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Open Water Test Series With Six-Bladed Propeller Models

By Atsuo Yazaki, *Member**
Einosuke Kuramochi, *Member**
and Michio Takahashi, *Member***

Abstract

The paper records the result of experiments with a systematic series of six-bladed aerofoil propeller models, designed in accordance with present-day practice.

Charts of series are shown by so called $\sqrt{B_P}\sim\delta$ design diagrams.

I. Introduction

Further to the work on five-bladed propellers, a paper read in the Society of Naval Architects of Japan (Vol. 102), and on the effect of number of propeller blades (Vol. 103), a systematic testing work with six-bladed propeller models has been carried out in the Experiment Tank of Ship Propulsion Division.

In this report, authors write the result of this work, and give the design diagrams for the six-bladed propellers.

II. Propeller Models

List of model propellers are given in Table1.

Constructional diagrams and tables, stating all particulars of blade sections of the AU-series and the AUw-series, are given in Fig. 1 and in the Tables 2 to 4.

The AU-series has no wash-back, but AUw-

Table 1
Particulars of Propeller Models

	AUw 6-55	AUw 6-70	AU 6-70
Diameter (m)	0.250	0.250	0.250
Boss Ratio	0.180	0.180	0.180
Exp. Area Ratio	0.550	0.700	0.700
Max. Blade Width Ratio	0.208	0.264	0.264
Blade Thickness Ratio	0.050	0.050	0.050
Angle of Rake	10° 0′	10° 0,	10° 0′
Number of Blades	6	6	6
Wash-Back on Trailing Part	With	With	Without

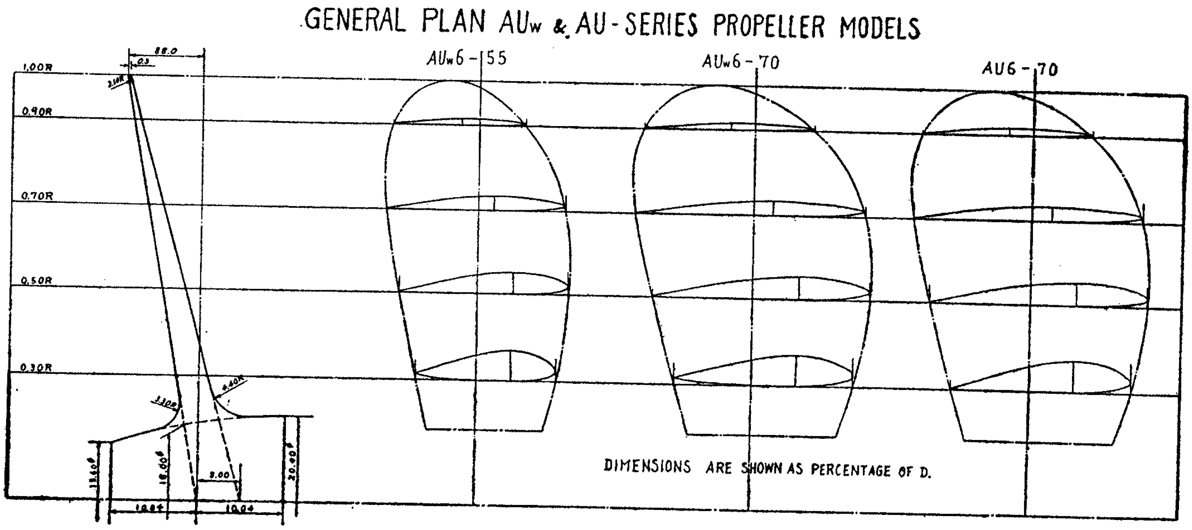

Fig. 1

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* Ship Propulsion Division, Transportation Technical Research Institute
** Amagasaki Iron and Steel Mfg. Co. Ltd.

Table 2

Dimensions of AU6 Series Prop.

	r/R	0.2	0.3	0.4	0.5	0.6	0.66	0.7	0.8	0.9	0.95	1.00	
Width of Blade As % of max. Blade Width	From Generator Line to Trailing Edge	27.96	33.45	38.76	43.54	47.96	49.74	51.33	52.39	48.49	42.07	17.29	Max. Blade Width at 0.66 R =0.2075 D for Fe/F=0.55
	From Generator Line to Leading Edge	38.58	44.25	48.32	50.80	51.15	50.26	48.31	40.53	25.13	13.55		
	Total Blade Width	66.54	77.70	87.08	94.34	99.11	100.00	99.64	92.92	73.62	55.62		
Blade Thickness As % of D		4.06	3.59	3.12	2.65	2.18	1.90	1.71	1.24	0.77	0.54	0.30	Max. Blade Thickness at Prop. axis =0.050 D
Distance of the Point of max. Thickness From the Leading Edge As % of Blade Width		32.0	32.0	32.0	32.5	34.9	37.9	40.2	45.4	48.9	50.0		

Table 3

Table of Ordinates for AUw-type.

1) Ordinates of X Value are given as of Blade Width.
2) Ordinates of Y Value are given as % of Y_{max}.

r/R 0.20	X	0	2.00	4.00	6.00	10.00	15.00	20.00	30.00	32.00	40.00	50.00	60.00	70.00	80.00	90.00	95.00	100.00
	Yo	35.00	51.85	59.75	66.15	76.05	85.25	92.20	99.80	100.00	97.80	91.10	81.25	69.35	56.60	42.00	34.20	25.55
	Yu		24.25	19.05	15.00	10.00	5.40	2.35					2.25	5.00	10.00	15.80	19.55	
0.30	X	0	2.00	4.00	6.00	10.00	15.00	20.00	30.00	32.00	40.00	50.00	60.00	70.00	80.00	90.00	95.00	100.00
	Yo	35.00	51.85	59.75	66.15	76.05	85.25	92.20	99.80	100.00	97.80	90.50	79.85	66.95	52.40	37.40	29.55	19.80
	Yu		24.25	19.05	15.00	10.00	5.40	2.35					1.00	4.00	7.50	12.15	14.85	
0.40	X	0	2.00	4.00	6.00	10.00	15.00	20.00	30.00	32.00	40.00	50.00	60.00	70.00	80.00	90.00	95.00	100.00
	Yo	35.00	51.85	59.75	66.15	76.05	85.25	92.20	99.80	100.00	97.80	90.30	78.50	63.95	47.95	31.16	22.40	12.80
	Yu		24.25	19.05	15.00	10.00	5.40	2.35						0.25	2.30	5.75	8.05	
0.50	X	0	2.03	4.06	6.09	10.16	15.23	20.31	30.47	32.50	40.44	50.37	60.29	70.22	80.15	90.07	95.04	100.00
	Yo	35.00	51.85	59.75	66.15	76.05	85.25	92.20	99.80	100.00	97.80	90.00	78.20	63.20	45.65	26.25	16.35	5.60
	Yu		24.25	19.05	15.00	10.00	5.40	2.35								0.25	1.20	
0.60	X	0	2.18	4.36	6.54	10.91	16.36	21.81	32.72	34.90	42.56	52.13	61.70	71.28	80.85	90.43	95.21	100.00
	Yo	35.00	51.85	59.75	66.15	76.05	85.25	92.20	99.80	100.00	97.75	89.95	78.15	63.15	45.25	25.30	15.00	4.50
	Yu		24.25	19.05	15.00	10.00	5.40	2.35										
0.70	X	0	2.51	5.03	7.54	12.56	18.84	25.12	37.69	40.20	47.23	56.03	64.82	73.62	82.41	91.21	95.60	100.00
	Yo	35.00	51.85	59.75	66.15	76.05	85.25	92.20	99.80	100.00	97.75	89.95	78.15	63.15	45.25	25.30	15.00	4.50
	Yu		24.25	19.05	15.00	10.00	5.40	2.35										
0.80	X	0	2.84	5.68	8.51	14.19	21.28	28.38	42.56	45.40	51.82	59.85	67.88	75.91	83.94	91.97	95.99	100.00
	Yo	35.00	51.85	59.75	66.15	76.05	85.25	92.20	99.86	100.00	97.75	89.95	78.15	63.15	45.25	25.30	15.00	4.50
	Yu		24.25	19.75	15.00	10.00	5.40	2.35										
0.90	X	0	3.06	6.11	9.17	15.28	22.92	30,56	45.85	48.90	54.91	62.42	69.94	77.46	84.97	92.49	96.24	100.00
	Yo	30.46	48.22	55.33	62.44	74.10	85.25	92.20	99.80	100.00	97.75	89.95	78.15	63.15	45.25	25.30	15.00	4.50
	Yu		23.10	19.04	15.23	10.15	5.40	2.35										
0.95	X	0	3.13	6.25	9.38	15.63	23.44	31.25	46.87	50.00	55.88	63.23	70.59	77.94	85.30	92.65	96.32	100.00
	Yo	0	15.88	25.99	34.66	50.55	68.36	83.75	99.80	100.00	97.75	89.95	78.15	63.15	45.25	25.30	15.00	4.50
	Yu																	

Series has wash-back on trailing part of blade sections.

Experiments have been done in two AUw-series of expanded-area ratio, namely 0.55 and 0.70, in order to provide means of interpolation and extrapolation, and in one AU-series of 0.70 expanded-area ratio.

As to pitch ratio, 0.5, 0.7, 0.9 and 1.1 are tested for all disc-area ratios. Pitch distribution is constant from the hub to the tip.

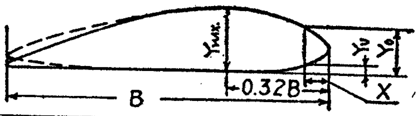
All twelve propeller models have a diameter of 250 mm, and are made of aluminium alloy.

Table 4

Table of Ordinates for AU-type.

(1) Ordinates of X Value are given as Percentage of Blade Width B.

(2) Ordinates of Y Value are given as Percentage of Y_{max}.



r/R																		
0.20	X	0	2.00	4.00	6.00	10.00	15.00	20.00	30.00	32.00	40.00	50.00	60.00	70.00	80.00	90.00	95.00	100.00
	Yo	35.00	51.85	59.75	66.15	76.05	85.25	92.20	99.80	100.00	97.75	89.95	78.15	63.15	45.25	25.30	15.00	4.50
	Yu		24.25	19.05	15.00	10.00	5.40	2.35										
0.30	X	0	2.00	4.00	6.00	10.00	15.00	20.00	30.00	32.00	40.00	50.00	60.00	70.00	80.00	90.00	95.00	100.00
	Yo	35.00	51.85	59.75	66.15	76.05	85.25	92.20	99.80	100.00	97.75	89.95	78.15	63.15	45.25	25.30	15.00	4.50
	Yu		24.25	19.05	15.00	10.00	5.40	2.35										
0.40	X	0	2.00	4.00	6.00	10.00	15.00	20.00	30.00	32.00	40.00	50.00	60.00	70.00	80.00	90.00	95.00	100.00
	Yo	35.00	51.85	59.75	66.15	76.05	85.25	92.20	99.80	100.00	97.75	89.95	78.15	63.15	45.25	25.30	15.00	4.50
	Yu		24.25	19.05	15.00	10.00	5.40	2.35										
0.50	X	0	2.03	4.06	6.09	10.16	15.23	20.31	30.47	32.50	40.44	50.37	60.29	70.22	80.15	90.07	95.04	100.00
	Yo	35.00	51.85	59.75	66.15	76.05	85.25	92.20	99.80	100.00	97.75	89.95	78.15	63.15	45.25	25.30	15.00	4.50
	Yu		24.25	19.05	15.00	10.00	5.40	2.35										
0.60	X	0	2.18	4.36	6.54	10.91	16.36	21.81	32.72	34.90	42.56	52.13	61.70	71.28	80.85	90.43	95.21	100.00
	Yo	35.00	51.85	59.75	66.15	76.05	85.25	92.20	99.80	100.00	97.75	89.95	78.15	63.15	45.25	25.30	15.00	4.50
	Yu		24.25	19.05	15.00	10.00	5.40	2.35										
0.70	X	0	2.51	5.03	7.54	12.56	18.84	25.12	37.69	40.20	47.23	56.03	64.82	73.62	82.41	91.21	95.60	100.00
	Yo	35.00	51.85	59.75	66.15	76.05	85.25	92.20	99.80	100.00	97.75	89.95	78.15	63.15	45.25	25.30	15.00	4.50
	Yu		24.25	19.05	15.00	10.00	5.40	2.35										
0.80	X	0	2.84	5.68	8.51	14.19	21.28	28.38	42.56	45.40	51.82	59.85	67.88	75.91	83.94	91.97	95.99	100.00
	Yo	35.00	51.85	59.75	66.15	76.05	85.25	92.20	99.80	100.00	97.75	89.95	78.15	63.15	45.25	25.30	15.00	4.50
	Yu		24.25	19.05	15.00	10.00	5.40	2.35										
0.90	X	0	3.06	6.11	9.17	15.28	22.92	30.56	45.85	48.90	54.91	62.42	69.94	77.46	84.97	92.49	96.24	100.00
	Yo	30.46	48.22	55.33	62.44	74.10	85.25	92.20	99.80	100.00	97.75	89.95	78.15	63.15	45.25	25.30	15.00	4.50
	Yu		23.10	19.04	15.23	10.15	5.40	2.35										
0.95	X	0	3.13	6.25	9.38	15.63	23.44	31.25	46.87	50.00	55.88	63.23	70.59	77.94	85.30	92.65	96.32	100.00
	Yo	0	15.88	25.99	34.66	50.55	68.36	83.75	99.80	100.00	97.75	89.95	78.15	63.15	45.25	25.30	15.00	4.50
	Yu																	

III. Open Water Tests

The tests were carried out by means of a propeller open water test dynamometer (Mitsubishi-type), according to the scheme of the Experiment Tank of Ship Propulsion Division. The arrangement of the test instruments is shown in Fig. 2.

All propeller models have been tested over a 100% slip range at an immersion to the center of propeller shaft equal to the screw diameter, and the number of revolutions was kept constant, namely 12 revolutions per second, and the speed of advance varied from zero to above the speed for zero thrust.

For fixing the net thrust, the correction for the resistance of the screw hub at various speed of advance was applied.

Mean temperature of water among these test is 9.0°C., and the Reynolds number

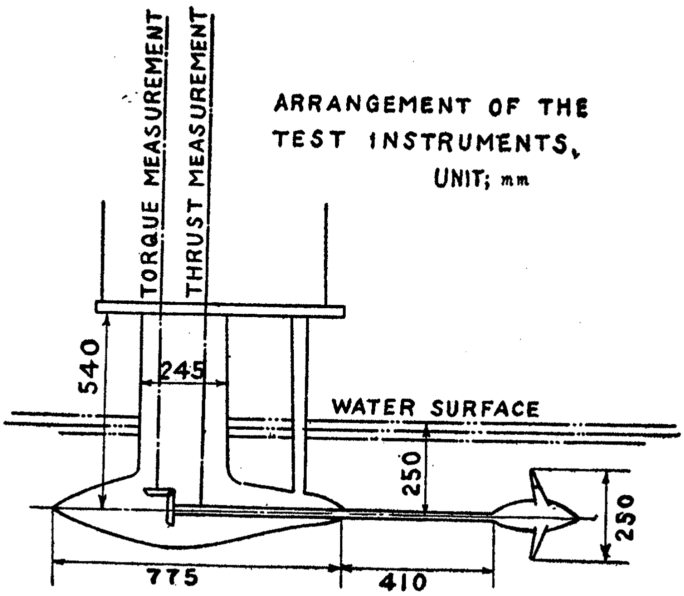


Fig. 2

Table 5
List of Reynolds Number

Type	Formula (1)	Formula (2)	Formula (3)
AUw 6-55	5.60×10^5	5.13×10^4	9.83×10^4
AUw 6-70 & AU 6-70	5.60×10^5	6.53×10^4	12.52×10^4

according to the following formulas are as in Table 5. So, it is considered scale effect is negligible.

$$R_{n1}=nD^2/\nu \quad (1)$$

$$R_{n2}=nD^2/\nu\cdot a_e/z \quad (2)$$

$$R_{n3}=b_{mn}\cdot nD^2/\nu \quad (3)$$

n=Revolutions per second

D=Diameter of screw

a_e=Expanded-area ratio

z=Number of blades

b_{mn}=Mean blade width ratio

ν=Kinematic viscosity coefficient

R_n=Reynolds number

IV. Diagrams

(a) Curves of K_T, K_Q and η_0 on a base of J; These curves are given in Figs. 3, 4 and 5.

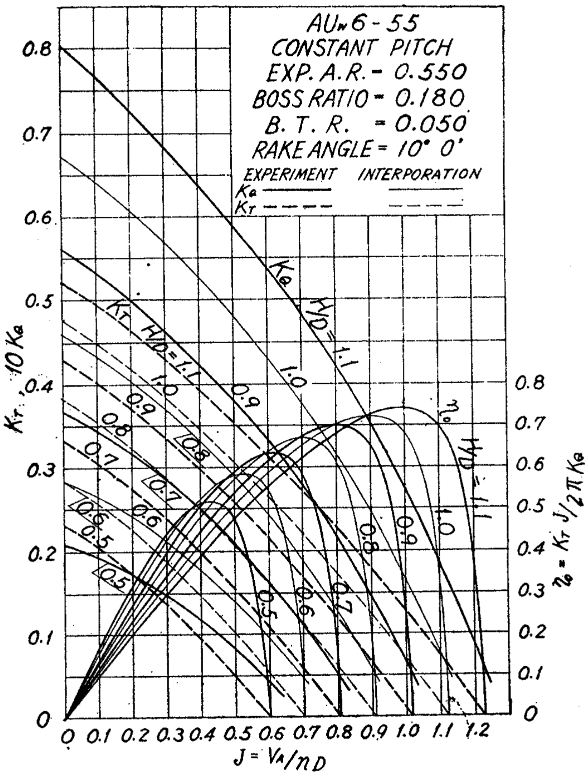


Fig. 3

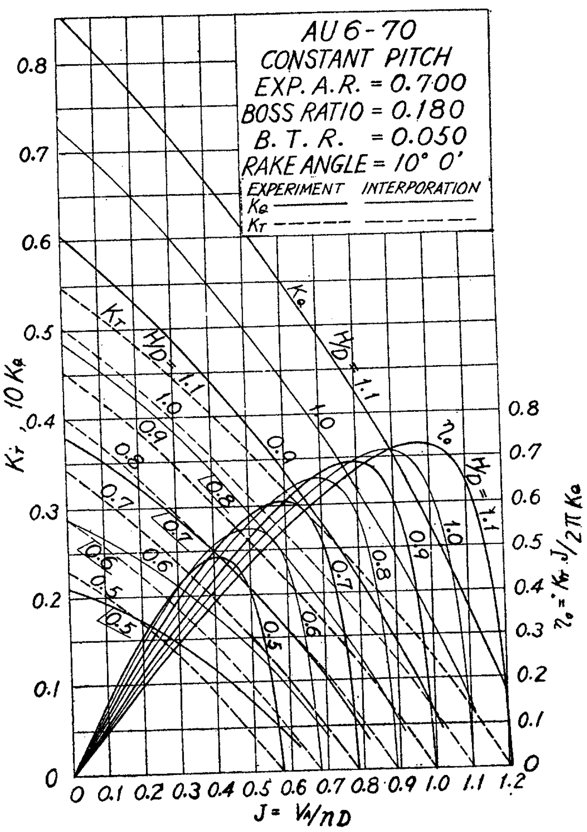


Fig. 4

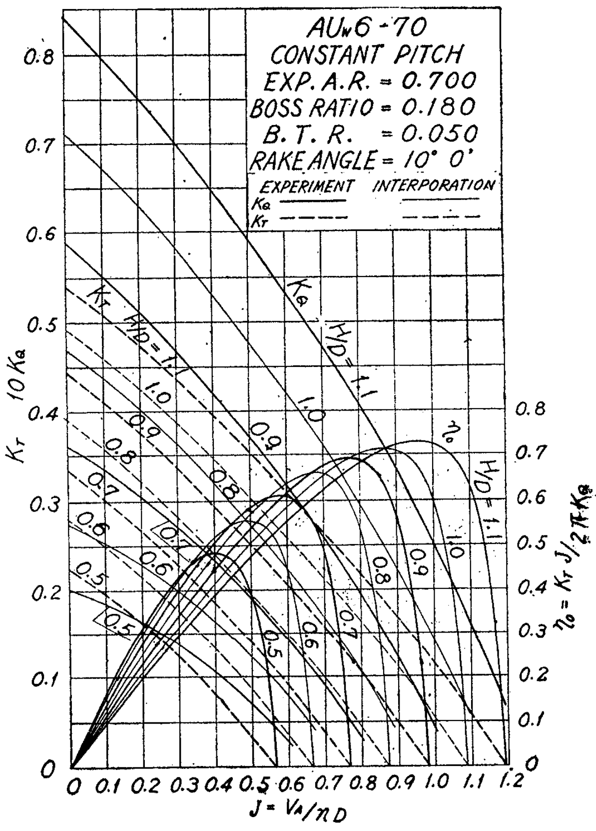


Fig. 5

The meaning of symbols is as follows : —

K_T = Thrust coefficient $= T/\rho n^2 D^4$

K_Q = Torque coefficient $= Q/\rho n^2 D^5$

η_0 = Propeller efficiency in open water $= K_T J/2\pi K_Q$

J = Advance coefficient $= V_A/nD$

T = Measured thrust $\qquad Q$ = Measured torque

V_A = Speed of advance $\qquad \rho$ = Density of tank water

(b) $\sqrt{B_P}\sim\delta$ design diagr ams;

In these diagrams, we used metric units, and density of sea water is assumed as 104. 51 kg m^{-4} sec^2. $\sqrt{B_P}\sim\delta$ design Diagrams are given in Figs. 6, 7 and 8. Propeller s of AU_W-type correspond to Figs. 6 and 7, and AU-type to Fig. 8.

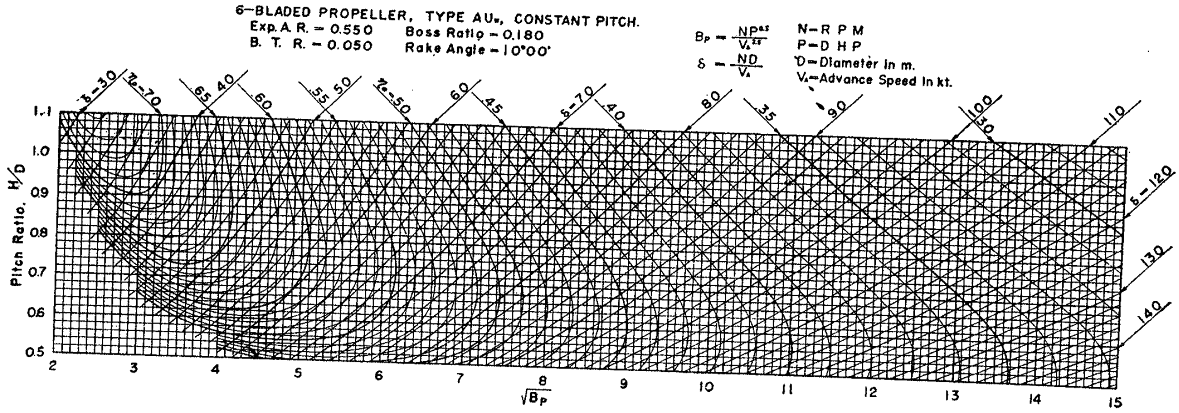


Fig. 6

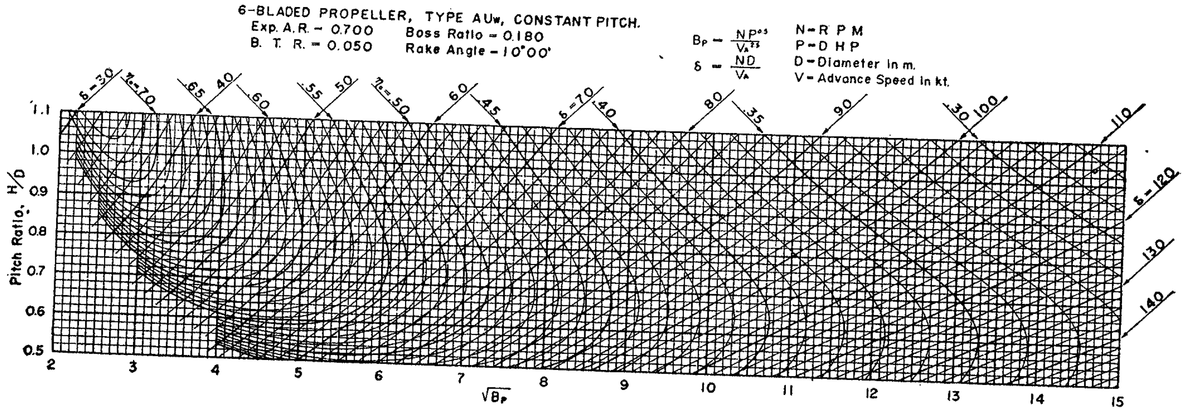


Fig. 7

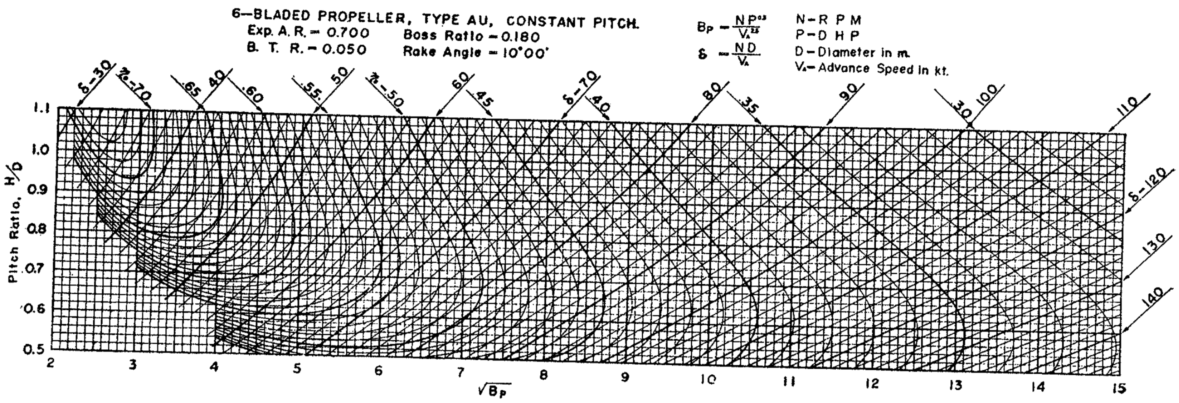


Fig. 8

The meaning of symbols is as follows : —

B_P = Power coefficient = $NP^{0.5}/V_A^{2.5}$

δ = Diameter constant = ND/V_A

H/D = Pitch ratio

N = Revolutions per minute for ship

P = Delivered horse power in sea water

V_A = Speed of advance through the wake water in knots

D = Screw diameter in meter

1 HP = 75 kg m sec^{-1}

V. Some Considerations

(a) Comparison between AU 6 and AUw 6

Table 6 gives the relation between optimum values of η_0 and δ (which means optimum diameter for given speed of advance and number of revolutions) for AU 6 and AUw 6 propellers, for various power coefficients.

Table 6

$\sqrt{B_P}$	AU 6-70			AUw 6-70			AUw 6-55		
	δ	H/D	η_0	δ	H/D	η_0	δ	H/D	η_0
4	46.2	.900	.652	46.3	.915	.653	46.3	.900	.658
5	56.0	.810	.597	56.2	.818	.600	56.5	.796	.604
6	65.7	.745	.550	66.0	.760	.554	66.3	.733	.557
8	84.3	.667	.473	84.0	.690	.476	85.2	.650	.481
10	101.2	.630	.414	101.5	.648	.418	104.1	.585	.423
12	118.5	.595	.371	118.2	.615	.378	122.0	.550	.380
14	134.7	.575	.335	135.0	.590	.338	139.7	.518	.344

Table 7

Pitch ratio	H_{WE}/H_E*
0.5	0.980
0.7	0.980
0.9	0.983
1.0	0.986

* H_{WE}=Effective pitch for AUw6-70
H_W=Effective pitch for AU 6-70

From this table, it is known that AU 6-70 and AUw 6-70 have almost same values of η_0 and δ, but in values of pitch ratio AUw 6 is larger than AU 6. Moreover, AUw 6-55 has larger values of η_0 and δ, and smaller values of pitch ratio than AUw 6-70.

Table 7 gives the ratio of a effective pitch of AU 6-70 and AUw 6-70 propellers for various face pitch ratio. This table shows wash back on trailing part of blade sections decreases a effective pitch by about 2%.

(b) Comparison between AU 5 and AU 6, AUw 6.

Table 8 gives the relation between optimum values of η_0 and δ for blade numbers for various power coefficients.

With large blade area ratio 0.70, as shown in Fig. 9 A, the six-bladed propellers have smaller values

Table 8

$\sqrt{B_P}$	AU 5-50			AUw 6-50*			AU 5-70			AU 6-70**		
	δ	H/D	η_0	δ	H/D	η_0	δ	H/D	η_0	δ	H/D	η_0
3	36.2	1.032	.725	35.8	1.067	.720	35.4	1.105	.720	35.8	1.065	.710
4	46.7	.888	.672	46.3	.895	.660	45.8	.941	.661	46.2	.900	.652
5	57.0	.788	.613	56.6	.789	.606	55.5	.849	.605	56.0	.810	.597
6	67.0	.720	.564	66.4	.725	.558	64.6	.787	.552	65.7	.745	.550
8	86.0	.635	.483	85.6	.637	.483	83.3	.707	.472	84.3	.667	.473
10	104.0	.583	.425	105.0	.564	.425	101.1	.652	.410	101.2	.630	.414
12	121.8	.550	.380	123.3	.527	.383	118.1	.614	.364	118.5	.595	.371
14	138.9	.525	.343	141.3	.491	.346	135.0	.585	.331	134.7	.575	.335

* Extrapolated from AUw 6-55 and AUw 6-70
** Extrapolated from AU 5-50 and AU 5-65

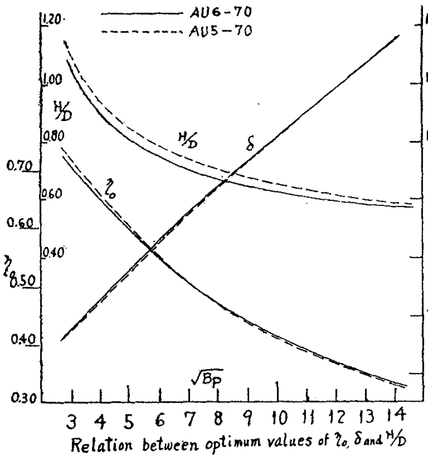


Fig. 9 A

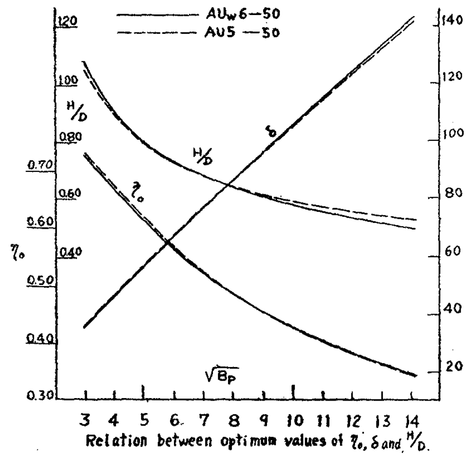


Fig. 9 B

of efficiency in low power coefficients, and have larger values of efficiency in high power coefficients than these values of the five-bladed propellers.

And, with small blade area ratio 0.50, as shown in Fig. 9 B, propeller efficiency of five-bladed propellers is better in low power coefficients and worse in high power coefficients, and diameter constant is larger in low power coefficients and smaller in high power coefficients, than these values of six-bladed propellers.

(c) Numerical examples

Below is given some numerical examples showing the principal dimensions of the optimum screws designed with the aid of the systematic AU and AUw screw series diagrams for some single screw ships.

(1) Catcher boat (780 GT class)

Say $BHP=3,500$ HP, $N=180$ and $V_A=15.1$ knots, result of screw design with five and six-bladed propellers having same expanded-area ratio 0.50 is as Table 9.

Table 9

Propeller Type	Number of Blades	Diameter (m)	Pitch Ratio	Propeller Efficiency (%)
AU 5-50	5	3.440	0.960	70.4
AUw 6-50	6	3.430	0.948	68.9

(2) High speed cargo boat (15,000 DWT class)

Say $P=15,000$ HP, $N=120$, $V_A=13.3$ knots and $a_e=0.55$, result of screw design is as Table 10.

Table 10

Propeller Type	Number of Blades	Diameter (m)	Ptich Ratio	Propeller Efficiency (%)
AU 5-55	5	6.150	0.809	61.5
AUw 6-55	6	6.210	0.795	60.8

(3) Super tanker (46,000 DWT class)

(A) Say $P=24,000$ HP, $N=120$, $V_A=11.6$ knots and $a_e=0.65$, result of screw design is as Table 11.

(B) Say $P=24,000$ HP, $N=350$, $V_A=10.8$ knots and $a_e=0.65$, result of screw design is as Table 12.

Table 11

Propeller Type	Number of Blades	Diameter (m)	Pitch Ratio	Propeller Efficiency (%)
AU 5-65	5	6.670	0.750	53.9
AUw 6-65	6	6.710	0.736	53.9

Table 12

Propeller Type	Number of Blades	Diameter (m)	Pitch Ratio	Propeller Efficiency (%)
AU 5-65	5	3.600	0.620	37.0
AUw 6-65	6	3.670	0.590	37.8

VI. Acknowledgement

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