National Exams December 2019
16-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. A Casio or Sharp approved calculator is permitted.
3. Attempt questions as indicated. 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. Hand in the entire exam paper, including any answers you give on the papers provided.

Attempt 7 of the first 7 questions.

1. [10] A dimensional analysis of the resistance of a conventional displacement ship in a real fluid shows that two dimensionless numbers should be the same at model scale and full scale in order to model resistance phenomena correctly. These are the Froude and Reynolds identities. We know that it is not possible to satisfy both scaling laws simultaneously in model scale tests.

(i) In practice, which of the two scaling laws do we obey?

(ii) What do we do to minimize the errors associated with not complying with the other scaling law? Explain this clearly and precisely, making explicit reference to any procedures that you would use.

2. [10] Define the following terms clearly. Illustrate your answer with a labeled sketch.

(i) pitch datum & pitch angle & pitch

(ii) rake

(iii) sheet cavitation

(iv) camber & camber distribution

(v) tip vortex

3. [10] You have to use a model resistance experiment to evaluate the resistance of a 160m long ship whose design speed is 20.0 knots and whose wetted surface is 6,650 m^2. You want to avoid laminar flow problems, so have decided to have a minimum Reynolds number of 1×10^6 at the lowest model speed that will be tested, which corresponds to a Froude number of 0.10.

(i) What is the minimum model size that you can use?

(ii) For this size model, what are the model test speed and Reynolds number that correspond to 20.0 knots full scale? Assume the tests are done in fresh water at 15°C. Watch your significant figures.

4. [10] For the case described above in question 3, assume the model that you use is 6 m long, rather than the minimum size you calculated. You then determine from your experiments at the model speed corresponding to the design speed (20.0 knots) that the total model resistance is 77.00N. 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 0.230, 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.

5. [15] Make a preliminary design for the propeller of a small coastal tanker. The ship has an operating speed of 12 knots and a maximum continuous rated power of 790kW. This includes a derating factor of 0.90 and a service allowance of 0.15. The shaft efficiency and transmission efficiency are estimated to be 0.98 and 0.97, respectively. The shaft speed is 360 rpm. The hull form can accommodate a maximum propeller diameter of 1.7 meters with a shaft centerline 2.40 meters below the free water surface. The original model test data results for this vessel are available: predicted resistance at 12 knots for the full-scale hull with appendages is 55.0kN; corresponding wake fraction is 0.24. Assume the water temperature is 15°C.

(i) Select a *P/D* ratio using the attached B4-55 chart

(ii) Determine the thrust delivered at 12 knots.

(iii) Calculate the open water efficiency η_o of the chosen propeller.

(iv) Calculate the propulsive efficiency η_D.

6. [10] Check the propeller selected in question 5 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 10 kPa, and the atmospheric pressure is 101 kPa.

(i) Approximately how much back cavitation do you expect to occur?

(ii) What are three negative effects of cavitation?

7. [15] The wave system around a moving ship is sometimes described in terms of a combination of Kelvin wave systems.

(i) Describe a simple Kelvin wave system. Use a labeled sketch to illustrate the wave system.

(ii) For a ship of a given length, what is meant by constructive interference? In what condition(s) would you expect constructive interference to occur?

Attempt 1 of the next 2 questions (question 8 or 9).

8. [20] In a wake survey of a single screw ship, the axial velocity component of the flow at any point into the propeller disk is $V(r,\theta)$ and the flow field can be described in terms of the wake fraction $w(r,\theta) = \dfrac{V_S - V(r,\theta)}{V_S}$, where V_S is the ship speed.

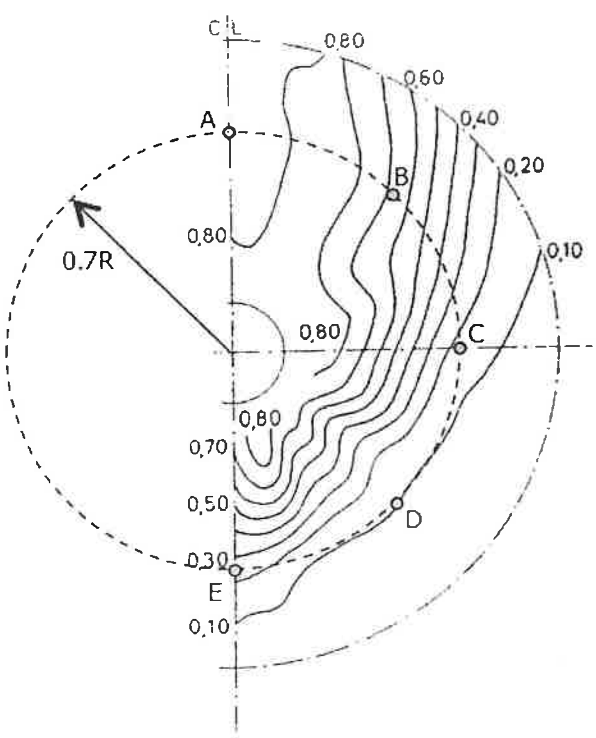
Several iso-lines of $w(r,\theta)$ are shown in the sketch below, along with a dashed outline of the 0.7 radius fraction. Five points, labeled A to E, on the 0.7 radius fraction are denoted by small circles, starting with the top dead centre position where θ is zero and then at intervals of $\pi/4$ to the bottom dead centre position.

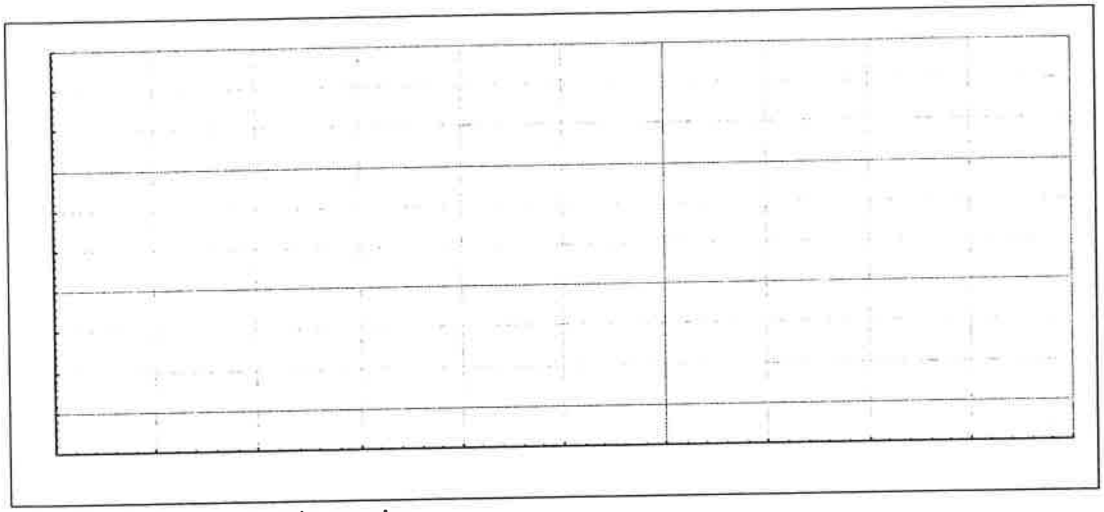
Using the grids on the exam sheet,

(i) for each of the five points, show clearly how the changes in local axial velocity change the resultant fluid velocity and angle of attack for a blade section at the 0.7 radius fraction. Label your diagram clearly.

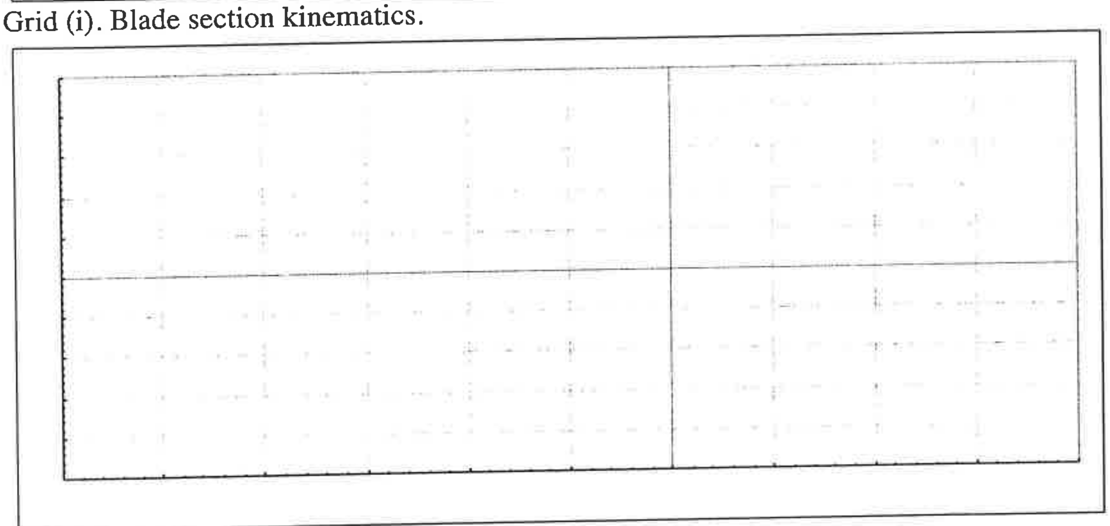
(ii) Further, explain what this means in terms of lift, using what you know about the relationship between lift coefficient and angle of attack to illustrate your answer. Again, label the diagram showing the correspondence between the wake field sketch below and the diagram from part (i).

(iii) Next, show what the consequences of the variable inflow conditions are in terms of the elemental thrust load on the blade section as it passes through an entire revolution. Identify the corresponding points from parts (i) and (ii).

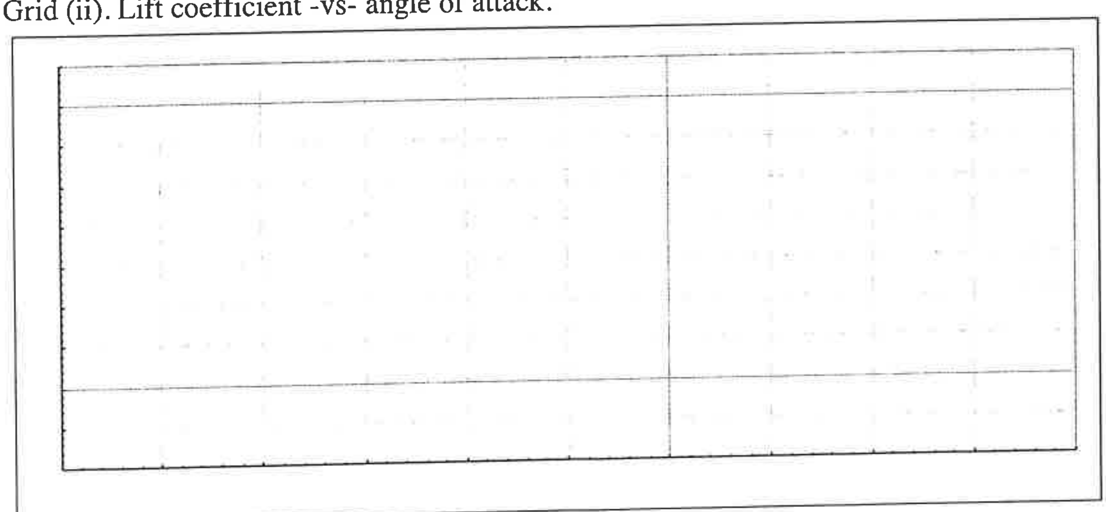




Grid (i). Blade section kinematics.



Grid (ii). Lift coefficient -vs- angle of attack.



Grid (iii). Elemental section load –vs- time.

9. [20] Plan an open water propeller performance test for a 200mm diameter model of a 4m diameter propeller whose chordlength at the 0.75 radius fraction is 1.30m. The local Reynolds number should not be less than 3×10^5. The tests will be carried out over a range of advance coefficient from 0 to about 1.1. Your dynamometer has maximum capacities of 10Nm and 250N. You have tested a similar (but not the same) propeller before and found its K_T and K_Q values at bollard to be 0.35 and 0.04, respectively.

- What are the minimum and maximum shaft speeds at which you should test the propeller model?
- Specify the values of the test parameters that you will set.

State any important assumptions you make.

Data sheet

$$C_T = \frac{R_T}{\frac{1}{2}\rho S V^2} \qquad R_n = \frac{VL}{\upsilon} \qquad R_n = \frac{c_{0.7R}\sqrt{V_A^2 + (0.7\pi nD)^2}}{\upsilon}$$

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

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

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

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

$$\eta_T = \eta_H \eta_B \eta_S \eta_M \frac{1}{1+x} d_r$$

$$\eta_o = \frac{K_T J}{2\pi K_Q} \qquad \eta_D = \eta_H \eta_B = \frac{P_E}{P_D} \qquad \frac{P_E}{P_{Bc}} = \frac{P_E}{P_T}\frac{P_T}{P_D}\frac{P_D}{P_S}\frac{P_S}{P_B}\frac{P_B}{P_{Bs}}\frac{P_{Bs}}{P_{Bc}}$$

$$K_T = \frac{T}{\rho n^2 D^4} \qquad K_Q = \frac{Q}{\rho n^2 D^5} \qquad \delta = 0.37x\left(\frac{\upsilon}{Vx}\right)^{1/5}$$

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

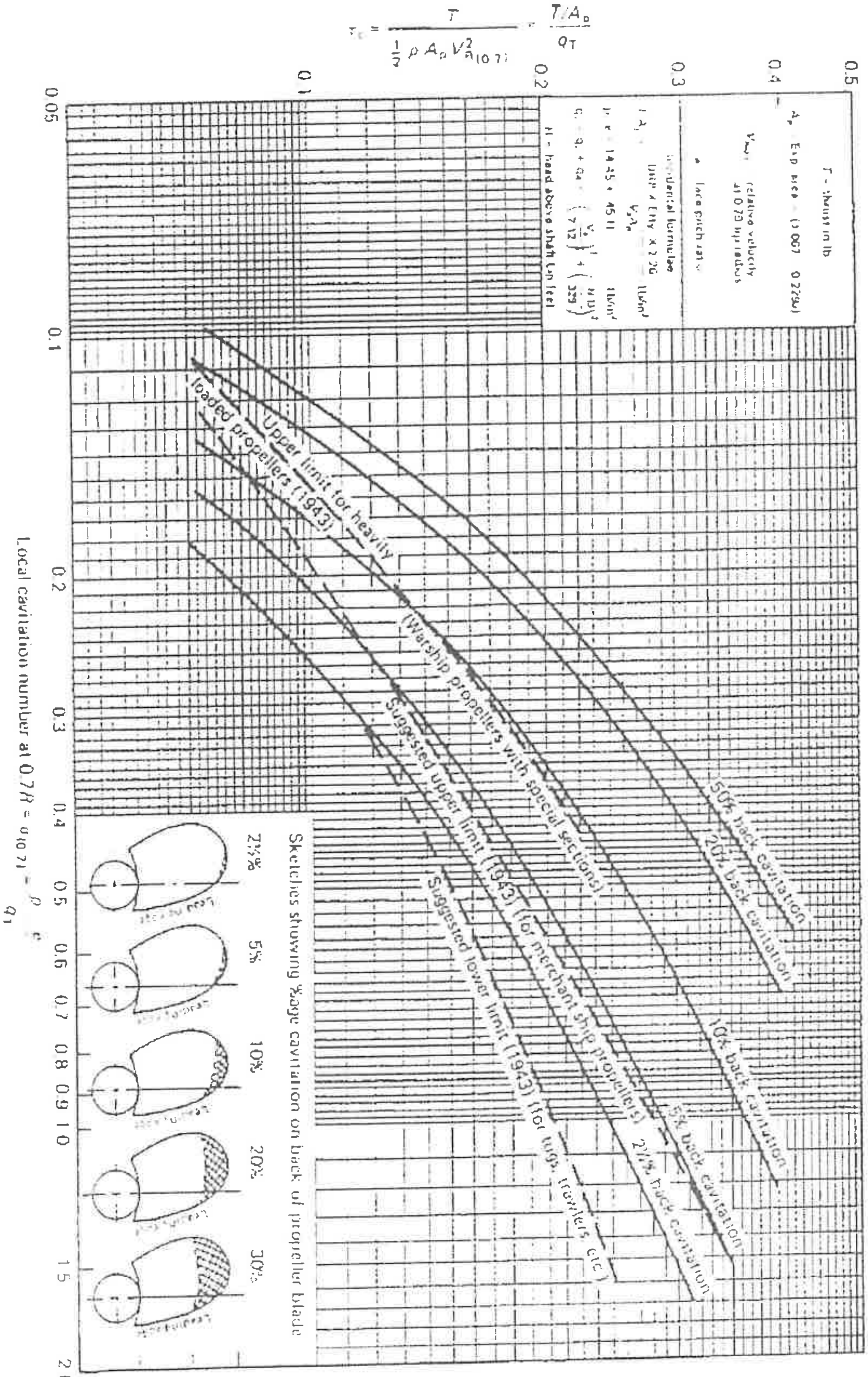
Equations for Burrill's chart

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

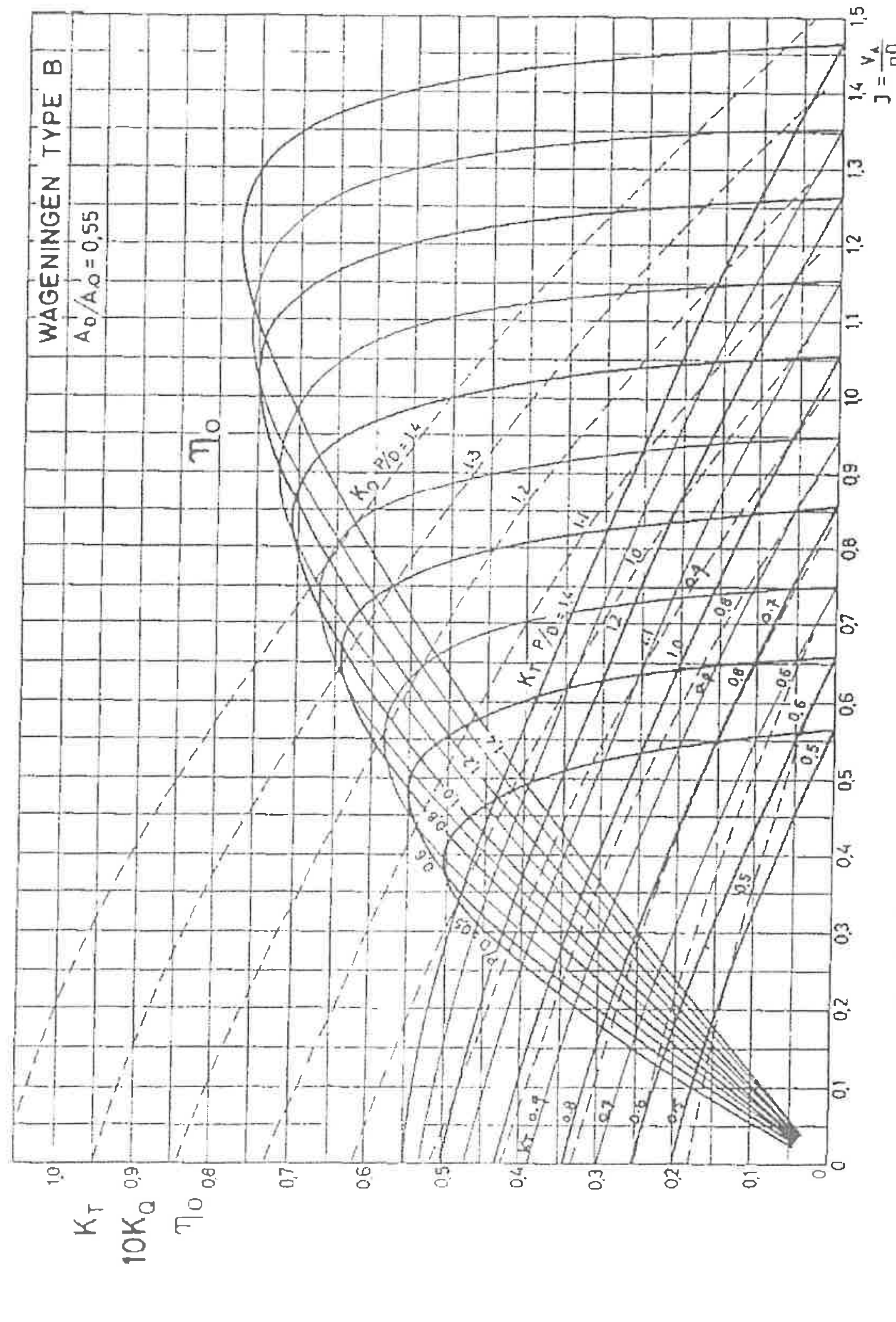
$$p_0 = p_{ATM} + \rho g h_0$$

Constants and data

1 knot = 0.5144 m/s	g=9.806 m/s²		
freshwater @ 15°C:	$\upsilon = 1.139\times10^{-6}$ m²/s	&	$\rho = 999$ kg/m³
saltwater @ 15°C:	$\upsilon = 1.188\times10^{-6}$ m²/s	&	$\rho = 1025$ kg/m³



Local cavitation number at 0.7R
Sketches showing %age cavitation on back of propeller blade
2½%
5%
10%
20%
30%
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.)
T - thrust in lb



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