7. 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

1. Basic design

By using semi-empirical methods (i.e. standard series model propeller data and cavitation diagrams) and simple beam theory, stress prediction, the diameter, pitch, blade surface area and weight of the propeller are obtained.

2. Wake adaptation

By using analytical procedures (e.g. vortex flow based lifting line methods) and simple blade section design methods the basic design is further optimised (i.e. pitch distribution and sectional blade shape) with respect to the non-uniform axial wake flow in which the propeller works.

3. Design analysis

Using advances analytical procedures (i.e. Lifting surface based methods), the optimised design is analysed in 3-D wake. If the analysis demonstrates unsatisfactory performance of cavitation hull pressures, shaft forces and moments, blade section geometry are modified by trial and error until the problem is solved.

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.

1. 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.

A contract between the ship owner and the shipyard will state that the ship should achieve V_{TRIAL} with the engine developing, say, 85% of its Maximum Continuous Power or Rating (MCR).

Under the above circumstances resistance (R) and the effective power (P_E) for a range of speed (covering V_{TRIAL} and $V_{SERVICE}$) are estimated using appropriate methodical series data or statistical analysis data, or model test results. This P_E is the effective power in trial condition. The effective power in service condition ($P_{ESERVICE}$) is then calculated such that

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

where (1+x) is the sea margin that the ship resistance is increased usually by 10 or 20% in average service conditions. Sea margin is due to the extra resistance on the ship caused by fouling on the hull and propeller, weather, waves and wind conditions.

b) The Use of Standard Series Data in Design

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

To determine an optimum rotational speed N (RPM) for a propeller when absorbing certain delivered power P_D and a propeller diameter D in association with the ship speed V_S.

i) Propeller type is chosen depending on the ship type, maximum efficiency, noise reduction, ease of manoeuvrability, initial installation coast, running cost, 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 chosen to avoid cavitation on the propeller blades. Larger the BAR results in less cavitation susceptibility but increase in section drag and hence a loss in the efficiency of the propeller. BAR is initially determined.

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 $V_A=(1-w_T)V_S$

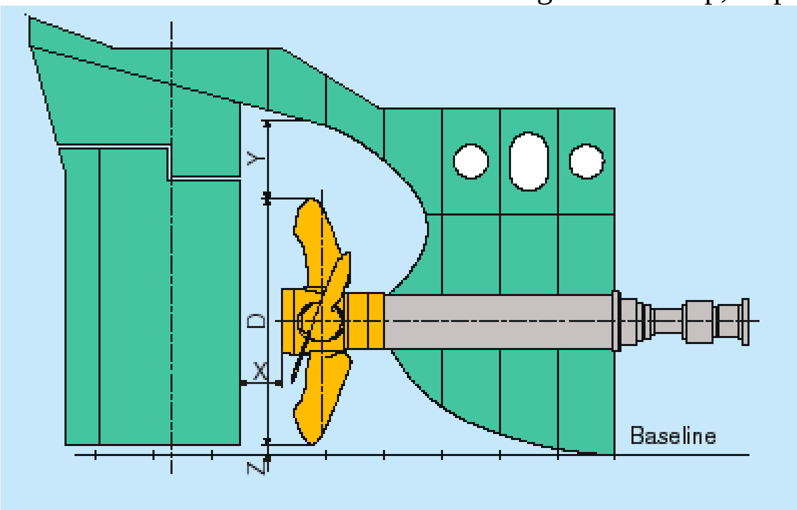
vi) Diameters of behind hull and open water are calculated as D_{max} is assumed to be usually percentage of the draught

$$D_{\max} = D_B = aT$$

a<0.65 for bulk carriers and tankers

a<0.74 for container ships

where D_B and T are the behind hull diameter and draught of the ship, respectively.



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

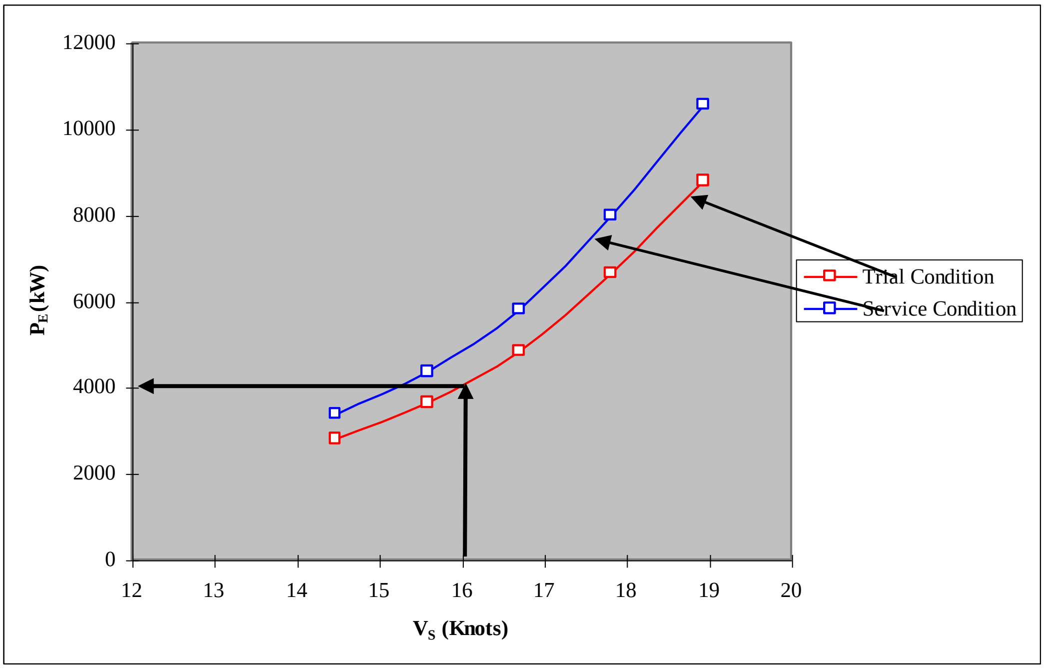
This D_B should not exceed the limits of propeller-hull clearances.

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

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

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}



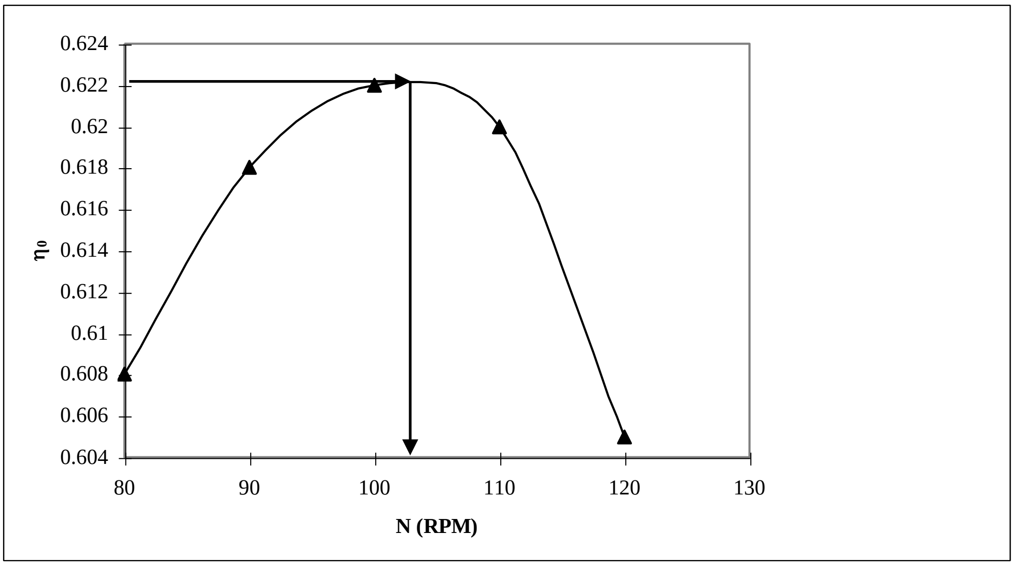
x) Propulsive efficiency η_D is obtained by iteration for the optimum RPM, N. Initially η_D is assumed (i.e. $\eta_{D(assumed)}$=0.7) and the delivered power P_D is calculated as:

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

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

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:

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

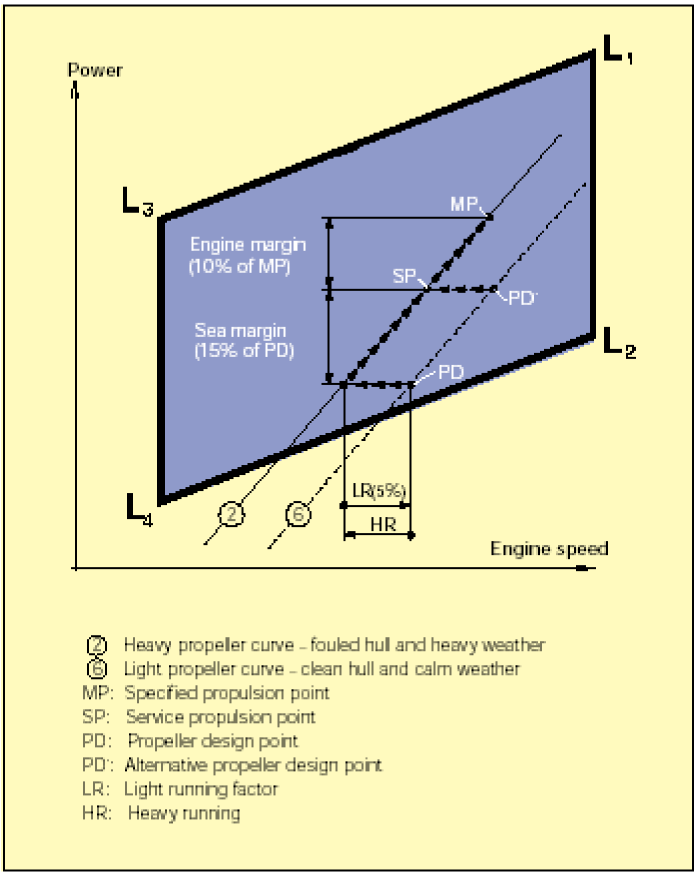
xvii) $P_D = P_{B(TRIAL)}\eta_S$

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

xix) 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

A typical engine layout diagram of is shown in the following figure.



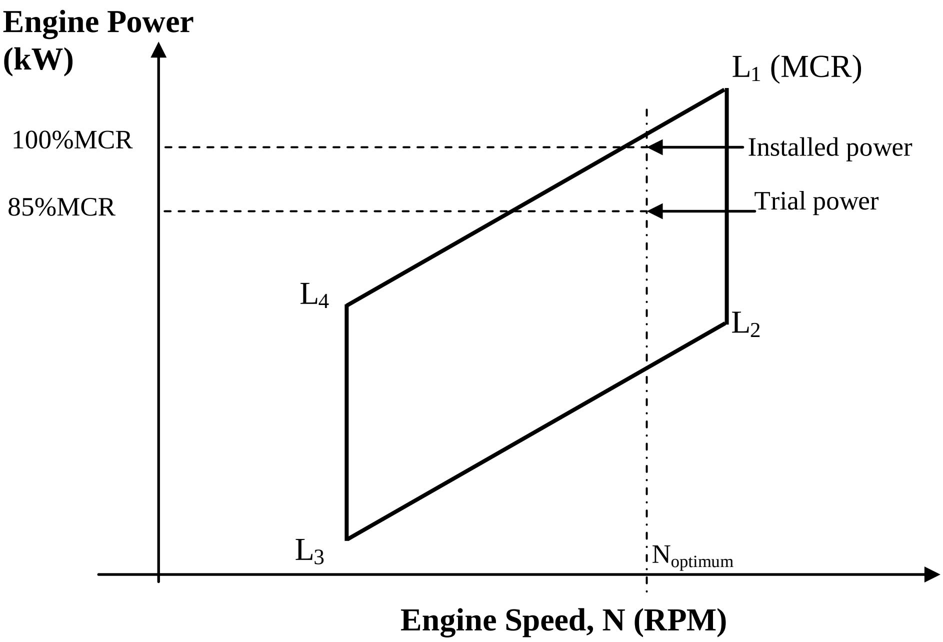
An engine's layout diagram is limited by two constant mean effective pressure (mep) lines L_1-L_3 and L_2-L_4, and by two constant engine speed lines L_1-L_2 and L_3-L_4. The L_1 point refers to the engine's nominal maximum continuous rating. Within the layout area there is full freedom to select the engines specified MCR point *M* and relevant optimising point *O*, which is optimum for the ship and the operating profile. Please note that the lowest specific fuel oil consumption for a given optimising point *O* will be obtained at 80% of point *O*'s power. Based on the propulsion and engine running points, the layout diagram of a relevant main engine may be drawn-in. The specified MCR point *M* must be inside the limitation lines of the layout diagram; if it is not, the propeller speed will have to be changed or another main engine type must be chosen.

Engine margin is an operational margin for the engine which is usually between 10 and 15% of MCR. This point is the continuous operational or service point of the engine required by the ship owner or the shipyard. It is not recommend to operate the engine at the 100% of MCR for a long time which may result losses in the performance of the engine

xx) We have optimum RPM (latest), brake power in trial condition P_{BTRIAL} and installed maximum continuous power is calculated taking into account engine margin and shaft generator (if installed) as.

Installed Maximum Continuous Power: $P_{B(INSTALLED)} = \dfrac{P_{B(TRIAL)} + PTO}{0.85\ or\ 0.90}$

Where PTO is power take off
For engine selection refer to engine layout diagrams provided by the manufacturers.



- assume the number of cylinders
- calculate the required installed power
- from a range of engine select the appropriate one compatible with the optimum RPM and power range

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

xxi) $P_{DSERVICE} = P_B \eta_S$

xxii) Choose a new value of w_T to allow for the effects of roughness, wind, waves, etc.

$$w_{TSERVICE} = 1.1 w_{TTRIAL}$$

xxiii) The previous values for t and η_R are assumed to be the same

xxiv) $\eta_{DSERVICE}$ is assumed (i.e. $\eta_{DSERVICE(assumed)}=0.7$)

xxv) Effective power is then calculated

$$P_{ESERVICE} = P_{DSERVICE} \eta_{DSERVICE}$$

xxvi) From the power vs. speed diagram $V_{SSERVICE}$ is read off at $P_{ESERVICE}$

xxvii) V_A is calculated

$$V_A = V_{SSERVICE}(1 - w_{TSERVICE})$$

xxviii) $B_p = 1.158 \frac{N P_D^{1/2}}{V_A^{2.5}}$ and $\delta_B = 3.2808 \frac{N D_B}{V_A}$ are calculated for a range of Ns and the calculated values of B_p-δ_B are plotted on the B_p-δ_B diagram

xxix) η_0 is read of at the intersection of B_p-δ_B curve with the P_B/D_B

xxx) η_D is calculated

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

xxxi) 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 (xxv) and assume $\eta_{D(assumed)}=\eta_{D(calculated)}$

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

xxxii) $P_{ESERVICE}=P_{DSERVICE}\eta_{DSERVICE(latest)}$

xxxiii) From the power vs. speed diagram $V_{SSERVICE}$ is again read off at $P_{ESERVICE}$ and this is the ship speed in service condition.

xxxiv) Bp and δ_B are read off at the above intersection obtained in (xxix). $N_{SERVICE}$ is calculated as:

$$N_{SERVICE} = \frac{\delta_B V_A}{3.2088 D_B}$$

5. Determination of Blade Surface Area (BAR) and 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

xxxv) Cavitation number σ_R is calculated for trial condition

xxxvi) Referring to Burril's cavitation diagram for upper limit load coefficient τ_c is read off at the σ_R

xxxvii) Projected area, A_p, developed area, A_D and Blade area ratio BAR are calculated

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.