

Propeller Design (Detail Stage)

To this point we have developed the K_T vs J^2 (J^4) design approach. Most references present the series data in alternative format. One version is curves of constant efficiency and $1/J$ on a scale of P/D vs B_{P1} or P/D vs $K_Q^{1/4} \cdot J^{-5/4}$. These are due to D. W. Taylor plotting the series data using B_P which we will define later. The best description of use of the forms of the charts I found was in PNA, page 159 Propulsion and Propellers Section 10: Propeller Design, by Karl Schoenherr. The following is excerpted from the text:

The procedure in using these charts depends on the nature of the problem to be solved; that is, on which data are known and which are unknown. In general, propeller design problems belong to one of the following categories:

1. Preliminary Design.

a. Given: The designed speed of the ship, the corresponding ehp and the propeller diameter .Required: The propeller pitch and the rpm for best efficiency.

b. Given: The designed speed of the ship the corresponding ehp and the engine rpm. Required: The propeller pitch and the propeller diameter for best efficiency.

2. Final Design.

Given: The ehp curve as a function of the ship speed, the propeller diameter, and the power output of the engine at the designed rpm.

Required: The propeller pitch, the efficiency and the ship speed obtainable under the given conditions.

3. Analysis.

Given: The propeller dimensions, the ship speed, power, thrust and rpm.

Required: The true slip, wake fraction and thrust deduction.

The K_T vs J^2 (J^4) design approach we have done to date is directed at 1. Preliminary Design. At this stage, the power required is determined based on a reasonable first estimate of propeller efficiency determined with this approach. The propulsion plant is then sized accordingly. The propulsion plant may have discrete incremental sizes and thus may not exactly match the first estimate exactly. The ship design proceeds, perhaps a new resistance (close to preliminary design) etc, is obtained and then Final Design takes place. At this point, P_D (power delivered) to the propeller is known. It may not match (exactly), the preliminary estimate, hence the V_s may be different.

Taylor selected two parameters for plotting information for design work:

$B_{Pn} = N \cdot P^{1/2} / V_A^{5/2}$ where $N = \text{rpm}$, $P = \text{power delivered (hp)}$ ($= Q \cdot 2 \cdot \pi \cdot N$) and $V_A = \text{speed of advance (kts)}$, $n = \text{number of blades}$
and ..

$B_{Un} = N \cdot U^{1/2} / V_A^{5/2}$ where $N = \text{rpm}$, $U = \text{useful power (hp)}$ ($= T \cdot V_A$) and $VA = \text{speed of advance (kts)}$, $n = \text{number of blades}$

These are not non-dimensional but Taylor thought that was ok "since propellers work in water of practically constant density, which will be taken care of by the constants used". S&P page 100

This motivated NSMB to present the data on plots of P/D vs $K_Q^{1/4} \cdot J^{-5/4} = B_{P1}^{1/2}$ constant which can be shown to be equivalent as follows:

$$\boxed{K_Q^{1/4} \cdot J^{-5/4} = 0.17279 \cdot (B_{P1})^{1/2}}$$

P in hp
 n in RPM
 V_A in kts

similarly, not developed here...

$$\boxed{K_Q^{1/4} \cdot J^{-3/4} = 1.75 \cdot (B_{P2})^{1/2}}$$

P in hpUK
 D in ft
 V_A in kts

see B_series_units_US.mcd

$$K_Q^{\frac{1}{4}} \cdot J^{\frac{-5}{4}} = \left(\frac{Q}{\rho \cdot n^2 \cdot D^5} \right)^{\frac{1}{4}} \cdot \left(\frac{V_A}{n \cdot D} \right)^{\frac{-5}{4}} = \left[\frac{P_D \cdot \text{hp} \cdot 550 \cdot \frac{\text{lb} \cdot \text{ft}}{\text{hp} \cdot \text{s}}}{2 \cdot \pi \cdot \rho \cdot \text{lb} \cdot \frac{\text{sec}^2}{\text{ft}^4} \cdot \left(V_A \cdot \text{kt} \cdot 1.688 \cdot \frac{\text{ft}}{\text{sec} \cdot \text{kt}} \right)^5 \cdot \text{rpm}^2 \cdot \frac{\text{min}^{-2}}{\left(60 \cdot \frac{\text{sec}}{\text{min}} \right)^2}} \right]^{\frac{1}{4}} \quad \rho \text{ in } \frac{\text{lb} \cdot \text{sec}^2}{\text{ft}^4}$$

$$P_D = Q \cdot 2 \cdot \pi \cdot n \quad Q = \frac{P_D}{2 \cdot \pi \cdot n} \quad B_P = \frac{n \cdot P_D^{0.5}}{V_A^{2.5}}$$

$$K_Q^{\frac{1}{4}} \cdot J^{\frac{-5}{4}} = \left[\frac{P_D \cdot \text{hp}}{(V_A \cdot \text{kt})^5} \cdot \text{rpm}^2 \right]^{\frac{1}{4}} \cdot \left(\frac{550}{2 \cdot \pi \cdot \rho \cdot \text{lb} \cdot \frac{\text{sec}^2}{\text{ft}^4} \cdot 1.688^5 \cdot 60^2} \right)^{\frac{1}{4}} = \left(\frac{P_D \cdot n^2}{V_A^5} \right)^{\frac{1}{4}} \cdot \frac{1}{4} = \left(\frac{P_D^{\frac{1}{2}} \cdot n}{V_A^{\frac{5}{2}}} \right)^{\frac{1}{2}} \cdot \frac{1}{4} = B_P^{\frac{1}{2}} \cdot \frac{1}{4}$$

removing units

$$\rho := 1.99 \quad \left(\frac{550}{2 \cdot \pi \cdot \rho \cdot 1.688^5 \cdot 60^2} \right)^{\frac{1}{4}} = 0.1728$$

another approach which accommodates other units for P_D , V_A and n is shown in

B series units conversion.xmcd

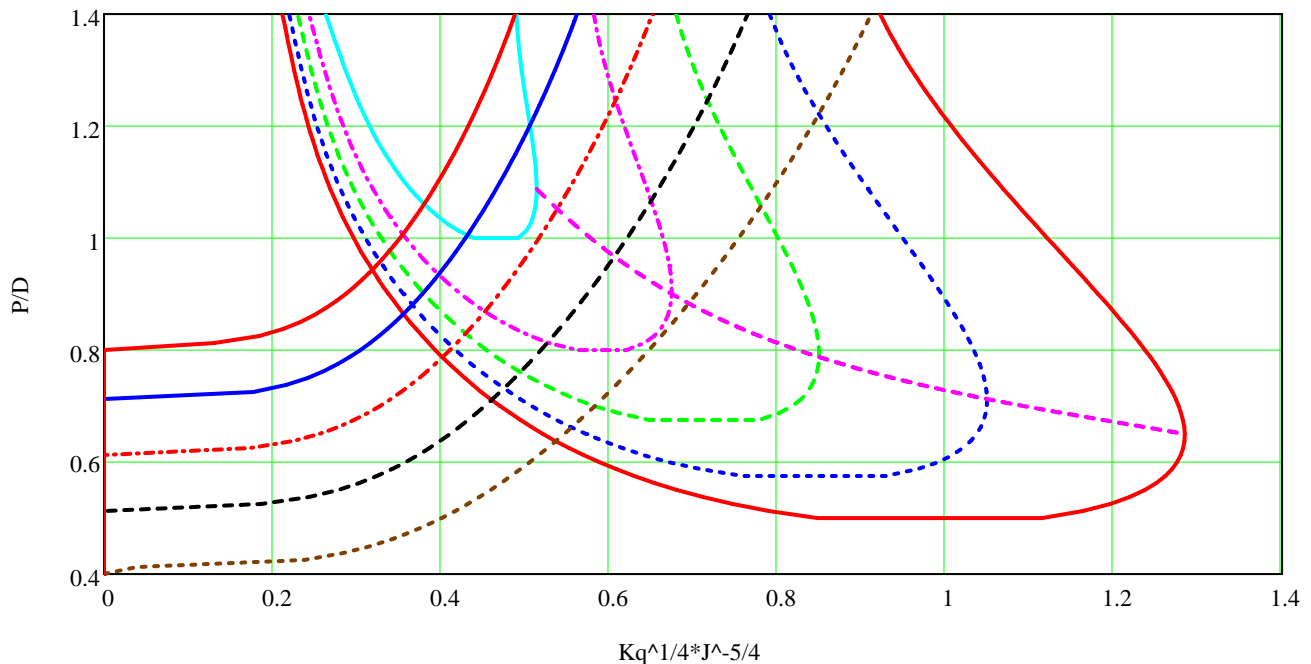
▢ regression coeff. $Re=2 \cdot 10^6$

▢ details

form of plot shown in PNA: P/D vs $Kq^{1/4} \cdot J^{-5/4}$. Curves are constant η and $1/J$. These are derived from the same data as our previous K_T K_Q curves.

these are fixed;

EAR \equiv 0.40 z \equiv 4



another form of the same information

conversion of $Kq^{1/4} \cdot J^{-2.5}$ to B_p . note
abscissa is log scale

$$bp_{1,i,j} := \left(\frac{\text{abs.}_{i,j}}{0.17279} \right)^2$$

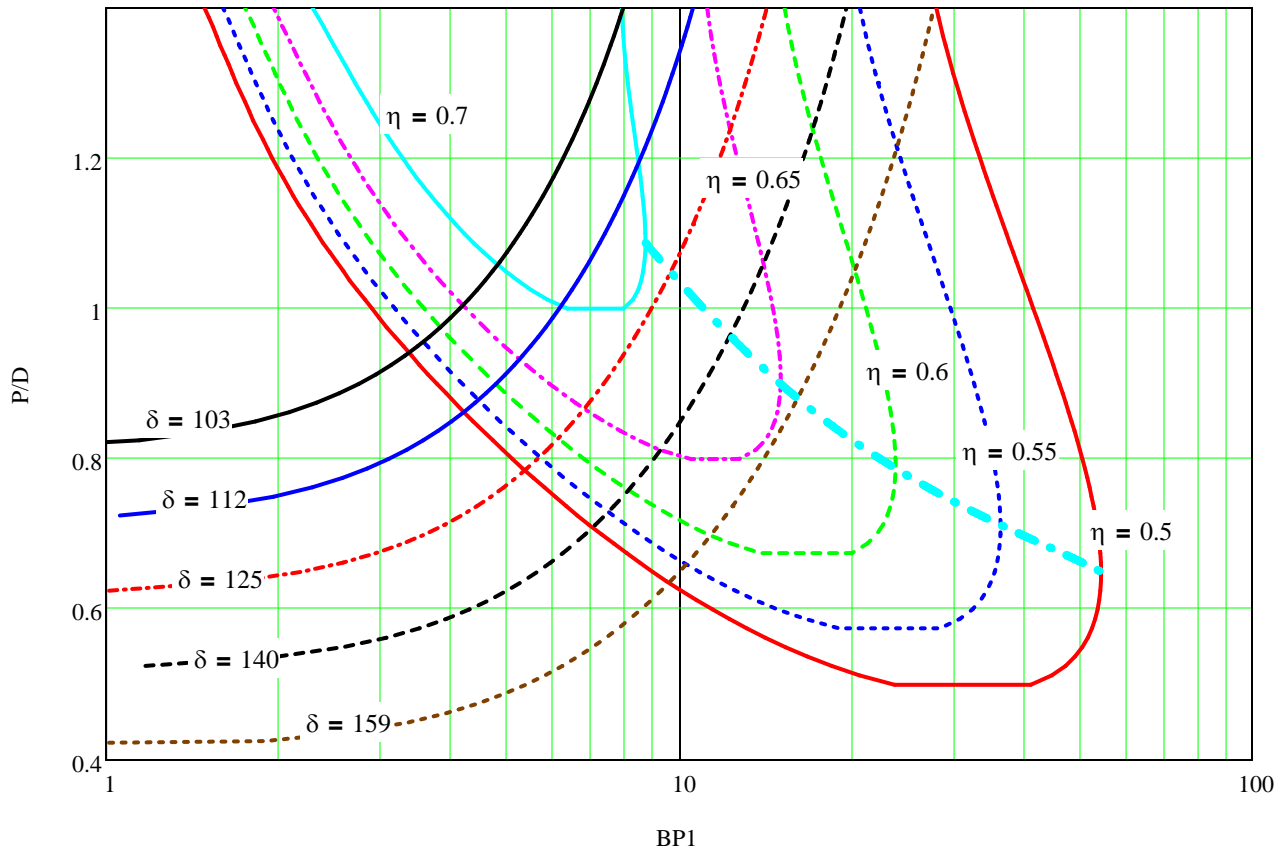
$$\delta = \frac{1}{J} \cdot 60 \cdot 1.6889$$

	constant efficiencies
$\delta =$	$\begin{pmatrix} 158.871 \\ 139.697 \\ 124.652 \\ 112.533 \\ 102.562 \end{pmatrix}$
$nm =$	$\begin{pmatrix} 0.5 \\ 0.55 \\ 0.6 \\ 0.65 \\ 0.7 \end{pmatrix}$

EAR = 0.4

z = 4

higher δ to right



an example of use of these curves ...

say we have a design such that:

$$P_D := 16000 \text{ hp}$$

$$n := \frac{100}{\text{min}}$$

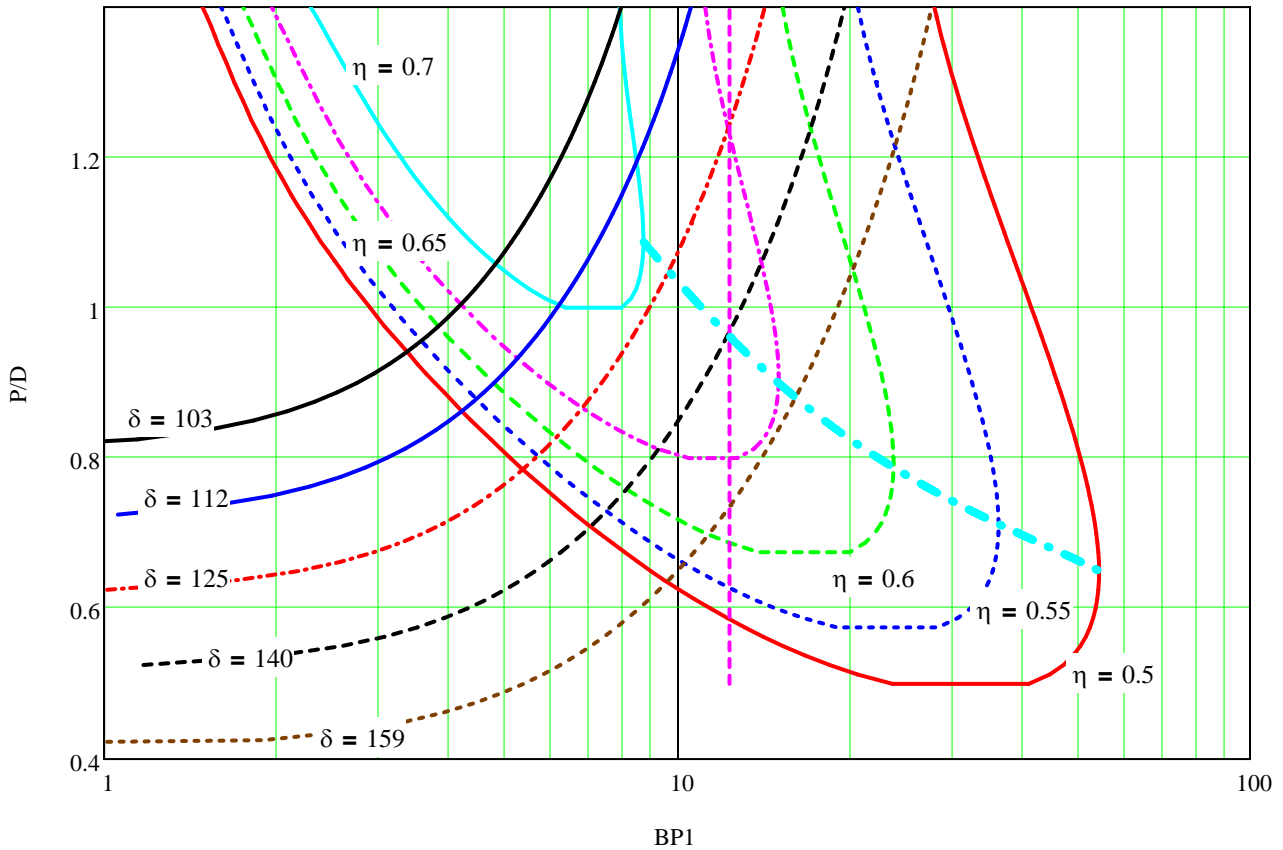
$$V_A := 16 \text{ knot}$$

$$BP1 := \frac{\frac{n \cdot P_D^{0.5}}{V_A^{2.5}}}{\frac{\text{hp}^{0.5}}{\text{min} \cdot \text{knot}^{2.5}}} \quad BP1 = 12.353$$

$$BP_ans := BP1$$

$$v_line := 0.5, 0.6 \dots 1.5$$

we will plot that vertical line on the curves and determine the maximum efficiency, P/D and δ



it appears that δ for the max η is $\delta_0 := 140$ $\eta_0 := 0.67$ $P_{\text{over}_D0} := 0.98$ approximately

$$\delta = \frac{\frac{n \cdot D}{V_A}}{\frac{\text{ft}}{\text{min} \cdot \text{knot}}} \quad D := \frac{\delta_0 \cdot V_A}{n} \cdot \frac{\text{ft}}{\text{min} \cdot \text{knot}} \quad D = 22.4 \text{ ft}$$

let's say the diameter is limited to 20 ft by another constraint $D_1 := 20 \text{ ft}$

$$\delta_1 := \frac{\frac{n \cdot D_1}{V_A}}{\frac{\text{ft}}{\text{min} \cdot \text{knot}}} \quad \delta_1 = 125 \quad \text{then the best situation is}$$

$$\eta_1 := 0.65 \quad P_{\text{over}_D1} := 1.25 \quad \text{approximately}$$

N.B. The shape of the developed curves is generally OK. I'm not completely confident in the exact values. The validation is not as close as I would like.