AD-A050 568 DAVID W TAYLOR NAVAL SHIP RESEARCH AND DEVELOPMENT CE--ETC F/G 13/10
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DAVID W. TAYLOR NAVAL SHIP RESEARCH AND DEVELOPMENT CENTER

Bethesda, Md. 20084

CAVITATION PERFORMANCE CHARACTERISTICS OF SUPERCAVITATING PROPELLERS 4698 AND 4699

by

James G. Peck

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SHIP PERFORMANCE DEPARTMENT

DEPARTMENTAL REPORT

December 1977

SPD-680-02

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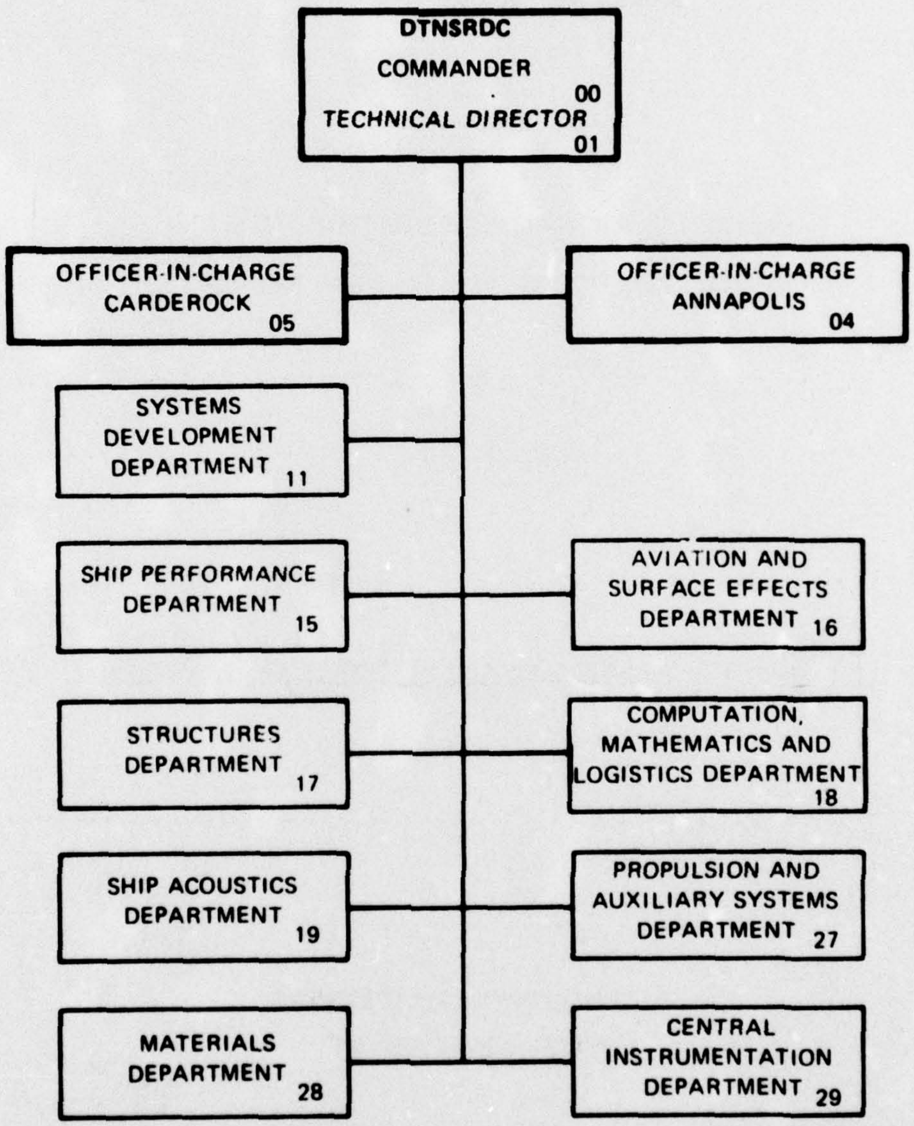

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

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14

1. REPORT NUMBER: SPD-680-02

2. GOVT ACCESSION NO.

3. RECIPIENT'S CATALOG NUMBER

6

4. TITLE (and Subtitle): CAVITATION PERFORMANCE CHARACTERISTICS OF SUPERCAVITATING PROPELLERS 4698 AND 4699

5. TYPE OF REPORT & PERIOD COVERED

6. PERFORMING ORG. REPORT NUMBER

10

7. AUTHOR(s): James G. Peck

8. CONTRACT OR GRANT NUMBER(s): 16 F43421

9. PERFORMING ORGANIZATION NAME AND ADDRESS: David W. Taylor Naval Ship R&D Center, Bethesda, MD 20084

10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS: 17 Work Unit 1-1500-200, Task Area ZF 43421001, Element 62543N

11. CONTROLLING OFFICE NAME AND ADDRESS: Naval Material Command, Washington, D.C. 203 0

12. REPORT DATE: 11 Dec[redacted] [redacted]977

13. NUMBER OF PAGES: 23

14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office): 12 24p.

15. SECURITY CLASS. (of this report): UNCLASSIFIED

15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

APPROVED FOR PUBLIC RELEASE: DISTRIBUTION UNLIMITED

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

18. SUPPLEMENTARY NOTES

21 ORIGINAL CONTAINS COLOR PLATES: ALL DDC REPRODUCTIONS WILL BE IN BLACK AND WHITE.

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

Supercavitating Propellers, Cavitation, Advance Coefficient

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

Two model supercavitating propellers were characterized over a range of cavitation numbers and advance coefficients. The results of these characterizations are presented in curves and tabular form. The propeller performance as predicted from these experiments is compared to design prediction. It was found that one of the propellers would reach 95 percent of design speed at design rpm whereas the other propeller would reach 109 percent of its design speed at design rpm.

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S/N 0102-LF-014-6601

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NOTATION

Symbol	Description	Dimensions
$C_{0.7}$	Blade-section length at 0.7 R	ft, m
D	Propeller diameter	ft, m
J	Advance coefficient $J = V_a/nD$	
K_Q	Torque coefficient $K_Q = Q/\rho n^2 D^5$	
K_T	Thrust coefficient $K_T = T/\rho n^2 D^4$	
K_T/J^2	Loading coefficient	
n	Revolutions per unit time	rps
P	Ambient static pressure	lb/ft^2, N/m^2
P_v	Ambient vapor pressure	lb/ft^2, N/m^2
Q	Torque	ft-lb, N·m
T	Thrust	lb, N
V	Velocity of boat	ft/sec, m/sec
V_a	Speed of advance V(1 - w)	ft/sec, m/sec
1 - t	Thrust deduction fraction	
$1 - w_t$	Wave fraction	
η	Propeller efficiency $\eta = K_T \cdot J/ K_Q \cdot 2\pi$	
ρ	Mass density of water	$lb\text{-}sec^2/ft^4$, Kg/m^3
σ	Cavitation number $\sigma = (P - P_v)/(\frac{1}{2}\rho V^2)$	

ABSTRACT

Two model supercavitating propellers were characterized over a range of cavitation numbers and advance coefficients. The results of these characterizations are presented in curves and tabular form. The propeller performance as predicted from these experiments is compared to design prediction. It was found that one of the propellers would reach 95 percent of design speed at design rpm whereas the other propeller would reach 109 percent of its design speed at design rpm.

ADMINISTRATIVE INFORMATION

This work was performed under Naval Material Command funding. Program identification at the David W. Taylor Naval Ship R&D Center was Work Unit 1-1500-200, Task Area ZF 43421001, and Project Element 62543N.

INTRODUCTION

David Taylor Naval Ship Research and Development Center (DTNSRDC) conducted an experimental program to evaluate two present day methods of supercavitating propeller design.

Two supercavitating propellers were designed, independently, for a typical 200 ton (181 metric tons) hydrofoil craft. The propeller design conditions are given in Table 1. The design methods are published in References 1 and 2.* The propeller design characteristics are given in Table 2.

Two model propellers were manufactured at DTNSRDC from these designs. The principal dimensions of these propellers are given in Table 3, and drawings of the propellers are shown in Figures 1 and 2. After manufacture the propellers were measured to verify the manufacturing process. Computer plots of the measured values of blade section offsets

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* References are listed on page 4

compared to design values are given for the 0.7 R section of one blade of each propeller in Figures 3 and 4. The sections are typical of all the sections of all the blades.

EXPERIMENTAL PROCEDURE

Cavitation performance characteristics of the propellers were obtained in the 36" Variable Pressure Water Tunnel. Tunnel water velocities were measured on the tunnel venturi system. The scope of the experiments is listed in Table 4.

Tunnel pressure and water velocity were set to establish each cavitation number and then propeller revolutions were varied to cover a range of speed coefficients. Propeller thrust and torque were measured at each condition, and sketches were made of the propeller cavitation present. The Reynolds numbers during the experiments ranged from 7.5×10^5 to 5.6×10^6.

PRESENTATION OF DATA AND DISCUSSION

The thrust and torque data were reduced to non-dimensional coefficients K_T and K_Q. Propeller efficiencies were calculated from faired values of K_T and K_Q. The cavitation performance characteristics of the two propellers are presented in Tables 5 and 6.

Curves representing the faired data from Tables 5 and 6 at three cavitation numbers for each propeller are shown in Figures 5 and 6. These curves show the performance of Propellers 4698 and 4699 to be typical of supercavitating propellers. Photographs of the propellers, at their design-operating condition, are shown in Figure 7 and Figure 8.

Curves of maximum speed thrust loading (K_T/J^2) have been added to the performance curves (Figure 5 and 6). The intersection of the K_T/J^2 curve and the K_T curve at the design sigma determines the predicted operational point for each propeller. A comparison between the design operational points and the points determined by the experimental data are listed in Table 7.

Sketches of back cavitation present on the propellers at two cavitation numbers are given in Figures 9 and 10. These sketches cover a range of advance coefficient from partially cavitating to fully cavitating conditions. The propellers at any advance coefficient lower than those shown, at the same cavitation number, would also be fully cavitating. There was no face cavitation present on either propeller over the range of cavitation numbers and advance coefficients covered in these experiments.

CONCLUSIONS

Although both propellers had no face cavitation and had essentially full back cavitation at the design operational point neither propeller performed as predicted. The method used in designing Propeller 4698 over predicted the available thrust. Propeller 4698 would require 5 percent more rpm and 19 percent more power than predicted to reach design speed. The method used in designing Propeller 4699 under predicted the available thrust. Propeller 4699 would reach design speed with 8 percent less rpm and 17 percent less power than predicted. If the operating point is defined as the speed and rpm where the propellers absorb the available maximum power, Propeller 4698 would operate at V = 55.6 knots and rpm = 1000; while the operating point for Propeller 4699 would be V = 61.0 and rpm = 970. The propeller efficiencies at these conditions are 52% and 73%, respectively.

REFERENCES

1. Bohn, J. and Altmann, R., "Two Supercavitating Propeller Designs for Hydrofoil Ships," Hydronautics, Inc. Technical Report 7607.01 (May 1976).

2. Baker, Elwyn S., "Engineering Design of Two Supercavitating Propellers Using Modified Lifting Surface Programs," DTNSRDC Report SPD-680-01 (Aug 1977).

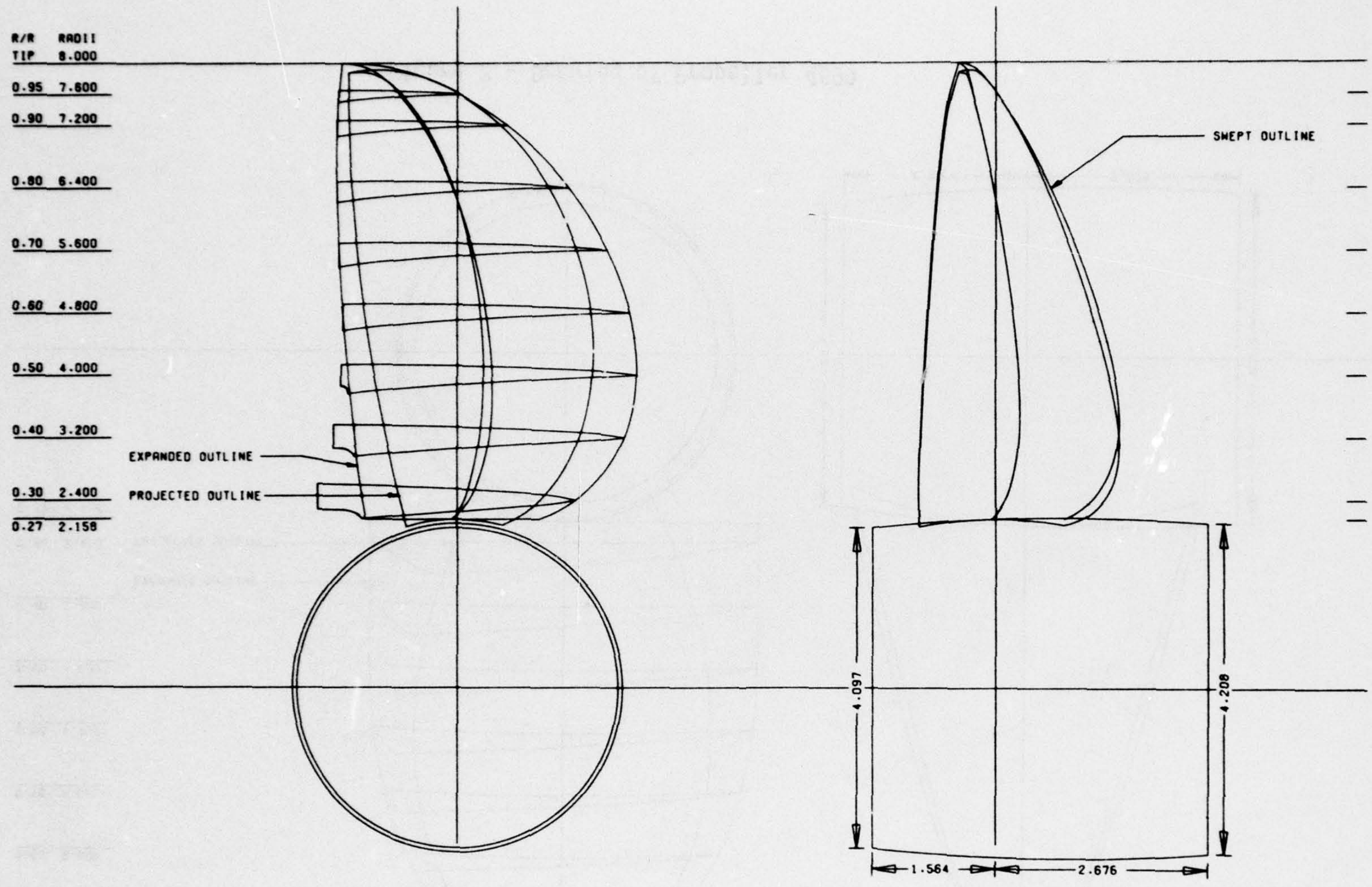


Figure 1 - Drawing of Propeller 4698

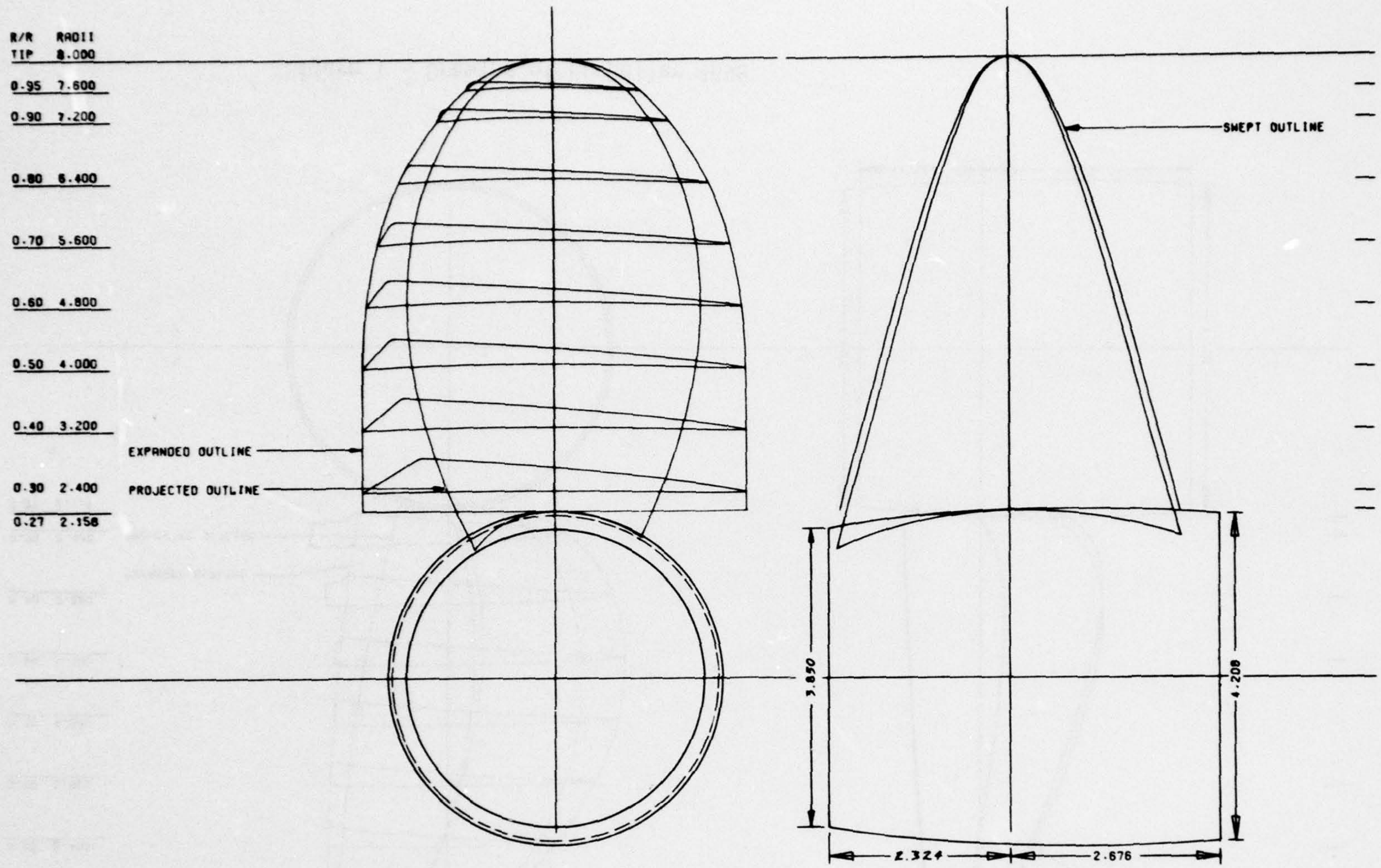


Figure 2 - Drawing of Propeller 4699

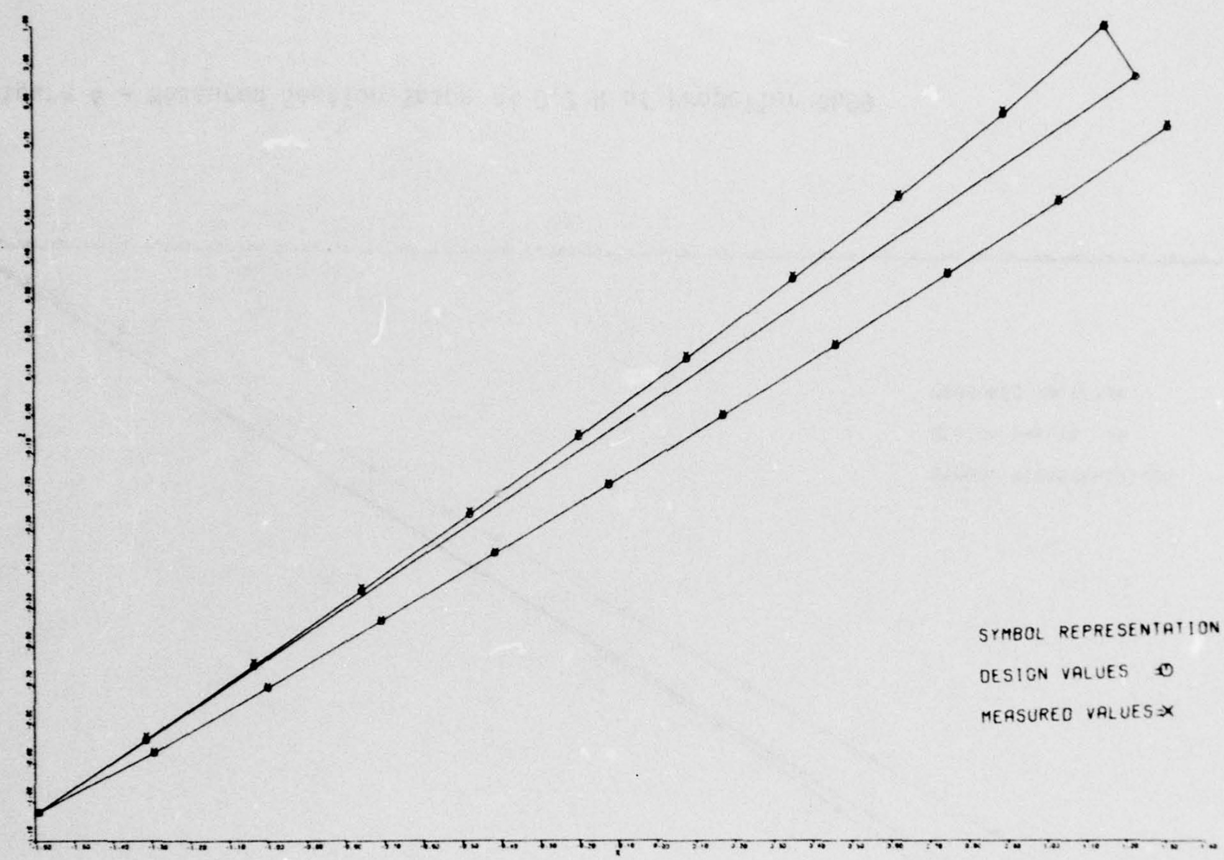


Figure 3 - Measured Section Shape at 0.7 R of Propeller 4698

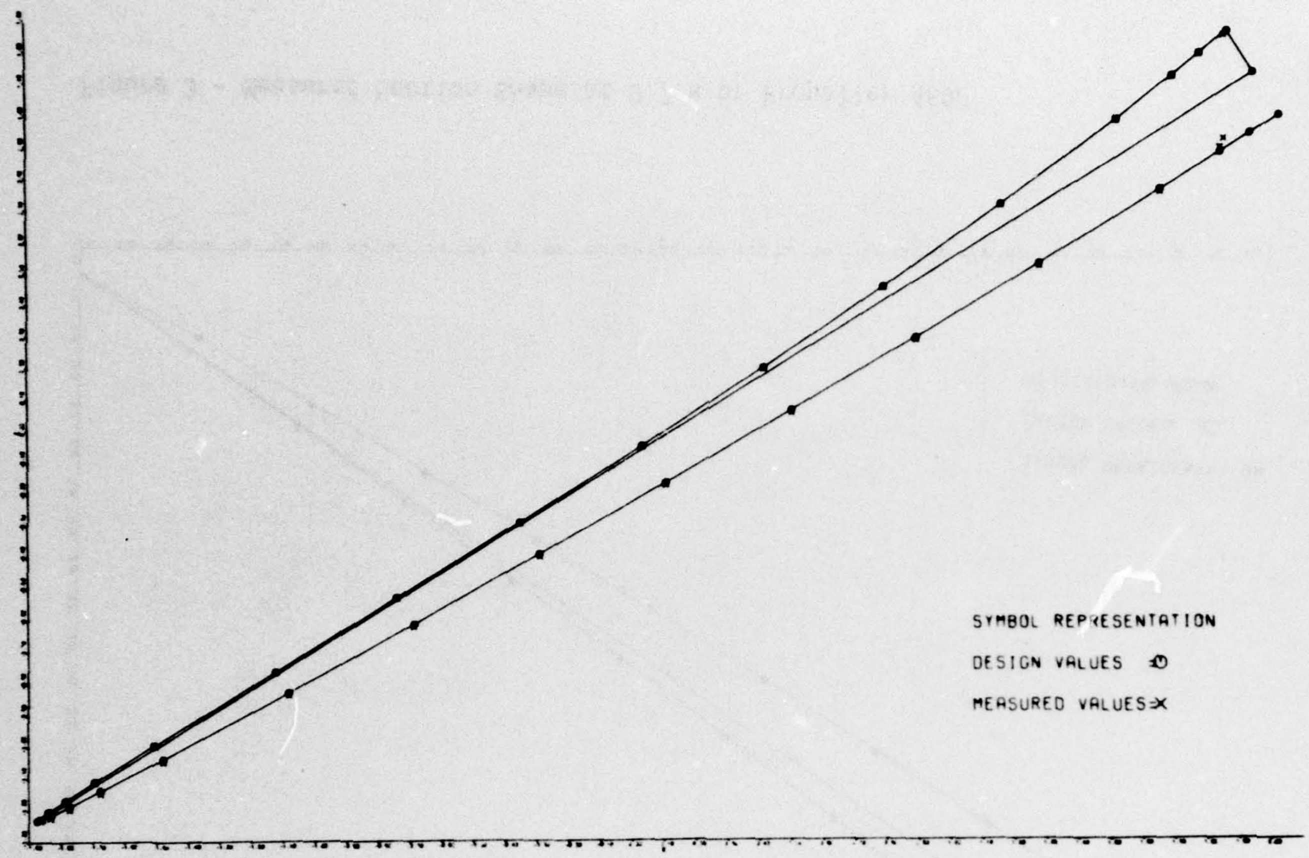


Figure 4 - Measured Section Shape at 0.7 R of Propeller 4699

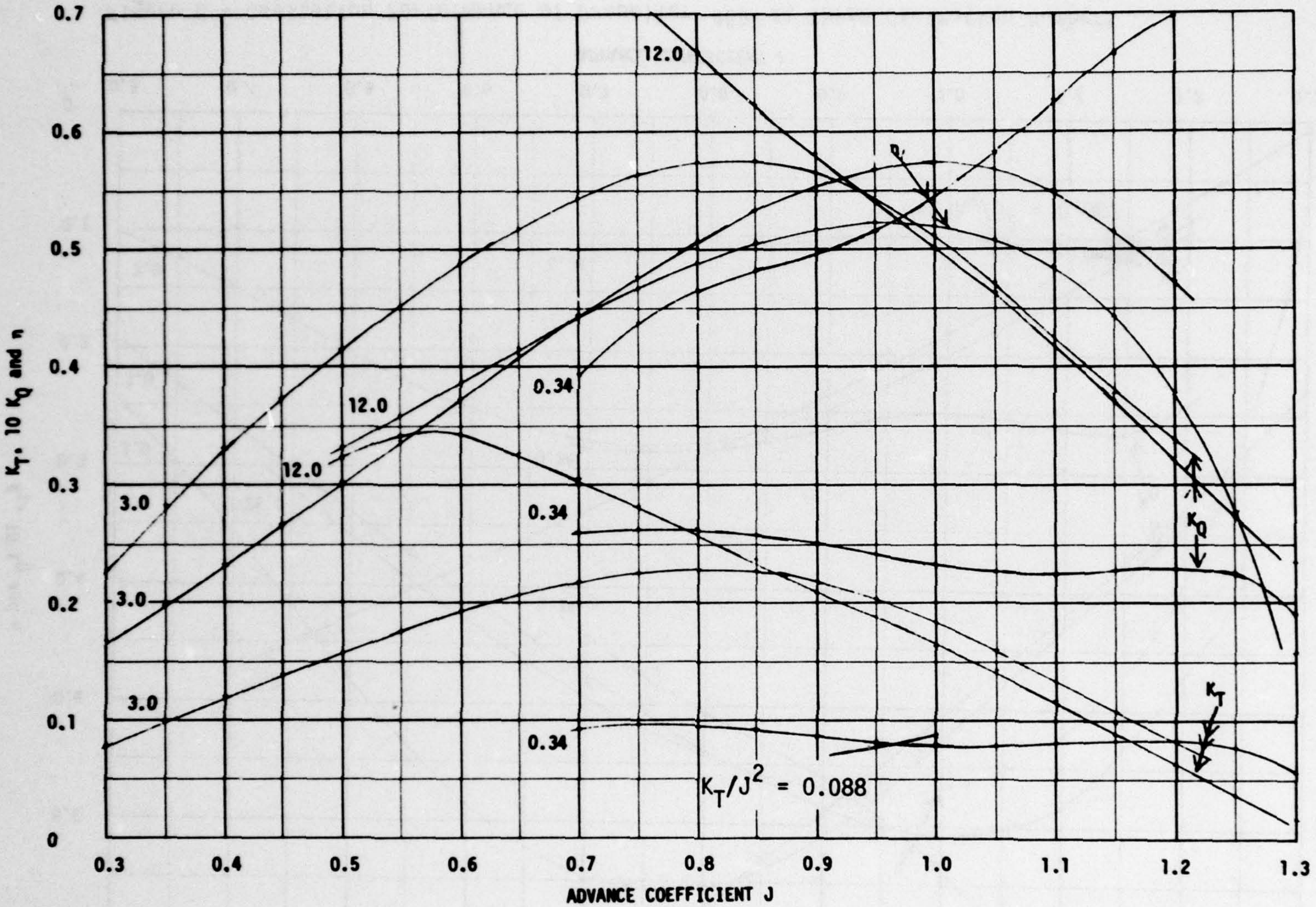


Figure 5 - Cavitation Performance of Propeller 4698 at Three Cavitation Numbers

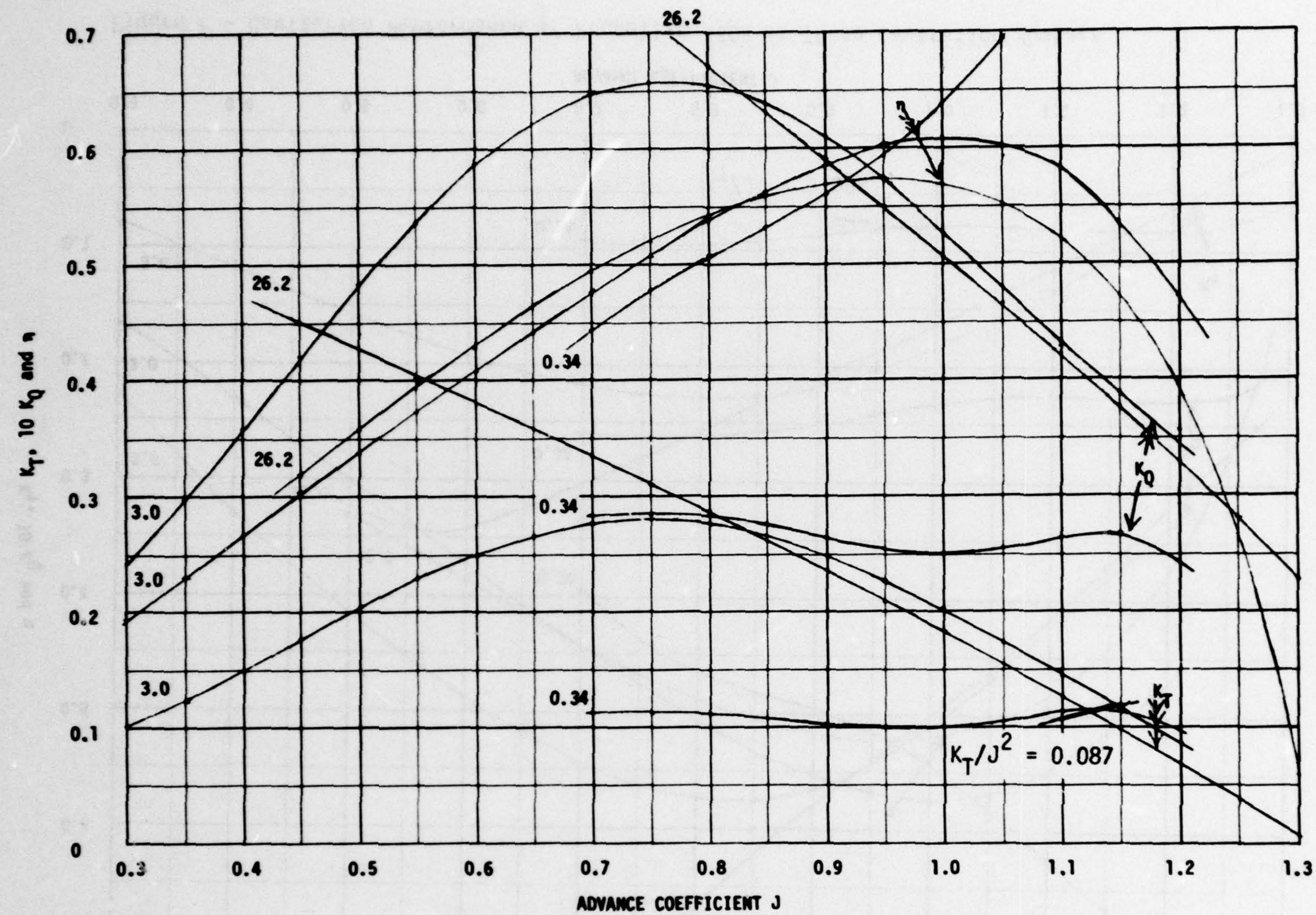


Figure 6 - Cavitation Performance of Propeller 4699 at Three Cavitation Numbers

Figure 7 - Photograph of Propeller 4698 at Design Condition

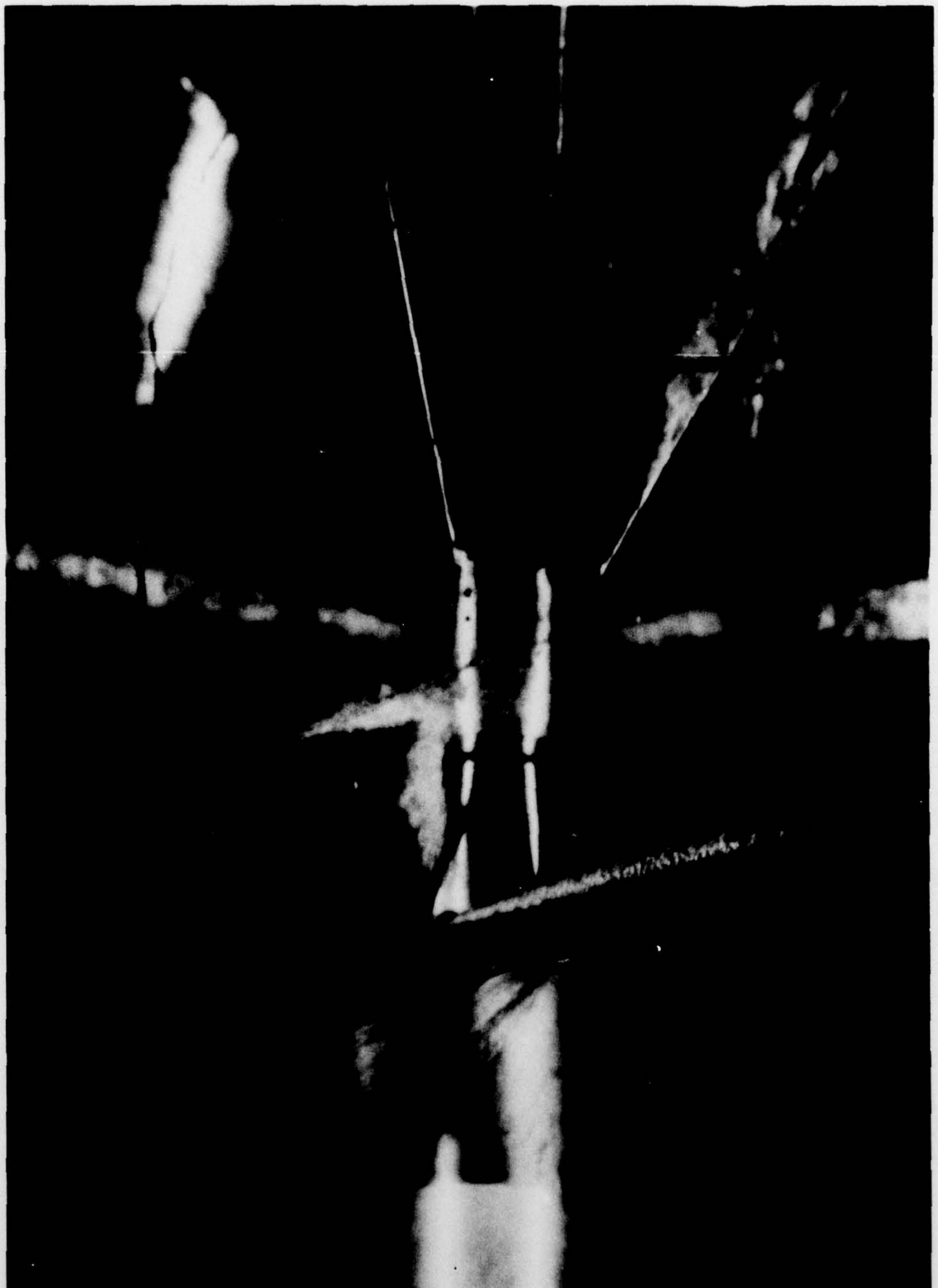


Figure 8 - Photograph of Propeller 4699 at Design Condition

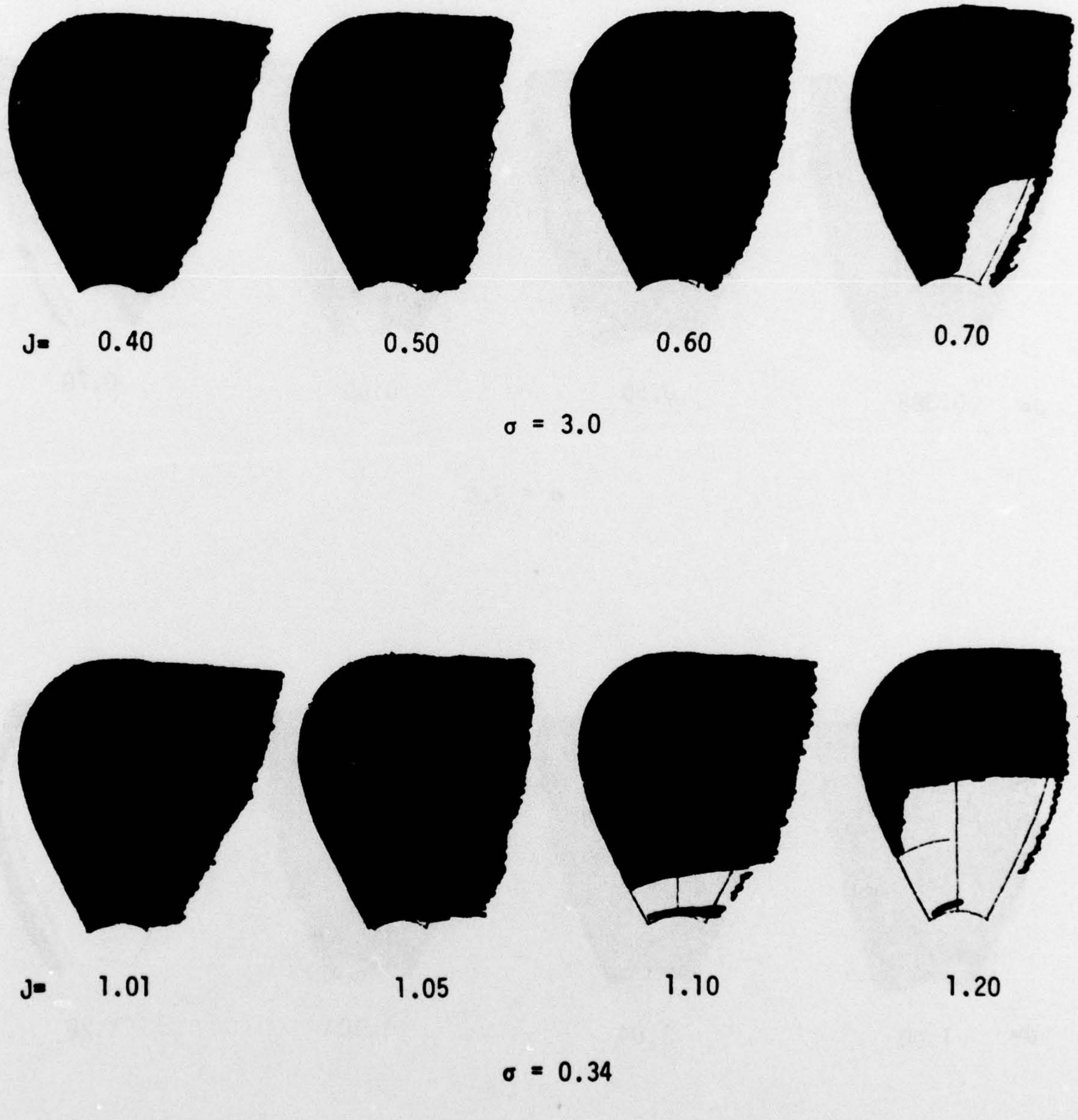
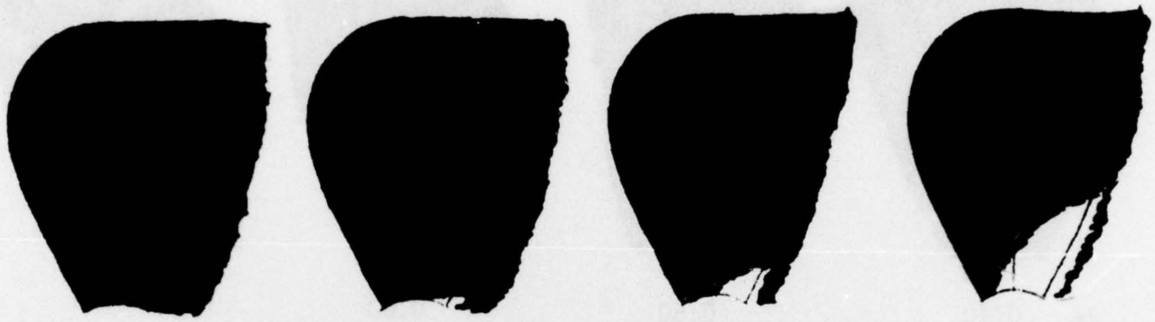


Figure 9 - Sketches of Cavitation Present on the Back of Propeller 4698 at Two Cavitation Numbers



J= 0.388 0.50 0.60 0.70

σ = 3.0

J= 1.00 1.04 1.10 1.20

σ = 0.34

Figure 10 - Sketches of Cavitation Present on the Back of Propeller 4699 at Two Cavitation Numbers

TABLE 1
PROPELLER DESIGN CONDITIONS

Power, max. cont.	16000 HP (16213.3 Metric HP) for two propellers
$1 - t$	0.925
$1 - w_t$	0.870
Shaft Centerline at Design Speed	6.82 ft (2.079 m)
Maximum D	5 ft (1.524 m)
No. of Blades	4
Design Objective	maximum speed
Minimum Rotative Speed	750 rpm
Hump Thrust Margin	20%

TABLE 2
PROPELLER DESIGN CHARACTERISTICS

Propeller Number	4698	4699
Designed by	Hydronautics, Inc.	DTNSRDC
V_S	58.5 kts	59.0 kts
N_S	1020	1000
K_T	0.090	0.0943
J	1.01	1.04
σ	0.34	0.34
η	0.62	0.64

TABLE 3

MODEL PROPELLER GEOMETRY

Propeller Number	4698	4699
Number of Blades	4	4
Diameter, Inches (m)	16.000 (.4064)	16.000 (.4064)
Pitch at 0.7R, Inches (m)	22.389 (.5687)	22.683 (.5761)
P/D at 0.7R	1.399	1.418
Expanded Area Ratio	0.350	0.492
Chord Length at 0.7R, Inches (m)	3.421 (.0869)	4.547 (.1155)

TABLE 4

SCOPE OF EXPERIMENTS

Propeller 4698			Propeller 4699		
σ	V_{fps}	J	σ	V_{fps}	J
12.0	15.0	0.5-1.3	26.2	15.0	0.45-1.5
6.0	15.0	0.4-1.5	3.0	15.0	0.3-1.2
3.0	30.0	0.337-1.2	1.5	30.0	0.5-1.2
0.4	35.0	0.7-1.2	0.75	30.0	0.5-1.2
0.34	35.0	0.7-1.2	0.4	35.0	0.7-1.2
0.3	35.0	0.7-1.2	0.34	35.0	0.7-1.2
			0.3	35.0	0.7-1.2

TABLE 5

CAVITATION PERFORMANCE OF PROPELLER 4698

SIGMA = 12.000

J	KTOUT	10KQOUT	EFFIC
.5000	.3240	.7790	.3310
.5500	.3429	.8364	.3588
.6000	.3410	.8405	.3874
.6500	.3264	.8125	.4156
.7000	.3050	.7680	.4426
.7500	.2807	.7177	.4669
.8000	.2559	.6679	.4879
.8500	.2320	.6219	.5046
.9000	.2090	.5800	.5162
.9500	.1867	.5411	.5216
1.0000	.1642	.5028	.5197
1.0500	.1408	.4627	.5085
1.1000	.1160	.4190	.4847
1.1500	.0898	.3711	.4429
1.2000	.0631	.3207	.3759
1.2500	.0380	.2725	.2775
1.3000	.0180	.2350	.1585

SIGMA = 6.000

J	KTOUT	10KQOUT	EFFIC
.4000	.1916	.4952	.2463
.4500	.2195	.5456	.2881
.5000	.2430	.5953	.3248
.5500	.2611	.6389	.3577
.6000	.2734	.6726	.3882
.6500	.2797	.6940	.4169
.7000	.2799	.7022	.4441
.7500	.2743	.6971	.4698
.8000	.2634	.6795	.4936
.8500	.2477	.6510	.5148
.9000	.2279	.6136	.5320
.9500	.2048	.5696	.5435
1.0000	.1790	.5214	.5465
1.0500	.1516	.4714	.5373
1.1000	.1231	.4216	.5110
1.1500	.0942	.3737	.4614
1.2000	.0656	.3286	.3812
1.2500	.0376	.2869	.2612
1.3000	.0105	.2464	.0883
1.3500	-.0157	.2063	-.1631
1.4000	-.0412	.1627	-.564[illegible]

SIGMA = 3.000

J	KTOUT	10KQOUT	EFFIC
.3000	.0779	.2220	.1675
.3500	.1003	.2806	.1991
.4000	.1203	.3302	.2320
.4500	.1391	.3742	.2663
.5000	.1572	.4147	.3018
.5500	.1747	.4524	.3380
.6000	.1910	.4872	.3744
.6500	.2055	.5183	.4102
.7000	.2172	.5442	.4448
.7500	.2252	.5633	.4773
.8000	.2285	.5739	.5069
.8500	.2263	.5747	.5327
.9000	.2182	.5647	.5534
.9500	.2040	.5434	.5676
1.0000	.1843	.5117	.5732
1.0500	.1601	.4714	.5677
1.1000	.1334	.4255	.5486
1.1500	.1067	.3791	.5153
1.2000	.0841	.3389	.4738

SIGMA = .400

J	KTOUT	10KQOUT	EFFIC
.7000	.0970	.2620	.4124
.7500	.0987	.2645	.4454
.8000	.0961	.2630	.4554
.8500	.0886	.2580	.4637
.9000	.0848	.2513	.4831
.9500	.0842	.2453	.5190
1.0000	.0863	.2417	.5679
1.0500	.0896	.2416	.6194
1.1000	.0922	.2441	.6613
1.1500	.0922	.2459	.6863
1.2000	.0880	.2405	.6987

SIGMA = .340

J	KTOUT	10KQOUT	EFFIC
.7000	.0919	.2600	.3936
.7500	.0959	.2606	.4390
.8000	.0953	.2610	.4650
.8500	.0917	.2578	.4815
.9000	.0869	.2508	.4963
.9500	.0924	.2416	.5155
1.0000	.0796	.2330	.5435
1.0500	.0791	.2274	.5817
1.1000	.0808	.2260	.6263
1.1500	.0833	.2280	.6685
1.2000	.0835	.2292	.6960
1.2500	.0770	.2211	.6923
1.3000	.0569	.1900	.6193

SIGMA = .300

J	KTOUT	10KQOUT	EFFIC
.7000	.0940	.2580	.4059
.7500	.0916	.2603	.4199
.8000	.0939	.2607	.4586
.8500	.0941	.2574	.4948
.9000	.0906	.2503	.5176
.9500	.0866	.2406	.5303
1.0000	.0791	.2304	.5463
1.0500	.0773	.2217	.5828
1.1000	.0798	.2162	.6464
1.1500	.0834	.2143	.7118
1.2000	.0798	.2151	.7017

TABLE 6

CAVITATION PERFORMANCE OF PROPELLER 4699

SIGMA = 26.200

J	KTOUT	10KQOUT	EFFIC
.4500	.4517	1.0128	.3194
.5000	.4271	.9516	.3577
.5500	.4035	.8963	.3940
.6000	.3803	.8457	.4294
.6500	.3572	.7988	.4626
.7000	.3339	.7546	.4929
.7500	.3101	.7124	.5196
.8000	.2857	.6714	.5419
.8500	.2607	.6311	.5590
.9000	.2351	.5908	.5700
.9500	.2087	.5501	.5737
1.0000	.1817	.5087	[illegible]
1.0500	.1541	.4662	.5525
1.1000	.1259	.4223	.5221
1.1500	.0971	.3768	.4718
1.2000	.0677	.3294	.3923
1.2500	.0375	.2802	.2662
1.3000	.0066	.2288	.0579
1.3500	-.0258	.1752	-.3166
1.4000	-.0595	.1193	******
1.4500	-.0950	.0610	******
1.5000	-.1331	.0002	******

SIGMA = 3.000

J	KTOUT	10KQOUT	EFFIC
.3000	.1001	.2448	.1955
.3500	.1229	.2970	.2304
.4000	.1495	.3576	.2661
.4500	.1775	.4210	.3020
.5000	.2048	.4825	.3377
.5500	.2296	.5385	.3732
.6000	.2504	.5859	.4081
.6500	.2660	.6223	.4422
.7000	.2758	.6463	.4754
.7500	.2790	.6568	.5070
.8000	.2755	.6537	.5367
.8500	.2655	.6376	.5634
.9000	.2493	.6096	.5858
.9500	.2278	.5719	.6027
1.0000	.2019	.5271	.6096
1.0500	.1730	.4785	.6043
1.1000	.1430	.4305	.5814
1.1500	.1137	.3877	.5366
1.2000	.0875	.3558	.460[illegible]

SIGMA = 1.500

J	KTOUT	10KQOUT	EFFIC
.5000	.1200	.3099	.3081
.5500	.1350	.3368	.3510
.6000	.1519	.3713	.3907
.6500	.1698	.4089	.4296
.7000	.1872	.4454	.4683
.7500	.2027	.4773	.5070
.8000	.2146	.5016	.5448
.8500	.2216	.5162	.5806
.9000	.2226	.5198	.6128
.9500	.2166	.5119	.6393
1.0000	.2038	.4929	.6580
1.0500	.1853	.4644	.6670
1.1000	.1631	.4291	.6653
1.1500	.1401	.3909	.6559
1.2000	.1210	.3550	.6516

SIGMA = .750

J	KTOUT	10KQOUT	EFFIC
.5000	.1020	.2556	.3175
.5500	.1141	.2835	.3521
.6000	.1160	.2910	.3807
.6500	.1159	.2924	.4100
.7000	.1182	.2963	.4444
.7500	.1248	.3066	.4858
.8000	.1352	.3233	.5326
.8500	.1476	.3437	.5811
.9000	.1592	.3635	.6273
.9500	.1669	.3780	.6675
1.0000	.1690	.3828	.6986
1.0500	.1612	.3756	.7176
1.1000	.1464	.3558	.7203
1.1500	.1262	.3277	.7067
1.2000	.1059	.2946	.6752

SIGMA = .400

J	KTOUT	10KQOUT	EFFIC
.7000	.1120	.2810	.4441
.7500	.1196	.2839	.5028
.8000	.1149	.2810	.5205
.8500	.1080	.2738	.5337
.9000	.1046	.2660	.5630
.9500	.1064	.2621	.6142
1.0000	.1126	.2648	.6768
1.0500	.1199	.2742	.7306
1.1000	.1238	.2849	.7594
1.1500	.1186	.2853	.7610
1.2000	.1000	.2550	.7497

SIGMA = .340

J	KTOUT	10KQOUT	EFFIC
.7000	.1120	.2820	.4424
.7500	.1131	.2818	.4792
.8000	.1172	.2811	.5082
.8500	.1086	.2749	.5333
.9000	.1033	.2644	.5596
.9500	.0998	.2545	.5929
1.0000	.1003	.2505	.6375
1.0500	.1054	.2548	.6915
1.1000	.1124	.2645	.7439
1.1500	.1138	.2680	.7772
1.2000	.0960	.2420	.7975

SIGMA = .300

J	KTOUT	10KQOUT	EFFIC
.7000	.1118	.2791	.4437
.7500	.1087	.2735	.4745
.8000	.1138	.2786	.5207
.8500	.1149	.2776	.5600
.9000	.1097	.2668	.5888
.9500	.1015	.2510	.6117
1.0000	.0981	.2383	.6416
1.0500	.0975	.2353	.6927
1.1000	.1056	.2429	.7595
1.1500	.1118	.2505	.8110
1.2000	.0940	.2321	.7730

TABLE 7

PROPELLER OPERATIONAL POINTS

Propeller Number	4698		4699	
	Design	Model Data	Design	Model Data
V kts	58.5	58.5	59.0	59.0
J	1.01	0.96	1.04	1.13
N	1020	1073	1000	920
η	0.62	0.52	0.64	0.77

DTNSRDC ISSUES THREE TYPES OF REPORTS

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