Massachusetts Institute of Technology

DEPARTMENT OF MECHANICAL ENGINEERING
Center of Ocean Engineering

2.611 SHIP POWER and PROPULSION
Fall 2006, Quiz 1 - Solutions

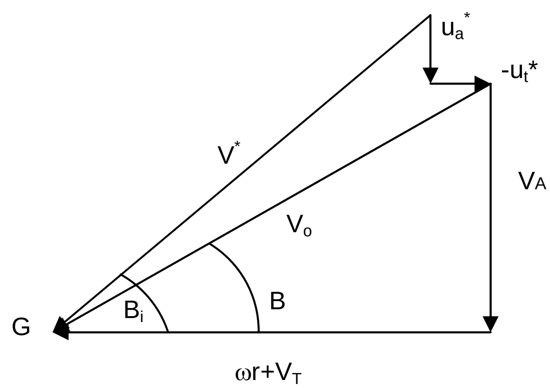
1) (20 pts)

a) Discuss how Controllable Reversible Pitch (CRP) propellers can help prevent engine overloading. Consider your answer in terms of Torque (Q), angle of attack (α), Lift, Drag, Velocity of Advance (J), Pitch, and shaft speed. (The use of all terms is not necessary as long as a logical sound argument is made.) (10pts)

A number of factors such as heavy seas, towing evolutions, and / or excessive loading conditions may cause J to decrease. Generally, with CRP propellers operating above 12 knots, the speed of the shaft is programmed to remain constant. To compensate for the decrease in relative water velocity the angle of attack should increase. This will result in an increase in lift and thus require additional torque from the main engines. To bring the engine torque back to its original designed value the pitch is reduced by controlling the angle of attack. This allows the engine to operate at designed torque and prevent overloading

b) Discuss the cause of u_a and u_t.

The vortex produced by the propeller action affects the flow field over the propeller. These effect velocity in the direction of advance and transverse directions and are represented by u_a and u_t. This changes the angle of inflow and produces V* (10 pts)



2) (50 pts) A ship captain must purchase a new propeller to replace the damaged one currently installed on his ship. The supplier only has two propellers in stock. Both are fixed pitch, 5 blade Wageningen B-series propeller with an EAR of .45, one has a pitch of 17.1 ft and the other a pitch of 20.9 ft. The details of the ship are as follows:

Ship and Propeller characteristics:
B-series 5-45 propeller (see attached sheet)
$Pitch_1$ = 17.1 ft or $Pitch_2$ = 20.9 ft
Diameter = 19 ft
Wake Reduction Factor, w = .2
Thrust Reduction Factor, t = .12
Relative Rotative Efficiency, η_R = 0.89
Ship Resistance at max Power, 174800 lbf
Velocity of the ship = 20 kts

Conversion factors

$$knot = 1.688 \frac{ft}{sec}$$

$$\rho := 1.9905 lbf \cdot \frac{sec^2}{ft^4}$$

a) Using the provided Wageningen B-Series design curves, determine the best choice between the two propellers in stock with respect to efficiency η_o. (J^2 function, η_o, and correct choice – 20 pts)

b) Determine $J_{optimum}$, $K_{Toptimum}$, $K_{Qoptimum}$ (15 pts)

c) Determine the Optimal propeller speed n_p. (5pts)

d) Calculate Thrust (T) and Torque (Q) (5pts)

e) The ship's engines are capable or producing 16 x 10^3 HP, will the ships engines be adequate for propeller selected? (5pts)

<u>Solution</u>

only thing unknown is n, eliminate ...

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

Kt/J^2 is constant; independent of n and P/D, Determine n, P/D which gives maximum η_o.

$V_s := 20 knot \qquad w := 0.2 \qquad t := 0.12 \qquad D := 19 \cdot ft \qquad R := 174800 lbf$

$V_A := (1 - w) \cdot V_s \qquad V_A = 16 knot \qquad T := \frac{R}{1 - t} \qquad T = 1.986 \times 10^5 \ lbf$

$Kt\_over\_J\_sq := \frac{T}{\rho \cdot D^2 \cdot V_A^{\ 2}} \qquad Kt\_over\_J\_sq = 0.379$

a) Draw K_T=.379*J^2 function on B 5-45 Chart to determine the most efficient design

b) From the B 5-45 Charts

For P/D of .9	For P/D of 1.1
J_1= .655	J_2= .755
K_T= .14	K_T= .22
K_Q= .027	K_Q= .04
ηo= .63	ηo= .65

Using the above J and P/D=1.1 on the B 5-45 plot, we get $K_T := 0.22$ and $K_Q := \frac{0.4}{10}$

c)

$$n_p := \frac{V_A}{J\_2 \cdot D} \qquad n_p = 112.952 \frac{1}{min}$$

$T := K_T \cdot \rho \cdot n_p^2 \cdot D^4$ $\quad$ $T = 2.022 \times 10^5\ \text{lbf}$

$Q := K_Q \cdot \rho \cdot n_p^2 \cdot D^5$ $\quad$ $Q = 6.987 \times 10^5\ \text{lbf} \cdot \text{ft}$

d) Power delivered by the engines is not quite enough to support the optimum propeller.

$\eta_0 := .65$ $\quad$ $P_E := \dfrac{R \cdot V_s}{550 \cdot \dfrac{\text{lbf} \cdot \text{ft}}{\text{s} \cdot \text{hp}}}$ $\quad$ $\eta_R := .89$

$P_E = 1.073 \times 10^4\ \text{hp}$

$\eta_H := \dfrac{1 - t}{1 - w}$ $\quad$ $QPC := \eta_0 \cdot \eta_H \cdot \eta_R$ $\quad$ $P_D := \dfrac{P_E}{QPC}$

$QPC = 0.636$

$P_D = 1.686 \times 10^4\ \text{hp}$

Power delivered by the engines is not quite enough to support the optimum propeller.

Looking at exercise 1 in chapter 10, the required propeller power P_D is what was being asked for. P_E in this case required looking at the resistance due to hull form. That is the reason it is calculated this way. Only 2-4 pts taken for incorrect answers.

2) (30 pts) The same Captain asks you to design a new propeller for his pleasure boat. You run PVL and get the following results at r/R=.7:

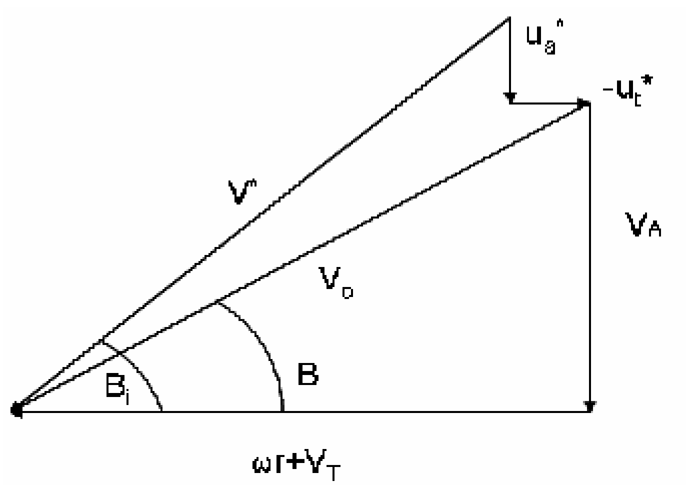
Given:
r/R = .7
Nprop = 220 rpm
D = 1 m
Va = 18 m/s
Vt = 0 m/s
Ut* = -.9 m/s
Ua* = .9 m/s
G = .7 m^2/s
c = .18 m
w = 0

a) Draw the inflow vector diagram at .7R (10 pts)
b) Find V* (10 pts)
   i) Hint: ω = 2*pi*N
c) What is C_L? (5 pts)

d) How do we determine if the blade will cavitate? No calculations are required. You can describe or use formulas. You do not have enough information to calculate a number for this blade. (5pts)

3) Lifting Line theory Question

a) Flow Vector Diagram



$w := 0$ $\quad c := .18 \cdot m$

b) Find V*

$D := 1 \cdot m$ $\quad V_a := 18 \cdot \frac{m}{s}$ $\quad N_{prop} := 220 \cdot min^{-1}$ $\quad \Gamma := .7 \cdot \frac{m^2}{s}$ $\quad G := \Gamma$

$utstar := -.9 \cdot \frac{m}{s}$ $\quad uastar := .9 \cdot \frac{m}{s}$ $\quad R := \frac{D}{2}$ $\quad \frac{r}{R} = .7$ $\quad r := .7 \cdot R$ $\quad r = 0.35\,m$

$\omega := 2 \cdot \pi \cdot N_{prop}$ $\quad \omega = 23.038 \frac{1}{s}$ $\quad \omega r := \omega \cdot r$ $\quad \omega r = 8.063 \frac{m}{s}$

$$Vstar := \left[\sqrt{(\omega r + utstar)^2 + (V_a + uastar)^2}\right]$$

Note: The Vs cancels out of the eqn so able to use PVL values

$Vstar = 20.212 \frac{m}{s}$

c) find CL

Now we know that $\quad L = \rho \cdot Vstar \cdot \Gamma = \frac{1}{2} \cdot \rho \cdot Vstar^2 \cdot c \cdot C_L$

therefore: $\quad C_L := \frac{\Gamma \cdot 2}{Vstar \cdot c}$ $\quad C_L = 0.385$

d) How to determine if a blade will cavitate

If -Cpmin is greater than σ_{local} then the blade will cavitate.

$P_{inf} = P_{atm} + \rho \cdot g \cdot h$

$$\sigma_{local} := \frac{P_{inf} - P_{vap}}{\frac{1}{2} \cdot \rho \cdot V_{star}^2}$$

The lowest P_{inf} occurs at the shallowest blade depth of the blade section