Table 6.4 Extent of the Wageningen B-screw series (taken from Reference 6)

Blade number (Z)	*Blade area ratio* A_E/A_O													
2	0.30													
3		0.35			0.50			0.65			0.80			
4			0.40			0.55			0.70			0.85	1.00	
5				0.45			0.60			0.75				1.05
6					0.50			0.65			0.80			
7						0.55			0.70			0.85		

6.5.1 Wageningen B-screw series

This is perhaps the most extensive and widely used propeller series. The series was originally presented in a set of papers presented by Troost (References 3 to 5) in the late 1940s and, amongst many practitioners, is still referred to as the 'Troost series'. Over the years the model series has been added to so as to provide a comprehensive fixed pitch, non-ducted propeller series. From analysis of the early results it was appreciated that a certain unfairness between the various design diagrams existed and this was considered to result from the scale effects resulting from the different model tests. This led to a complete re-appraisal of the series in which the differences in test procedures were taken into account and the results of this work were presented by van Lammeren *et al.* (Reference 6).

The extent of the series in terms of a blade number versus blade area ratio matrix is shown in Table 6.4 from which it may be seen that the series numbers some 20 blade area–blade number configurations. The geometry of the series is shown in Table 6.5, from which it can be seen that a reasonably consistent geometry is maintained between the members of the series with only a few anomalies; notably the non-constant nature of the face pitch near the root of the four-blade series and the blade outline of the three-bladed propellers. For completeness purposes Figure 6.11 shows the geometric outline of the B5 propeller set. Note that the propellers of this series are generally referred to by the notation $BZ \cdot y$, where B denotes the 'B'-series, Z is the blade number and y is the blade expanded area. The face pitch ratio for the series is in the range 0.6 to 1.4.

The results of the fairing exercise reported by Oosterveld paved the way for detailed regression studies on the performance characteristics given by this model series. Oosterveld and van Oossanen (Reference 7) reported the findings of this work in which the open water characteristics of the series are represented at a Reynolds number 2×10^6 by an equation of the following form:

$$\left.\begin{aligned} K_Q &= \sum_{n=1}^{47} C_n (J)^{S_n} (P/D)^{t_n} (A_E/A_O)^{u_n} (Z)^{v_n} \\ K_T &= \sum_{n=1}^{39} C_n (J)^{S_n} (P/D)^{t_n} (A_E/A_O)^{u_n} (Z)^{v_n} \end{aligned}\right\} \quad (6.17)$$

where the coefficients are reproduced in Table 6.6.

To extend this work further so that propeller characteristics can be predicted for other Reynolds numbers within the range 2×10^6 to 2×10^9 a set of corrections of the following form was derived:

$$\begin{Bmatrix} K_T(R_n) \\ K_Q(R_n) \end{Bmatrix} = \begin{Bmatrix} K_T(R_n = 2 \times 10^6) \\ K_Q(R_n = 2 \times 10^6) \end{Bmatrix} + \begin{Bmatrix} \Delta K_T(R_n) \\ \Delta K_Q(R_n) \end{Bmatrix} \quad (6.18)$$

where

$$\begin{aligned} \Delta K_T = {} & 0.000353485 \\ & - 0.00333758\,(A_E/A_O)J^2 \\ & - 0.00478125\,(A_E/A_O)(P/D)J \\ & + 0.000257792(\log R_n - 0.301)^2 \cdot (A_E/A_O)J^2 \\ & + 0.0000643192(\log R_n - 0.301)(P/D)^6 J^2 \\ & - 0.0000110636(\log R_n - 0.301)^2 (P/D)^6 J^2 \\ & - 0.0000276305(\log R_n - 0.301)^2 Z(A_E/A_O)J^2 \\ & + 0.0000954(\log R_n - 0.301)Z(A_E/A_O)(P/D)J \\ & + 0.0000032049(\log R_n - 0.301)Z^2(A_E/A_O) \\ & \quad \times (P/D)^3 J \end{aligned}$$

$$\begin{aligned} \Delta K_Q = {} & -0.000591412 \\ & + 0.00696898(P/D) \\ & - 0.0000666654Z(P/D)^6 \\ & + 0.0160818(A_E/A_O)^2 \\ & - 0.000938091(\log R_n - 0.301)(P/D) \\ & - 0.00059593(\log R_n - 0.301)(P/D)^2 \\ & + 0.0000782099(\log R_n - 0.301)^2 (P/D)^2 \\ & + 0.0000052199(\log R_n - 0.301)Z(A_E/A_O)J^2 \\ & - 0.00000088528(\log \mathrm{R_n} - 0.301)^2 Z(A_E/A_O) \\ & \quad \times (P/D)J \\ & + 0.0000230171(\log R_n - 0.301)Z(P/D)^6 \\ & - 0.00000184341(\log R_n - 0.301)^2 Z(P/D)^6 \\ & - 0.00400252(\log R_n - 0.301)(A_E/A_O)^2 \\ & + 0.000220915(\log R_n - 0.301)^2 (A_E/A_O)^2 \end{aligned}$$

The Wageningen series is a general purpose, fixed pitch, non-ducted propeller series which is used extensively for design and analysis purposes. A variant of the series, designated the BB-series, was introduced, since it was felt that the B-series had tip chord lengths that were not entirely representative of modern practice. Accordingly the BB-series had a re-defined blade outline with wider tips than the parent form. However, the BB-series, of which only a few members exist, has not been widely used.

Table 6.5 Geometry of the Wageningen B-screw series (taken from Reference 7)

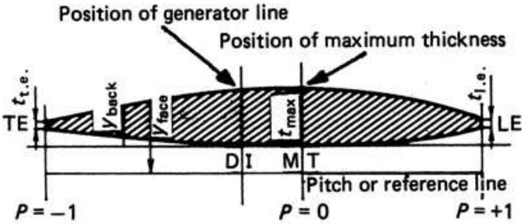
Dimensions of four-, five-, six- and seven-bladed propellers

r/R	$\frac{c}{D} \cdot \frac{Z}{A_E/A_O}$	a/c	b/c	$t/D = A_r - B_r Z$	
				A_r	B_r
0.2	1.662	0.617	0.350	0.0526	0.0040
0.3	1.882	0.613	0.350	0.0464	0.0035
0.4	2.050	0.601	0.351	0.0402	0.0030
0.5	2.152	0.586	0.355	0.0340	0.0025
0.6	2.187	0.561	0.389	0.0278	0.0020
0.7	2.144	0.524	0.443	0.0216	0.0015
0.8	1.970	0.463	0.479	0.0154	0.0010
0.9	1.582	0.351	0.500	0.0092	0.0005
1.0	0.000	0.000	0.000	0.0030	0.0000

Dimensions for three-bladed propellers

r/R	$\frac{c}{D} \cdot \frac{Z}{A_E/A_O}$	a/c	b/c	$t/D = A_r - B_r Z$	
				A_r	B_r
0.2	1.633	0.616	0.350	0.0526	0.0040
0.3	1.832	0.611	0.350	0.0464	0.0035
0.4	2.000	0.599	0.350	0.0402	0.0030
0.5	2.120	0.583	0.355	0.0340	0.0025
0.6	2.186	0.558	0.389	0.0278	0.0020
0.7	2.168	0.526	0.442	0.0216	0.0015
0.8	2.127	0.481	0.478	0.0154	0.0010
0.9	1.657	0.400	0.500	0.0092	0.0005
1.0	0.000	0.000	0.000	0.0030	0.0000

A_r, B_r = constants in equation for t/D.
a = distance between leading edge and generator line at r.
b = distance between leading edge and location of maximum thickness.
c = chord length of blade section ar radius r.
t = maximum blade section thickness at radius r



LE = leading edge
TE = trailing edge
MT = location of maximum thickness
DI = location of directrix

$$\left.\begin{aligned} Y_{face} &= V_1(t_{max} - t_{t.e.}) \\ Y_{back} &= (V_1 + V_2)(t_{max} - t_{t.e.}) + t_{t.e.} \end{aligned}\right\} \text{for } P \leq 0$$

and

$$\left.\begin{aligned} Y_{face} &= V_1(t_{max} - t_{l.e.}) \\ Y_{back} &= (V_1 + V_2)(t_{max} - t_{l.e.}) + t_{l.e.} \end{aligned}\right\} \text{for } P \geq 0$$

Referring to the diagram, note the following:

Y_{face}, Y_{back} = vertical ordinate of a point on a blade section on the face and on the back with respect to the pitch line.
t_{max} = maximum thickness of blade section.
$t_{t.e.r}, t_{l.e.}$ = extrapolated blade section thickness at the trailing and leading edges.
V_1, V_2 = tabulated functions dependent on r/R and P.
P = non-dimensional coordinate along pitch line from position of maximum thickness to leading edge (where $P = 1$), and from position of maximum thickness to trailing edge (where $P = -1$).

Values of V_1 for use in the equations

r/R P	−1.0	−0.95	−0.9	−0.8	−0.7	−0.6	−0.5	−0.4	−0.2	0
0.7–1.0	0	0	0	0	0	0	0	0	0	0
0.6	0	0	0	0	0	0	0	0	0	0
0.5	0.0522	0.0420	0.0330	0.0190	0.0100	0.0040	0.0012	0	0	0
0.4	0.1467	0.1200	0.0972	0.0630	0.0395	0.0214	0.0116	0.0044	0	0
0.3	0.2306	0.2040	0.1790	0.1333	0.0943	0.0623	0.0376	0.0202	0.0033	0
0.25	0.2598	0.2372	0.2115	0.1651	0.1246	0.0899	0.0579	0.0350	0.0084	0
0.2	0.2826	0.2630	0.2400	0.1967	0.1570	0.1207	0.0880	0.0592	0.0172	0
0.15	0.3000	0.2824	0.2650	0.2300	0.1950	0.1610	0.1280	0.0955	0.0365	0

r/R P	+1.0	+0.95	+0.9	+0.85	+0.8	+0.7	+0.6	+0.5	+0.4	+0.2	0
0.7–1.0	0	0	0	0	0	0	0	0	0	0	0
0.6	0.0382	0.0169	0.0067	0.0022	0.0006	0	0	0	0	0	0
0.5	0.1278	0.0778	0.0500	0.0328	0.0211	0.0085	0.0034	0.0008	0	0	0
0.4	0.2181	0.1467	0.1088	0.0833	0.0637	0.0357	0.0189	0.0090	0.0033	0	0
0.3	0.2923	0.2186	0.1760	0.1445	0.1191	0.0790	0.0503	0.0300	0.0148	0.0027	0
0.25	0.3256	0.2513	0.2068	0.1747	0.1465	0.1008	0.0669	0.0417	0.0224	0.0031	0
0.2	0.3560	0.2821	0.2353	0.2000	0.1685	0.1180	0.0804	0.0520	0.0304	0.0049	0
0.15	0.3860	0.3150	0.2642	0.2230	0.1870	0.1320	0.0920	0.0615	0.0384	0.0096	0

Table 6.5 (cont)

Values of V_2 for use in the equations

r/R P	−1.0	−0.95	−0.9	−0.8	−0.7	−0.6	−0.5	−0.4	−0.2	0
0.9–1.0	0	0.0975	0.19	0.36	0.51	0.64	0.75	0.84	0.96	1
0.85	0	0.0975	0.19	0.36	0.51	0.64	0.75	0.84	0.96	1
0.8	0	0.0975	0.19	0.36	0.51	0.64	0.75	0.84	0.96	1
0.7	0	0.0975	0.19	0.36	0.51	0.64	0.75	0.84	0.96	1
0.6	0	0.0965	0.1885	0.3585	0.5110	0.6415	0.7530	0.8426	0.9613	1
0.5	0	0.0950	0.1865	0.3569	0.5140	0.6439	0.7580	0.8456	0.9639	1
0.4	0	0.0905	0.1810	0.3500	0.5040	0.6353	0.7525	0.8415	0.9645	1
0.3	0	0.0800	0.1670	0.3360	0.4885	0.6195	0.7335	0.8265	0.9583	1
0.25	0	0.0725	0.1567	0.3228	0.4740	0.6050	0.7184	0.8139	0.9519	1
0.2	0	0.0640	0.1455	0.3060	0.4535	0.5842	0.6995	0.7984	0.9446	1
0.15	0	0.0540	0.1325	0.2870	0.4280	0.5585	0.6770	0.7805	0.9360	1

r/R P	+1.0	+0.95	+0.9	+0.85	+0.8	+0.7	+0.6	+0.5	+0.4	+0.2	0
0.9–1.0	0	0.0975	0.1900	0.2775	0.3600	0.51	0.6400	0.75	0.8400	0.9600	1
0.85	0	0.1000	0.1950	0.2830	0.3660	0.5160	0.6455	0.7550	0.8450	0.9615	1
0.8	0	0.1050	0.2028	0.2925	0.3765	0.5265	0.6545	0.7635	0.8520	0.9635	1
0.7	0	0.1240	0.2337	0.3300	0.4140	0.5615	0.6840	0.7850	0.8660	0.9675	1
0.6	0	0.1485	0.2720	0.3775	0.4620	0.6060	0.7200	0.8090	0.8790	0.9690	1
0.5	0	0.1750	0.3056	0.4135	0.5039	0.6430	0.7478	0.8275	0.8880	0.9710	1
0.4	0	0.1935	0.3235	0.4335	0.5220	0.6590	0.7593	0.8345	0.8933	0.9725	1
0.3	0	0.1890	0.3197	0.4265	0.5130	0.6505	0.7520	0.8315	0.8020	0.9750	1
0.25	0	0.1758	0.3042	0.4108	0.4982	0.6359	0.7415	0.8259	0.8899	0.9751	1
0.2	0	0.1560	0.2840	0.3905	0.4777	0.6190	0.7277	0.8170	0.8875	0.9750	1
0.15	0	0.1300	0.2600	0.3665	0.4520	0.5995	0.7105	0.8055	0.8825	0.9760	1

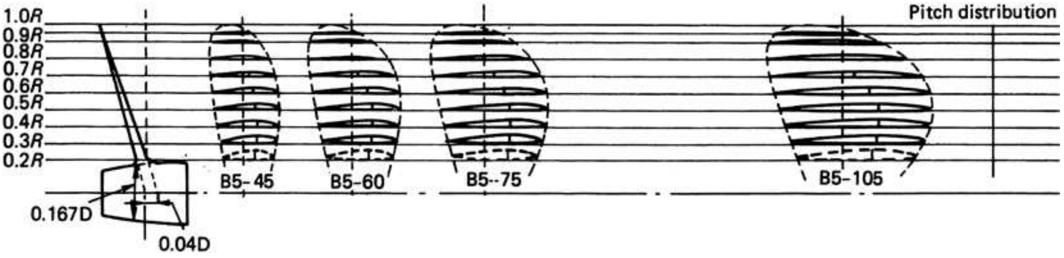


Figure 6.11 General plan of B5-screw series (Reporduced with permission from Reference 6)

6.5.2 Japanese AU-series

This propeller series is many ways complementary series to the Wageningen B-series; however, outside of Japan it has not gained the widespread popularity of the B-series. The series reported by Reference 8 comprises some propellers having a range of blade numbers from four to seven and blade area ratios in the range 0.40 to 0.758. Table 6.7 details the members of the series and Table 6.8, the blade geometry. The propeller series, as its name implies, has AU-type aerofoil sections and was developed from an earlier series having Unken-type sections.

6.5.3 Gawn series

This series of propellers whose results were presented by Gawn (Reference 9) comprised a set of 37 three-bladed propellers covering a range of pitch ratios from 0.4 to 2.0 and blade area ratios from 0.2 to 1.1.

The propellers of this series each had a diameter of 503 mm (20 in.), and by this means many of the scale effects associated with smaller diameter propeller series have been avoided. Each of the propellers has a uniform face pitch; segmental blade sections; constant blade thickness ratio, namely 0.060, and a boss diameter of 0.2D. The developed blade outline was of elliptical form with the inner and outer vertices at 0.1*R* and the blade tip, respectively. Figure 6.12 shows the outline of the propellers in this series. The entire series were tested in the No. 2 towing rank at A.E.W. Haslar within a range of slip from zero to 100 per cent: to achieve this the propeller rotational speed was in the range 250 to 500 rpm. No cavitation characteristics are given for the series.

Table 6.6 Coefficients for the K_T and K_Q polynomials representing the Wageningen B-screen series for a Reynolds number of 2×10^6 (taken from Reference 7)

Thrust (K_T)						*Torque* (K_Q)					
n	$C_{s,t,u,v}$	$s\,(J)$	$t\,(P/D)$	$u\,(A_E/A_O)$	$v\,(Z)$	n	$C_{s,t,u,v}$	$s\,(J)$	$t\,(P/D)$	$u\,(A_E/A_O)$	$v\,(Z)$
1	+0.00880496	0	0	0	0	1	+0.00379368	0	0	0	0
2	−0.204554	1	0	0	0	2	+0.00886523	2	0	0	0
3	+0.166351	0	1	0	0	3	−0.032241	1	1	0	0
4	+0.158114	0	2	0	0	4	+0.00344778	0	2	0	0
5	−0.147581	2	0	1	0	5	−0.0408811	0	1	1	0
6	−0.481497	1	1	1	0	6	−0.108009	1	1	1	0
7	+0.415437	0	2	1	0	7	−0.0885381	2	1	1	0
8	+0.0144043	0	0	0	1	8	+0.188561	0	2	1	0
9	−0.0530054	2	0	0	1	9	−0.00370871	1	0	0	1
10	+0.0143481	0	1	0	1	10	+0.00513696	0	1	0	1
11	+0.0606826	1	1	0	1	11	+0.0209449	1	1	0	1
12	−0.0125894	0	0	1	1	12	+0.00474319	2	1	0	1
13	+0.0109689	1	0	1	1	13	−0.00723408	2	0	1	1
14	−0.133698	0	3	0	0	14	+0.00438388	1	1	1	1
15	+0.00638407	0	6	0	0	15	−0.0269403	0	2	1	1
16	−0.00132718	2	6	0	0	16	+0.0558082	3	0	1	0
17	+0.168496	3	0	1	0	17	+0.0161886	0	3	1	0
18	−0.0507214	0	0	2	0	18	+0.00318086	1	3	1	0
19	+0.0854559	2	0	2	0	19	+0.015896	0	0	2	0
20	−0.0504475	3	0	2	0	20	+0.0471729	1	0	2	0
21	+0.010465	1	6	2	0	21	+0.0196283	3	0	2	0
22	−0.00648272	2	6	2	0	22	−0.0502782	0	1	2	0
23	−0.00841728	0	3	0	1	23	−0.030055	3	1	2	0
24	+0.0168424	1	3	0	1	24	+0.0417122	2	2	2	0
25	−0.00102296	3	3	0	1	25	−0.0397722	0	3	2	0
26	−0.0317791	0	3	1	1	26	−0.00350024	0	6	2	0
27	+0.018604	1	0	2	1	27	−0.0106854	3	0	0	1
28	−0.00410798	0	2	2	1	28	+0.00110903	3	3	0	1
29	−0.000606848	0	0	0	2	29	−0.000313912	0	6	0	1
30	−0.0049819	1	0	0	2	30	+0.0035985	3	0	1	1
31	+0.0025983	2	0	0	2	31	−0.00142121	0	6	1	1
32	−0.000560528	3	0	0	2	32	−0.00383637	1	0	2	1
33	−0.00163652	1	2	0	2	33	+0.0126803	0	2	2	1
34	−0.000328787	1	6	0	2	34	−0.00318278	2	3	2	1
35	+0.000116502	2	6	0	2	35	+0.00334268	0	6	2	1
36	+0.000690904	0	0	1	2	36	−0.00183491	1	1	0	2
37	+0.00421749	0	3	1	2	37	+0.000112451	3	2	0	2
38	+0.0000565229	3	6	1	2	38	−0.0000297228	3	6	0	2
39	−0.00146564	0	3	2	2	39	+0.000269551	1	0	1	2
						40	+0.00083265	2	0	1	2
						41	+0.00155334	0	2	1	2
						42	+0.000302683	0	6	1	2
						43	−0.0001843	0	0	2	2
						44	−0.000425399	0	3	2	2
						45	+0.0000869243	3	3	2	2
						46	−0.0004659	0	6	2	2
						47	+0.0000554194	1	6	2	2

The propeller series represents a valuable data set, despite the somewhat dated propeller geometry, for undertaking preliminary design studies for warships and other high-performance craft due to the wide range of P/D and A_E/A_O values covered. Blount and Hubble (Reference 10) in considering methods for the sizing of small craft propellers developed a set of regression coefficients of the form of equation (6.17) to represent the Gawn series. The coefficients for this series are given in Table 6.9 and it is suggested that the range of applicability of the regression study should be for pitch ratio values from 0.8 to 1.4, although the study was based on the wider range of 0.6 to 1.6. Inevitably, however, some regression formulations of model test data tend to