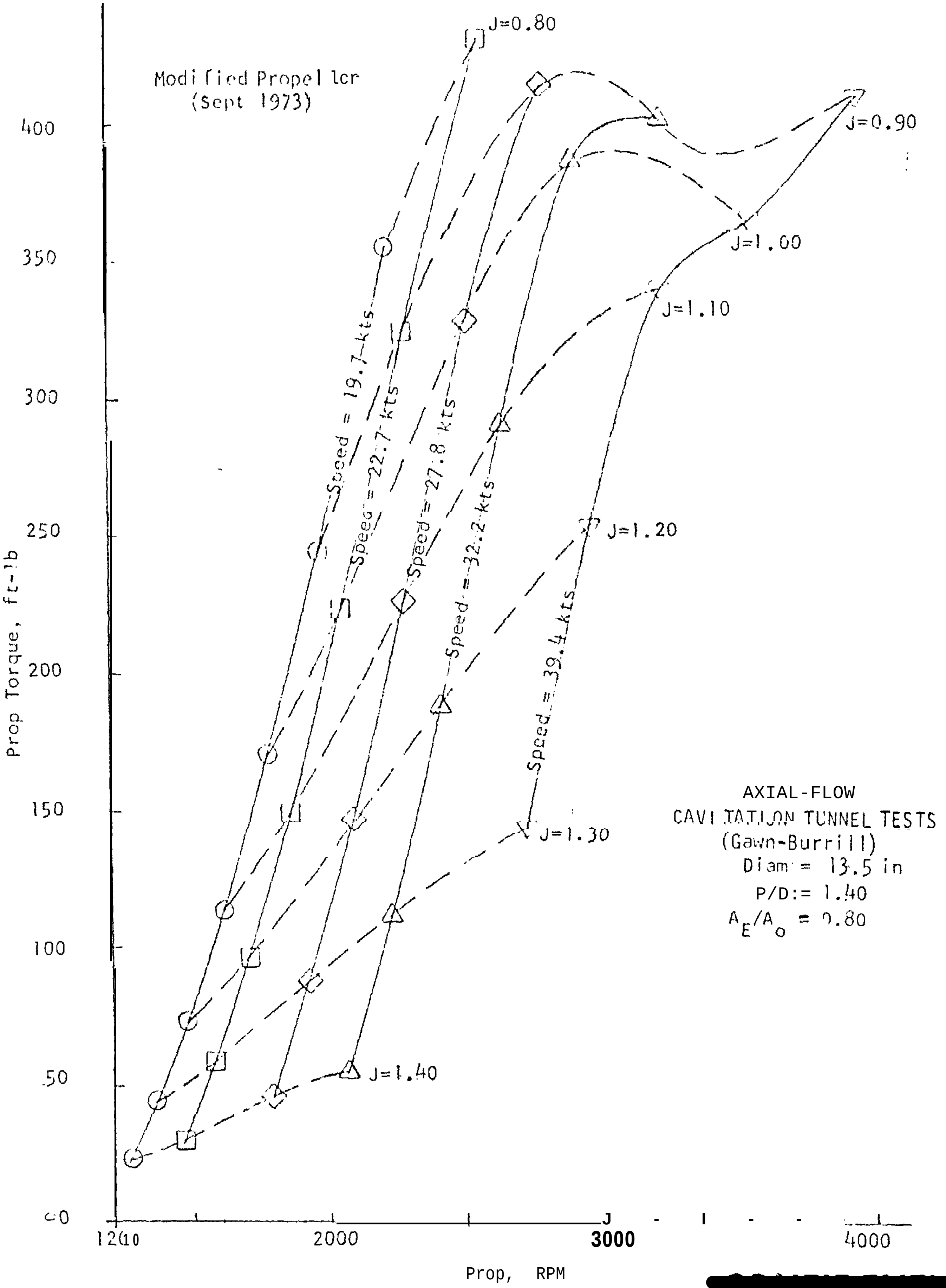

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FIGURE **I-5.** MODIFIED PROPELLER (Sept 1973)

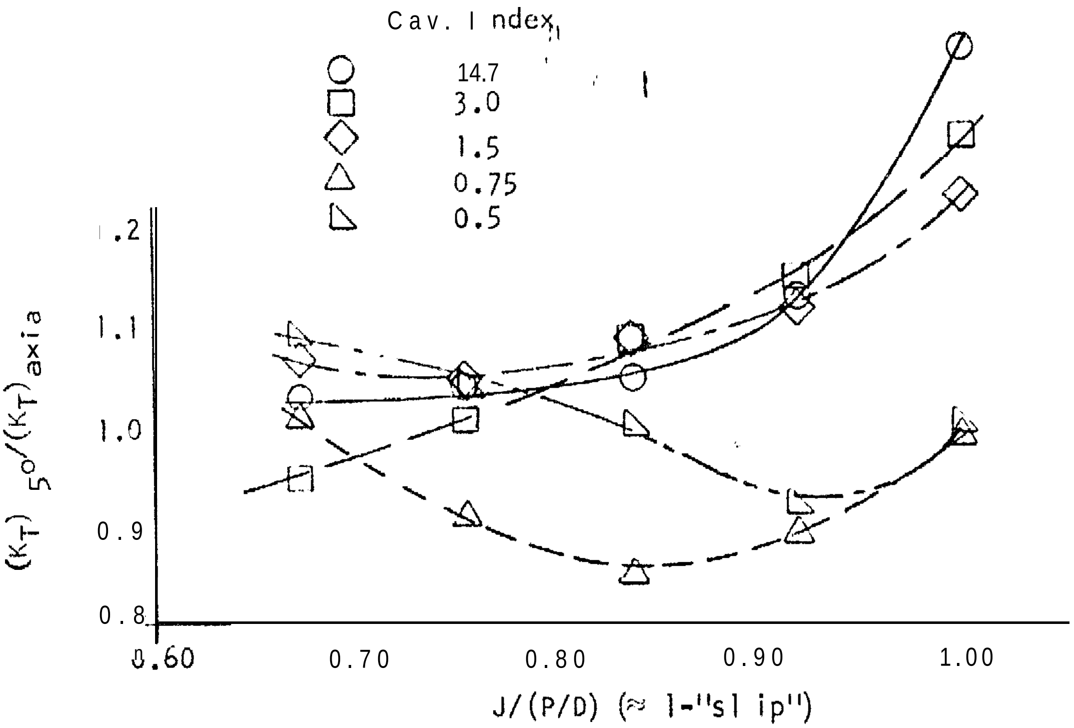


FIGURE 1-6. EFFECT OF CAVITATION INDEX AND ADVANCE COEFFICIENT ON RATIO OF THRUST FOR 15-DEG SHAFT INCLINATION TO THRUST IN AXIAL FLOW. REF: PECK AND MOORE, PROPELL 4530, P/D = 1.19.

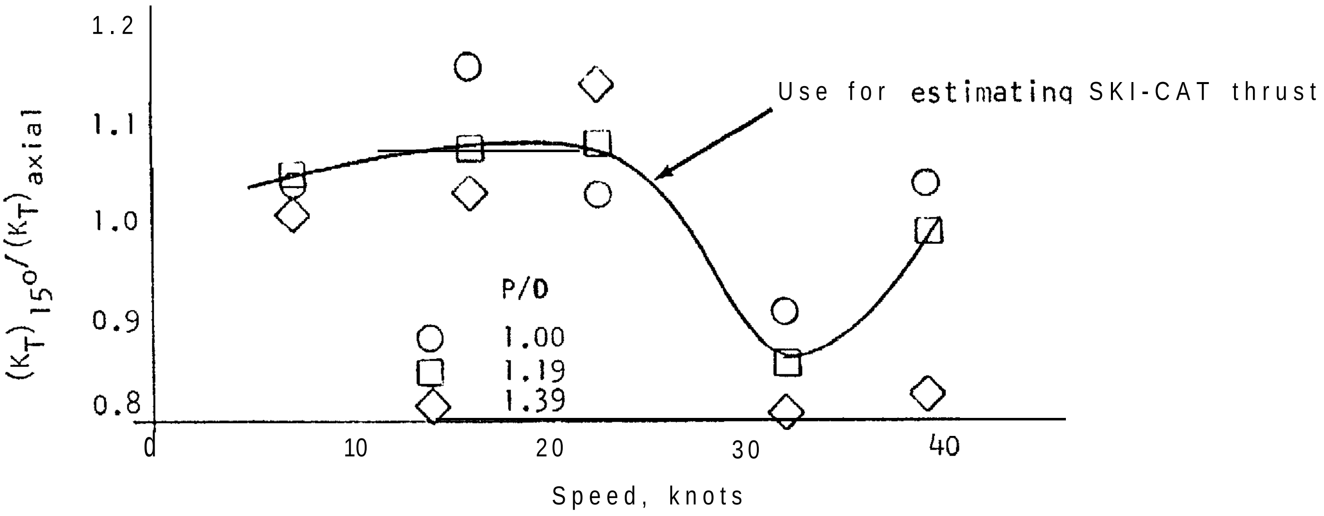


FIGURE 1-7. EFFECT OF SPEED ON RATIO OF THRUST FOR 15-DEG SHAFT INCLINATION TO THRUST IN AXIAL FLOW, J/(P/D) ≈ 0.85.

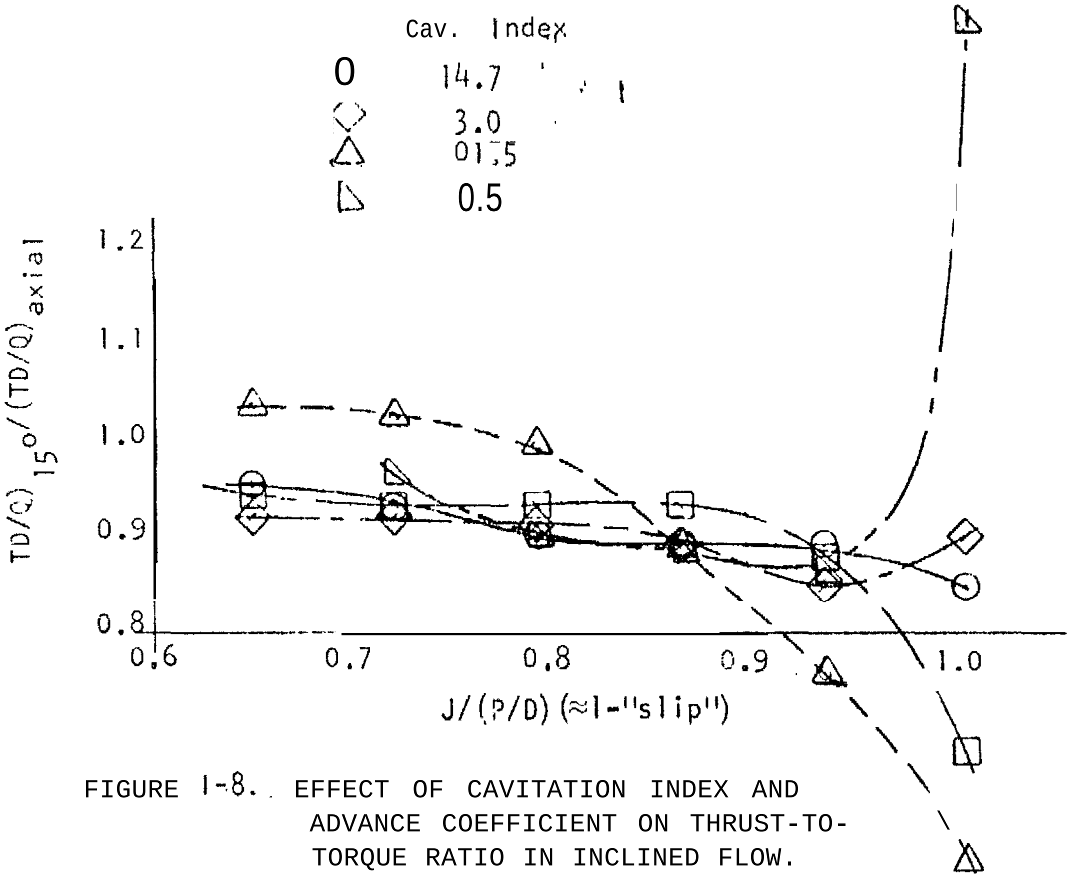
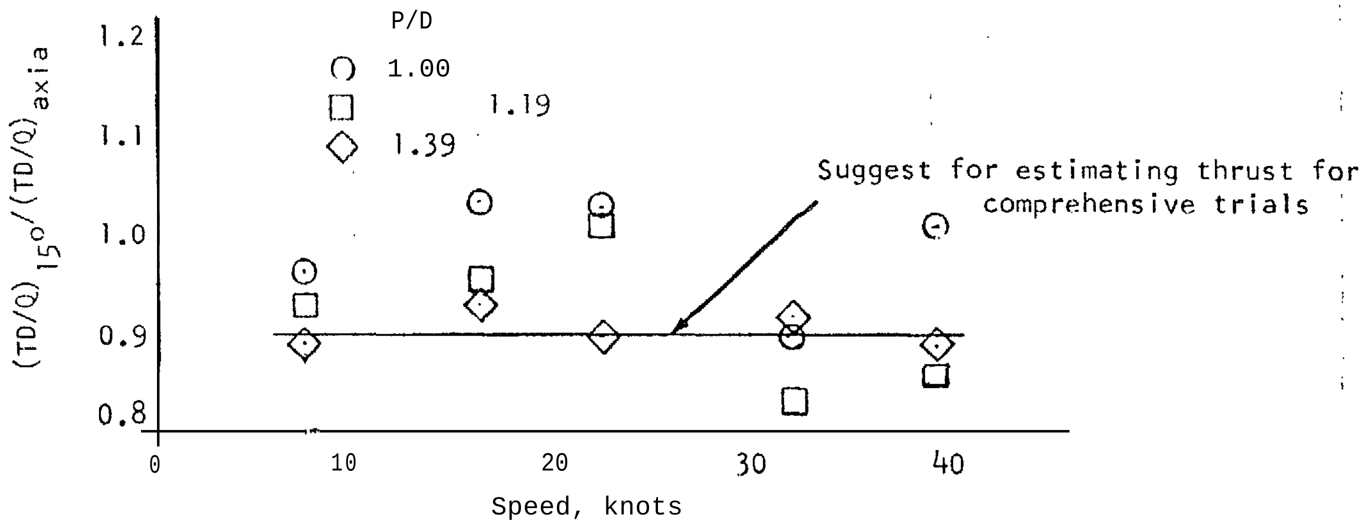


FIGURE I-8. EFFECT OF CAVITATION INDEX AND ADVANCE COEFFICIENT ON THRUST-TO-TORQUE RATIO IN INCLINED FLOW.
REF: PECK AND MOORE, PROPELLER 4531, P/D = 1.39



Suggest for estimating thrust for comprehensive trials

FIGURE I-9., EFFECT OF SPEED ON THRUST TO TORQUE RATIO IN INCLINED FLOW, $J/(P/D) \approx 0.85$.

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