Using $K_T$ and $K_Q$ for design

we have seen in general the development of the Wageningen B series. The performance curves are available either in chart form or can be generated from polynomials:

| regression coeff. $Re=2\times10^6$
| polynomial representation

**use in design**

A typical design problem calls for designing a propeller that will provide the required thrust at a given speed of advance. These parameters result from applying thrust deduction and wake fraction to resistance and ship velocity respectively. Design will imply selecting a P/D from a B-series plot that will maximize open water efficiency.

For now we will arbitrarily pick a number of blades and expanded area ratio. Later we will address the criteria in their selection. Reviewing the non-dimensional forms of the parameters associated with thrust and speed:

$$K_T = \frac{T}{\rho n^2 D^4}, \quad J = \frac{V_A}{n D}$$

we have independent variables $n$ and $D$. Normally one of these is determined by other criteria, e.g. maximum diameter by hull form, or $n$ by the propulsion train design, so we will look at two cases, one in which $D$ is fixed - determine $n$, and the other where $n$ is fixed determine $D$

**case 1**

given: $V_A, T, D$

find $n$ and P/D for maximum efficiency

only thing unknown is $n$, eliminate ... from ratio of $K_T$ and $J$

$$\frac{K_T}{J^2} = \frac{T}{\rho n^2 D^4} \cdot \frac{n^2 D^2}{V_A^2} = \frac{T}{\rho D^2 V_A^2}$$

this says that propeller (full scale and model) must match this ratio which is a constant determined by $T$, $V_A$, $D$ and $\rho$

$$K_t_{over J_{sq}} := \frac{T}{\rho D^2 V_A^2}$$

we can plot a curve of $K_T$ vs $J^2$ and determine the points (values of $J$) for which $K_T$ vs $J$ for a given P/D match.

the design point for a particular propeller (B.n.nn) i.e. $n$ is determined from the value of $J$ that satisfies:

$$K_t(J) = \text{constant} \cdot J^2$$

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for example, let \( K_{t\_over\_J\_sq} := 0.544 \)

\[ K_{t\_design(J)} := K_{t\_over\_J\_sq} J^2 \]

what \( n \) i.e. \( J \) will satisfy the relationship for a B 5.75 propeller with P/D -1.0

select using B_series

\( z = 5 \quad \text{EAR} = 0.75 \quad P\_over\_D := 1.0 \)

determine intersection

intersection occurs at \( J = 0.64 \)

\[ n = \frac{V_A}{J - D} \]

where \( V_A \) and \( D \) are known as described above

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selection of the optimum n for this B z.EAR propeller is a matter of comparing similar curves for a range of P/D and choosing the maximum open water efficiency $\eta_o$.

B series $z = 5$ EAR = 0.75

<table>
<thead>
<tr>
<th>P_over_D</th>
<th>1.4</th>
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</thead>
<tbody>
<tr>
<td>1.2</td>
<td></td>
</tr>
<tr>
<td>1.0</td>
<td></td>
</tr>
<tr>
<td>0.8</td>
<td></td>
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<tr>
<td>0.6</td>
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</tbody>
</table>

busy plot of Kt, Kq, $\eta_o$ and Kt = constant * J^2. see breakdown below. P/D not labeled but ~ J at Kt = 0

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intersection solution

plot with only Kt but vertical lines at J for Kt/J^2 = Kt to show points which satisfy the design requirements
note the \( \eta_0 \) at each J intersection and select the maximum (P/D curves not well labeled, P/D \( \sim \) J at \( K_T=0 \). left to right lowest to highest

\[
\text{Plot for P/D = } P_{\text{over}_D}^T = (1.4 \ 1.2 \ 1 \ 0.8 \ 0.6 ) \quad \text{calculated using regression relationships}
\]

this case appears to have maximum at 
\[ J_{\text{ans}} = 0.64 \quad P_{\text{over}_D\_ans} = 1 \quad \eta(J_{\text{ans}}, \text{EAR}, z, P_{\text{over}_D\_ans}) = 0.61 \]

so ... 
\[ n = \frac{V_A}{J_{\text{ans}}D} \]

where \( V_A \) and D are known as described above

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**case 2**

given: \( V_A, T, n \)  
find P/D and D for maximum efficiency

only thing unknown is D, eliminate ... from ratio of \( K_T \) and J

\[
\frac{K_t}{J^4} = \frac{T}{\rho n^4 D^4} \frac{n^2}{V_A^4} = \frac{T}{\rho V_A^4}
\]

this says that propeller (full scale and model) must match this ratio which is a constant determined by \( T, V_A, n \) and \( \rho \)

\[
K_{t\_over\_J\_4} := \frac{T}{\rho D^4 V_A^2}
\]

we can plot a curve of \( K_T \) vs \( J^4 \) and determine the points (values of J) for which \( K_T \) vs J for a given P/D match.

for example, let \( K_{t\_over\_J\_4} := 0.544 \)

\[
K_{t\_design(J)} := K_{t\_over\_J\_4} J^4
\]

select using B_series \( z := 5 \), EAR := 0.75

the design point for a particular propeller (B.n.nn) i.e. n is determined from the value of J that satisfies: \( K_t(J) = \text{constant} \cdot J^4 \)

since the process is identical to case 1, only the final result is shown
note the $\eta_0$ at each $J$ intersection and select the maximum ($P/D$ curves not well labeled, $P/D \sim J$ at $K_T = 0$. left to right lowest to highest)

Plot for $P/D = \frac{P}{D} = (1.4 \ 1.2 \ 1 \ 0.8 \ 0.6)$ calculated using regression relationships

This case appears to have maximum at $J_{ans} = 0.74$, $P_{over_D}_{ans} = 1$, $\eta(J_{ans}, EAR, z, P_{over_D}_{ans}) = 0.67$

and $D = \frac{V_A}{J_{ans} \cdot n}$ where $V_A$ and $n$ are known as described above

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