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WOODS HOLE OCEANOGRAPHIC INSTITUTION

TECHNICAL MEMORANDUM #DS-25

TESTS OF PROPELLERS FOR ALVIN SIDE PROPULSION UNITS

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by

Arnold G. Sharp and James R. Sullivan

July 1967

This work has been carried out under Contract Nonr-3484(00), NR 260-107 with the Office of Naval Research.

ABSTRACT

Full scale dynamometer tests were run on a series of unshrouded propellers in the range of propeller diameters considered practical for use on the side propulsion units of the research submarine ALVIN. Measurements taken included static thrust, torque, and RPM for various values of hydraulic power input to the driving motor.

In other tests, propellers having 14 inch diameter and 20 inch pitch (the present ALVIN configuration) were compared for static thrust as follows: conventional blade shape, unshrouded; conventional blade shape in ALVIN flow-accelerating nozzle unit; square-ended blades in ALVIN nozzle unit.

Recommendations are given concerning the proposed new ALVIN side propulsion units.

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I INTRODUCTION AND DESCRIPTION OF TESTS

The operators of the deep-diving research submarine DSRV ALVIN have indicated that the side propulsion units, as originally installed on the vehicle, are not capable of producing the desired amount of thrust, especially during emergency braking or in other high-propeller-load situations. To improve this aspect of the vehicle's propulsion system, it is contemplated that new side units will be designed and constructed in the near future.

The present series of tests was undertaken as the first step in the new design, in an effort to determine (a) the optimum size of side propeller for the existing ALVIN propulsion plant, and (b) how much advantage is gained through the use of a flow-accelerating duct or nozzle.

It was decided to do full scale tests for several reasons. First, direct thrust readings could be obtained and scale factor corrections would not be necessary. Secondly, readily available full-size propellers could be used; and finally, full scale testing would permit the use of one of the present ALVIN side propulsion units attached to the test dynamometer.

All tests were done in one of the WHOI concrete salt water tanks. Tank size is approximately 9 feet X 18 feet X 5 feet deep. A bridge of heavy timber was built across the width of the tank at about mid-length, and clamped in place. The test dynamometer was then supported by trunnions from this bridge (see Figure 2). The basic parts of the test unit are: the propeller shaft, which runs in a split Teflon-lined bearing; the propeller, mounted on one end of the shaft; and the ORBIT-A hydraulic motor, shaft-mounted on the other end. The torque arm, fastened to the motor, constrains the housing from rotating and permits measurements of reaction torque. Load cells consist of tension bars made from strips of sheet steel to which are fastened electrical resistance strain gages. These load cells were calibrated in the laboratory prior to the tests, using dead weights.

Hydraulic power was supplied by a Greer hydraulic test stand capable of supplying pressures up to 3000 p.s.i. and flows up to about 12 G.P.M. The test motor was connected to the hydraulic pump unit using 1/2 inch I.D. hydraulic hose. A portable flow meter was located in the return line.

For each propeller selected, three complete tests were made, and the results were averaged. During each test, the hydraulic flow was varied over the range 2 G.P.M. to about 7 or 8 G.P.M., depending on the propeller under test. In general, maximum pressure was held at 1500 p.s.i., the rated maximum for the ORBIT-A motor, but this value was exceeded in a few cases, for brief periods of time, in order to insure a sufficient number of test points.

Rotational speed was obtained in the unshrouded tests by means of a small magnet fastened to the propeller shaft and a magnetic-reed proximity switch fixed close to the path of the moving magnet. Revolutions were read directly from an electronic counter.

In the tests of the actual ALVIN side propeller unit, readings of torque and RPM were omitted.

Since time did not permit the construction of Kort-type nozzles for the various propeller diameters tested, the tests of the ALVIN side propulsion unit provided the necessary comparison of the unshrouded and ducted conditions for the 14 inch diameter only. This comparison was then used to estimate the ducted performance of the larger diameter wheels.

In the ducted tests, two basic blade forms were tested. The first was the typical rounded-blade shape used almost exclusively in non-ducted applications (referred to as "conventional" elsewhere in this report). This is the blade pattern originally used with the Kort-type nozzle units of ALVIN. The second form (referred to elsewhere as "square-ended" or "square-tipped") had wide blade tips, not actually square, but machined on a lathe for close conformity with the inside wall of the nozzle. Tip clearance in the ALVIN 14 inch duct varied from 1/16 inch to 1/8 inch, owing to a slight out-of-roundness of the ALVIN units.

II RESULTS

The results obtained in these tests are presented in tabular form. Table 1. shows the results of the unshrouded tests of eight different propellers, while Table 2. gives the results of the tests of the 14 X 20 diameter-pitch combination presently in use on ALVIN. These results also are presented graphically, along with predicted values of thrust for some other propeller-nozzle combinations, in Figure 6.

Referring to the computation sheets (Appendix C) it can be seen that the Thrust/Input Horsepower ratio was not constant for a given propeller, but rather had relatively high values at low horsepower, then decreased, and appeared to level off at higher horsepowers. This meant that comparisons between propellers would have to be made at some particular value of input horsepower. The selection of this value was based on the fact that the performance of the side or "lift" propellers in the "emergency stop" condition is probably of greatest interest. A value of 75 amperes of current drain (for each side propulsion unit) was established as representing this emergency condition. Using average values of efficiencies of electric motor, variable volume pump, and hydraulic motor as obtained in tests of these components done by Litton (Ref. 1), the value 3.2 input horsepower to the hydraulic motor was determined as the basis for comparison. (See Figure 1.)

It should be noted that the usual expression for propeller efficiency (Ref. 3) involves the speed of advance of the propelled vehicle, and therefore cannot be used in the static thrust situation. In the work described herein, the ratio of static thrust (pounds) to hydraulic horsepower input to the driving motor is used as a measure of propeller efficiency.

Table 1

Performance of Various Unshrouded Propellers

at 3.2 Hydraulic Horsepower
(3 bladed except where noted)

D inches	P inches	Pressure psi	Flow GPM	Speed RPM	Thrust lbs
14	20	940	5.83	392	97
16	16	920	5.97	395	121
18[a]	14	960	5.72	385	125
19	18	1200	4.57	303	132
19[b]	18	1120	4.90	330	136
20	14	1000	5.50	368	117
20	20	1320	4.16	269	155
21	25	1480	3.71	216	143

a - 5 blades
b - 2 blades

Table 2

Performance of 14x20 Propeller in Various Mountings
at 3.2 Hydraulic Horsepower

Unshrouded	Kort-Type Nozzle	Blade Tip Form	Pressure psi	Flow GPM	Thrust lbs	Gain in Thrust Per Cent
Yes		Rounded	940	5.83	97	
	Yes	Rounded*	915	6.00	113	17
	Yes	Squared	930	5.90	127	31

* Original ALVIN Propeller

III DISCUSSION

High propeller efficiency is usually associated with large screw diameter and low rotational speed (Ref. 2). It is therefore not surprising that, in the unshrouded test series, there was definite trend toward higher thrusts as the wheel diameter was increased. Of the propellers tested, the 20 X 20 wheel showed the highest Thrust/Input Horsepower ratio. Although the number of wheels tested was fairly small, it seems reasonable to assume that this size is quite close to being the optimum for the present hydraulic drive motor. The 21 X 25 wheel showed less efficiency, probably because the torque required to rotate it caused the hydraulic pressure to go up to and beyond the rated maximum pressure (1500 p.s.i.) for the ORBIT-A drive motor. The speed fall-off or slip of the motor using this propeller was markedly greater than it was for the other wheels (See Figure 5).

An important factor to be considered in the selection of a new propeller for the ALVIN lift units is physical size. The present 14 X 20 wheel and its duct make up a unit measuring 19 inches, outside diameter. Each unit extends beyond the nominal ALVIN hull outline approximately 5 inches (about 3 inches beyond sponsons). Assuming that for any larger wheel the nozzle will increase the O.D. of the unit by a proportional amount, we get, for a 16 inch wheel: 22 inches O.D., 7 inches minimum overhang beyond sponsons; and for a 20 inch wheel: 27 inches O.D. and 12 inches minimum overhang.

In addition, these nozzles will have an L/D ratio of at least .5 and possibly more (this is discussed in greater detail below). This means an axial length L of at least 8 inches for the 16 inch duct and at least

10 inches for the 20 inch duct. Since these ducts must be rotated in azimuth, it must be made certain that there will be clearance for this rotation. A brief inspection of the drawings has indicated that the duct for the 16 inch wheel would clear if a certain amount of buoyancy material is removed, but that the duct for the 20 inch wheel would have to be moved farther out from center, giving more than the 12 inch overhang previously noted. It is doubtful if a 14-15 inch extension of the side propulsion units beyond the ALVIN hull could be tolerated. Therefore, maximum diameter of the screw will be limited by the space available for its installation.

Concerning the L/D ratio (See Appendix B) for a flow accelerating nozzle, Van Manen and Oosterveld (Ref. 3) have indicated that a long nozzle (L/D = 0.7-1.0) is preferable for higher screw loading ($C_T > 2$) while a short nozzle (L/D $\leq$ 0.5) is better for light loading ($C_T \leq 1.0$). Since, in the case of the ALVIN side propellers, primary concern is for maximum performance during emergency stops and in other situations approaching the static thrust condition, it is evident that this application is in the category of the towing vessel where, according to Van Manen (Ref. 3) C_T may equal 6 or greater. This would indicate the desirability of a nozzle L/D ratio in the range 0.7 to 1.0. The nozzles presently in use on ALVIN have an L/D ratio of 0.5.

Still another aspect of the flow-accelerating nozzle can have an effect upon efficiency. This is the nozzle section or profile, i.e., the shape of the section produced by passing a plane through the axial centerline of the duct. A considerable amount of work has been done in the study of various nozzle profiles, particularly by researchers at the Netherlands Ship Model Basin. A nozzle profile is generally a foil shape, and most of those tested at NSMB were derived from various NACA profiles. NSMB has adopted as a standard, their profile No. 19a which is based on NACA profile No. 25015 (Ref. 3).

The present ALVIN side propeller nozzles have a profile which departs quite noticeably from a typical foil shape. While these ducts provide an increase in efficiency, as seen in the results of the present tests, it is felt that a greater improvement can be obtained by the use of a nozzle profile of proven performance.

IV CONCLUSIONS AND RECOMMENDATIONS

Based on the results of the present series of tests the following conclusions may be drawn:

1. At 3.2 hydraulic horsepower input to the ORBIT-A driving motor (corresponding to a current drain of 75 amp.) the present ALVIN propeller-nozzle combination provides an increase in thrust of about 17 percent over the thrust of a similar unshrouded propeller. The use of a propeller having square-ended blades, i.e., wide blade ends machined to conform closely to the nozzle I.D., provided an additional 14 percent increase in thrust. At lower horsepower values the percentage of increase is even greater.
2. The unshrouded tests indicate that a 20 inch diameter wheel having a P/D ratio of 1.0 is approximately the optimum size for the present ORBIT-A driving motor.
3. In tests involving 19 inch diameter, 18 inch pitch wheels, one having 3 blades, the other having 2 blades, the 2 bladed wheel showed slightly greater thrust at 3.2 horsepower. (About 3 percent increase.)

The following recommendations are made concerning any future changes to be made in the side propulsion units:

1. A larger diameter propeller should be used, to take fuller advantage of the low-speed, high-torque characteristics of the ORBIT-A motor. While the 20 X 20 size appears to be optimum, it may extend too far beyond the side of the vehicle to be practical. A good compromise would be a 16 X 20 wheel.

2. A new nozzle design should be based on some standard foil profile of known performance. The NSMB No. 19a profile is suggested.
3. A nozzle L/D ratio greater than the present 0.5 should improve performance of the units under the heavy loading conditions encountered. A value of L/D of 0.7 to 1.0 is recommended if space permits.
4. The propeller should have blade ends which are shaped to conform to the inside wall of the duct. This can be done by purchasing oversized wheels and machining them on a lathe to the desired diameter. Clearance between the blade tip and the nozzle wall should be about 0.01 times the diameter, remembering that if the nozzle structure is of solid material, and not free-flooding, some radial contraction will occur at depth.
5. It is felt that additional full scale testing should be done for the side propulsion units, and perhaps for the stern propeller, as well. Some attention should be given to the effect of overall blade shape on efficiency. It may be that in the low-speed, low-power domain of the deep submergence vehicle, the conventional propeller designs associated with surface craft should be replaced by less conventional, more effective wheels designed especially for the application. The effects of blade cross-section (foil vs ogival) also should be studied. A good beginning point would be to investigate the stern propeller design proposed by Professor Fejer (Ref. 4).

V ACKNOWLEDGEMENTS

The authors are indebted to William Shultz for his assistance in the instrumentation of these tests.

They also wish to thank Carleton Wing for his cooperation and help on numerous occasions in the course of this work.

VI REFERENCES

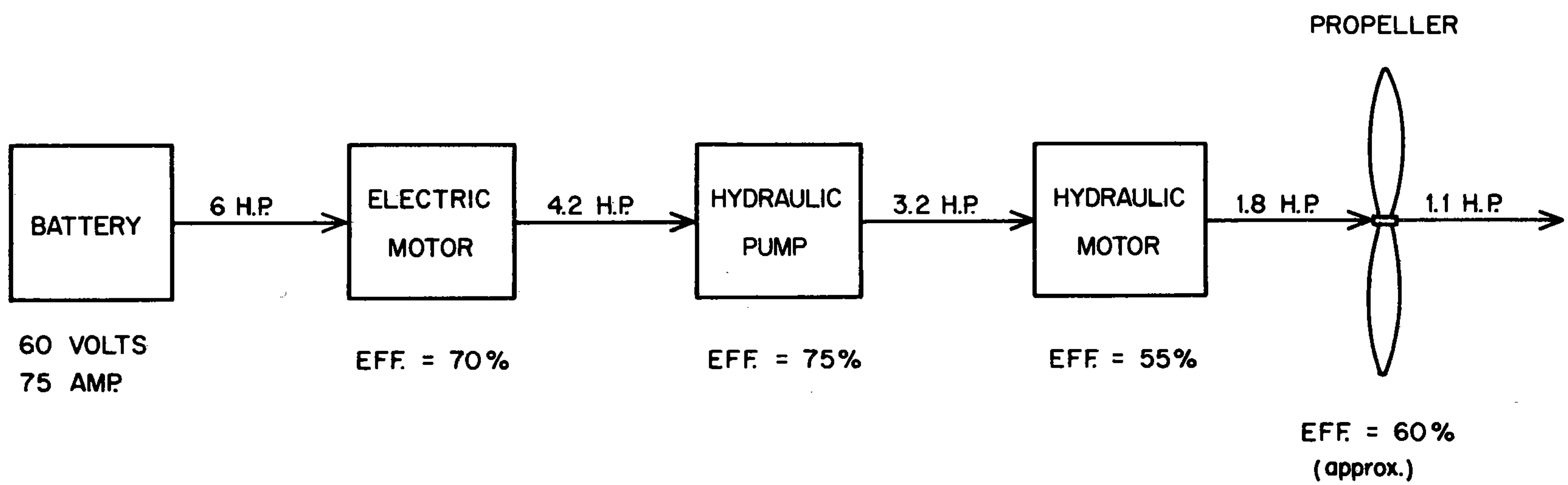
1. "ALVIN High Pressure Test Report", Litton Systems Inc., Applied Science Division, Minneapolis, Minn., July, 1964.

2. Seward, H. L. (Editor), "Marine Engineering", Vol. 1, Society of Naval Architects and Marine Engineers, New York, N.Y., 1942.

3. Van Manen, J. D., and Oosterveld, M. W. C., "Analysis of Ducted Propeller Design", Society of Naval Architects and Marine Engineers, New York, N.Y., November, 1966.

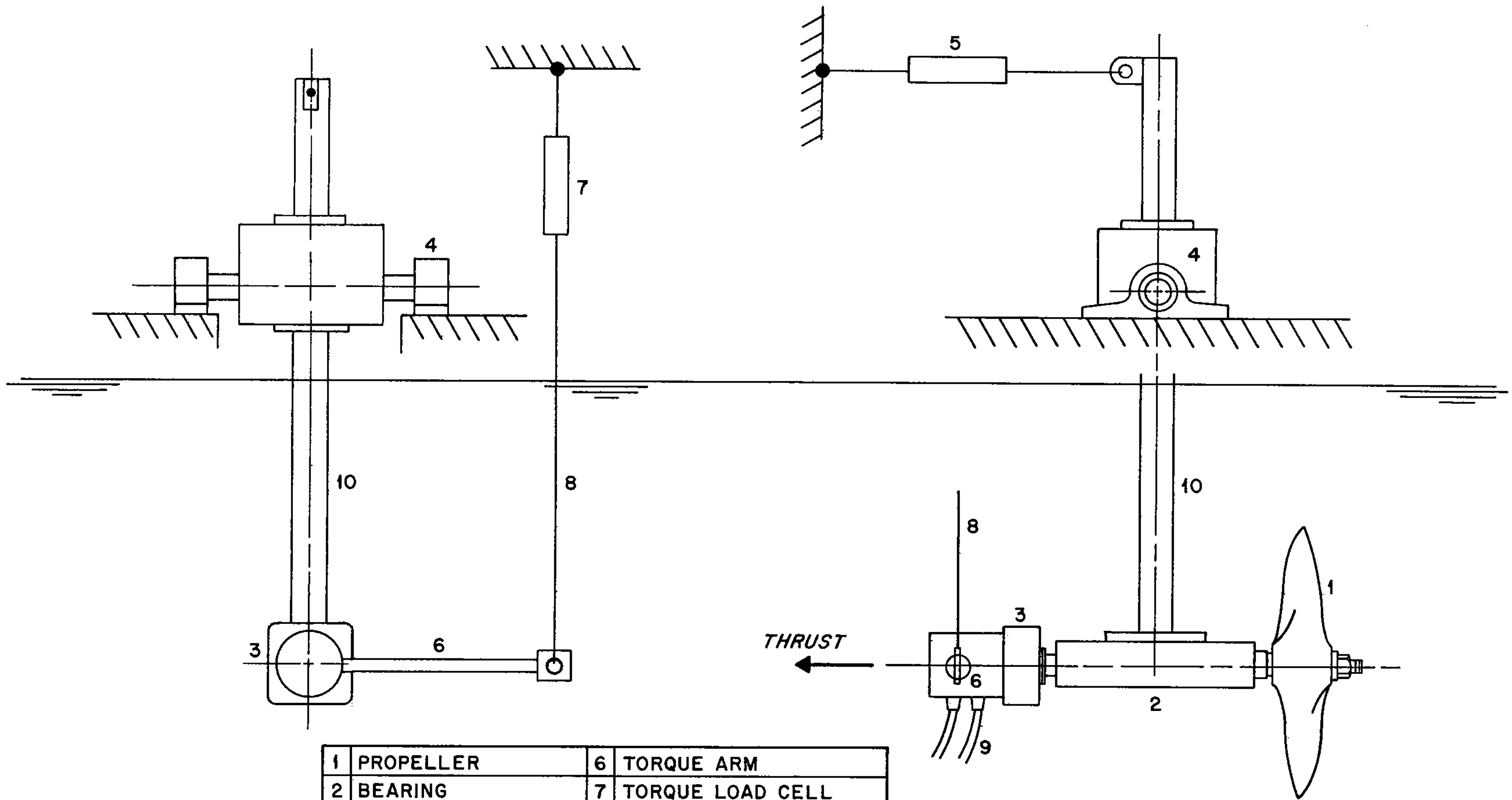
4. Fejer, A. A., "Notes on the Design of a Stern Propeller for a Deep Diving Submarine of the ALVIN Type", Unpublished Manuscript, W.H.O.I., Woods Hole, Mass., August, 1965.

APPENDIX A - Figures



$$\text{OVERALL EFFICIENCY OF SYSTEM} = \frac{1.1}{6} \times 100 = 18\%$$

Figure 1 Block Diagram of ALVIN Lift Propulsion System (One of Two Units)



1	PROPELLER	6	TORQUE ARM
2	BEARING	7	TORQUE LOAD CELL
3	HYDRAULIC MOTOR	8	TORQUE ARM CABLE
4	TRUNNIONS	9	HYDRAULIC HOSES
5	THRUST LOAD CELL	10	MAIN VERTICAL MEMBER

Figure 2 Schematic Drawing of Propeller Test Apparatus

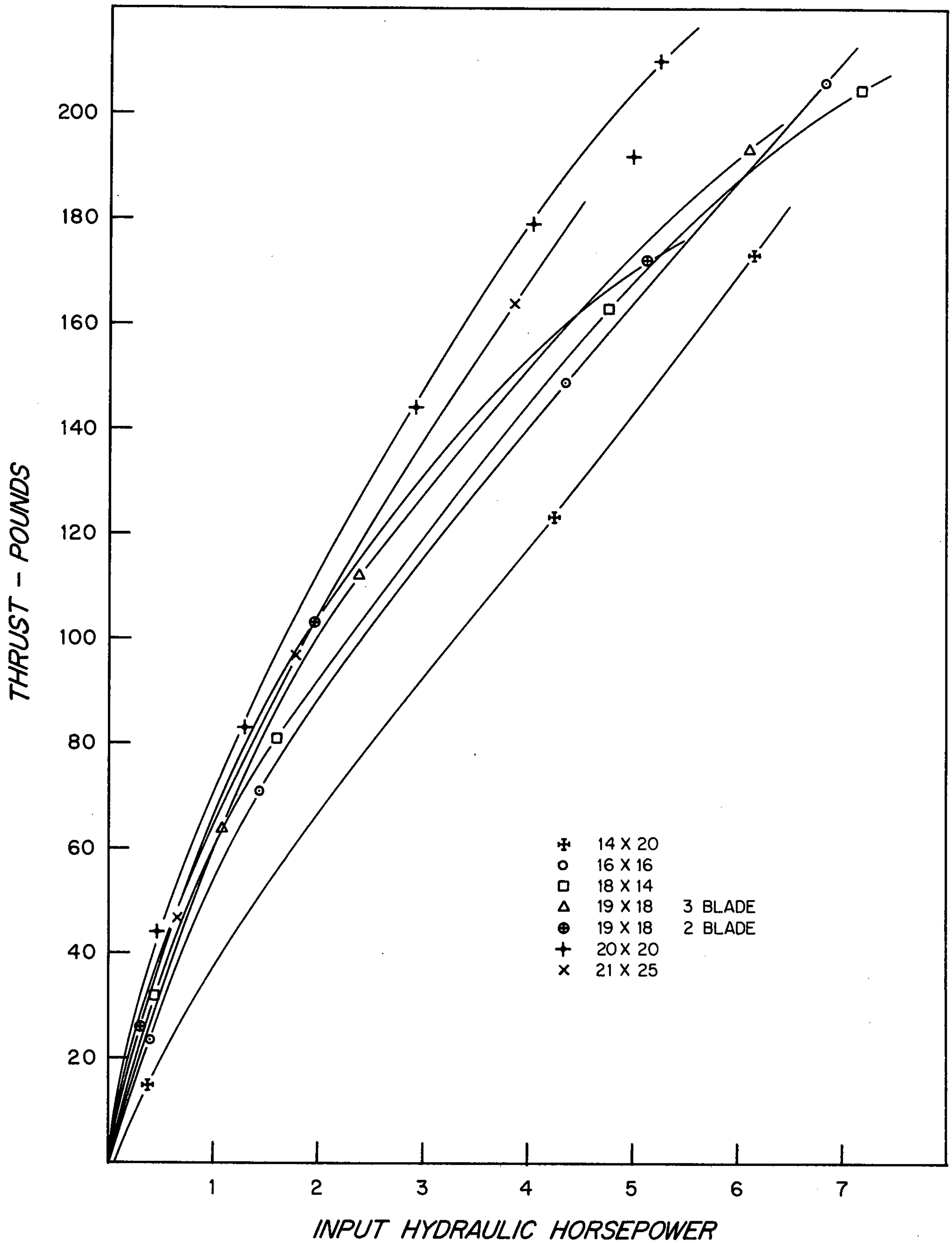


Figure 3 Thrust-Horsepower Characteristics of Various Unshrouded Propellers

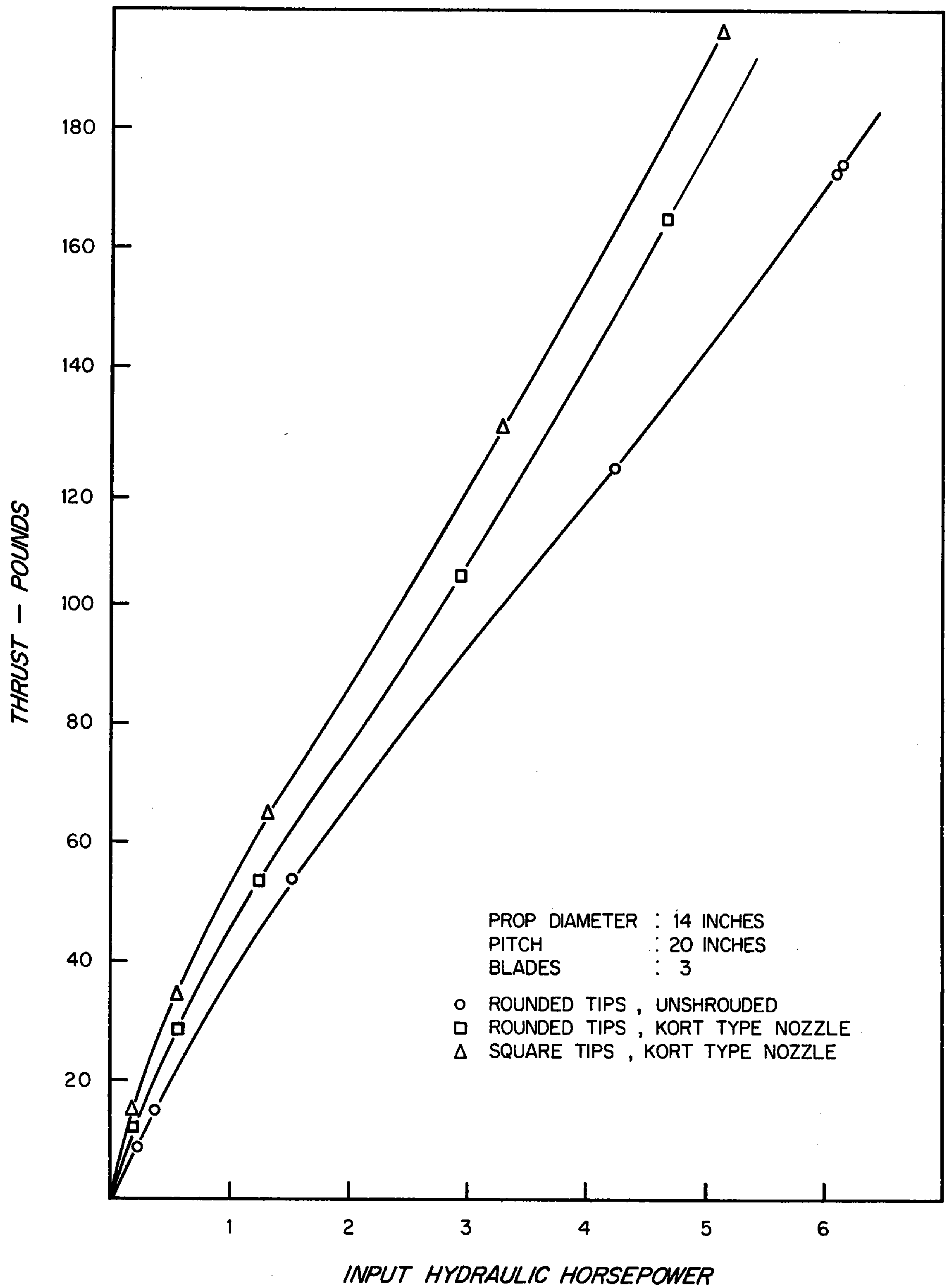


Figure 4 Thrust-Horsepower Characteristics of 14 Inch Diameter, 20 Inch Pitch Propeller

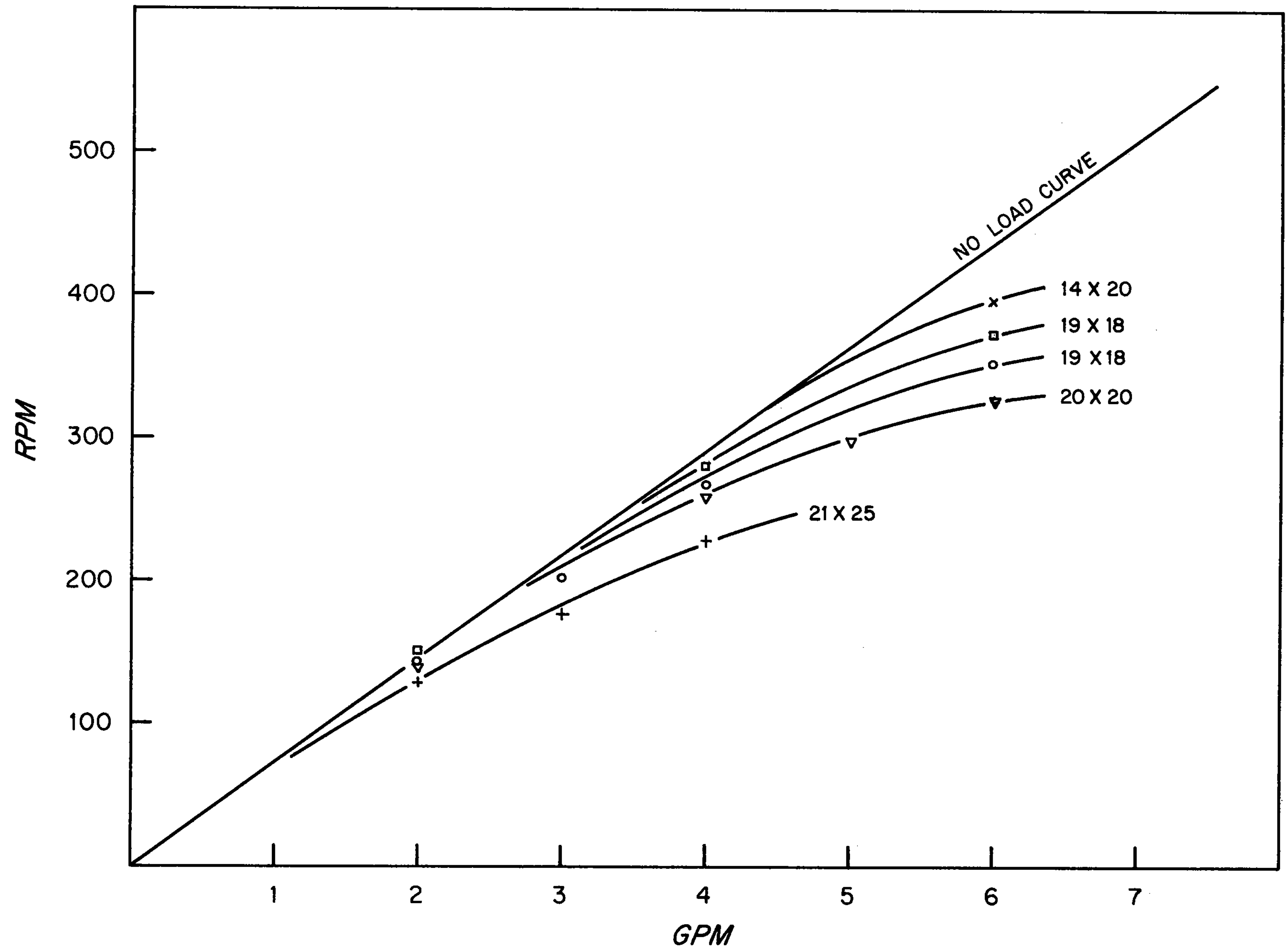


Figure 5 Speed-Flow Characteristics of ORBIT-A Motor for various loadings

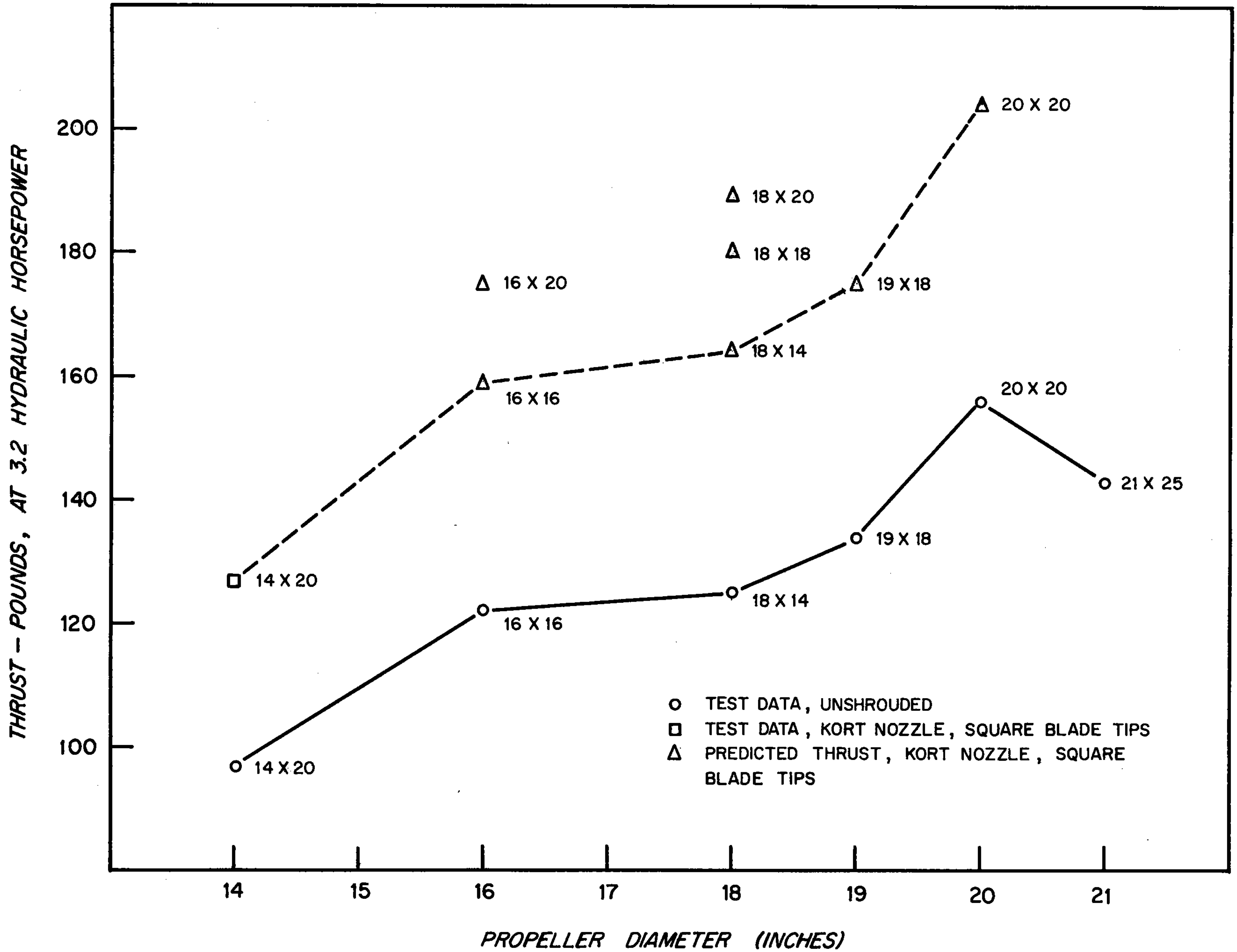


Figure 6 Static Thrust of Various Propellers at 3.2 Hydraulic Horsepower

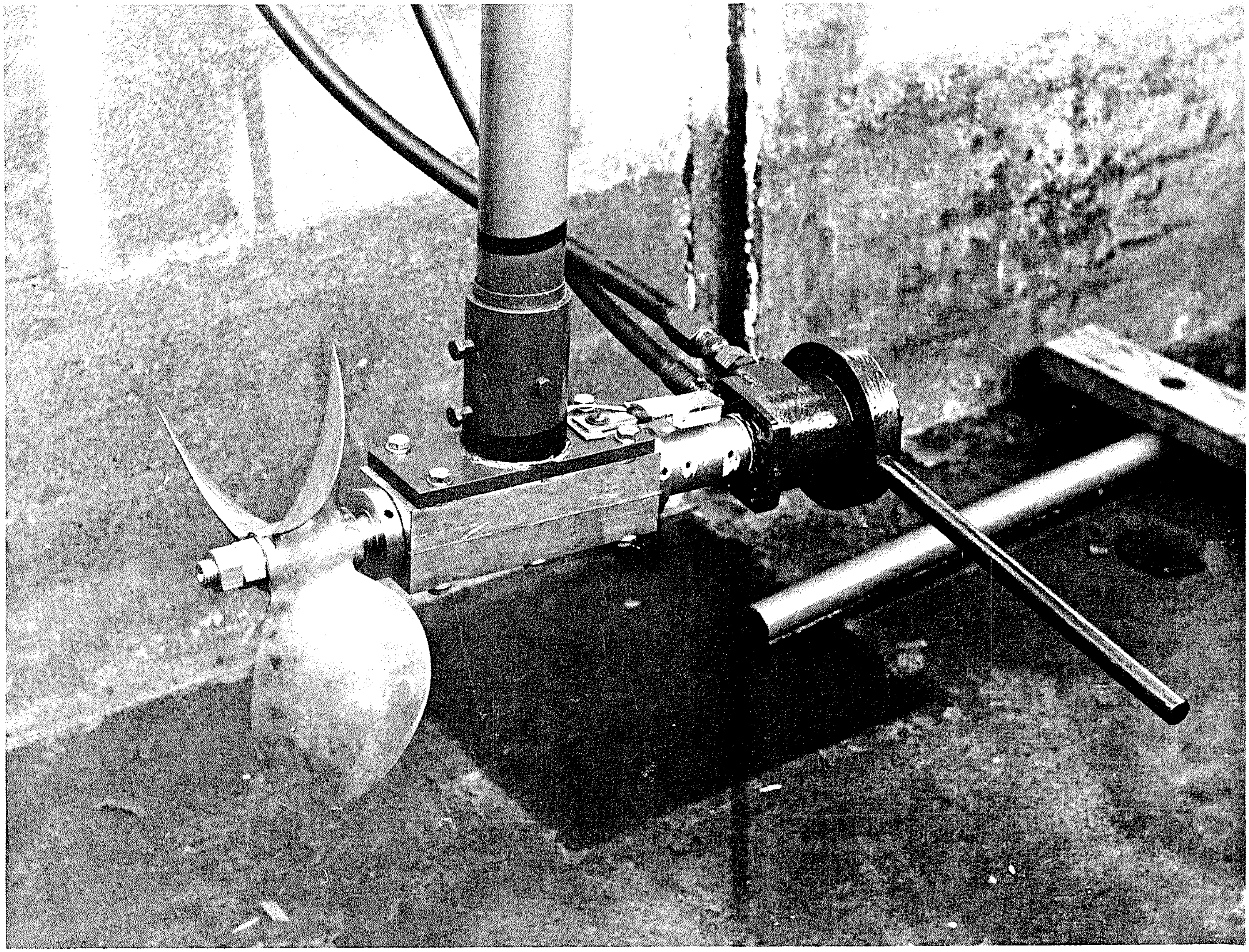


Figure 7   Lower Portion of Test Apparatus for Unshrouded Tests

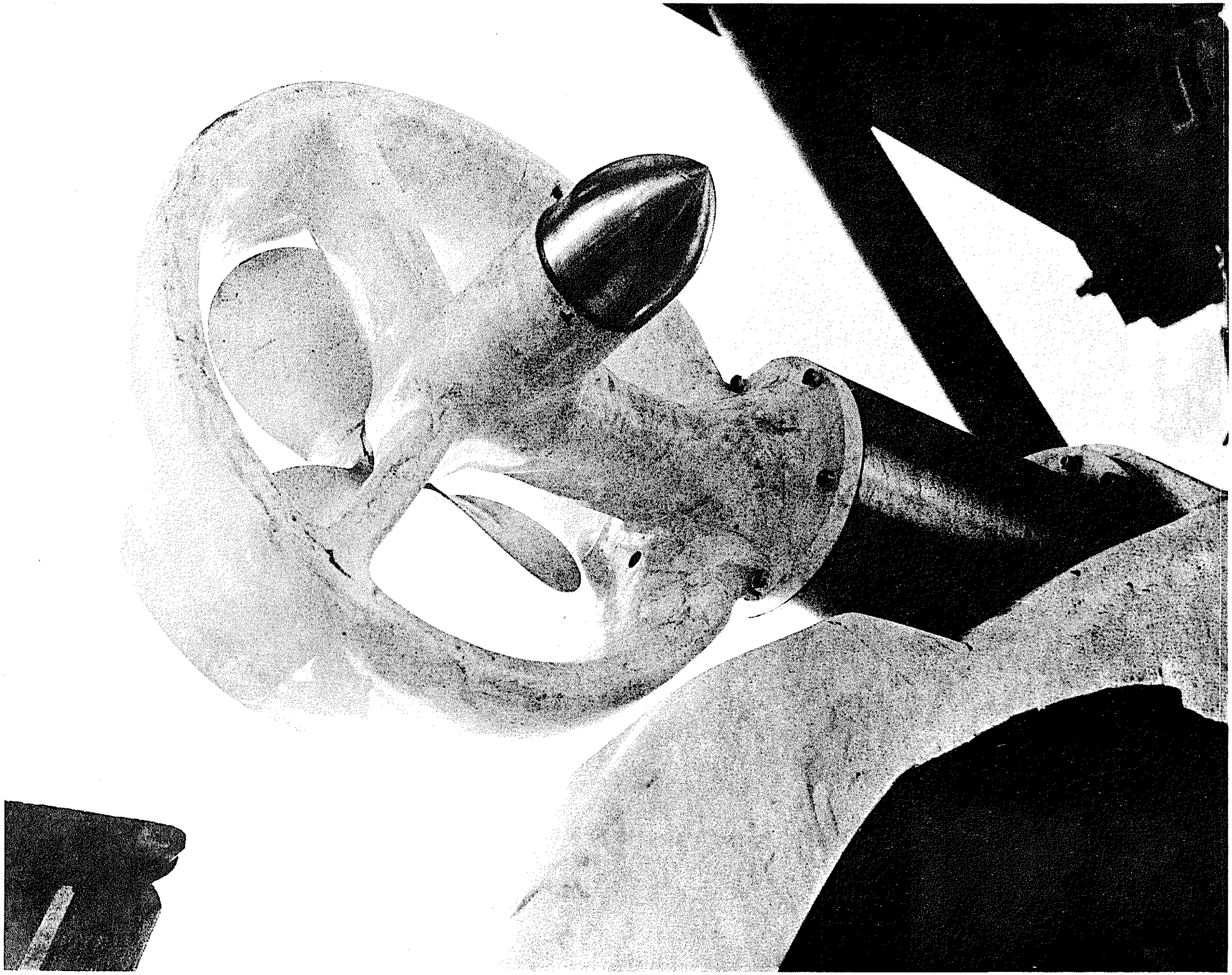


Figure 8   ALVIN Side Propulsion Unit Showing Original Propeller

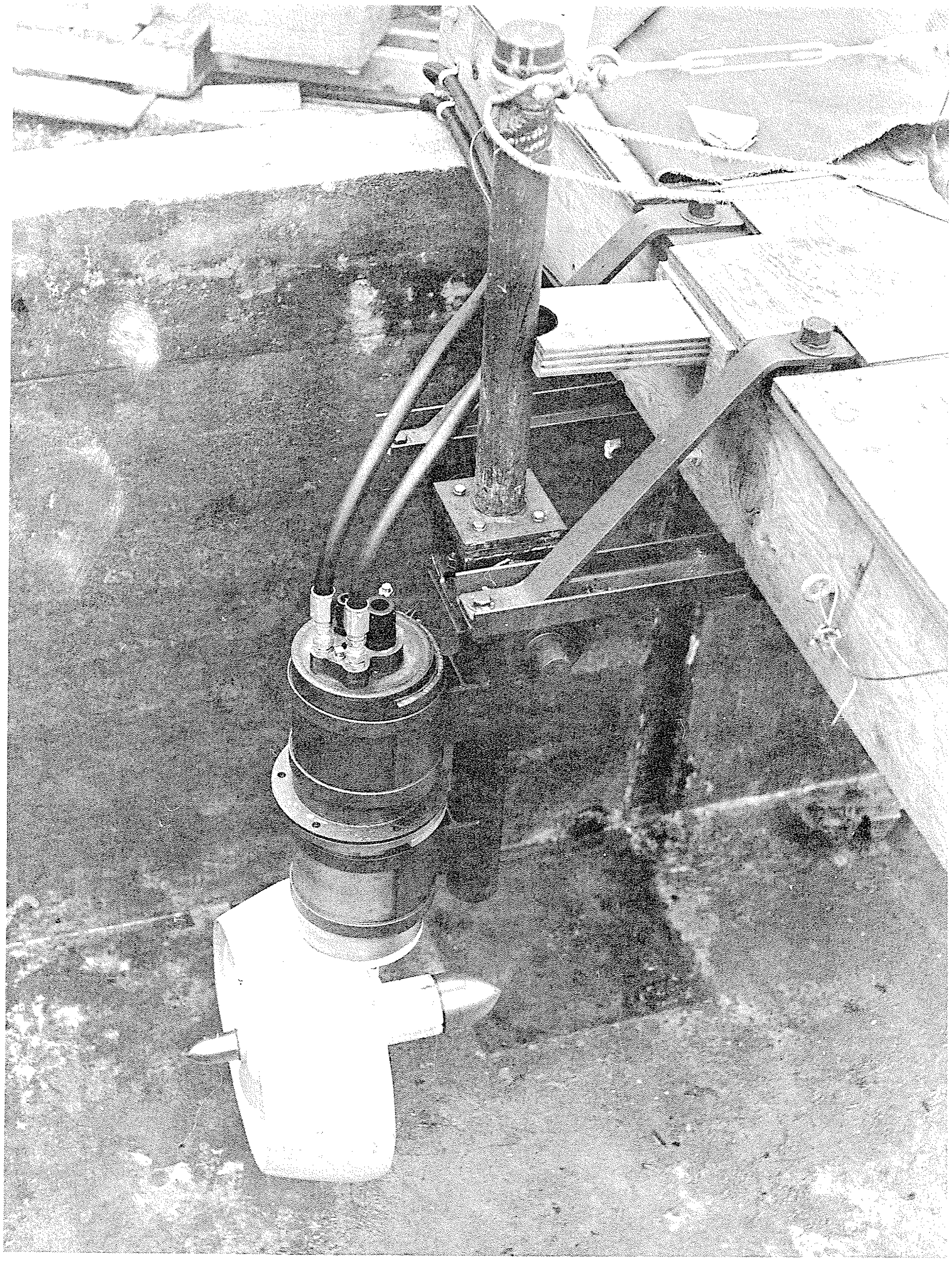


Figure 9 ALVIN Side Propulsion Unit Mounted on Test Apparatus

APPENDIX B - Nomenclature

C_T = thrust coefficient = $\dfrac{T}{\frac{1}{2}\rho V^2 \frac{\pi}{4} D^2}$

D = diameter of propeller or nozzle

L = axial length of nozzle

T = propeller thrust

V = velocity of advance

ρ = mass density of medium

APPENDIX C - Data and Calculations

PROPELLER TEST DATA SHEET

Propeller Diam. 14 Date OCT. 3, 1966

Pitch 20

Blades 3 RH

Blade Shape CONV. Ducted NO

Test No.	1	2	3	4	5	6	7
GPM - Setting							
Gallons							
Time - sec.							
GPM - Actual	2.5	4.1	6.6	7			
Pressure - psig	253	567	1100	1500			
RPM	181	299	419	497			
Thrust:							
Indicator Rdg							
Lbs. at gage							
Lbs. at prop.	14.9	57.3	123	173			
Torque:							
Indicator Rdg							
Force - Lbs.							
Torque - Ft.-Lbs.							
Ratio: Thrust/Torque							
Input H.P.=.000583 pV	.37	1.35	4.23	6.13			
Ratio: Thrust/Inp.H.P.	40.3	42.7	29.1	28.2			
Shaft H.P.=TN/5250							
Motor Eff.=Shaft H.P./Input H.P.							

PROPELLER TEST DATA SHEET

Propeller Diam. 14 Date NOV. 15, 1966

Pitch 20

Blades 3 RH

Blade Shape CONV. Ducted NO

Test No.	1	2	3	4	5	6	7
GPM - Setting							
Gallons							
Time - sec.							
GPM - Actual	2	4	6	7			
Pressure - psig	200	650	1133	1517			
RPM	145	289	385	502			
Thrust:							
Indicator Rdg							
Lbs. at gage							
Lbs. at prop.	9	54	98	174			
Torque:							
Indicator Rdg							
Force - Lbs.							
Torque - Ft.-Lbs.							
Ratio: Thrust/Torque							
Input H.P.=.000583 pV	.23	1.52	3.96	6.18			
Ratio: Thrust/Inp.H.P.	39.2	35.6	24.8	28.2			
Shaft H.P.=TN/5250							
Motor Eff.=Shaft H.P./Input H.P.							

PROPELLER TEST DATA SHEET

Propeller Diam. 16 Date OCT. 4, 1966

Pitch 16

Blades 3 RH

Blade Shape CONV. Ducted NO

Test No.	1	2	3	4	5	6	7
GPM - Setting							
Gallons							
Time - sec.							
GPM - Actual	2.55	4.20	6.80	8			
Pressure - psig	270	588	1100	1500			
RPM	184	299	424	498			
Thrust:							
Indicator Rdg							
Lbs. at gage							
Lbs. at prop.	23.6	71.2	149	207			
Torque:							
Indicator Rdg							
Force - Lbs.							
Torque - Ft.-Lbs.	7.2	14.8	27.8	37.6			
Ratio: Thrust/Torque							
Input H.P.=.000583 pV	.40	1.44	4.36	7.00			
Ratio: Thrust/Inp.H.P.	59	49	34	30			
Shaft H.P.=TN/5250							
Motor Eff.=Shaft H.P./Input H.P.							

PROPELLER TEST DATA SHEET

Propeller Diam. 18 Date OCT. 5, 1966

Pitch 14

Blades 5 RH

Blade Shape CONV. Ducted NO

Test No.	1	2	3	4	5	6	7
GPM - Setting							
Gallons							
Time - sec.							
GPM - Actual	2.50	4.10	6.70	7.80			
Pressure - psig	297	675	1225	1550			
RPM	182	293	414	460			
Thrust:							
Indicator Rdg							
Lbs. at gage							
Lbs. at prop.	32	81	163	206			
Torque:							
Indicator Rdg							
Force - Lbs.							
Torque - Ft.-Lbs.	12.4	21	34	41.5			
Ratio: Thrust/Torque							
Input H.P.=.000583 pV	.43	1.61	4.78	7.25			
Ratio: Thrust/Inp.H.P.	74	50	34	28			
Shaft H.P.=TN/5250							
Motor Eff.=Shaft H.P./Input H.P.							

PROPELLER TEST DATA SHEET

Propeller Diam. 19 Date NOV. 7, 1966

Pitch 18

Blades 3 RH

Blade Shape CONV. Ducted NO

Test No.	1	2	3	4	5	6	7
GPM - Setting							
Gallons							
Time - sec.							
GPM - Actual	2	3	4	6			
Pressure - psig	325	600	1017	1750			
RPM	142	202	266	351			
Thrust:							
Indicator Rdg							
Lbs. at gage							
Lbs. at prop.	27	64	112	193			
Torque:							
Indicator Rdg							
Force - Lbs.							
Torque - Ft.-Lbs.	6.2	12.1	21.8	35.4			
Ratio: Thrust/Torque							
Input H.P.=.000583 pV	.38	1.05	2.31	6.12			
Ratio: Thrust/Inp.H.P.	71	61	47	32			
Shaft H.P.=TN/5250							
Motor Eff.=Shaft H.P./Input H.P.							

PROPELLER TEST DATA SHEET

Propeller Diam. 19

Pitch 18

Blades 2

Blade Shape CONV. Ducted NO

Date NOV. 7, 1966

Test No.	1	2	3	4	5	6	7
GPM - Setting							
Gallons							
Time - sec.							
GPM - Actual	2	4	6				
Pressure - psig	292	850	1470				
RPM	150	281	372				
Thrust:							
Indicator Rdg							
Lbs. at gage							
Lbs. at prop.	26	103	172				
Torque:							
Indicator Rdg							
Force - Lbs.							
Torque - Ft.-Lbs.	9.2	21	33.3				
Ratio: Thrust/Torque							
Input H.P.=.000583 pV	.34	1.98	5.14				
Ratio: Thrust/Inp.H.P.	76.5	52	33.5				
Shaft H.P.=TN/5250							
Motor Eff.=Shaft H.P./Input H.P.							

PROPELLER TEST DATA SHEET

Propeller Diam. 20

Pitch 14

Blades 3 RH

Blade Shape CONV. Ducted NO

Date NOV. 14, 1966

Test No.	1	2	3	4	5	6	7
GPM - Setting							
Gallons							
Time - sec.							
GPM - Actual	2	3	4	6			
Pressure - psig	217	358	658	1167			
RPM	151	213	284	384			
Thrust:							
Indicator Rdg							
Lbs. at gage							
Lbs. at prop.	20	42	71	138			
Torque:							
Indicator Rdg							
Force - Lbs.							
Torque - Ft.-Lbs.							
Ratio: Thrust/Torque							
Input H.P.=.000583 pV	.25	.63	1.54	4.1			
Ratio: Thrust/Inp.H.P.	80	67	46	34			
Shaft H.P.=TN/5250							
Motor Eff.= Shaft H.P. / Input H.P.							

PROPELLER TEST DATA SHEET

Propeller Diam. 20 Date NOV. 1, 1966

Pitch 20

Blades 3 RH

Blade Shape CONV. Ducted NO

Test No.	1	2	3	4	5	6	7
GPM - Setting							
Gallons							
Time - sec.							
GPM - Actual	2	3	4	4.6	5	6	
Pressure - psig	400	750	1250	1500	1717	2150	
RPM	140	190	258	276	296	324	
Thrust:							
Indicator Rdg							
Lbs. at gage							
Lbs. at prop.	44	83	144	179	192	246	
Torque:							
Indicator Rdg							
Force - Lbs.							
Torque - Ft.-Lbs.	13.4	20.2	32.1	37.3	41.2	50.5	
Ratio: Thrust/Torque							
Input H.P.=.000583 pV	.47	1.31	2.92	4.02	5	7.56	
Ratio: Thrust/Inp.H.P.	94	63	49	45	38	33	
Shaft H.P.=TN/5250							
Motor Eff.=Shaft H.P./Input H.P.							

PROPELLER TEST DATA SHEET

Propeller Diam. 21 Date NOV. 2, 1966

Pitch 25

Blades 3 RH

Blade Shape CONV. Ducted NO

Test No.	1	2	3	4	5	6	7
GPM - Setting							
Gallons							
Time - sec.							
GPM - Actual	2	3	4				
Pressure - psig	558	1017	1667				
RPM	129	176	228				
Thrust:							
Indicator Rdg							
Lbs. at gage							
Lbs. at prop.	47	97	162				
Torque:							
Indicator Rdg							
Force - Lbs.							
Torque - Ft.-Lbs.	17.5	27.1	41.3				
Ratio: Thrust/Torque							
Input H.P.=.000583 pV	.65	1.78	3.88				
Ratio: Thrust/Inp.H.P.	72	54	42				
Shaft H.P.=TN/5250							
Motor Eff.=Shaft H.P./Input H.P.							

PROPELLER TEST DATA SHEET

Propeller Diam. 14 Date DEC. 22, 1966

Pitch 20

Blades 3 LH

Blade Shape CONV. Ducted YES

Test No.	1	2	3	4	5	6	7
GPM - Setting							
Gallons							
Time - sec.							
GPM - Actual	2	3	4	6	7	8.5	
Pressure - psig	160	320	533	843	1145	1600	
RPM							
Thrust:							
Indicator Rdg							
Lbs. at gage							
Lbs. at prop.	16	29	54	105	165	238	
Torque:							
Indicator Rdg							
Force - Lbs.							
Torque - Ft.-Lbs.							
Ratio: Thrust/Torque							
Input H.P.=.000583 pV	.18	.56	1.24	2.94	4.67	7.92	
Ratio: Thrust/Inp.H.P.	89	52	43.5	36	35	30	
Shaft H.P.=TN/5250							
Motor Eff.=Shaft H.P./Input H.P.							

PROPELLER TEST DATA SHEET

Propeller Diam. 14 Date DEC. 27, 1966

Pitch 20

Blades 3 RH

Blade Shape SQ. END Ducted YES

Test No.	1	2	3	4	5	6	7
GPM - Setting							
Gallons							
Time - sec.							
GPM - Actual	2	3	4	6	7	8.5	
Pressure - psig	175	325	562	945	1262	1810	
RPM							
Thrust:							
Indicator Rdg							
Lbs. at gage							
Lbs. at prop.	17.5	34	65	130	196	275	
Torque:							
Indicator Rdg							
Force - Lbs.							
Torque - Ft.-Lbs.							
Ratio: Thrust/Torque							
Input H.P.=.000583 pV	.20	.57	1.31	3.30	5.15	8.98	
Ratio: Thrust/Inp.H.P.	87.5	59	49.6	39.4	38	31	
Shaft H.P.=TN/5250							
Motor Eff.=Shaft H.P./Input H.P.							