National Exams May 2002
98-NAV-A2, Hydrodynamics of Ships I: 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. 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.

1.a) [6] Do a dimensional analysis for the resistance of a deeply submerged submarine in a viscous fluid (assume we are concerned with geometrically similar submarines so that a single characteristic dimension describes the geometry). Arrive at an expression that shows resistance coefficient to be a function of a dimensionless group of terms. Begin with the two steps shown below and show all subsequent work.

Step 1: Write a functional expression:

$$R_V = \phi[\rho, \mu, V, L]$$

where ρ is the fluid density, μ is the dynamic viscosity of fluid, V is speed, and L is length.

Step 2: Then write an equation as

$$R_V = k\rho^a \mu^b V^c L^d$$

where k is a constant. Continue from here.

1.b) [6] Do a dimensional analysis for the resistance of a conventional displacement surface ship in an inviscid fluid (again, assume we are concerned with geometrically similar ships so that a single characteristic dimension describes the geometry). Arrive at an expression that shows resistance coefficient to be a function of a dimensionless group of terms.

1.c) [6] A dimensional analysis of (surface) ship resistance in a viscous fluid shows us that in order to model resistance correctly, we should follow Froude and Reynolds scaling laws simultaneously. This is not possible to do in model experiments in a tow tank, where resistance tests are normally done. In practice, which of the two laws do we follow? What do we do to minimize the errors associated with not complying with the other law?

2. You have to use a model resistance experiment to evaluate the resistance of a 165m long ship whose design speed is 16.5 knots and whose wetted surface is 10,100 m^2. You want to avoid laminar flow problems, so have decided to have a minimum Reynolds number of 2×10^6 at the model speed that corresponds to 16.5 knots full scale.

2.a) [6] What is the minimum model size that you can use? For this size model, what is the model test speed that corresponds to 16.5 knots full scale? Comment on the use of turbulence stimulation for this model.

2.b) [10] Assume the model that you use is 4 m long. You then determine from your experiments at the model speed corresponding to the design speed (16.5 knots) that the total model resistance is 33.40N. Make an estimate of ship total resistance and the effective power at this speed using the ITTC 78 method with the following simplifications and assumptions: air resistance is negligible and the roughness resistance coefficient C_A is 0.0004; the form factor is 0.25; the temperature of the tow tank water is 15°C and the water temperature for which full scale predictions are to be made is 15°C. Show all work.

3.a) [6] A displacement ship that moves with constant forward speed at the surface of a calm body of water will generate waves in response to the pressure field that is set up in the water around the ship. What is the influence of the ship's speed on the waves it generates? Include the effects on wave height, wave speed, wave phase and interference in your answer.

3.b) [5] Explain how wave interference can affect ship resistance? Use a sketch to illustrate your answer.

3.c) [5] What is the purpose of a bulbous bow? Would a bulb be potentially more useful on a fast container ship, or a slow tanker? Explain your answer.

4.a) [6] Define the following propeller geometry terms using words *and* labeled sketches:

- blade section, chord, face & back
- pitch, pitch datum, pitch angle
- rake
- camber distribution
- root

4.b) [6] Consider a propeller blade section at 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 incidence and advance angles, the lift and drag vectors, and the thrust and torque load vectors.

5. Propeller performance depends on the following parameters:

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 (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:

$$\frac{V_A^2}{\ } \quad \frac{V_A}{\ } \quad \frac{\Delta p}{\ } \quad \frac{c_{0.7}\sqrt{V_A^2 + (0.7\pi nD)^2}}{\upsilon}$$

5.a) [6] 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.

5.b) [6] If you want to check a model propeller for cavitation, then you need to test it in a cavitation tunnel. Briefly explain the relevance of each of the 4 dimensionless groups above for cavitation tunnel tests, that is, say whether they are used or not, and why.

6.a) [10] As part of a fast ferry design team, you are working on a concept design for a 31 knot displacement ship with a length of 192m, draft of 7.0m, and breadth of 26.5m. Model scale resistance and self-propulsion tests have been done on the hull form, which has a twin screw propeller arrangement. The tests showed that the ship resistance to be expected at the design speed is 2554kN. Wake fraction and thrust deduction fraction were found to be 0.24 and 0.16, respectively. The hull form can accommodate twin propellers with a maximum diameter of 5.70m.

Using the attached standard series chart of B4-85 propellers, find a *P/D* ratio that will provide the thrust required to reach the design ship speed at a shaft speed of 170 rpm. Estimate the open water propeller efficiency η_o and the hydrodynamic propulsive efficiency η_D at the design condition. Pass in the chart with your exam.
Also, calculate the total installed propulsion power (P_{Bc}) required (for both shafts) if the shaft efficiency η_S is 99%, the gear efficiency η_M is 96%, and the diesels are to be run at 90% of their maximum continuous rating at the design ship speed (i.e. derating d_r is 0.90). Assume the water temperature is 15°C.

6.b) [10] Check the propeller selected in 6a) above for cavitation using Burrill's method (use the attached sheet). Show all work and pass in the chart with the exam. The vapor pressure of water can be taken to be 4 kPa, and the atmospheric pressure is 101 kPa. The depth of the hub from the free surface is 4.0 meters. Approximately how much back cavitation can be expected to occur?

6.c) [6] What are three negative effects of cavitation? If a preliminary propeller design is found to be likely to cavitate to an unacceptable extent, what are two design changes that might be implemented in order to reduce cavitation and/or mitigate the effects of cavitation? Explain how each design change would reduce cavitation and how the change might affect propeller performance.

Data sheet for 98-NAV-A2

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

$$C_F = \frac{0.075}{(\log_{10} R_n - 2)^2} \qquad F_n = \frac{V}{\sqrt{gL}} \qquad P_E = RV \qquad P_T = TV_A$$

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

$$P_D = 2\pi n Q \qquad J = \frac{V_A}{nD} \qquad V_A = V_S(1-w) \qquad R = T(1-t)$$

$$\eta_o = \frac{K_T J}{2\pi K_Q} \qquad \eta_D = \eta_H \eta_B = \frac{P_E}{P_D} \qquad \eta_T = \eta_H \eta_B \eta_S \eta_M \frac{1}{1+x} d_r$$

$$\frac{P_E}{P_{Bc}} = \frac{P_E}{P_T}\frac{P_T}{P_D}\frac{P_D}{P_S}\frac{P_S}{P_B}\frac{P_B}{P_{Bs}}\frac{P_{Bs}}{P_{Bc}}$$

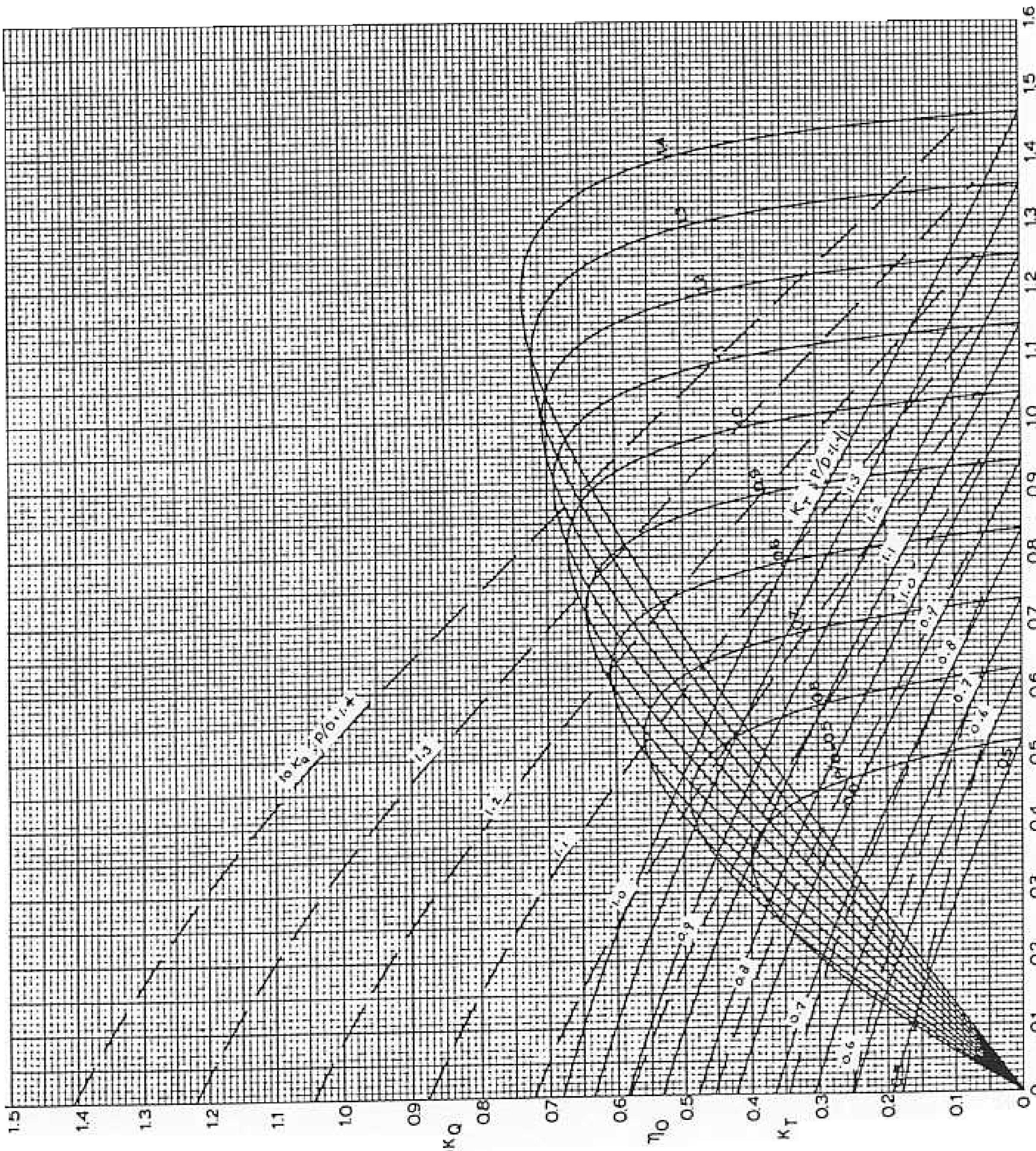
$$K_T = \frac{T}{\rho n^2 D^4} \qquad K_Q = \frac{Q}{\rho n^2 D^5}$$

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
υ= 1.139×10^{-6} m^2/s ρ= 999 kg/m^3 (freshwater @ 15°C)
υ= 1.188×10^{-6} m^2/s ρ= 1026 kg/m^3 (saltwater @ 15°C)



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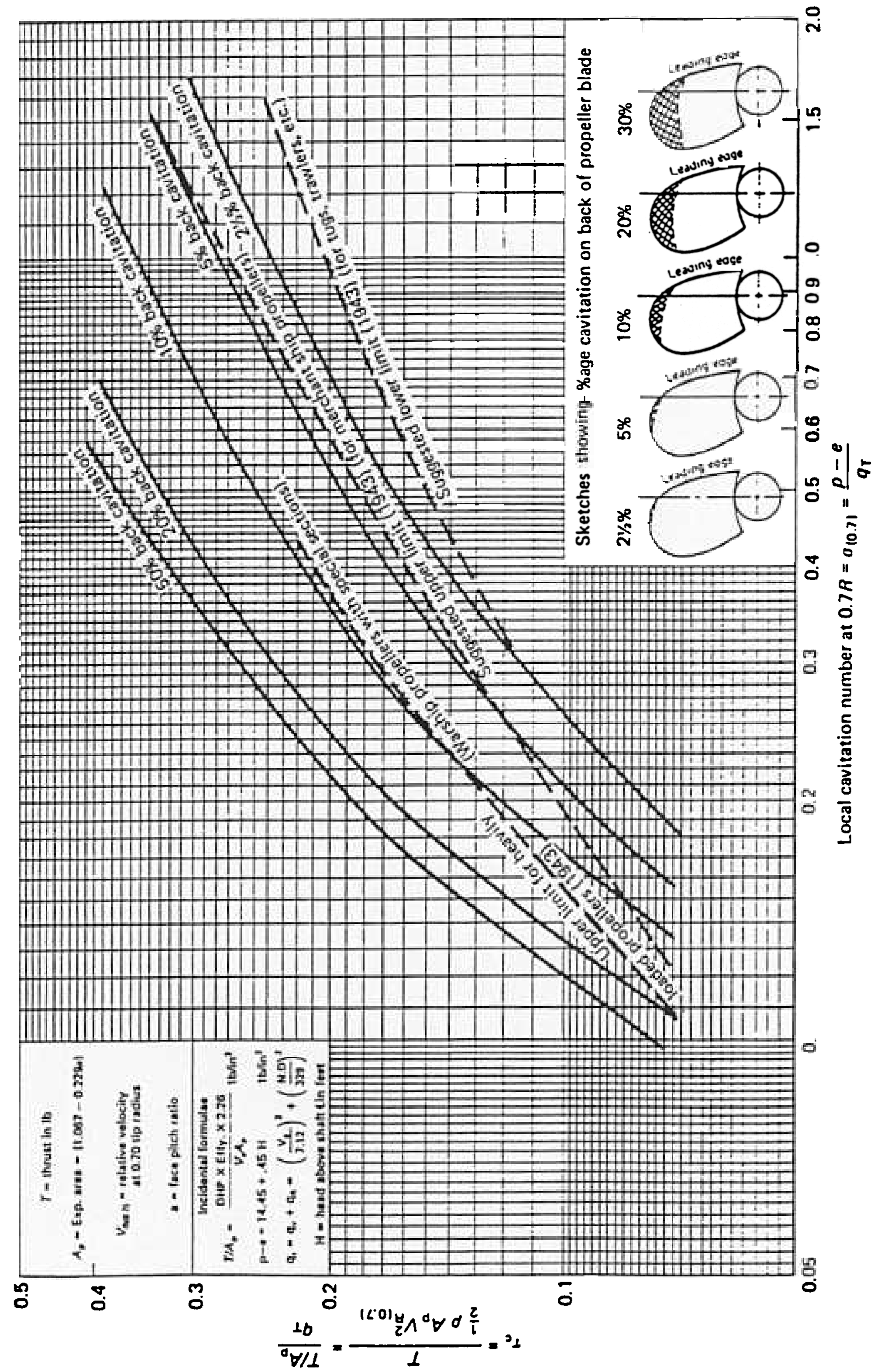

50% back cavitation
20% back cavitation
10% back cavitation
5% back cavitation
2½% back cavitation
Warship propellers with special sections
Suggested upper limit (1943) for merchant ship propellers
Suggested lower limit (1943) for tugs, trawlers, etc.
Upper limit for heavily loaded propellers (1943)
Sketches showing %age cavitation on back of propeller blade
2½%
5%
10%
20%
30%
Leading edge
Local cavitation number at 0.7R = $\sigma_{(0.7)} = \frac{p-e}{q_T}$
$\tau_c = \frac{T}{\frac{1}{2}\rho A_p V_{R(0.7)}^2} = \frac{T/A_p}{q_T}$
T = thrust in lb
A_p = Exp. area ÷ (1.067 − 0.229a)
$V_{R0.7R}$ = relative velocity at 0.70 tip radius
a = face pitch ratio
Incidental formulae
H = head above shaft ⊄ in feet