Advanced Propulsion System
GEM 423E

Week 7: Propeller Selection

Dr. Ali Can Takinacı
Associate Professor
in
The Faculty of Naval Architecture and Ocean Engineering
34469
Maslak – Istanbul – Turkey

Contents

- Case 1: Optimum rotation rate for a given diameter
- Case 2: Optimum diameter for a given rotation rate
- Case 3: Optimum propeller for given power and rate
- Case 4: Maximum bollard pull
- Case 5: Existing propeller
- Viscous Effects – ITTC Analysis Procedure

Case 1: Optimum Rotation Rate for a Given Diameter

- A common problem for the propeller is the design of a propeller when the required propeller thrust is known and the propeller diameter is known.
- The advance velocity of a propeller can be estimated from the ship speed and the wake fraction.
- The unknowns are the required power and especially the rate of rotation.
- The latter is important for the choice of the engine or for the choice of the gear ratio.

- Suppose that a four-bladed propeller is chosen. In that case the following data are known:
  - The propeller thrust T =1393 kN.
  - The propeller diameter D = 7 m.
  - The advance velocity V_a = 8.65 m/s.
  - The density of water ρ = 1025 kg/m^3.
  - The number of blades Z = 4.
- Estimate the required area ratio to be 0.55. The diagram to be used is that of the B 4.55 series.
- The thrust and diameter are *known* but the rotation rate is *not*.

- This means that the parameters K_t and J cannot be calculated yet.
- However, the parameters K_T/J^2 can be calculated because it ***<u>does not contain the rotation rate</u>***:

$$\frac{K_T}{J^2} = \frac{T}{\rho V^2 D^2} = \frac{1,393,000}{1025 \times 8.65^2 \times 7^2} = 0.3707$$

- K_T/J^2 has to be found from variation of the pitch ratio.

- By starting with a pitch ratio of 0.8 the following search is possible

i	P/D	J	Kt	10Kq	eta0	Bp	delta
31	0.800	0.595	0.1310	0.1951	0.6356	16.9452	170.3291
41	0.900	0.648	0.1557	0.2480	0.6478	15.3963	156.2336
46	0.950	0.674	0.1684	0.2777	0.6503	14.7781	150.2568
51	1.000	0.699	0.1811	0.3095	0.6512	14.2379	144.8587
61	1.100	0.747	0.2071	0.3793	0.6493	13.3371	135.4951
71	1.200	0.793	0.2333	0.4568	0.6448	12.6087	127.6514

WAGENINGEN B SERISI
SECILEN PERVANE = 46. PERVANEDIR
P/D=0.950
J= 0.674 Kt= 0.168 10Kq= 0.278 eta= 0.650
Bp= 14.7781 delta= 150.2568
T= 1393.00 kN Va= 8.650 m/s RHO = 1025.0 kg/m3
Z = 4. EAR = 0.550 D = 7.000 m
RPS= 1.834 dev/san RPM= 110.01 TORK=1608.316 kNm Pd=18528.5 kW

- After running the program, the conclusion is that the optimum efficiency can be reached with a pitch ratio of 0.95.
- The optimum efficiency is 0.650. The advance ratio J is 0.699 and from this the required rotation rate can be derived:

$$n = \frac{V_a}{JD} = \frac{8.65}{0.674 \times 7} = 1.834\ RPS = 110\ RPM$$

- The required power to propel ship can be derived from the torque coefficient K_Q=0.0278. The torque is found to be

$$Q = K_Q \times \rho \times n^2 \times D^5 = 0.0277 \times 1025 \times 1.834^2 \times 7^5 = 1608.316\ kNm$$

- The power to be delivered to the propeller is therefore

$$P_D = 2\pi \times Q \times n = 2\pi \times 1608.316 \times 1.834 = 18528.5\ kW$$

- These data can be used to find a suitable engine

Case 2: Optimum diameter for a given rotation rate

- When the optimum rate of case 1 is chosen the question can be posed if the diameter of 7 meters was the optimum diameter.
- The optimum diameter can be calculated in a similar way as the optimum rotation rate, but now the value of K_T/J^4 can be calculated because the ***diameter is absent*** in the parameter

$$\frac{K_T}{J^4} = \frac{T \times n^2}{\rho \times V^4} = \frac{1{,}393{,}000 \times 1.834^2}{1025 \times 8.65^4} = 0.816$$

- The optimum pitch ratio can again be found by iteration:

i	P/D	J	Kt	10Kq	eta0	Bp	delta
34	0.830	0.631	0.1294	0.2001	0.6497	14.7837	160.4543
35	0.840	0.635	0.1326	0.2060	0.6506	14.7737	159.4914
36	0.850	0.639	0.1358	0.2119	0.6513	14.7657	158.5511
41	0.900	0.657	0.1519	0.2434	0.6524	14.7529	154.1675
51	1.000	0.690	0.1851	0.3148	0.6459	14.8266	146.7318
71	1.200	0.747	0.2535	0.4886	0.6166	15.1745	135.6321
81	1.300	0.771	0.2880	0.5883	0.6007	15.3752	131.3755
91	1.400	0.793	0.3225	0.6936	0.5867	15.5564	127.7158

WAGENINGEN B SERISI
SECILEN PERVANE = 35. PERVANEDIR
P/D=0.840
J= 0.635 Kt= 0.133 10Kq= 0.206 eta= 0.651
Bp= 14.7737 delta= 159.4914
T= 1393.00 kN Va= 8.650 m/s RHO = 1025.0 kg/m3
Z = 4. EAR = 0.550 D = 7.431 m
RPS= 1.833 dev/san RPM= 110.00 TORK=1607.891 kNm Pd=18521.6 kW

- The optimum efficiency remains almost the same 0.65, but the pitch ratio is different.

- The diameter corresponding to the design is found from the advance ratio J=0.635:

$$D = \frac{V_a}{n \times J} = \frac{8.65}{1.833 \times 0.635} = 7.431m$$

- As a result of this optimization at a given rotation ***rate the diameter will always increase***.

Case 3: Optimum propeller for given power and rate

- It is quite common to start the design from the available engine power.
- In that case the engine will develop a certain power at a given rotation rate.
- The ship speed is *assumed to be known*.

- Assume the following data are known for a fast petrol boat:
  - Power P_D = 440 kW
  - Advance velocity V_a=14.42 m/sec (28 knots)
  - Rotation rate RPM = 720 (12 Hz or RPS)
  - Blade number Z=5
  - Blade area ratio EAR=0.75.
- The parameter to be used in this case is K_Q/J^5 since in this parameter the ***power and the rotation rate are present*** and the ***diameter is eliminated***.

$$\frac{K_Q}{J^5} = \frac{Q \times n^3}{\rho \times V^5} = \frac{2\pi \times Q \times n \times n^2}{2\pi \times \rho \times V^5} = \frac{P_D \times n^2}{2\pi \times \rho \times V^5}$$

- The value of this parameter in the example is

$$\frac{K_Q}{J^5} = \frac{440,000 \times 12^2}{2\pi \times 1025 \times 14.42^5} = 0.016$$

- In the program the optimum pitch ratio is found from an iteration

i	P/D	J	Kt	10Kq	eta0	Bp	delta
51	1.000	0.965	0.0506	0.1322	0.5879	4.1538	104.9130
71	1.200	1.085	0.0980	0.2369	0.7144	4.1538	93.3631
81	1.300	1.141	0.1237	0.3046	0.7373	4.1538	88.7839
86	1.350	1.167	0.1371	0.3422	0.7445	4.1538	86.7411
87	1.360	1.173	0.1398	0.3500	0.7458	4.1538	86.3510
88	1.370	1.178	0.1426	0.3579	0.7470	4.1538	85.9669
89	1.380	1.183	0.1454	0.3659	0.7482	4.1538	85.5887
90	1.390	1.188	0.1481	0.3739	0.7493	4.1538	85.2163
91	1.400	1.193	0.1509	0.3821	0.7505	4.1538	84.8499

```
  WAGENINGEN B SERISI
SECILEN PERVANE = 91. PERVANEDIR
P/D=1.400
J= 1.193 Kt= 0.151 10Kq= 0.382 eta= 0.750
Bp=   4.1538 delta=  84.8499
T=      22.90 kN  Va=  14.420 m/s  RHO = 1025.0 kg/m3
Z = 5. EAR = 0.750 D =  1.007 m
RPS= 12.000 dev/san RPM= 720.00 TORK=   5.836 kNm Pd=  440.0 kW
```

- In this case the limit in pitch ratio is the optimum value.
- It is not advisable to extrapolate outside the bounds of the diagrams, so the pitch ratio of 1.4 should be used.
- In this case the diameter can again be found from the J value J=1.193:

$$D = \frac{V_a}{n \times J} = \frac{14.42}{12 \times 1.193} \cong 1m$$

- A diameter of 1 meter should be used.
- This efficiency is high because the propeller loading is extremely low.
- In this case the speed was prescribed.
- In practice, a resistance curve is known, from which the required thrust as a function of speed can be derived.
- In the above example the delivered thrust can be found from the thrust coefficient K_T=0.153.

$$T = K_T \times \rho \times n^2 \times D^4 = 0.1509 \times 1025 \times 12^2 \times 1 = 22.9\,kN$$

- When the delivered thrust is not in accordance with the ship resistance the same calculation should be carried out for a different speed.
- The actual speed will the be found from an interpolation between the resistance curve and the curve of delivered thrust.
- It can be checked if the blade area ratio is not too small from this diameter.
- Assume the shaft immersion to be 1 meter. From Keller's formula the minimum blade area ratio is found to be

$$EAR = \frac{(1.3 + 0.3 \times 5) \times 22{,}900}{(10^5 + 9.81 \times 1025 \times 1.0 - 1700)} = 0.591$$

- The chosen blade area ratio of 0.75 therefore is too large.

Case 4: Maximum bollard pull

- Consider a tug with an engine which delivers 800kW at 180 RPM.
- The propeller is directly coupled, so the rotation rate of the engine is that of the propeller.
- What is the maximum bollard pull which can be obtained?

- Again the blade area ratio and the number of blades should be chosen first.
- Take a 4-bladed propeller with a EAR=1.
- In the Bollard pull condition the parameter K_Q/J^5 is useless because at J=0 it become infinity.
- In this case the diameter is directly varied.
- It is unavoidable to calculate K_Q value at every diameter which is tried.

- The following table can be obtained:

i	D	10Kq	P/D	Kt	T
1	2.000	1.4374	1.369	0.7166	105767.
2	2.500	0.4711	0.800	0.3759	135464.
3	3.000	0.1887	0.519	0.1977	147727.

```
WAGENINGEN B SERISI
SECILEN PERVANE =
P/D=0.800 Kt= 0.376 10Kq= 0.471
RPS=  3.000 RPM=180.000 T= 135.464 kN D=  2.500 m
Z= 4 EAR=1.000
RHO = 1025.0 kg/m3
TORK=  42.440 kNm Pd=  800.0 kW
```

- The value of pitch ratio is found from the B4-100 diagrams by iterating P/D at J=0 until the required torque coefficient is reached.

- Some typical guidelines are:

1. Good bollard performance is often found with propeller at about P/D=0.6
2. Typical speed is 3-4 knots for continuous towing, and 9-12 knots at free-run (case 1).
3. Efficient bollard operation should produce about 130 N of thrust per engine brake horse power.
4. Use equilibrium-torque towing analysis to provide achievable thrust at bollard.

Case 5: Existing propeller

- If a propeller and operating conditions exist the program calculates the performance of the propeller behind ship condition including viscous scale effects.

- In the extrapolation to full scale case, the method of ITTC 78 is used.

- The sample output for this case is:

i	J	Kt	10Kq	eta0	Bp	delta
1	0.050	0.4402	0.6610	0.0530	15207.6494	2025.3160
2	0.100	0.4250	0.6413	0.1055	2648.1819	1012.6580
3	0.150	0.4088	0.6203	0.1573	945.1010	675.1053
4	0.200	0.3915	0.5979	0.2084	452.0052	506.3290
5	0.250	0.3733	0.5742	0.2587	253.5594	405.0632
6	0.300	0.3543	0.5492	0.3080	157.2072	337.5526
7	0.350	0.3344	0.5231	0.3562	104.3533	289.3308
8	0.400	0.3138	0.4958	0.4030	72.7588	253.1645
9	0.450	0.2925	0.4674	0.4483	52.6262	225.0351
10	0.500	0.2706	0.4380	0.4917	39.1471	202.5316
11	0.550	0.2481	0.4076	0.5329	29.7587	184.1196
12	0.600	0.2251	0.3763	0.5713	23.0043	168.7763
13	0.650	0.2017	0.3442	0.6062	18.0107	155.7935
14	0.700	0.1779	0.3113	0.6366	14.2314	144.6654
15	0.750	0.1537	0.2777	0.6609	11.3112	135.0210
16	0.800	0.1293	0.2434	0.6766	9.0114	126.5822
17	0.850	0.1047	0.2084	0.6796	7.1668	119.1362
18	0.900	0.0799	0.1729	0.6622	5.6589	112.5175
19	0.950	0.0551	0.1369	0.6084	4.3991	106.5956
20	1.000	0.0302	0.1005	0.4789	3.3153	101.2658
21	1.050	0.0054	0.0637	0.1424	2.3363	96.4436

```
  WAGENINGEN B SERISI
T=  38637.82 kN  Va=   6.680 m/s  RHO = 1025.0 kg/m3
Z = 4. EAR = 0.700 D =  3.500 m
P/D=1.000
J= 0.939 Kt= 0.061 10Kq= 0.145 eta= 0.625
Bp=   4.6636 delta= 107.8797
RPS=  2.033 dev/san RPM= 122.00 TORK=  32.311 kNm Pd=  412.8 kW
TAM OLCEGE EKTRAPOLASYONDA
ITTC78 VISKOZ DUZELTME YONTEMI KULLANILMISTIR
```

Viscous Effects – ITTC Analysis Procedure

- Model propeller size : 24 cm
- Model and full scale drag coefficients

$$C_{DM} = 2\left(2+2\frac{t}{c}\right)\left[\frac{0.044}{Rn_{0.75R}^{1/6}} - \frac{5}{Rn_{0.75R}^{2/3}}\right]$$

$$C_{DS} = 2\left(2+2\frac{t}{c}\right)\left[1.89+1.62\log\frac{c}{k_p}\right]^{-2.5}$$

- $Rn_{0.75R}$ must not be lower 2×10^5 during open water tests

t: max. thickness

c: chord length

$k_p = 30\times10^{-6}\ m$

- Calculation of propeller characteristics:

$$\Delta C_D = C_{DM} - C_{DS}$$

$$\Delta K_T = -0.30Z\left(\frac{c}{D}\right)_{0.75R}\left(\frac{P}{D}\right) - \Delta C_D$$

$$\Delta K_Q = 0.25Z\left(\frac{c}{D}\right)_{0.75R} \Delta C_D$$

- Full-scale propeller characteristics:

$$K_{TS} = K_{TM} - \Delta K_T$$

$$K_{QS} = K_{QM} - \Delta K_Q$$

- Since C_{DM} in general is larger than C_{DS} , the full-scale K_Q at given advance ratio is lower and K_T is slightly higher than in the model case