Propeller Testing

Screw propeller replaced paddle wheel ~1845 in Great Britain (vessel) - Brunel
In test;

independent variables are

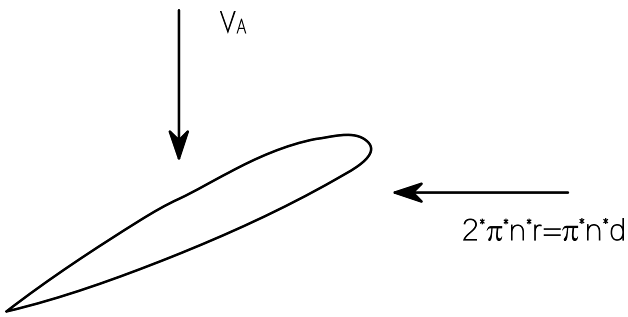
- velocity of advance V_A
- shaft rotation speed n (rev/sec), N (rev/min)

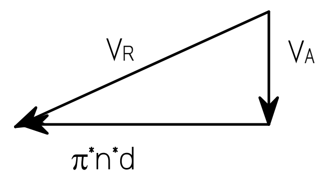
dependent variables are:

- torque Q
- thrust T

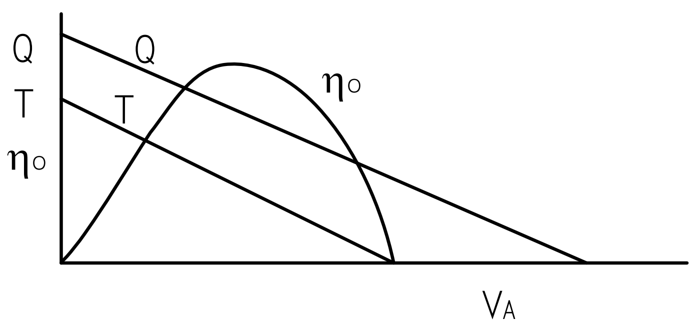
i.e. we build a propeller, rotate it a a given speed in a given flow and measure thrust and torque (at this point - conceptually - not practical at full scale)

are considering propeller in general, no ship present, => open water
velocities relative to blade:





test at given n, vary V_A, measure thrust (T), torque (Q) and calculate efficiency (η_o)



typical performance curve at given rotaion speed, note zero efficiency at V_A = 0 and T = 0

Obviously, testing at full scale impractical, hence use model scale and apply to geopmetrically similar propeller.
Expect performance to depend on:

- VA velocity of advance
- D diameter of propeller
- n rotational speed
- ρ fluid density
- μ dynamic viscosity ($\nu = \mu/\rho$ = kinematic viscosity
- $p - p_v$ pressure of fluid (upstream static pressure) compared to vapor pressure

First non-dimensionalize: using n and D

Thrust $K_T := \frac{T}{\rho \cdot n^2 \cdot D^4}$

Torque $K_Q := \frac{Q}{\rho \cdot n^2 \cdot D^5}$

advance_velocity $J := \frac{V_A}{n \cdot D}$

Reynold's number based on diameter: $Re_D := \frac{\rho \cdot D \cdot V_A}{\mu}$

nominal cavitation index (presure) $\sigma_N := \frac{p - p_v}{\frac{1}{2} \cdot \rho \cdot V_A^2}$

dimensional analysis would show: $K_T = f(J, Re_D, \sigma_N)$ $K_Q = f(J, Re_D, \sigma_N)$

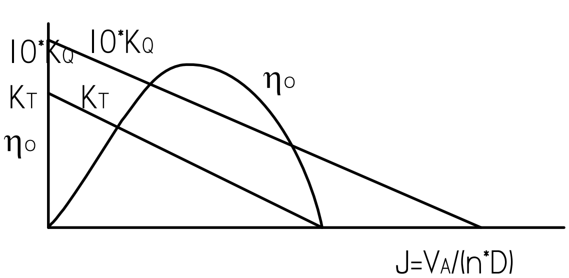
Typical propeller: fully turbulent, hence only weakly dependent on Re_D
deeply submerged, σN not influential, hence:

$K_T = f(J)$ $K_Q = f(J)$

substituting the above coefficients ...

recall open water efficiency efficiency $\eta_o := \frac{T \cdot V_A}{2 \cdot \pi \cdot n \cdot Q_o}$ $\eta_o \rightarrow \frac{1}{2} \cdot K_T \cdot \frac{J}{\pi \cdot K_Q}$ $\eta_o := \frac{1}{2 \cdot \pi} \cdot \frac{K_T}{K_Q} \cdot J$

so now we test a model scale propeller ~ 12 inches diameter measuring thrust and torque and plotting non-dimensionally: (10 * K_Q is used for similar scales, K_Q has extra D when non-dimensionalized)



Propeller Series Testing

ref: PNA pg 186 ff

Early series done by Taylor, Gawn, Schaff, NSMB
For design purposes NSMB became standard
NSMB = Netherlands Ship Model Basin; now MARIN Maritime Research Institute Netherlands

first series designated A were airfoil shapes had some cavitation
revised shapes to avoid cavitation:

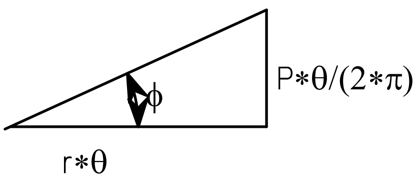
- widened blade tips
- circular section near tip
- airfoil near hub, etc.

designated B series see figure 48 in PNA for geometry

Propeller pitch

Pitch = distance moved along axis of propeller by an imaginary line parallel to the blade chord line for one rotation of the blade

- unyielding fluid - chord defined as line between nose and tip



usually non-dimensionalized by D $\tan(\phi) = \frac{P\cdot\theta}{2\cdot\pi\cdot r\cdot\theta} = \frac{P}{\pi\cdot D}$

typically use at r =0.7*R if variable $D = D(r) = D(\text{radius})$

B series is family of curves of open water performance at model scale for numbers of blades and area ratio

Blade area ratio A_E/A_0

Number of blades Z

$$\begin{pmatrix} 2 & 0.30 & . & . & . & . & . & . & . & . & . & . & . & . & . & . \\ 3 & . & 0.35 & . & . & 0.5 & . & . & 0.65 & . & . & 0.80 & . & . & . & . \\ 4 & . & . & 0.40 & . & . & 0.55 & . & . & 0.70 & . & . & 0.85 & . & 1.0 & . \\ 5 & . & . & . & 0.45 & . & . & 0.6 & . & . & 0.75 & . & . & . & . & 1.05 \\ 6 & . & . & . & . & 0.5 & . & . & 0.65 & . & . & 0.80 & . & . & . & . \\ 7 & . & . & . & . & . & 0.55 & . & . & 0.7 & . & . & 0.85 & . & . & . \end{pmatrix}$$

above performance curve (K_T, K_Q, η vs. J shown for particular number of blades, P/D A_E/A_0
member designated as: B.5.50 =>
B series
5 blades
0.50 area ratio

This introduced Expanded area ratio =

- consider section along cylindrical surface at radius r using helix of pitch P
- flatten helix
- rotate to show cross section at radius r

sum expanded section over radius = expanded area of blade * number of blades Z = expanded area
EAR (Expanded area ratio) = Expanded area / disk area

$$EAR = \frac{Expanded\_area}{disk\_area} = \frac{A_E}{\frac{\pi \cdot D^2}{4}}$$

can also express developed area and projected area see **hydrocomp report**

Troost published a set of these curves in "notebook"

later Oosterveld and Van Oossanen published a set of curves based on an empirical curve fit
ref: "Further Compiuter - Analyzed Data of the Wageningen B-Screw Series", *International Shipbuilding Progress*, Volume 22

$$K_T = f_1\left(J, \frac{P}{D}, \frac{A_E}{A_0}, Z, R_n, \frac{t}{c}\right)$$ and .... $$K_Q = f_2\left(J, \frac{P}{D}, \frac{A_E}{A_0}, Z, R_n, \frac{t}{c}\right)$$

the coefficients for Re = 2*10^6 without t/c in the fit are listed in Table 17 page 191 of PNA
corrections for t/c and Re can be added later
this provides a set of curves as indicated. e.g.

regression coefficients Re=2*10^6

plot for B.5.75 for single value of P/D $P\_over\_D := 0.6$ $EAR := 0.75$ $z := 5$

$$Kt(J, P\_over\_D) := \sum_{n=0}^{38} \left(a_n \cdot J^{sKt_n} \cdot P\_over\_D^{tKt_n} \cdot EAR^{uKt_n} \cdot z^{vKt_n}\right)$$

$$Kq(J, P\_over\_D) := \sum_{n=0}^{46} \left(b_n \cdot J^{sKq_n} \cdot P\_over\_D^{tKq_n} \cdot EAR^{uKq_n} \cdot z^{vKq_n}\right)$$

$$\eta(J, P\_over\_D) := \frac{Kt(J, P\_over\_D)}{2 \cdot \pi} \cdot \frac{J}{Kq(J, P\_over\_D)}$$

$$\eta = \frac{trust\_power}{propeller\_power} = \frac{T \cdot V_A}{Q \cdot 2 \cdot \pi \cdot n}$$ $$n = \frac{revolutions}{second}$$

$$\frac{T \cdot V_A}{Q \cdot 2 \cdot \pi \cdot n} = \frac{T}{\frac{1}{2} \cdot \rho \cdot n^2 \cdot D^4 \cdot D} \cdot \left(\frac{\frac{1}{2} \cdot \rho \cdot n^2 \cdot D^4 \cdot D}{Q}\right) \cdot \frac{V_A}{2 \cdot \pi \cdot n} = \frac{Kt}{2 \cdot \pi} \cdot \frac{J}{Kq}$$

we have some data problem with polynomials as they calculate some values beyond real data (K_T <0)

$\eta(J, P\_over\_D) := \text{if}\left(Kt(J, P\_over\_D) > 0, \eta(J, P\_over\_D), 0\right)$

correct η first - before Kt is made positive definite

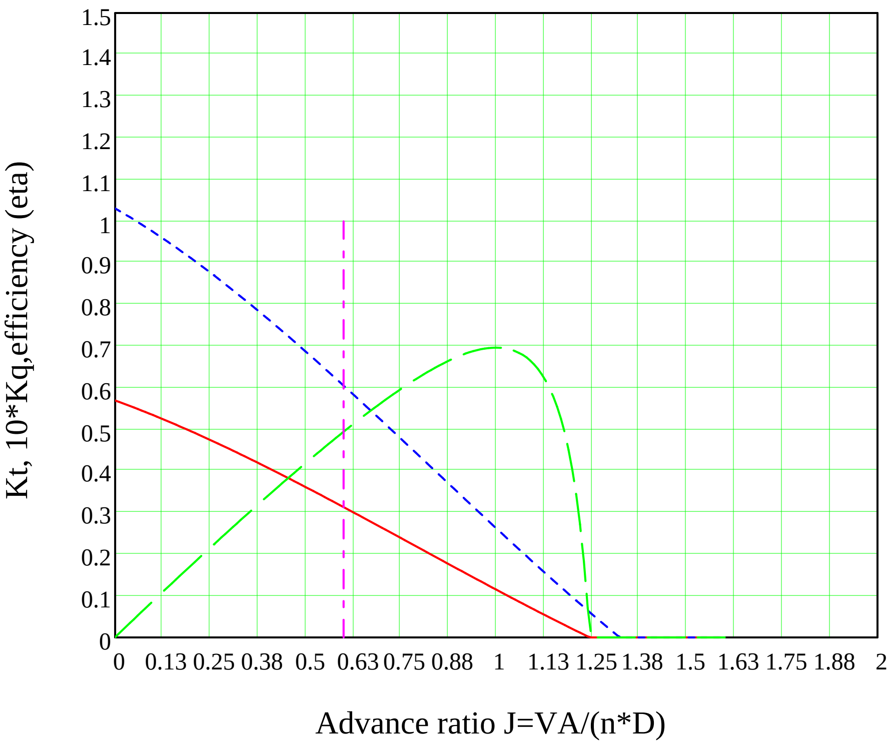
$Kt(J, P\_over\_D) := \text{if}\left(Kt(J, P\_over\_D) > 0, Kt(J, P\_over\_D), 0\right)$

eliminate negative segments - make positive definite

$Kq(J, P\_over\_D) := \text{if}\left(Kq(J, P\_over\_D) > 0, Kq(J, P\_over\_D), 0\right)$

plotting constructs

$EAR := 0.75$ $z := 3$ $P\_over\_D := 1.2$



Plot for P/D = 1.4, 1.2, 1.0, 0.8, 0.6 calculated using regression relationships

B_series z := 3 EAR := 0.75