1. A survey vessel has a 10 ft diameter, B 5-90 propeller with a pitch of 10 ft. The propeller speed is 200 rpm, the boat speed is 20 knots, and the thrust reduction factor (t) is 0.12, wake fraction (w) is 0.18, and the relative rotational efficiency η_R is 1.0.

The propeller operates as indicated by the Wageningen (Troost) Series B propeller charts. Determine:

a. Thrust
b. Shaft torque
c. EHP of the boat
d. The propeller shaft power (delivered power) P_D
e. The (Quasi) PC or η_D

The propeller is also tested at zero ship speed (bollard pull) and it is found that the engine limits the torque to 50,000 lbf ft. Determine:

f. the propeller rpm and thrust at this condition

a. Prop. Thrust.

Given variables

$d := 10ft$ $\quad p := 10ft$ $\quad p\_over\_d := \frac{p}{d}$ $\quad n\_rpm := 20($ $\quad V_s := 20knot$

$t := .12$ $\quad w := .18$ $\quad \eta_R := 1$ $\quad \rho := 1.9905lb \cdot \frac{sec^2}{ft^4}$

Velocity of Approach $\quad V_A := V_s \cdot (1 - w)$ $\quad V_A = 8.437\frac{m}{s}$

Advance Ratio $\quad n := \frac{n\_rpm}{60 \cdot sec}$ $\quad n = 3.333\frac{1}{s}$ $\quad J_1 := \frac{V_A}{n \cdot d}$ $\quad J_1 = 0.83$

Use the B 5-90 prop curve to determine K_T and K_Q $\quad K_T := .12$ $\quad K_Q := .02\text{:}$

$Thrust := K_T \cdot \rho \cdot n^2 \cdot d^4$ $\quad Thrust = 2.654 \times 10^4\, lb$

b. Shaft Torque

$Torque := K_Q \cdot \rho \cdot n^2 \cdot d^5$ $\quad Torque = 5.087 \times 10^4\, lb \cdot ft$

c. Shaft powerr delivered

$$PD := 2 \cdot \pi \cdot n \cdot \frac{Torque}{550 \cdot \frac{lb \cdot \frac{ft}{sec}}{hp}}$$

$PD = 1.937 \times 10^3\, hp$

d. EHP

$$PE := Thrust \cdot (1 - t) \cdot \frac{V_s}{550 \cdot \frac{lb \cdot \frac{ft}{sec}}{hp}}$$

$PE = 1.433 \times 10^3\ hp$

e. Quasi Efficiency

$$\eta_D := \frac{PE}{PD}$$

$\eta_D = 0.74$

f. Propeller rpm and thrust at 50,000.

$Advance\_velocity := 0$ $Torque_{max} := 50000\,lb \cdot ft$

$$n_o := \sqrt{\frac{Torque_{max}}{\rho \cdot K_Q \cdot d^5 \cdot \eta_R}}$$

$n_o = 3.305 \frac{1}{s}$

$n_q := n_o \cdot 60 \cdot sec$

$n_q = 198.286$

$Thrust_q := K_T \cdot \rho \cdot n_q^2 \cdot d^4$ $Thrust_q = 9.391 \times 10^7\ s^2\ lb$

2. A propeller is to be selected for a single-screw container ship with the following features:

EHP = 80000 HP, ship speed = 25 kts, maximum propeller diameter = 34 ft, w = 0.249, t = 0.18, η_R = 1.0, centerline depth, h = 25 ft

a. Using the maximum prop diameter, determine the optimum B 5-90 design. Use the metrics below to confirm your design.

a. P/D
b. K_T (optimum)
c. K_Q (optimum)
d. η_o (optimum)
e. J
f. Developed HP
g. The (Quasi) PC or η_D
h. RPM

From the consideration of cavitation, determine:

i. The predicted cavitation (%) using the Burrill correlation
j. The expanded area ratio (EAR) to provide 5% cavitation for a commercial ship.

Assume the operating conditions are similar to the B 5-90 propeller.

Given $V_2 := 25 \cdot knot$ $EHP := 80000\,hp$ $d_2 := 34 \cdot ft$ $w_2 := .249$ $t_2 := .18$ $\eta_R := 1$ $h := 25$

First we must combine a couple of equations in order to get all the information we know in terms of K_T and J.

$$R_2 := \left(550 \cdot \frac{lb \cdot \frac{ft}{sec}}{hp}\right) \cdot \frac{EHP}{V_2} \qquad T_2 := \frac{R_2}{1 - t_2} \qquad K_t := \frac{T_2}{\rho \cdot n_2^{\,2} \cdot d_2^{\,4}} \qquad J_2 := \frac{V_2}{n_2 \cdot d_2}$$

$$\frac{K_t}{J_2^{\,2}} \rightarrow \frac{\left(550 \cdot \frac{lb \cdot \frac{ft}{sec}}{hp}\right) \cdot (EHP)}{\rho \cdot V_2^{\,3} \cdot d_2^{\,2} \cdot (1 - t_2) \cdot (1 - w_2)^2} = 0.55$$

Now we can plot the function $K_T = 0.55 * J^2$ on the B 5-90 curve graph. Drawing a verticle line where the function plot and each K_T - P/D intersect will provide a value for K_T and η_O. Starting with a logical P/D (.5 for example), step though P/D values, recording K_T and η_O. Take note at the peak value for η_O, That will determine optimal values. Using the curves posted on the web, I found:

P/D = 1.2 K_T=.29 η_O = .6

$K_t := .29$

a. P/D = 1.2

b. $K_{T(opt)}$ = .29

$$J_2 := \sqrt{\frac{K_t}{.55}}$$

$K_q := .055$

c. $K_{Q(opt)}$ = .055

$\eta_{o2} := .6$

d. η_O = .6

$$Q_2 := K_q \cdot \rho \cdot n^2 \cdot d^5$$

$J_2 = 0.726$

e. J = 0.726

$$PC := \eta_{o2} \cdot \left(\frac{1 - t}{1 - w}\right) \cdot \eta_R$$

f. HP = 124200 HP

$$PD_2 := \frac{EHP}{PC}$$

$PD_2 = 1.242 \times 10^5\ hp$

g. PC = .644

$$n_2 := V_2 \cdot \frac{1 - w_2}{J_2 \cdot d_2}$$

$n_2 = 1.284 \frac{1}{s}$

$PC = 0.644$

h. RPM = 77.012

$$N_2 := n_2 \cdot 60 \cdot s$$

$N_2 = 77.012$

Cavitation Calculations

$EAR := .90$ $P\_over\_D\_ans := 1.2$ $h := 25ft$

$$A_E := EAR \cdot \frac{\pi \cdot d_2^{\,2}}{4}$$

assume $A_D \sim A_E$

$$A_P := A_E \cdot [1.067 - 0.229 (P\_over\_D\_ans)]$$

$$V_R := \left[\left[V_2 \cdot (1 - w_2)\right]^2 + (0.7\pi \cdot n \cdot d_2)^2\right]^{\frac{1}{2}}$$

$$\tau_C := \frac{\frac{T}{A_P}}{\frac{1}{2} \cdot \rho \cdot V_R^2} \qquad A_E = 7.591 \times 10^3 \ m^2 \qquad \tau_C = 5.421 \times 10^{-10} \frac{1}{A \cdot s^2}$$

$$\sigma_{0.7R} := \frac{2026 \frac{ft^4}{sec^4} + 64.4 \frac{ft^3}{sec^4} \cdot h}{V_R^2 + 4.836 \left(N_2 \cdot \frac{1}{s}\right)^2 \cdot d_2^2} \cdot \frac{sec^2}{ft^2} \qquad \sigma_{0.7R} = 1.095 \times 10^{-4}$$

$$C := \frac{\tau_C \cdot A \cdot s^2 + 0.3064 - 0.523 \sigma_{0.7R}^{0.2}}{0.0305 \sigma_{0.7R}^{0.2} - 0.0174} \qquad C = -17.791$$

% cavitation

Negative cavitation indicates that it is not a problem with at this speed

i. Cavitation = - 17.8%

$$\tau_{Cn} := C \cdot \left[.0305 \left(\sigma_{0.7R}^{0.2}\right) - . \times 0174\right] - .3064 + .523 \sigma_{0.7R}^{0.2}$$

$$A_{pn} := \frac{T}{\left(.5 \cdot \rho \cdot \tau_{Cn} \cdot V_R^2\right)} \qquad EAR_n := \frac{A_{pn}}{\left[1.067 - .229 \cdot 1.2 \cdot \pi \frac{\left(34^2\right)}{4}\right]}$$

j. = EAR is much less than one, Changing to meet these requirements would not be necessary. (This will be considered extra credit)

3. List the advantages and disadvantages of the fixed pitch propeller, controllable pitch propeller, and waterjet propulsion systems. List the best applications (or platform(s)) for each propulsor and supporting reasons considering the mission of the platform. (expectation: half a page of concise thought).

For full credit - A brief discussion similar to that in chapter 6 of the text, At least 2 advantages and 2 disadvantages of each and an example of where each has been used sucessfully.