4. BASIC OUTLINES OF PROPELLER DESIGN

Propellers are designed to absorb minimum power and to give maximum efficiency, minimum cavitation and minimum hull vibration characteristics.

The above objectives can be achieved in the following stages:

1. Basic design
2. Wake adaptation
3. Design analysis

a) Propeller Design Basis

The term propeller design basis refers to:

i. Power
ii. Rotational speed
iii. Ship speed.

that are chosen to act as the basis for the design of the principal propeller geometric features.

Resistance and Power Estimation

A ship owner usually requires that the ship will achieve an average speed in service condition (fouled hull in full displacement and rough weather), $V_{SERVICE}$, at a certain engine power. Initial acceptance will be the basis of demonstration of a higher speed on trial condition (clean ship usually in light displacement), V_{TRIAL}, at some power, i.e.

$$V_{TRIAL} = V_{SERVICE} + \delta V$$

where δV is the speed increase due to the fouled hull, rough weather and other effects, and is usually taken as 1 knot.

$$P_{ESERVICE} = (1 + x) P_{ETRIAL}$$

where (1+x) is the sea margin that the ship resistance is increased usually by 10 to 20% in average service conditions.

b) The Use of Standard Series Data in Design

Propeller design diagrams of Standard Series, such as Wageningen-B, can be used in five design options as:

Known variables **Required**

1. Known power (P_D), rotation rate (N) and advanced velocity (V_A) D_{opt}

In this case the unknown variable optimum diameter, D_{opt}, can be eliminated from the diagrams by plotting K_Q/J^5 versus J instead of K_Q vs J. K_Q/J^5 can be written as:

$$\frac{K_Q}{J^5} = \frac{Q}{\rho N^2 D^5}\left(\frac{ND}{V_A}\right)^5 = \frac{QN^3}{\rho V_A^5}$$

since $P_D = 2\pi QN$

$$\frac{K_Q}{J^5} = \frac{P_D N^2}{2\pi\rho V_A^5} \approx \frac{NP_D^{1/2}}{V_A^{2.5}} = B_p$$

This parameter B_p is plotted against $\frac{1}{J} = \delta = \frac{ND}{V_A}$ and these diagrams are called Bp-δ diagrams. On these diagrams optimum η_0 and δ are read off at the intersection of known Bp value on the optimum efficiency line. D_{opt} is then calculated.

2. Known power (P_D), diameter (D) and advanced velocity (V_A) N_{opt} (required)

If the delivered power P_D and the diameter D are known a diagram of K_Q/J^3 can be obtained.

$$\frac{K_Q}{J^3} = \frac{Q}{\rho N^2 D^5}\left(\frac{ND}{V_A}\right)^3 = \frac{QN}{\rho D^2 V_A^3} = \frac{P_D}{2\pi\rho D^2 V_A^3}$$

From these diagrams N_{opt} is calculated on the optimum efficiency line.

3. Known thrust (T), diameter (D) and advanced velocity (V_A) N_{opt}(required)

If the resistance values of the ship are available, thrust T can be calculated using the thrust deduction factor t:

$$T = R_T/(1-t)$$

T and D are known optimum rate of rotation N_{opt} can be eliminated using K_T/J^2.

$$\frac{K_T}{J^2} = \frac{T}{\rho N^2 D^4}\left(\frac{ND}{V_A}\right)^2 = \frac{T}{\rho V_A^2 D^2}$$

4. Known thrust (T), rotation rate (N) and advanced velocity (V_A) D_{opt}(required)

T and N are known and optimum diameter D_{opt} can be eliminated similarly using K_T/J^4.

$$\frac{K_T}{J^4} = \frac{T}{\rho N^2 D^4}\left(\frac{ND}{V_A}\right)^4 = \frac{TN^2}{\rho V_A^4}$$

5. Determination of Optimum RPM and Propeller Size (Diameter) (General Case)

To determine the propeller diameter D and rate of rotation N for a propeller when absorbing certain delivered power P_D in association with the ship speed V_S.

i) Propeller type is chosen depending on the ship type, initial installation coast, running costs, maintenance requirements.

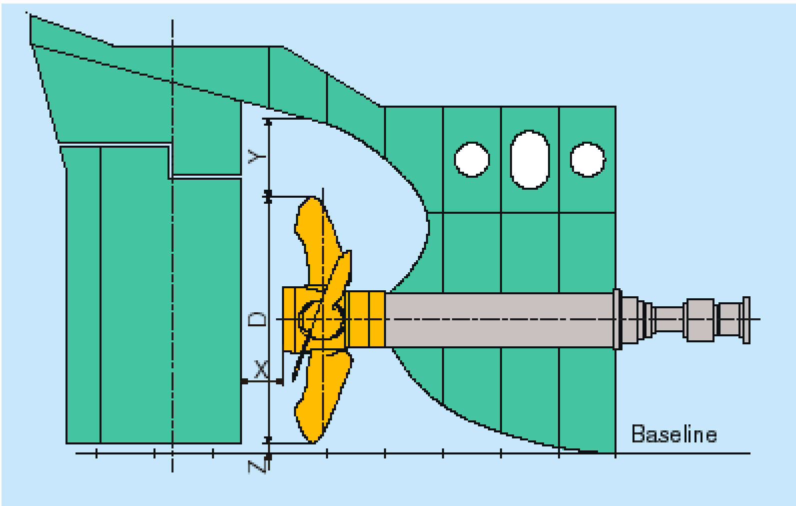
ii) Number of blades is determined by the need to avoid harmful resonant frequencies of the ship structure and the machinery.

iii) BAR is initially determined using Keller's formula.

iv) First it is necessary to determine a mean design Taylor wake fraction (w_T) from experience, published data or model test results.

v) Advance propeller speed V_A can be determined as $V_A=(1-w_T)V_S$

vi) Diameters of behind hull and open water are determined as



When the diameter is determined the diameter should be as large as the stern of hull can accommodate, to obtain the maximum propeller efficiency. The typical figures of the clearances of propeller-hull, propeller-rudder and propeller-baseline should be:

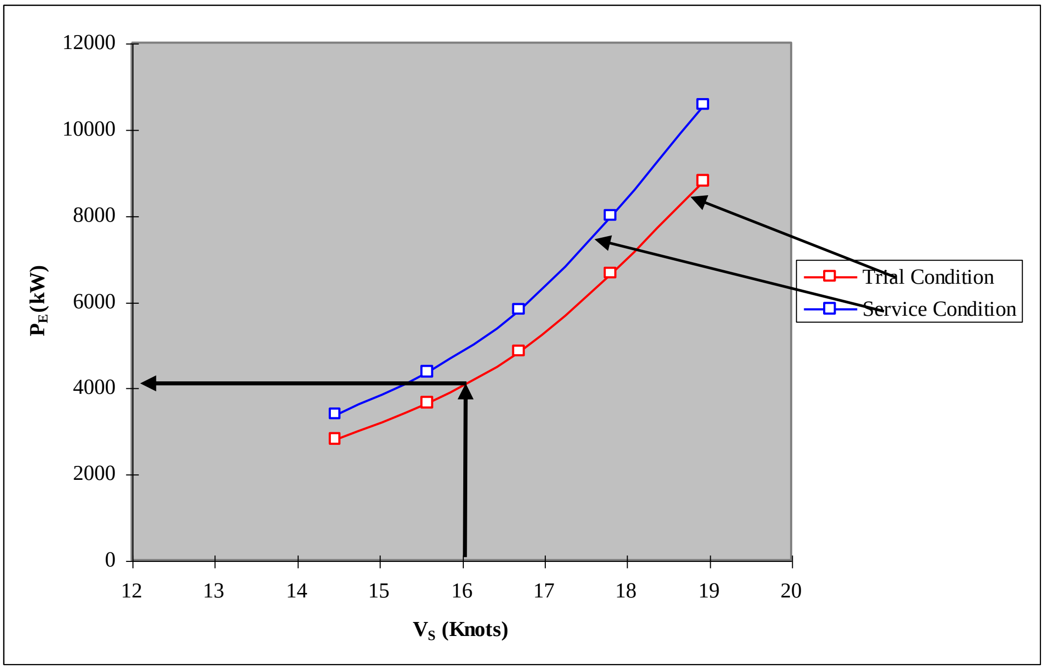
X	5% to 10% of D
Y	15% to 25% of D
Z	up to 3% of D

vii) Open water diameter D_0 is then calculated by increasing the D_B by 5% and 3% for single and twin screws respectively.

$$D_0 = \frac{D_B}{1 - 0.05} \text{ for single screw propellers}$$

viii) This diameter D_0 should absorb the delivered power for trial condition at the optimum RPM which would correspond to the maximum propeller efficiency.

ix) From the Power-Speed diagram (P_E vs. V_S) P_{ETRIAL} is read off at the V_{STRIAL}



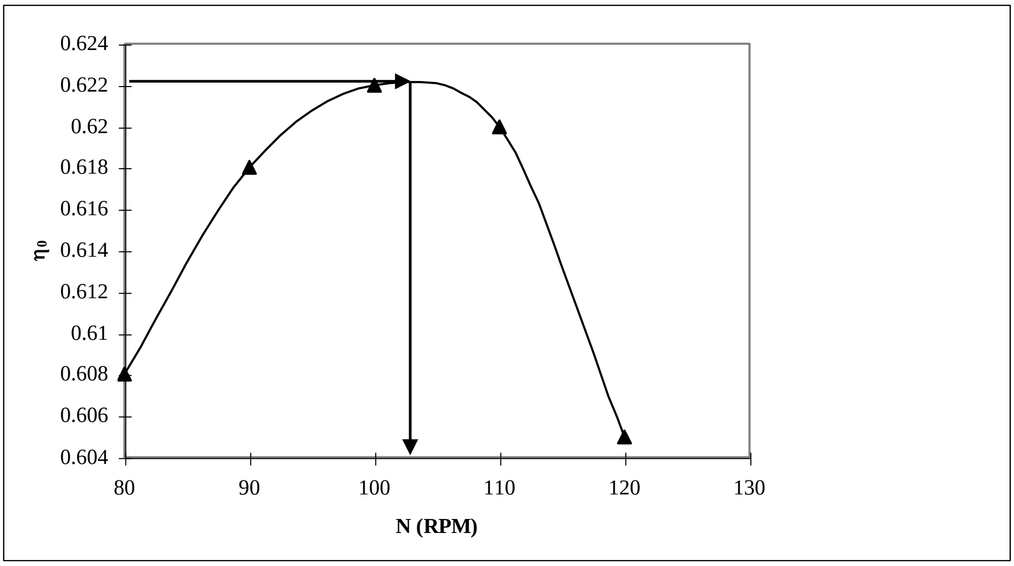
x) Propulsive efficiency η_D is obtained by iteration for the optimum RPM, N. Initially η_D is assumed (i.e. $\eta_{D(assumed)}$=0.7) and the delivered power P_D is calculated as:

$$P_{D(TRIAL)} = \frac{P_{E(TRIAL)}}{\eta_{D(assumed)}}$$

xi) B_p and δ values are calculated for a range of N (e.g. N=80 to 120)

xii) From the B_p-δ diagram open water propeller efficiency, η_0 is read off at the corresponding B_p-δ (D_0)

xiii) N (RPM) vs. η_0 diagram is plotted and η_{0max} and N values are read off from the diagram



xiv) η_D is calculated

$$\eta_{D(calculated)} = \eta_H \eta_R \eta_0 = \frac{1-t}{1-w}\eta_R \eta_0$$

xv) The difference between the $\eta_{D(calculated)}$ and $\eta_{D(assumed)}$ is calculated as:

$$\varepsilon = \left|\eta_{D(calculated)} - \eta_{D(assumed)}\right|$$

iterate if required

if ε value > $\varepsilon_{threshold}$, go back to step (x) and assume $\eta_{D(assumed)}=\eta_{D(calculated)}$

if ε value ≤ $\varepsilon_{threshold}$, $\eta_{D(calculated)}$ is converged

and η_D is the latest calculated $\eta_{D(calculated)}$

xvi) Based upon the latest value of η_D break power in trial condition $P_{B(TRIAL)}$ is calculated as:

$$P_{B(TRIAL)} = \frac{P_{E(TRIAL)}}{\eta_D \eta_S} = \frac{P_D}{\eta_S}$$

xvii) Installed Maximum Continuous Power is taken as by taking into account engine margin and shaft generator (if installed) as

$$P_{B(INSTALLED)} = \frac{P_{B(TRIAL)} + PTO}{0.85\, or\, 0.90}$$

where PTO is power take off

xviii) $P_D = P_B \eta_S$

xix) $B_p = 1.158 \frac{NP_D^{1/2}}{V_A^{2.5}}$ and $\delta_B = 3.2808 \frac{ND_B}{V_A}$ are calculated

xx) P_B/D_B is read off at the calculated (B_p, δ_B) from the B_p-δ diagram and the mean face pitch is calculated.

3. Engine Selection

xxi) We have optimum RPM (latest), brake power in trial condition P_{BTRIAL} and installed maximum continuous power. For engine selection refer to engine layout diagrams provided by the manufacturers.

4. Prediction of Performance in Service

Prediction of the ship speed and propeller rate of rotation in service condition with the engine developing 85% of MCR

5. Determination of Blade Surface Area and BAR (Cavitation Control)

Cavitation control is carried out for trial condition. This is due to fact that the ship will have the maximum speed in trial condition

If the calculated BAR is less than the selected BAR, the design stage is completed.

If the calculated BAR is greater than the selected BAR, a new BAR greater than the calculated BAR is chosen. All the calculations are performed for the new BAR.