(昭和 34 年 11 月造船協会秋季講演会において講演) Open Water Test Series With Six-Bladed

Propeller Models

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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 sixbladed propellers.

II. Propeller Models

List of model propellers are given in Table1. Constructional diagrams and tables, stating all particulars of blade sections of the AUseries 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 1Particulars 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



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Table 2 Dimensions of AU6 Series Prop.

and a second												
r/R	0.2	0.3	0.4	0.5	0.6	0.66	0.7	0.8	0.9	0.95	1.00	
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
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		at 0.66 R =0.2075 D for $Ee/E=0.55$
Total Blade Width	66.54	77.70	87.08	94.34	99.11	100.00	99.64	92.92	73.62	55.62		
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	32.5	34.9	37.9	40.2	45.4	48.9	50.0		
	r/R From Generator Line to Trailing Edge From Generator Line to Leading Edge Total Blade Width As % of D oint of max. the Leading Edge idth	r/R0.2From Generator Line to Trailing Edge27.96From Generator Line to Leading Edge38.58Total Blade Width66.54As % of D4.06oint of max. the Leading Edge32.0	r/R0.20.3From Generator Line to Trailing Edge27.9633.45From Generator Line to Leading Edge38.5844.25Total Blade Width66.5477.70As % of D4.063.59oint of max. the Leading Edge32.032.0	r/R 0.2 0.3 0.4 From Generator Line to Trailing 27.96 33.45 38.76 Edge 38.58 44.25 48.32 From Generator Line to Leading 38.58 44.25 48.32 Edge 38.58 44.25 48.32 Total Blade Width 66.54 77.70 87.08 As % of D 4.06 3.59 3.12 oint of max. the Leading Edge 32.0 32.0 32.0	r/R 0.2 0.3 0.4 0.5 From Generator Line to Trailing 27.96 33.45 38.76 43.54 Edge 38.58 44.25 48.32 50.80 Edge 38.58 44.25 48.32 50.80 Total Blade 66.54 77.70 87.08 94.34 As % of D 4.06 3.59 3.12 2.65 oint of max. 32.0 32.0 32.0 32.5	r/R0.20.30.40.50.6From Generator Line to Trailing Edge27.9633.4538.7643.5447.96From Generator Line to Leading Edge38.5844.2548.3250.8051.15Total Blade Width66.5477.7087.0894.3499.11As % of D4.063.593.122.652.18oint of max. the Leading Edge32.032.032.032.534.9	r/R0.20.30.40.50.60.66From Generator Line to Trailing Edge27.9633.4538.7643.5447.9649.74From Generator Line to Leading Edge38.5844.2548.3250.8051.1550.26Total Blade Width66.5477.7087.0894.3499.11100.00As % of D4.063.593.122.652.181.90oint of max. the Leading Edge32.032.032.032.534.937.9	r/R0.20.30.40.50.60.660.7From Generator Line to Trailing Edge27.9633.4538.7643.5447.9649.7451.33From Generator Line to Leading Edge38.5844.2548.3250.8051.1550.2648.31Total Blade Width66.5477.7087.0894.3499.11100.0099.64As % of D4.063.593.122.652.181.901.71oint of max. the Leading Edge32.032.032.032.534.937.940.2	r/R0.20.30.40.50.60.660.70.8From Generator Line to Trailing Edge27.9633.4538.7643.5447.9649.7451.3352.39From Generator Line to Leading Edge38.5844.2548.3250.8051.1550.2648.3140.53Total Blade Width66.5477.7087.0894.3499.11100.0099.6492.92As % of D4.063.593.122.652.181.901.711.24oint of max. the Leading Edge32.032.032.032.534.937.940.245.4	r/R0.20.30.40.50.60.660.70.80.9From Generator Line to Trailing Edge27.9633.4538.7643.5447.9649.7451.3352.3948.49From Generator Line to Leading Edge38.5844.2548.3250.8051.1550.2648.3140.5325.13Total Blade Width66.5477.7087.0894.3499.11100.0099.6492.9273.62As % of D4.063.593.122.652.181.901.711.240.77oint of max. the Leading Edge idth32.032.032.534.937.940.245.448.9	r/R0.20.30.40.50.60.660.70.80.90.95From Generator Line to Trailing Edge27.9633.4538.7643.5447.9649.7451.3352.3948.4942.07From Generator Line to Leading Edge38.5844.2548.3250.8051.1550.2648.3140.5325.1313.55EdgeTotal Blade Width66.5477.7087.0894.3499.11100.0099.6492.9273.6255.62As % of D4.063.593.122.652.181.901.711.240.770.54oint of max. the Leading Edge32.032.032.534.937.940.245.448.950.0	r/R0.20.30.40.50.60.660.70.80.90.951.00From Generator Line to Trailing Edge27.9633.4538.7643.5447.9649.7451.3352.3948.4942.0717.29From Generator Line to Leading Bdge38.5844.2548.3250.8051.1550.2648.3140.5325.1313.55Total Blade Width66.5477.7037.0894.3499.11100.0099.6492.9273.6255.62As % of D4.063.593.122.652.181.901.711.240.770.540.30oint of max. the Leading Edge32.032.032.534.937.940.245.448.950.0

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 Yo Yu	0 35.00	2.00 51.85 24.25	4.00 59.75 19.05	6.00 66.15 15.00	10.00 76.05 10.00	15.00 85.25 5.40	20.00 92.20 2.35	30.00 99.80	32.00 100.00	40.00 97.80	50.00 91.10	60.00 81.25 2.25	70.00 69.35 5.00	80.00 56.60 10.00	90.00 42.00 15.80	95.00 34.20 19.55	100.00 25.55
0.30	X Yo Yu	0 35.00	2.00 51.85 24.25	4.00 59.75 19.05	6.00 66.15 15.00	10.00 76.05 10.00	15.00 85.25 5.40	20.00 92.20 2.35	30.00 99.80	32.00 100.00	40.00 97.80	50.00 90.50	60.00 79.85 1.00	70.00 66.95 4.00	80.00 52.40 7.50	90.00 37.40 12.15	95.00 29.55 14.85	100.00 19.80
0.40	X Yo Yu	0 35.00	2.00 51.85 24.25	4.00 59.75 19.05	6.00 66.15 15.00	10.00 76.05 10.00	15.00 85.25 5.40	20.00 92.20 2.35	30.00 99.80	32.00 100.00	40.00 97.80	50.00 90.30	60.00 78.50	70.00 63.95 0.25	80.00 47.95 2.30	90.00 31.16 5.75	95.00 22.40 8.05	100.00 12.80
0.50	X Yo Yu	0 35.00	2.03 51.85 24.25	4.06 59.75 19.05	6.09 66.15 15.00	10.16 76.05 10.00	15.23 85.25 5.40	20.31 92.20 2.35	30.47 99.80	32.50 100.00	40.44 97.80	50.37 90.00	60.29 78.20	70.22 63.20	80.15 45.65	90.07 26.25 0.25	95.04 16.35 1.20	100.00 5.60
0.60	X Yo Yu	0 35.00	2.18 51.85 24.25	4.36 59.75 19.05	6.54 66.15 15.00	10.91 76.05 10.00	16.36 85.25 5.40	21.81 92.20 2.35	32.72 99.80	34.90 100.00	42.56 97.75	52.13 89.95	61.70 78.15	71.28 63.15	80. 85 45. 25	90. 4 3 25. 30	95.21 15.00	100.00 4.50
0.70	X Yo Yu	0 35.00	2.51 51.85 24.25	5.03 59.75 19.05	7.54 66.15 15.00	12.56 76.05 10.00	18.84 85.25 5.40	25.12 92.20 2.35	37.69 99.80	40.20 100.00	47.23 97.75	56.03 89.95	64.82 78.15	73.62 63.15	82. 41 45. 25	91.21 25.30	95.60 15.00	100.00 4.50
0.80	X Yo Yu	0 35.00	2.84 51.85 24.25	5.68 59.75 19.75	8,51 66,15 15,00	14.19 76.05 10.00	21,28 85,25 5,40	28.38 92.20 2.35	42.56 99.86	45.40 100.00	51,82 97,75	59,85 89,95	67.88 78.15	75.91 63.15	83.94 45.25	91.97 25.30	95.99 15.00	100.00 4.50
0.90	X Yo Yu	0 30.46	3.06 48.22 23.10	6.11 55.33 19.04	9.17 62.44 15.23	15.28 74.10 10.15	22.92 85.25 5.40	30, 56 92, 20 2, 35	45.85 99.80	48.90 100.00	54.91 97.75	62.42 89.95	69.94 78.15	77.46 63.15	84.97 45.25	92.49 25.30	96.24 15.00	100.00 4.50
0.95	X Yo Yu	0	3.13 15.88	6.25 25.99	9.38 34.66	15.63 50.55	23.44 68.36	31.25 83.75	46.87 99.80	50.00 100.00	55.88 97.75	63.23 89.95	70.59 78.15	77.94 63.15	85.30 45.25	92.65 25.30	96.32 15.00	100.00 4.50

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.

								<u> </u>		101 11	.u-ty]	με.				• •		
(1)) Ordi	nates (of X V	⁷ alue a	re giv	en as	Perce	ntage	of Bla	de Wi	dth B.	,					×	
(2)) Ordi	nates o	of Y V	⁷ alue a	re giv	en as	Perce	ntage	of Ym	ax.			/		¥		D >	<u>ک</u>
												-		- B -	-	-0.32B		X
r/R	X	0	2.0	0 4.00	6.00	10.00	15.00	20.00	30.00	0 32.00	40.00	50.00	60.00	70.00	80 00	00.00		
0.20	Yo Yu	35.00	24.2	5 59.75 5 19.05	66.15	76.05	85.25	5 92.20	99.80	0 100.00	97.75	5 89.95	78.15	63.15	45.25	25.30	15.00	4.50
	x	0	2.0		6.00	10.00	15.40	2.30										
0.30	Yo	35.00	51.8	5 59.75	66.15	76.05	15.00	20.00		32.00	40.00	50.00	60.00	70.00	80.00	90.00	95.00	100.00
·	Yu		24.25	5 19.05	15.00	10.00	5.40	2.35	55.00	100.00	97.75	89.95	78.15	63.15	45.25	25.30	15.00	4.50
A 4A	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	00.00	05 00	100.00
0.40	Yu Yu	35.00	51.85 24.25	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
	x	0	2 02	1 1 00	10.00	10.00	5.40	2.35	1	<u> </u>								
0.50	Yo	35.00	51.85	4.06	66 15	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
	Yu		24.25	19.05	15.00	10.00	5.40	92.20	99.80	100.00	97.75	89.95	78.15	63.15	45.25	25.30	15.00	4.50
	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 00	00.00	00.40	07.01	
0.60	Yo V	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	90.43 25.30	95.21 15 00	100.00
	<u>i</u>		24.25	19.05	15.00	10.00	5.40	2.35								20.00	10.00	4.00
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
	Yu	55.00	24.25	59.75 19.05	66.15 15.00	76.05 10.00	85.25 5.40	92.20	99. 80	100.00	97.75	89.95	78,15	63.15	45.25	25.30	15.00	4.50
	x	0	2.84	5.68	8 51	14 10	01 00	2.00	10									
0.80	Yo	35.00	51.85	59.75	66.15	76.05	85.25	48.38 92.20	42.56	45.40	51.82	59.85	67.88	75.91	83.94	91.97	95.99	100.00
	Yu		24.25	19.05	15.00	10.00	5.40	2.35	55.00	100.00	91.15	99.95	78.15	63.15	45.25	25.30	15.00	4.50
A 00	X	0	3.06	6.11	9.17	15.28	22.92	30, 56	45,85	48.90	54 01	62 42	60.04	777 40	84.07	00 10	00.04	
0.90	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	84.97 45.25	92.49	96.24	100.00
	IU		23.10	19.04	15.23	10.15	5.40	2.35							.0.20	20.00	10.00	4.00
0.95	X Yo	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
	Y ₁₁	v	10.08	∡ ɔ. 99	34.06	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

Table 4

Table of Ordinates for AU-type.

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





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	Tabl	e 5	
	List of Reyn	olds Number	
Туре	Formula(1)	Formula (2)	Formula (3)
AUW 6-55	5.60×10^{5}	5.13×104	9.83×104
AUw 6-70 & AU 6-70	5.60×10 ⁵	6.53×104	$12.52\!\times\!10^4$

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

$$R_{n1} = nD^2/\nu \tag{1}$$

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

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

$$R_{n3} = b_{mn} \cdot nD^2 / \nu$$

- n =Revolutions per second
- D = Diameter of screw
- $a_e = Expanded$ -area ratio
- z = Number of blades
- $b_{mn} =$ Mean blade width ratio
 - v =Kinematic viscosity coefficient
- $R_n = \text{Reynolds}$ 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.







The meaning of symbols is as follows : ---

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

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

 $\eta_0 = ext{Propeller}$ efficiency in open water $= K_T J/2 \ \pi K_Q$

 $I = Advance \ coefficient = V_A/nD$

T = Measured thrust Q = Measured torque

 $V_{\mathcal{A}} =$ Speed of advance $\rho =$ 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 sec². $\sqrt{B_P} \sim \delta$ 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.8

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The meaning of symbols is as follows : --

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

 $\delta = \text{Diameter constant} = ND/V_A$

H/D = Pitch ratio

N =Revolutions per minute for ship

P = Delivered horse power in sea water

 $V_{\mathcal{A}}$ = Speed of advance through the wake water in knots

D =Screw diameter in meter

 $1 \text{H}=75 \text{ kg m sec}^{-1}$

V. Some Considerations

(a) Comparison between AU 6 and $AU_W 6$

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.

12		AU 6-70			AUw 6-70			AU _W 6-55	
~ Bp	δ	H/D	70	δ	H/D	ηο	δ	H/D	70
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 6

Table 7

Pitch ratio	H _{WE} /HE*
0.5	0.980
0.7	0.980
0.9	0.983
1.0	0.986

* HWE=Effective pitch for AUW6-70 Hw=Effective pitch for AU6-70 From this table, it is known that AU 6-70 and AU_W 6-70 have almost same values of η_0 and δ , but in values of pitch ratio AU_W 6 is larger than AU 6. Moreover, AU_W 6-55 has larger values of η_0 and δ , and smaller values of pitch ratio than AU_W 6-70.

Table 7 gives the ratio of a effective pitch of AU 6-70 and AU_w 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 AU5 and AU6, 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. 9A, the six-bladed propellers have smaller values

Table 8

15		AU 5-50			AUw 6-50*	:		AU 5-70			AU 6-70**	4
~ Bp	δ	H/D	70	δ	H/D	70	δ	H/D	70	δ	H/D	70
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 AU_W 6-55 and AU_W 6-70

** Extrapolated from AU 5-50 and AU 5-65

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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.9B, 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 sixbladed 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 AU _W 6-50	5 6	3.440 3.430	0.960 0.948	70. 4 68. 9
		1		i

(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.

T	`able	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.

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Propeller TypeNumber of BladesDiameter (m)Pitch RatioPropeller EfitAU 5-6556.6700.75053.9AUw 6-6566.7100.73653.9Table 12	
AU 5-65 5 6.670 0.750 53.9 AUw 6-65 6 6.710 0.736 53.9 Table 12	fficiency (%)
AUw 6-65 6 6.710 0.736 53.9	.9
Table 12	. 9
Propeller Type Number of Blodes Diameter (m) Pitch Ratio Propeller Ff	fficiency (%
Tropener Type Trumber of Blades Diameter (III) Then Katto Tropener Er	
AU 5-65 5 3.600 0.620 37.0	. 0
AUw 6-65 6 3.670 0.590 37.8	. 8

Table 11

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