National Exams May 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. Approved Casio or Sharp 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. Pass in the entire exam paper, including any answers you give on the papers provided.

Attempt 8 of the first 8 questions.

1. [10] A thin flat plate measuring 5.0 m long and 0.5 m wide is to be towed at a series of constant speeds in a towing tank. The plate will be deeply submerged during towing, and the towing force will be measured at each speed.

(a) Make an estimate of the towing force when the plate's speed is 5 m/s. Justify the choice of equation that you use to make the estimate. Assume the test is in freshwater that is maintained at 15°C.
(b) Estimate the boundary layer thickness at a point 2.0 m from the plate's leading edge when the plate's speed is 5 m/s.
(c) If the plate towed in an ideal fluid, how would the boundary layer thickness be influenced?

2. [10] Dimensional analysis tells us that we should use the Froude and Reynolds identities when we do model resistance tests.

(a) Show that it is impossible to obey both of these requirements simultaneously (except for the special case where the scale is 1).
(b) In practice, which identity do we obey, and why?
(c) In terms of using the results of the resistance experiment, what component of resistance can we scale to make a prediction of full-scale resistance? What do we do to account for the other main component of resistance, which we cannot scale from the experimental results?

3. [10] Use the ITTC'78 method to estimate the total ship resistance for the case described below. Your estimate should be for saltwater at 15°C.

You have completed model tests with a 6.0 m long model of a 180 m long ship. The ship's design speed is 11.8 m/s. At the corresponding model speed, the measured total resistance was 119.0 N. The water temperature measured at the time of the test was 15°C. You estimated the form factor to be 0.20, based on measurements made during resistance tests at Froude numbers between 0.1 and 0.2. The wetted surface of the ship is 9,460 m^2. Air resistance and hull roughness effects can both be neglected for this case.

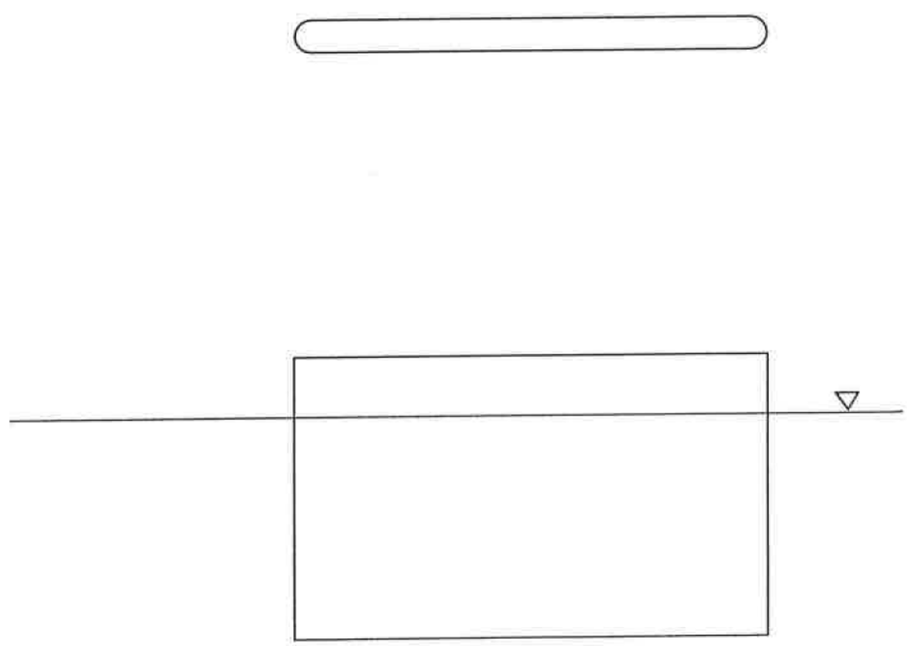
4. **[10]** The drawing below shows a simple body in plan view (shown on top) and profile (at bottom). Illustrate and label on the drawing the transverse and divergent wave patterns that you expect to be setup at the bow and stern when the body is moving at a constant speed for the case where

$L_{WT} = \frac{2L}{3}$, where L is the length of the body and L_{WT} is the transverse wavelength.

Illustrate and describe the transverse wave interference pattern.

Derive the corresponding Froude number for this case, showing all work.

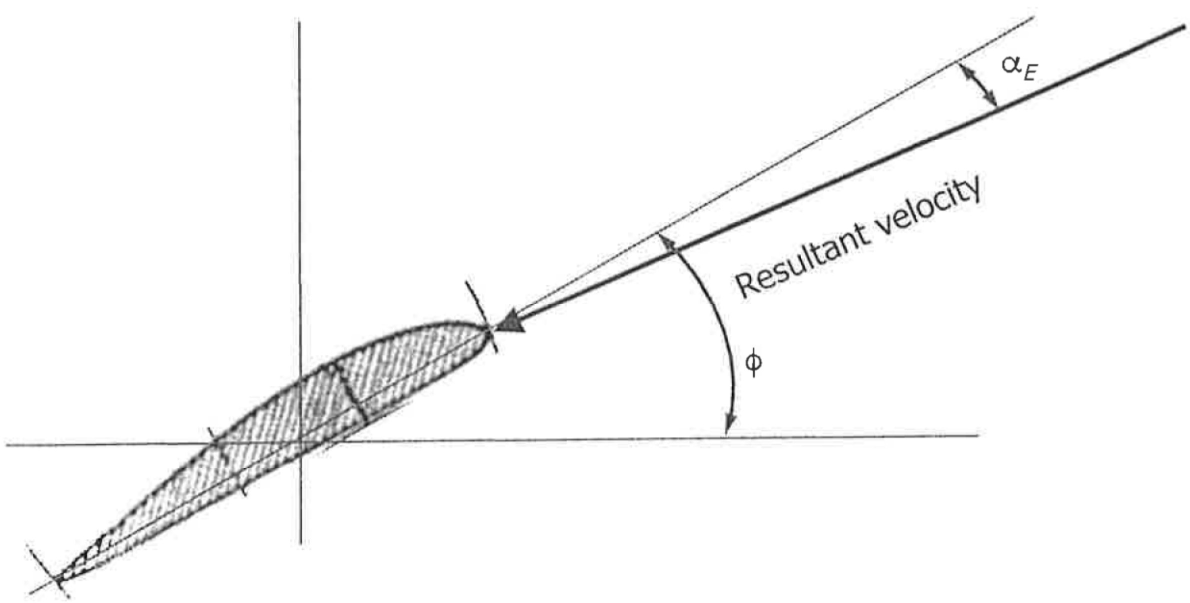
Use the exam sheet for your illustration and pass it in with your exam.



5. [10] Define the following terms clearly. Illustrate each of your answers with a labeled sketch.

(i) pitch datum, pitch angle, pitch
(ii) propeller rake & rake angle
(iii) camber line & camber
(iv) sheet cavitation, including its typical characteristics (location, appearance, dynamics)
(v) blade section chord length, back side, face side, & leading edge

6. [10] An expanded view of a propeller blade element at a radius *r* is illustrated below. For the resultant velocity vector shown, draw and label the corresponding elemental lift, drag, thrust and torque force vectors. Do this carefully on the sketch *on the exam sheet*.



7. [10] You have been tasked with doing a preliminary propeller selection for a product tanker. The vessel's design speed is 15.25 knots in calm water. It has a length of 132 m and the hull form can fit a single 4.0 m diameter screw propeller. Model tests have shown that the ship resistance at the design speed is 305.6 kN, the thrust deduction fraction is 0.124, and the speed of advance is 5.90 m/s. A geared diesel engine will drive the propeller shaft at 147.5 rpm.

(i) Use the attached standard B4-55 series chart to find a *P/D* ratio that will provide the thrust required to reach the design ship speed. Take care when using the chart to be as precise as you can be. You can assume the developed area is equal to the expanded area. Pass in the chart with your exam.

(ii) Estimate the open water propeller efficiency η_o and the hydrodynamic propulsive efficiency η_D at the design condition. Assume the water temperature is 15°C.

8. [10] Check the propeller selected in question 7 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 11 kPa, and the atmospheric pressure is 101 kPa. The depth of the hub from the free surface is 3.6 meters.

(i) How much back cavitation can be expected to occur?

(ii) If the maximum acceptable cavitation is 5%, adjust your expanded blade area to suit and determine the corresponding expanded area ratio.

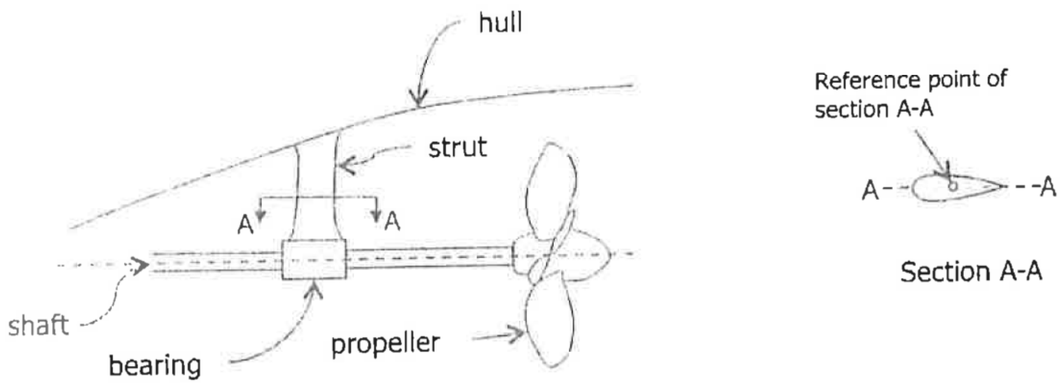
Answer one of following two questions (9 & 10).

9. [20] A ship owner has found that the propeller fitted to her new vessel failed to provide sufficient thrust to drive the ship at its targeted design speed on trials. Subsequently, she was advised by a consulting naval architect that the propeller manufacturer may be at fault, so she has had a model replica of the as-fitted propeller made so that it can be tested. She has hired you to plan and execute a propeller open water experiment to evaluate the model propeller's performance. It has a diameter of 240 mm. The full-scale version of the propeller has a diameter of 4.2 m, and a chord length of 1.1 m at the 0.7R section. The ship's propeller shaft is driven at 165 rpm and the speed of advance at the ship's target design speed is 7.0 m/s. The thrust and torque coefficients at bollard conditions were found on trials to be just under 0.3 and 0.04, respectively.
You intend to use an open water towing tank that has a maximum carriage speed of 5 m/s, a propeller open water test boat that has a maximum shaft speed of 20 rps, and a propeller shaft dynamometer that has safe working limits for thrust and torque of 300 N and 15 Nm, respectively.

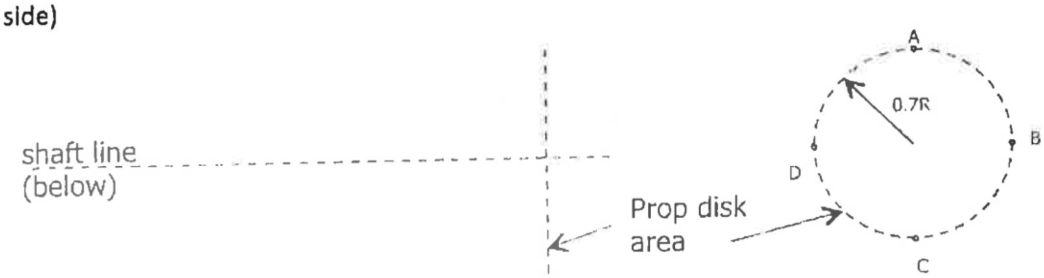
(i) First, explain in writing to the ship owner what laws of similitude must be obeyed.

(ii) Then, report the model test parameters (shaft speed n, and carriage speed V) that you plan to use to evaluate propeller performance at the ship's design speed. Show any calculations you make in arriving at your decisions.

10. [20] A shaft arrangement on a twin-screw vessel is illustrated in the sketch (a) below. Sketch (b) shows four points in the propeller disk at the 0.7R radius fraction. The axial fluid velocity measured during a wake survey indicated that the axial velocity at points A, B, C, and D were $0.2V_A$, $0.8V_A$, $1.2V_A$, and $0.8V_A$, respectively, where V_A is the mean speed of advance.
Explain how the variation in axial velocity at the 0.7R radius fraction will (i) affect the angle of attack at each of the four points, (ii) affect the elemental lift force on the local blade section at each of the four points, and (iii) result in a varying lift force as the propeller rotates. Illustrate your explanation with a clearly labeled drawing or drawings.



(a) Shaft, bearing, strut and propeller in profile. (Strut cross-section shown on the right hand side)



(b) 4 points in the propeller disk area at the 0.7R radius fraction shown at right.

Data sheet

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

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

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

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

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

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

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

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

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

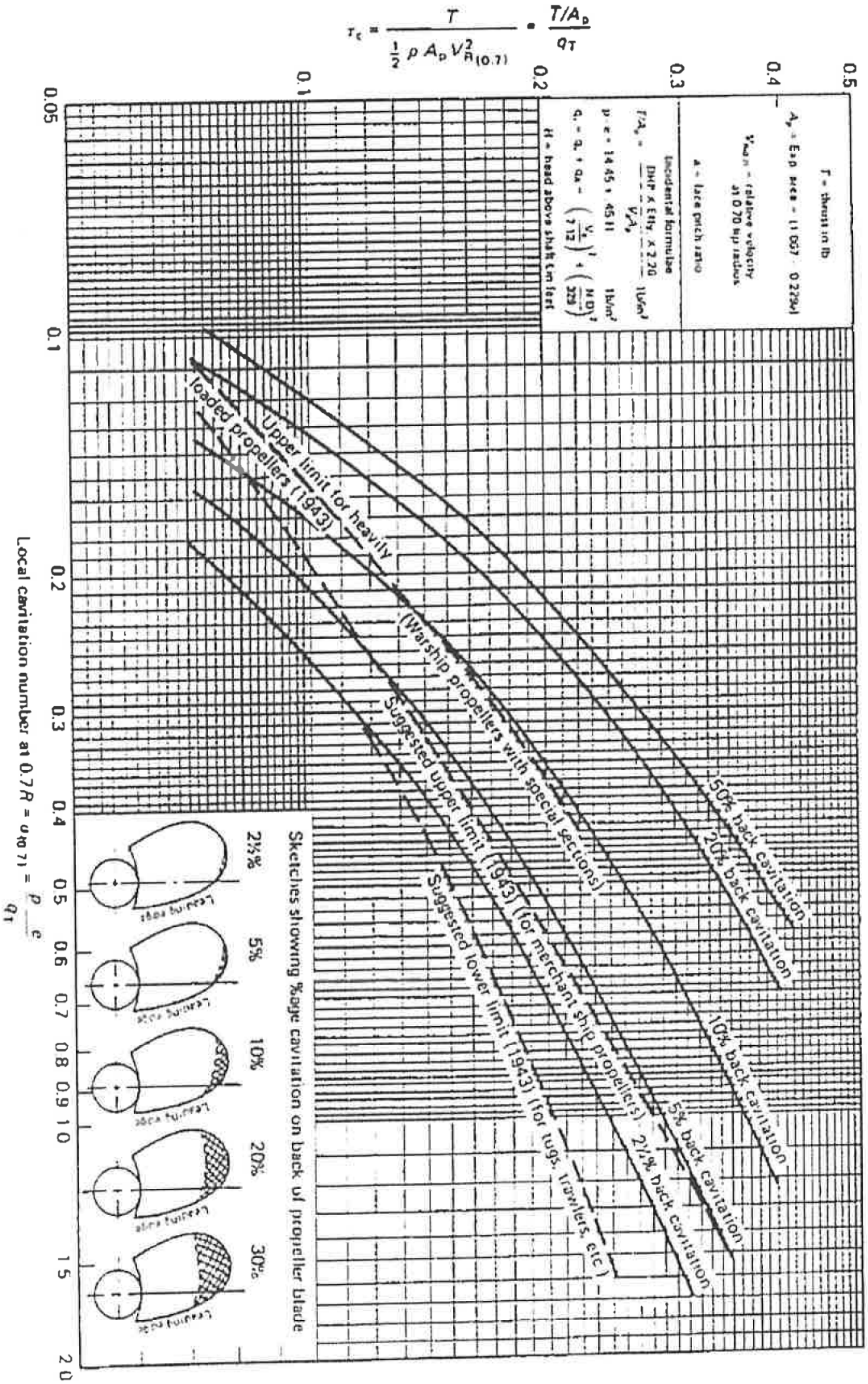
Equations for Burrill's chart

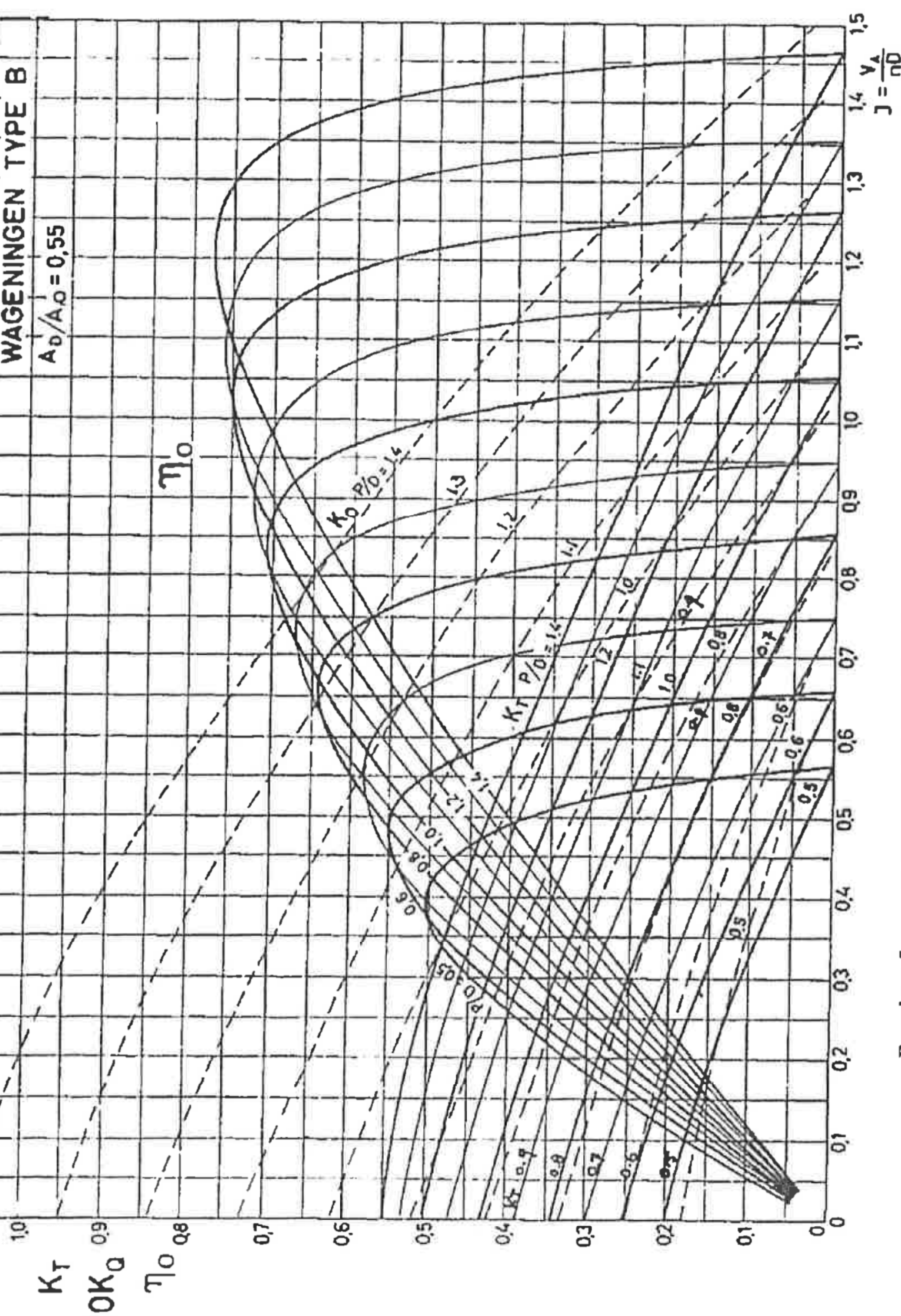
$$\sigma_{0.7R} = \frac{p_o - p_v}{\frac{1}{2}\rho\left(V_A^2 + (0.7\pi n D)^2\right)} \qquad \tau_c = \frac{T}{A_p q_{0.7R}} \qquad A_E \cong \frac{A_p}{1.067 - 0.229\, P/D}$$

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

Constants and data

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


$\tau_c = \frac{T}{\frac{1}{2}\rho A_p V^2_{R(0.7)}} = \frac{T/A_p}{q_T}$
T = thrust in lb
V = relative velocity at 0.70 tip radius
Incidental formulae
H = head above shaft ¢ in feet
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.)
50% back cavitation
20% back cavitation
10% back cavitation
5% back cavitation
2½% back cavitation
Sketches showing %age cavitation on back of propeller blade
2½%
5%
10%
20%
30%
Local cavitation number at 0.7R



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