National Exams December 2009

98-Nav-A2, Hydrodynamics of Ships (1): Resistance and Propulsion

3 hours duration

Notes:

1. If doubt exists as to the interpretation of any question, the candidate is urged to submit with the answer paper, a clear statement of any assumptions made.
2. This is a closed book exam. Casio or Sharp approved calculators are permitted.
3. Attempt all questions. The value of each question is noted in square brackets. The total value of the questions is 100.
4. A data sheet, a propeller chart and a cavitation chart are provided. Please write neatly.
5. Pass in the entire exam paper, including any answers you give on the papers provided.

1. Please answer the following questions.

(1). [5] What is ``Froude's Hypothesis"?

(2). [5] Explain why there are humps and hollows in the wave-making resistance (or residuary resistance) curve as it plotted against ship speeds.

(3). [5] How does the bulbous bow reduce the ship resistance? Does it reduce the resistance for all speed?

2. [15] A cruise ship line has designed a 180m long vessel with a design cruising speed of 30 knots. The design firm has built a 6m long model, which they want to ship to you (resistance test expert) to test in your small tow tank. Your tow tank has a maximum carriage speed of 2.5 m/s and the fresh water is kept at 15°C.

(1). [5] Will you be able to use the designer's model to do resistance tests over the range of speeds called for?

(2). [5] What is the maximum model size that your tank could accommodate?

(3). [5] If you determine that you can build a model cheaper than the cost of shipping the designer's model to your tank, what is the *minimum* size model you must build assuming that you want Reynolds numbers of at least 1×10^6 even at lowest model speed which corresponds to a Froude number of 0.1?
- Explain your decisions.

3. [20] The total resistance of a ship 200m long, moving at 20 knots in salt water (15^0 C), is to be determined from towing-tank tests of a 2m model in fresh water (15^0 C). The ship's wetted surface is 6000 m2 and its displacement is 190 MN. Find

(1). [5] The weight of the model

(2). [5] What is the wetted surface area of the model?

(3). [5] What speed should be used in the model test?

(4). [5] If the model resistance at this speed is 1.8N, what is the predicted full scale resistance based on the ITTC-78 with the following simplifications and assumptions: air resistance is negligible and the roughness resistance coefficient C_A is 0.0004, the form factor is 0.2. Show all work.

4. [10] Define the following terms. Use a sketch or sketches to illustrate your answer.
   - Suction and pressure side
   - Skew and rake
   - Pitch angle, and pitch distribution
   - slip
   - Controllable pitch propeller

5. [5] Consider a propeller blade section a radius r with a pitch angle ϕ and rotational speed n advancing in a flow with velocity V_A. Draw and label a sketch showing the fluid velocity components and resultant, the lift and drag vectors and thrust and torque load vectors.

6. [9] In simple momentum theory, the details of the propeller geometry are not considered. Rather, we are concerned with the overall changes in water velocity and pressure due to the action of the propeller, and how those changes give rise to thrust.

• On the top grid provided below, sketch the spatial distribution of the propeller race. Show the upstream and downstream portions of the propeller race and indicate clearly where the propeller disk is. Label the velocity and pressure far upstream of the disk V_A and p_o, respectively, where p_o is the free stream pressure. Label the velocity and pressure far downstream of the disk V_2 and p_o, where p_o is again the free stream pressure.

• On the middle plot, draw a sketch of the velocity distribution along the propeller race that corresponds to the spatial distribution sketch. Label the velocity at the disk V_1.

• On the bottom plot, draw a sketch of the pressure distribution that corresponds to the spatial and velocity distribution sketches. Label the pressures immediately up- and downstream of the propeller disk p_1 and p'_1, respectively. Pass in these sketches with your exam.

7. [6]. Propeller performance depends on the following parameters for a family of scaled models:

ρ	fluid density	μ	dynamic viscosity of fluid
g	gravitational acceleration	p	fluid pressure
n	shaft speed	V_A	speed of advance
D	propeller diameter (a characteristic length)		

A dimensional analysis of thrust (or torque) yields four dimensionless groups that can be used in planning experiments with propeller models. With some manipulation, these four groups may be written as follows:

$$\frac{V_A^2}{Dg}, \frac{V_A}{nD}, \frac{\Delta p}{\rho n^2 D^2}, \frac{c_{0.7}\sqrt{V_A^2 + (0.7\pi n D)^2}}{\upsilon}$$

If you are planning a propeller open water performance experiment in a tow tank, briefly explain the relevance of each of these 4 dimensionless groups. That is, say whether they are used or not, and why.

8. [20] A single screw ship is to be fitted with a B4-55 propeller. The propelling power is supplied by a direct drive diesel engine, designed to deliver its rated power output at 200rpm. The effective horsepower, EHP is 700 HP at 12.5 knots. The wake fraction w=0.23 and the thrust deduction fraction t = 0.14. The water depth to the axle of the propeller is 2m. Find

(1). [8] The diameter, D, and the pitch ratio of the optimum propeller, P/D. The diameter range is from 2.4m to 3m.

(2). [4] Required deriver power if relative rotative efficiency η_r =1.05.

(3). [8] Check cavitations with Burrill's curves. Approximately how much back cavitation do you expect to occur? Show all work and pass in the chart with the exam. The vapor pressure of water can be taken as 10kPa and the atmospheric pressure is 101kPa.

Data sheet for 98-NAV-A2

$$C_T = \frac{R_T}{\frac{1}{2}\rho V^2 S} \qquad R_n = \frac{VL}{\upsilon} \qquad F_n = \frac{V}{\sqrt{gL}} \qquad R_n = \frac{c_{0.75R}\sqrt{V_A^2 + (0.75\pi nD)^2}}{\upsilon}$$

$$C_F = \frac{0.075}{(\log_{10} R_n - 2)^2} \qquad C_F = 0.072\left(\frac{VL}{\upsilon}\right)^{-0.2} \qquad C_F = 1.327\left(\frac{VL}{\upsilon}\right)^{-0.5}$$

$$P_E = RV \qquad P_T = TV_A \qquad P_D = 2\pi nQ = \eta_S \eta_M P_B$$

$$C_{TS} = (1+k)C_{FS} + C_{TM} - (1+k)C_{FM} + C_A + C_{AA} \qquad L_{WT} = 2\pi \frac{V^2}{g}$$

$$J = \frac{V_A}{nD} \qquad V_A = V_S(1-w) \qquad R = T(1-t)$$

$$\eta_o = \frac{K_T J}{2\pi K_Q} \qquad \eta_D = \frac{P_E}{P_D} = \eta_H \eta_B = \eta_H \eta_0 \eta_r = \frac{1-t}{1-w}\eta_0 \eta_r$$

$$\eta_T = \eta_H \eta_B \eta_S \eta_M \frac{1}{1+x} d_r \qquad \frac{P_E}{P_{Bc}} = \frac{P_E}{P_T}\frac{P_T}{P_D}\frac{P_D}{P_S}\frac{P_S}{P_B}\frac{P_B}{P_{Bs}}\frac{P_{Bs}}{P_{Bc}}$$

$$K_T = \frac{T}{\rho n^2 D^4} \qquad K_Q = \frac{Q}{\rho n^2 D^5}$$

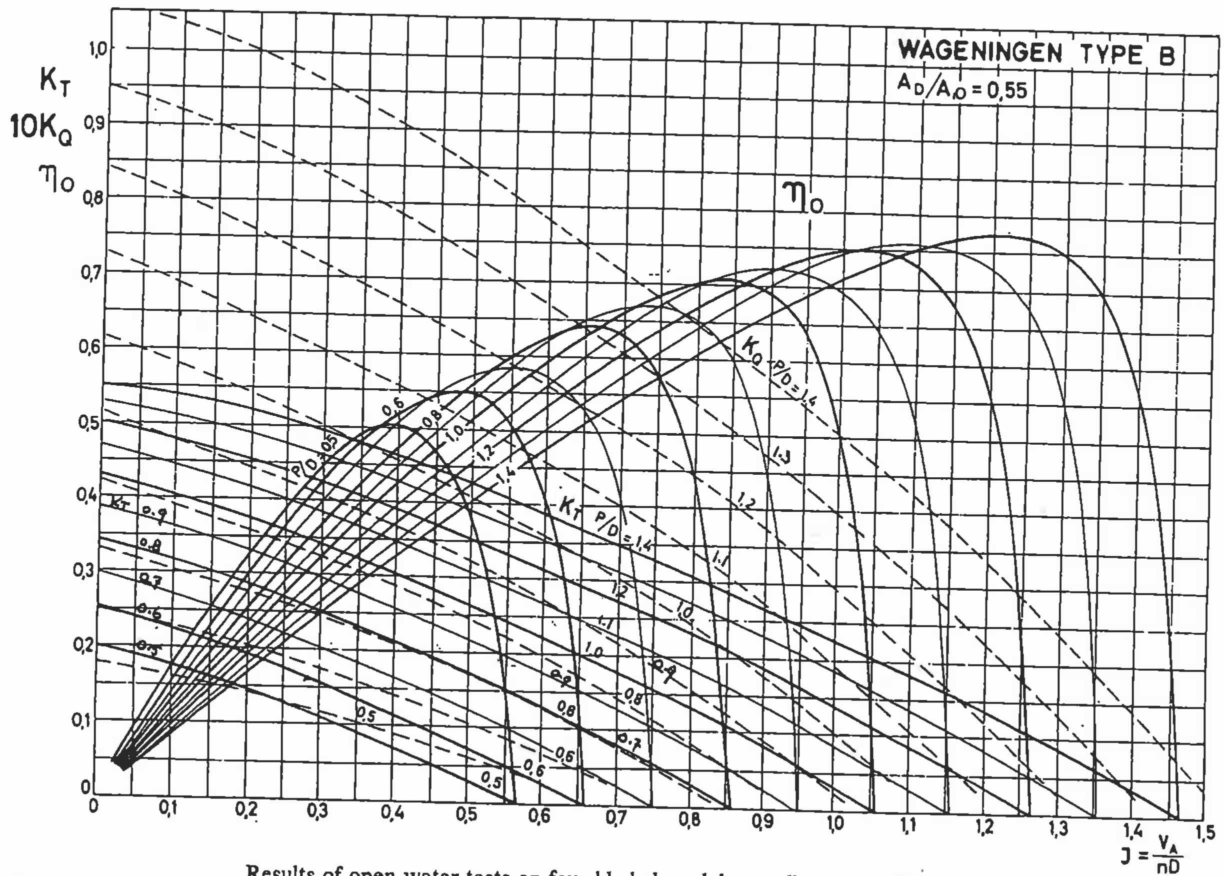
$$\frac{1}{2}\rho V_1^2 + p_1 = \frac{1}{2}\rho V_2^2 + p_2 \qquad C_L = \frac{L}{\frac{1}{2}\rho c b V^2}$$

Equations for Burrill's chart

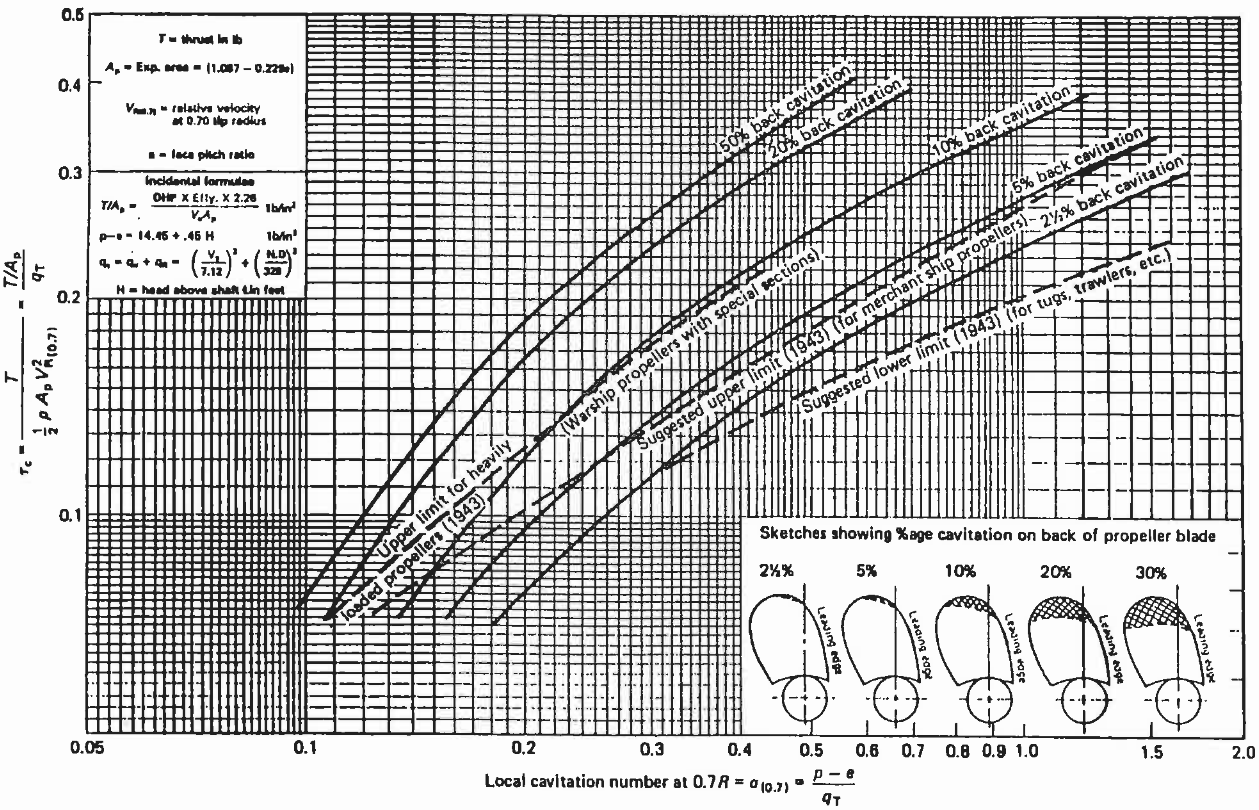
$$\sigma_{0.7R} = \frac{p_o - p_v}{\frac{1}{2}\rho\left(V_A^2 + (0.7\pi nD)^2\right)} \qquad \tau_c = \frac{T}{A_p q_{0.7R}} \qquad A_E \cong \frac{A_p}{1.067 - 0.229\, P/D}$$

Constants and data

1 knot = 0.5144 m/s
g=9.806 m/s^2
$\upsilon = 1.139\times10^{-6}$ m^2/s $\rho = 999$ kg/m^3 (freshwater @ 15°C)
$\upsilon = 1.188\times10^{-6}$ m^2/s $\rho = 1025$ kg/m^3 (saltwater @ 15°C)



Results of open-water tests on four-bladed model propellers of the Wageningen B 4-55 type.


T = thrust in lb
Exp. area
relative velocity at 0.70 tip radius
face pitch ratio
Incidental formulas
p—e = 14.45 + .45 H lb/in²
H = head above shaft in feet
50% back cavitation
20% back cavitation
10% back cavitation
5% back cavitation
2½% back cavitation
Upper limit for heavily loaded propellers (1943)
(Warship propellers with special sections)
Suggested upper limit (1943) (for merchant ship propellers)
Suggested lower limit (1943) (for tugs, trawlers, etc.)
Sketches showing %age cavitation on back of propeller blade
2½%
5%
10%
20%
30%
Leading edge
0.05
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
1.5
2.0
Local cavitation number at 0.7R