



UNIVERSITI KUALA LUMPUR
MALAYSIAN INSTITUTE OF MARINE ENGINEERING TECHNOLOGY

FINAL EXAMINATION
JANUARY 2017 SEMESTER

COURSE CODE : LNB30203

COURSE NAME : SHIP RESISTANCE AND PROPULSION

PROGRAMME NAME : BACHELOR OF ENGINEERING TECHNOLOGY (HONS)
(FOR MPU: PROGRAMME LEVEL) IN NAVAL ARCHITECTURE & SHIPBUILDING

DATE : 14/07/2017 FRI

TIME : 9.00 AM - 12.00 PM

DURATION : 3 HOURS

INSTRUCTIONS TO CANDIDATES

1. Please read CAREFULLY the instructions given in the question paper.
 2. This question paper has information printed on both sides.
 3. This question paper consists of TWO (2) sections; Section A and Section B. Answer ALL questions in Section A and THREE (3) questions from Section B.
 4. Please write yours answers on the answer booklet provided.
 5. Write your answers only in BLACK or BLUE ink.
 6. Answer all questions in English.
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THERE ARE 26 PAGES OF QUESTIONS, INCLUDING THIS PAGE.

SECTION A (Total: 40 marks)

INSTRUCTION: Answer ALL questions.

Please use the objective answer sheet provided.

1. Besides the frictional and wave making resistance, name several other components that contribute to the total resistance of a ship.
 - A. viscous pressure drag resistance and air resistance
 - B. eddy resistance and separation resistance
 - C. wave breaking resistance and appendages resistance
 - D. all of the above

(2 marks)

2. Describe a way of minimizing a wave resistance of a ship?
 - A. Adding a bulbous bow to the ship
 - B. Adding a stabiliser to a ship
 - C. Adding a bow thruster at the forward end of the ship
 - D. Adding a bilge keel to the ship side

(2 marks)

3. Describe how bulbous bow plays in minimising the wave resistance of a ship.
 - A. The bulbous bow cuts the water pretty well compared with without having one.
 - B. The bulbous bow creates its own wave system and cancelling or interfere with the wave system from the stem hence reducing the merged wave system.
 - C. The bulbous bow reduces the frictional resistance by increasing the wetted surface area
 - D. The bulbous bow reduces the pressure resistance at the bow region hence reducing the wave resistance.

(2 marks)

4. Why a residuary resistance curves in some cases do exhibits a series of 'hump' and 'hollows'?
- A. The wave resistance oscillate about the mean curve as the frictional resistance become lower and higher with increasing of Froude number
 - B. The wave resistance would oscillate about a mean curve depending upon whether the interference effect arising from the bow system and the stern system yields a maximum or minimum resistance.
 - C. The wave resistance exhibits 'humps' and 'hollows' as the vessel heave and pitch on the free surface of the water.
 - D. The wave resistance exhibits 'humps' and 'hollows' as the vessel rolls and pitch on the free surface of the water.

(2 marks)

5. When the water is very deep, the wave pattern of a moving ship at the free water surface consists of the Kelvin transverse and diverging waves. The pattern being contained between the straight lines making an angle α on each side of the line of motion. State the amount of the angle α .
- A. 28 deg 19 min
 - B. 19 deg 19 min
 - C. 19 deg 28 min
 - D. 28 deg 28 min

(2 marks)

6. If the body of a ship is rather blunt at the after end the flow may detach at some point, called the separation point. State the effect of this separation point to the resistance of the ship.
- A. It reduces the total pressure on the afterbody and this increases the resistance.
 - B. It increases the total pressure on the afterbody and this decreases the resistance.
 - C. It increases the total pressure on the afterbody and this increases the resistance.
 - D. It reduces the total pressure on the afterbody and this reduces the resistance.

(2 marks)

7. Usually, towing tanks incorporate a correction factor, called correlation allowance C_A . Explain why do we need this correlation allowance in the extrapolation to full scale?
- A. This correlation allowance is used mainly to correct the scaling effect between the model and full scale.
 - B. This correlation allowance is used mainly to correct the roughness difference between the model and full scale.
 - C. This correlation allowance is used mainly to correct the 2D error in the frictional resistance line that was based on plank experiment.
 - D. This correlation allowance is used mainly to fine-tune model tests with full scale measurements.

(2 marks)

8. The resistance of a vessel is greater in shallow water than in deep water conditions. Is this statement correct or incorrect?
- A. Incorrect. The resistance of a vessel is lower in shallow water.
 - B. Correct. The resistance of a vessel is greater in shallow water.
 - C. Incorrect. The resistance of a vessel is lower in deep water.
 - D. Correct. The resistance of a vessel is higher in deep water.

(2 marks)

9. The dimensional analysis of the resistance of a ship can be expressed in its final form of three dimensionless numbers as shown below. One of the number is called Euler number. Name the other two non-dimensional numbers.

$$\frac{R}{1/2\rho SV^2} = f\left[-, -, \frac{P}{\rho V^2}\right]$$

- A. Reynolds and Mach number
- B. Cauchy and Mach number
- C. Froude and Reynolds number
- D. Cavitation and Reynolds number

(2 marks)

10. The frictional resistance formula was originally derived from:

- A. Experiments of a series of wood planks towed in a towing tank with varying length and roughness
- B. Experiments of series of round bilge hull towed in a towing tank with varying length and roughness
- C. Sea Trial data
- D. Experiments of series of double chine hull towed in a towing tank with varying length and roughness

(2 marks)

11. The Froude's law of comparison states that "The residuary resistance of geometrically similar (geosim) ships are in the ratio of the cubes of their linear dimensions when their speeds are in the ratio of the squares of their lengths" Is this statement correct or incorrect?

- A. Correct, the residuary resistance of 'geosim' ships are in the ratio of the cubes of their linear dimensions
- B. Incorrect, the residuary resistance of 'geosim' ships are in the ratio of the squares of their linear dimensions
- C. Correct, the residuary resistance of 'geosim' ships are in the ratio of the squares of their linear dimensions
- D. Incorrect, the residuary resistance of 'geosim' ships are in the ratio of the squares of the ship to model length.

(2 marks)

12. It is impossible to model the vessel complying with both Froude numbers and Reynolds number. Therefore it is not possible to directly convert the total resistance of the model to the total resistance of the ship using directly the scale ratio. It requires some extrapolations. Name three methods to extrapolate the model scale drag to full scale drag?
- Froude's 2 dimensional extrapolation
 - Hughes's 3 dimensional extrapolation
 - ITTC 1978 extrapolation method
 - All of the above

(2 marks)

13. The dimensional analysis of the thrust of a ship propeller can be expressed in its final form of four dimensionless numbers as shown below. But two of the non-dimensional numbers are missing in the equation below. Name the two missing non-dimensional numbers.

$$\frac{T}{\frac{1}{2}\rho D^2 V_A^2} = f \left[\frac{gD}{V_A^2}, \quad \text{---}, \quad \text{---}, \quad \frac{\nu}{V_A D} \right]$$

- Reynolds and Mach number
- Cauchy and Cavitation number
- Froude and Reynolds number
- Advance Coefficient and Cavitation number

(2 marks)

14. Explain why does the angle of the propeller blade change with increasing distance from the hub even though the pitch is constant throughout the radius of the propeller blade?
- A. The angle change as to maintain a constant inflow angle. The geometric angle has to increase as radius is decreased. Therefore the angle of the propeller blade change with increasing distance from the hub.
 - B. The pitch at each radius of the propeller blade decrease with increasing distance from the hub. Therefore the angle of the propeller blade change with increasing distance from the hub.
 - C. The pitch at each radius of the propeller blade increase with increasing distance from the hub. Therefore the angle of the propeller blade changes with increasing distance from the hub.
 - D. The angle change as to maintain a constant propeller shaft angle. Therefore the angle of the propeller blade change with increasing distance from the hub.

(2 marks)

15. When advance coefficient ratio is maintained model propeller revolutions are smaller than a geometrically similar full scale propeller. Is this statement correct or incorrect?
- A. Correct. In maintaining advance coefficient, the propeller revolutions in model scale are smaller than a geometrically similar full scale propeller.
 - B. Incorrect. In maintaining advance coefficient, the propeller revolutions in model scale are greater than a geometrically similar full scale propeller.
 - C. Correct. In maintaining advance coefficient, the propeller revolutions in model scale are greater than a geometrically similar full scale propeller.
 - D. Incorrect. In maintaining advance coefficient, the propeller revolutions in model scale are similar to a geometrically similar full scale propeller.

(2 marks)

16. From a design point of view, what can be done to increase the propeller efficiency? Name two (2) design parameters that do not alter the hull design significantly.

- A. Decrease the propeller diameter and increasing propeller turning speed.
- B. Decrease the propeller diameter and decreasing propeller turning speed
- C. Increase propeller diameter and increasing propeller turning speed
- D. Increase propeller diameter and decreasing propeller turning speed.

(2 marks)

17. How can cavitation on a propeller blade be reduced? Name two measures to reduce cavitation on propeller blades.

- A. Smaller BAR and shorter chord length
- B. Smaller BAR and longer chord length
- C. Larger BAR and shorter chord length
- D. Larger BAR and longer chord length

(2 marks)

18. In a model self-propulsion test, the ship model is towed at various speeds and at each speed a number of tests are made at differing propeller revolution, spanning the self-propulsion condition for the ship. Name two of the variables being measured in the self-propulsion test.

- A. Model pitch angle and propeller torque
- B. Model roll angle and yawing force
- C. Propeller shaft revolution and towing force
- D. Model surging force and propeller thrust

(2 marks)

19. One of the components of wake is frictional wake when the frictional drag causes retardation of the flow inside the ship's boundary layer. Describe the other two components of wake.

- A. Potential Wake and Wave Wake
- B. Tangential Wake and Wave Wake
- C. Turbulence Wake and Separation Wake
- D. Nominal Wake and Effective Wake

(2 marks)

20. Detailed measurements of wake may be carried out in the vicinity of the propeller plane. Name one of the techniques used for wake measurements.

- A. Particle image velocimetry
- B. High speed photography
- C. Radiographic imaging
- D. Sonar imaging.

(2 marks)

SECTION B (Total: 60 marks)

INSTRUCTION: Answer THREE (3) questions.

Please use the answer booklet provided.

Question 1

A 1/20 scale model of a 86m long ship having a displacement of 2495 tonnes in sea water and floating at a draft of 3.8 m with a C_B of 0.67, is tested in a towing tank in fresh water at 15° Celsius at a carriage speed of 1.8 m/sec. The resistance measured on the model is 35.65 N. The wetted surface area of the model is 2.85 m². The fresh and sea water properties are available in the **formula and data sheet** attached in this booklet.

- (a) Use ITTC 1978 extrapolation procedure and a correlation allowance of 0.0004 to determine the total resistance of the ship. The projected area of the ship above waterline is at 41 m². The air drag coefficient, C_{DA} is determined through wind tunnel testing as 0.9. The k in the form factor can be obtained by using the Watanabe empirical formula given as:

$$k = -0.095 + 25.6 \frac{C_B}{\left(\frac{L}{B}\right)^2 \left(\sqrt{\frac{B}{T}}\right)}$$

(19 marks)

- (b) Determine the effective power required for the full scale vessel.

(1 mark)

Question 2

A towing tank results were recorded for a model having the principal particulars given below as:

- $L_{WL} = 2.496 \text{ m}$
- Displacement = 28.41 kg
- WSA = 0.952 m²
- Scale factor = 50

Model Speed (m/sec)	Drag (grams)	Forward Sinkage (mm)	Aft Sinkage (mm)
1.39	498	- 2.2	- 1.7
1.52	655	- 2.2	- 3.2
1.66	720	- 3.0	- 2.9
1.81	824	- 3.8	- 3.4
1.96	1008	- 3.3	- 6.7
2.11	1217	- 1.3	- 10.8
2.25	1407	0.6	- 14.2

- (a) Determine the full scale total resistance and the effective power using ITTC 57 Frictional Line and 2D extrapolation procedure at full scale speed of 29 knots.
(10 marks)
- (b) Extrapolate the model forward and aft sinkage to full scale for **all model speed**.
(3 marks)
- (c) Calculate the dynamic trim of the vessel at each speed in degree **if the distance between the forward sinkage measurement post and the aft sinkage measurement post is 338mm**.
(3 marks)
- (d) Plot the Forward Sinkage and the Aft Sinkage in full-scale with respect to the ship speed in knots.
(2 marks)
- (e) Plot the dynamic trim in degree with respect to the ship speed in knots.
(2 marks)

Question 3

The towing tank results were recorded as in Table 1 for a model having the principal particulars given below as:

L_{WL}	=	4.30 m
B	=	0.25 m
Draft	=	0.049 m
C_M	=	0.95
Displacement	=	50 kg
WSA	=	1.18 m ²
Scale factor	=	29

Table 1 The towing tank test results for a 1/29 scaled ship model.

Speed	Drag	$C_{FM, 24^\circ C} * 10^3$	$C_{TM, 24^\circ C} * 10^3$
(m/sec)	(grams)	(-)	(-)
0.65	117	3.73	4.60
0.78	167	3.60	4.56
0.92	227	3.49	4.46
1.05	295	3.40	4.45
1.11	330	3.37	4.45

The test above was conducted in a towing tank with a width of 4m and a depth of 2.5m and the water temperature was measured to be 24°C. The form factor (1+k) was determined earlier using Prohaska's plot at 1.17. At Froude depth number of 0.212:

- (a) Correct the model speed using Shuster's blockage corrector.
(14 marks)
- (b) Correct the coefficient of the total resistance, $C_{TM, 24^\circ C}$ to a standard 15°C.
(6 marks)

Question 4



Figure 1 KD Perkasa, a 'Handalan' Class fast attack craft which was based on the design of Swedish SPICA class torpedo boat, were built by Karlskrona Varvet AB, Sweden in 1978. This craft are powered by three MTU 16V 538 TB91 diesel engines.

A triple screw fast attack craft owned by the Royal Malaysian Navy, 'KD Perkasa' as shown in Figure 1, had undergone a re-engine program and were planned to be fitted with three new Gawn series propellers. The Gawn propellers selected will be with a diameter of 1.2 meter and a blade area ratio of 0.95, for minimising cavitation. The total delivered power **at the three shafts** are estimated at 6.750 MW. The wake fraction is estimated to be 0.21. At the ship cruising speed of 25 knots;

- (a) Determine the optimum P/D that attained the maximum propeller efficiency. (17 marks)
- (b) Calculate the shaft speed in rev/min at this cruising speed. (3 marks)

Plot the K_Q-J^3 curve in the Gawn K_T-K_Q-J chart given in **Annex 1**. Attached it to the answer script.

Question 5

Your company is assigned to design a propeller for a 260m cruise ship for STX France for their newly designed cruise ship *Elena*, as shown in Figure 2. The ship is designed to be a single screw ship with a design speed of 25 knots. Early estimation reveals that the vessel will required a thrust of 912.6 kN with a 5.33m diameter four bladed propeller. The wake fraction is estimated to be 0.25.

- (a) Using Keller's equation (Keller, 1966), determine the required expanded blade area ratio if the propeller shaft axis immersion is 3.5 m. The ship has a transom stern, therefore the k in the Keller's equation is assumed to be 0.1.
- (4 marks)
- (b) Early powering prediction reveals that the vessel will be installed with a 21,740 kW internal combustion engine. Using the $B_P-\delta$ chart for propeller Wageningen series, select the appropriate $B_P-\delta$ chart **based on your estimation in (a)**, see Annex 2, 3, 4 and 5, and assuming the shafting efficiency to be 0.98, calculate
- i) the open water efficiency,
 - ii) pitch-diameter ratio; and
 - iii) the propeller shaft speed in rev/min.

(16 marks)



Figure 2 The new 260m long luxury cruise line, *Elena*, designed by STX France, capable of accommodating 550 passengers with spacious living areas, restaurants and salons. (Image taken from Rhinoceros.com, modeled in Rhino, rendered in V-Ray)

Question 6

A wake survey was done using Laser Doppler Velocimetry (LDV) for a model with a twin screw configuration in a towing tank. The local wake measurement was taken at the propeller plane. The results are presented in a contour plot as shown in Figure 3. The measurement were taken at radius 1.0R, 0.75R and 0.50R. The propeller diameter is at 7 m with the hub diameter at 1 m. Integrate the radial wake fraction to obtain the nominal mean wake fraction for this twin screw ship.

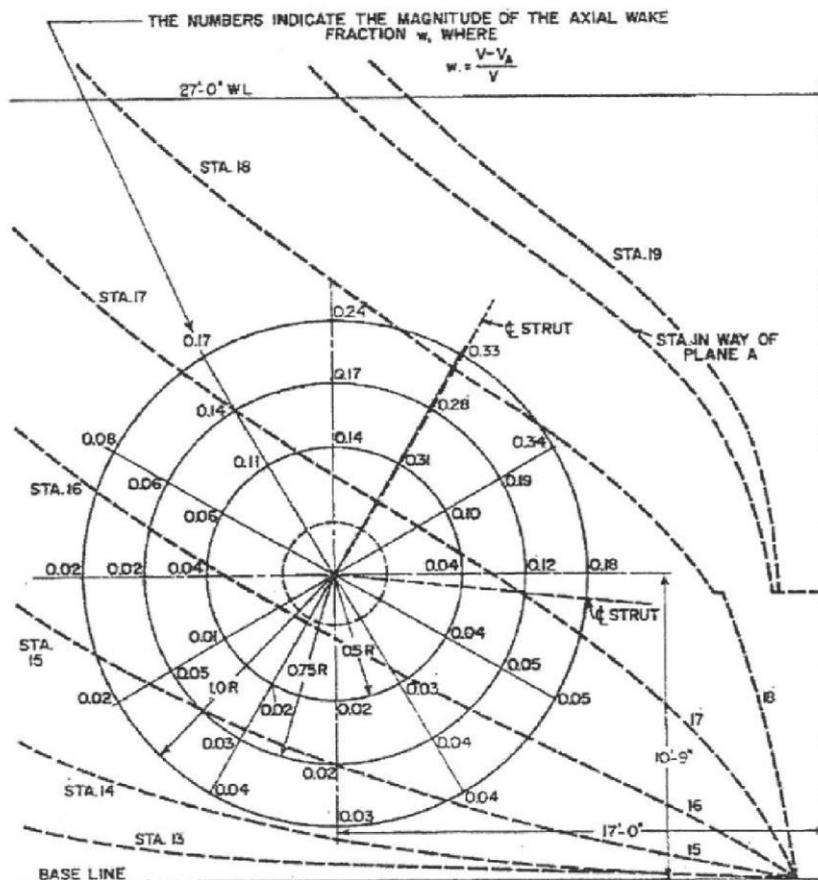


Fig. 98(a) Wake diagram for TS ship fitted with shaft-struts
 LOAD DISPLACEMENT, SHIP SPEED 20 KNOTS.
 TRANSVERSE SECTION, LOOKING FORWARD. THE WAKE SURVEY WAS
 MADE IN A PLANE PERPENDICULAR TO THE LONGITUDINAL AXIS AT A
 DISTANCE OF 5.77 FT. AFT OF STATION 18 1/2.

Figure 3 The local radial wake measurements for a twin screw ship

(20 marks)

Question 7

You are a towing tank engineer and are required to make a scale effect correction to the propeller thrust and torque using the method proposed by Lindgren et al (1978) which is currently used in the ITTC 1978 Extrapolation procedure no 7.5-02-03-01.4 to an open water propeller test results tabulated in Table 2 below.

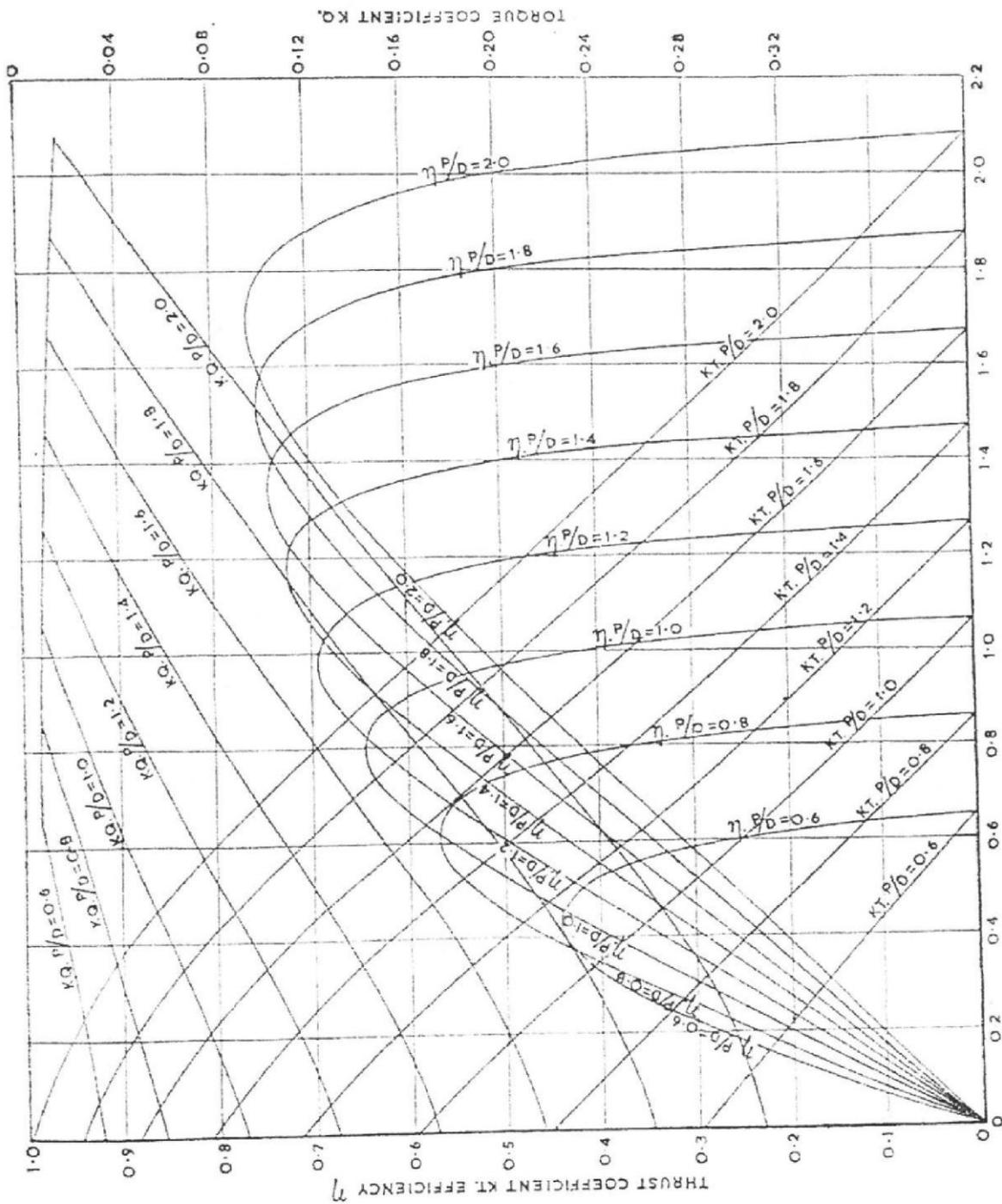
Table 2 The open water test results for a 1/29 scaled propeller running at 21 rev/secs.

V_A (metre /sec)	Q (Newton.metre)	T (Newton)
0.29	0.46	24.46
0.8	0.40	21.16
1.31	0.32	17.64
1.81	0.26	12.48

The open water test was done in a towing tank, with the advance velocity, V_A varied at each run as listed in the first column in Table 2. The propeller was set at a constant shaft speed of 21 rev/sec. The model propeller is 1:29 of the full scale propeller.

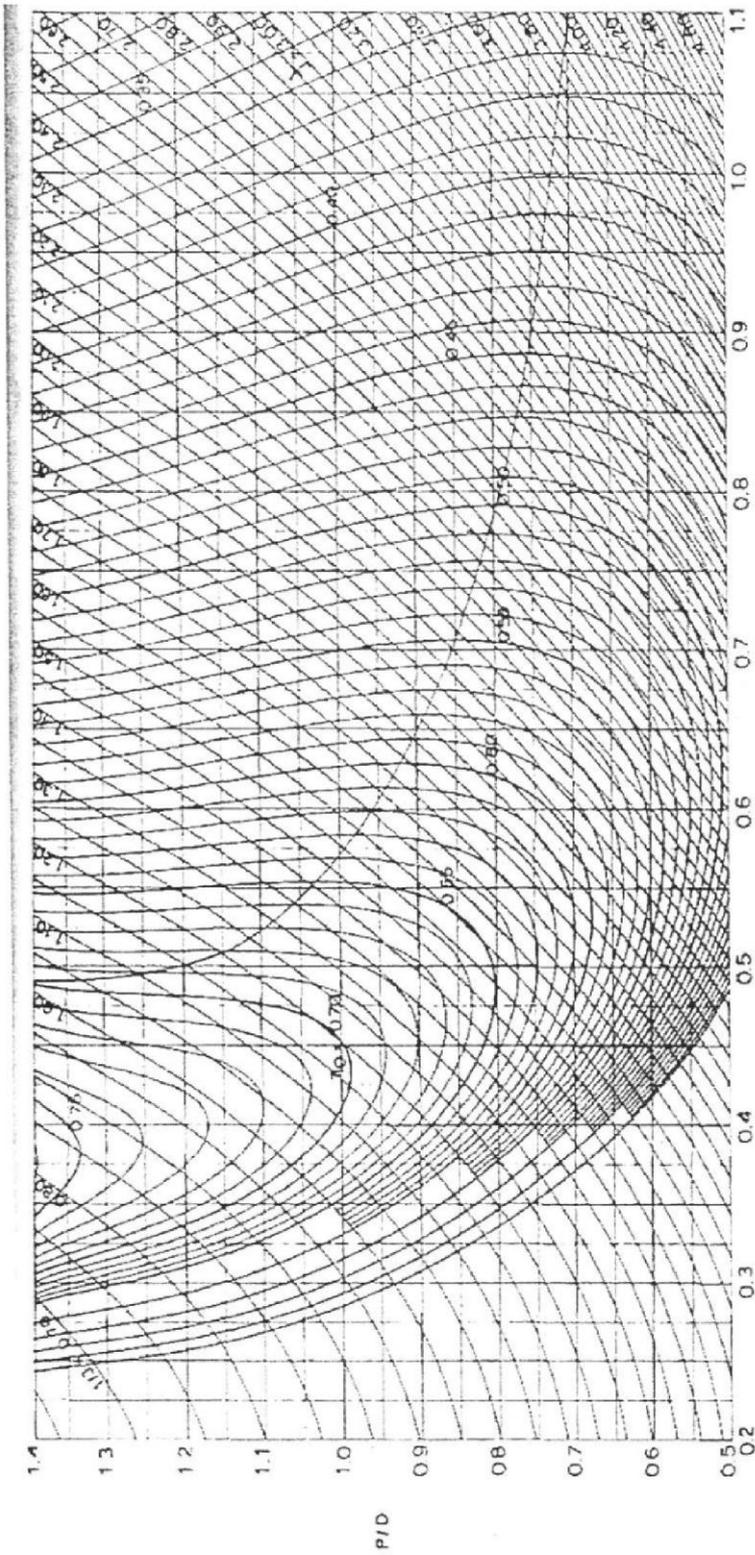
- (a) Calculate the corrected full scale propeller thrust and torque coefficient at $J = 0.52$. The propeller drawing is shown in **Annex 6 (all units in meter)**. You may find all the necessary data in the drawing. (Some interpolations are required).
(15 marks)
- (b) If this open water test was conducted in a cavitation tunnel with a circulation speed of 5.0 m/s, **maintaining J at 0.52**, determine the new rate of rotation for the same model propeller and the new local Reynolds number at 0.75 radius fraction of the propeller blade.
(5 marks)

END OF EXAMINATION PAPER



ADVANCE COEFFICIENT J.
Gawn Standard Screw Series k - J Chart - $\sigma = 0.95$

Annex 1 Gawn series K_T - K_Q - J chart for 3 blades propeller with BAR 0.95



1975

$$K_Q \cdot J^{-3/4} = \left[\frac{Q_n}{\rho D^2 V_A^3} \right]^{1/4}$$

$$= \left[\frac{P}{2\pi \rho D^2 V_A^3} \right]^{1/4}$$

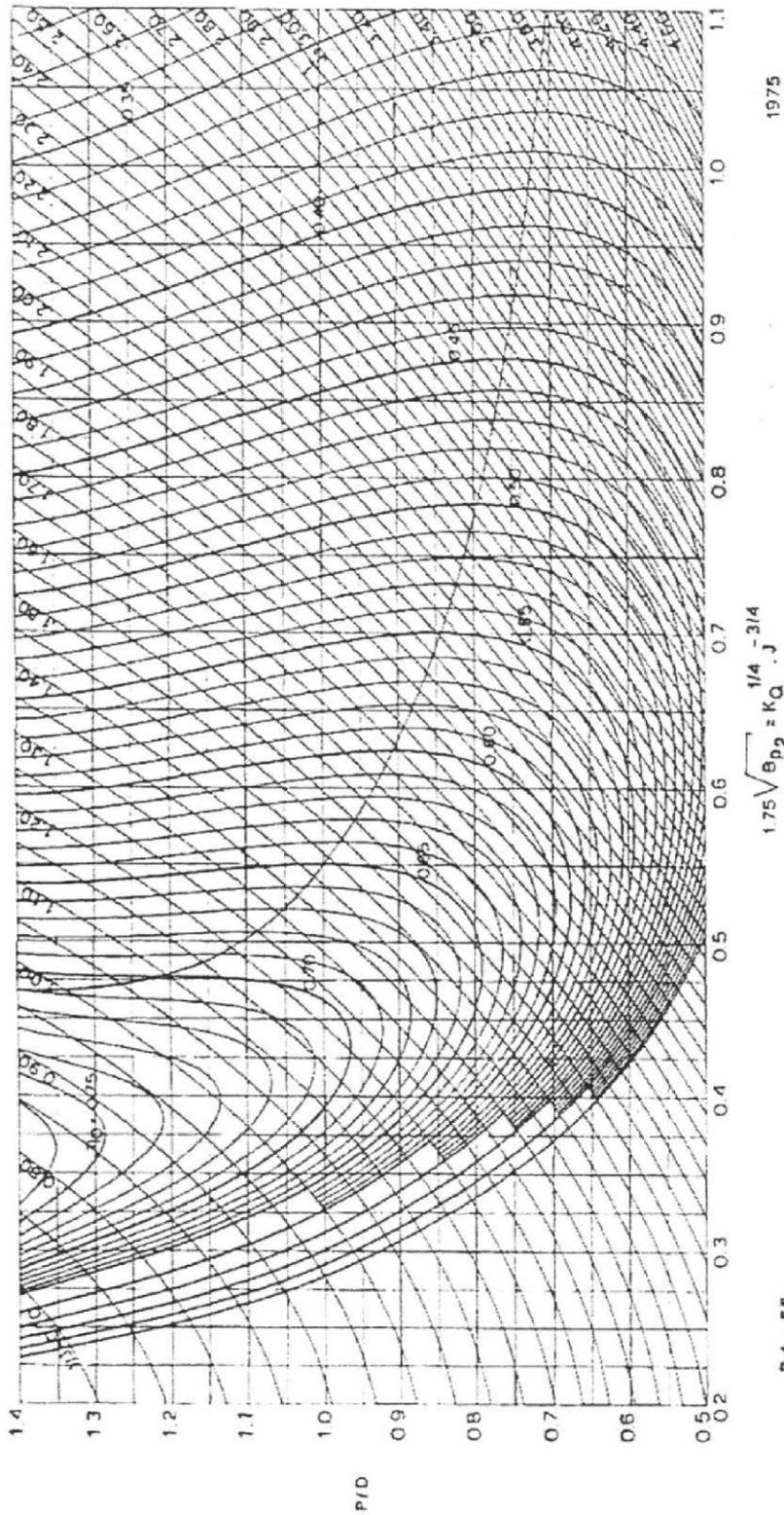
Q = PROPELLER TORQUE IN KGM
n = PROPELLER REVOLUTIONS PER SECOND
 ρ = WATER DENSITY (TANK) = 101.94 KG/SEC³ M⁻⁴
D = PROPELLER DIAMETER IN METER
 V_A = $V_S (1 - w)$
 V_S = SHIP SPEED IN M/SEC.
w = WAKE FRACTION
P = SHAFT POWER IN KGM/SEC.

B 4 - 40

$$B_{p2} = \rho^{1/2} \cdot D^{1/2} \cdot V_A^{-3/2}$$

D = PROPELLER DIAMETER IN FEET
 V_A = $V_S (1 - w)$
 V_S = SHIP SPEED IN KNOTS
w = WAKE FRACTION
P = SHAFT HORSEPOWER (BRITISH)

Annex 2 $B_p - \delta$ chart for 4 blades propeller with BAR 0.40



1975

$$1.75 \sqrt{B_{P2}} = K_Q \cdot J^{-3/4}$$

B4 - 55

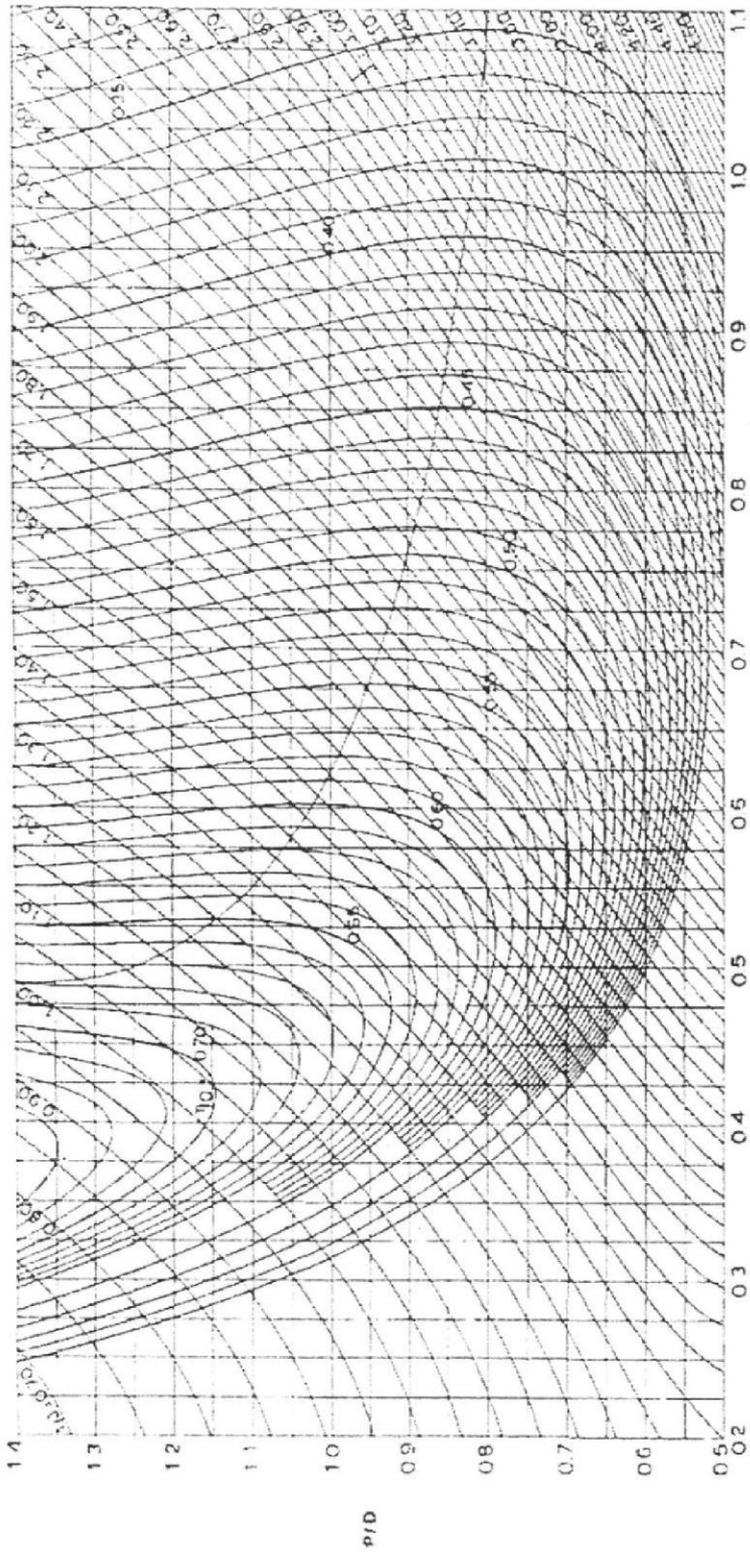
$K_Q \cdot J^{-3/4} = \left[\frac{Qn}{\rho D^2 V_A} \right]^{1/4}$
 $= \left[\frac{P}{2 \pi \rho D^2 V_A} \right]^{1/4}$

Q = PROPELLER TORQUE IN KGM
n = PROPELLER REVOLUTIONS PER SECOND
ρ = WATER DENSITY (TANK) = 101.94 KG/SEC² M⁻⁴
D = PROPELLER DIAMETER IN METER
V_A = V_S (1 - w)
V_S = SHIP SPEED IN M/SEC
w = WAKE FRACTION
P = SHAFT POWER IN KGM/SEC

$B_{P2} = P^{1/2} \cdot D^{-1} \cdot V_A^{-3/2}$

D : PROPELLER DIAMETER IN FEET
V_A : V_S (1 - w)
V_S : SHIP SPEED IN KNOTS
w : WAKE FRACTION
P : SHAFT HORSEPOWER (BRITISH)

Annex 3 $B_P - \delta$ chart for 4 blades propeller with BAR 0.55



1975

$$1.75 \sqrt{B_{D2}} = K_Q \cdot J^{1/4} - 3/4$$

B4 - 85

Q = PROPELLER TORQUE IN KGM
 n = PROPELLER REVOLUTIONS PER SECOND
 p = WATER DENSITY (TANK) = 101.94 KG/SEC²M⁻⁴
 D = PROPELLER DIAMETER IN METER
 V_A = V_S (1 - w)
 V_S = SHIP SPEED IN M/SEC
 w = WAKE FRACTION
 P = SHAFT POWER IN KG/M/SEC

$$K_Q \cdot J^{1/4} - 3/4 = \left[\frac{Qh}{\rho D^2 V_A^3} \right]^{1/4}$$

$$= \left[\frac{P}{2\pi \rho D^2 V_A^3} \right]^{1/4}$$

D = PROPELLER DIAMETER IN FEET
 V_A = V_S (1 - w)
 V_S = SHIP SPEED IN KNOTS
 w = WAKE FRACTION
 P = SHAFT HORSEPOWER (BRITISH)

$$B_{D2} = P^{1/2} \cdot D^{-3/2} \cdot V_A^{-3/2}$$

Annex 5 $B_{D2} - \delta$ chart for 4 blades propeller with BAR 0.85

USEFUL FORMULA & DATA

Density

Fresh water = 1000 kg/m³
 Sea water = 1025 kg/m³
 Air at 15°C = 1.225 kg/m³

Kinematic viscosity

Fresh water at 15°C = 1.139 x 10⁻⁶ m²/s
 Sea water at 15°C = 1.183 x 10⁻⁶ m²/s
 Fresh water at 24°C = 9.131 x 10⁻⁷ m²/s

Granville Line Formulation

$$C_{FO} = \frac{0.0776}{(\log_{10} Re - 1.88)^2} + \frac{60}{Re}$$

Hughes Line Formulation

$$C_{FO} = \frac{0.066}{(\log_{10} Re - 2.03)^2}$$

ATTC Line Formulation

$$\frac{0.242}{\sqrt{C_F}} = \log_{10}(Re \cdot C_F)$$

ITTC 1957 Model Ship Correlation Formulation

$$C_F = \frac{0.075}{(\log_{10} Re - 2)^2}$$

Non-dimensional coefficient for total resistance

$$C_T = \frac{R_T}{\frac{1}{2} \rho S V^2}$$

Froude's approach

$$R_T = R_F + R_R$$

$$C_T = C_F + C_R$$

Hughes's approach

$$R_T = R_V + R_W$$

$$C_T = C_V + C_W$$

$$= C_F(1+k) + C_W$$

ITTC 1978 Resistance Prediction – Updated 2014

The total ship resistance coefficient without bilge keels is given by;

$$C_{TS} = C_{FS}(1+k) + C_R + \Delta C_F + C_A + C_{AAS}$$

where;

C_{FS} = frictional coefficient of ship according to the ITTC 1957 ship model correlation line

C_R = residual resistance calculated from the total and viscous resistance of the model

$$= C_{TM} - (1+k)C_{FM}$$

Bilge keels can be allowed for by multiplying the C_{FS} and C_A terms by the ratio

$$\frac{S + S_{BK}}{S}, S_{BK} = \text{surface area of the bilge keels}$$

The correlation allowance is calculated from

$$C_A = (5.68 - 0.6 \log Re) \times 10^{-3}$$

The roughness allowance is calculated from

$$\Delta C_F = 0.044 \left[\left(\frac{k_s}{L_{WL}} \right)^{\frac{1}{3}} - 10 \cdot Re^{-\frac{1}{3}} \right] + 0.000125$$

k_s can be taken as 150 x 10⁻⁶ m.

Air resistance is calculated from

$$C_{AAS} = C_{DA} \frac{\rho_A \cdot A_{VS}}{\rho_S \cdot S_S}$$

A_{VS} = transverse projected area of ship above the waterline

Propeller scale effect correction

$$K_{TOS} = K_{TO} - \Delta K_T$$

$$K_{QOS} = K_{QO} - \Delta K_Q$$

$$\Delta K_T = -\Delta C_D \times 0.3 \frac{P}{D} \cdot \frac{cZ}{D}$$

$$\Delta K_Q = \Delta C_D \times 0.25 \frac{cZ}{D}$$

$$\Delta C_D = C_{DM} - C_{DS}$$

$$C_{DM} = 2 \left(1 + 2 \frac{t}{c} \right) \left[\frac{0.044}{R_{nco}^{1/6}} - \frac{5}{R_{nco}^{2/3}} \right]$$

$$C_{DS} = 2 \left(1 + 2 \frac{t}{c} \right) \left[1.89 + 1.62 \log_{10} \frac{c}{k_p} \right]^{-2.5}$$

$$k_p = 30 \times 10^{-6} m$$

$$R_{nco} = \frac{c \sqrt{V_A^2 + (2\pi r)^2}}{v}$$

Emerson Blockage correction

$$\frac{\Delta V}{V} = 1.65 \frac{m_3}{1 - m_3 - F_{nh}^2}$$

$$m_1 = \frac{A_M}{A}$$

$$m_2 = \frac{\nabla}{A \times L}$$

$$m_3 = \frac{m_1 + m_2}{2}$$

$$F_{nh} = \frac{V}{\sqrt{gh}}$$

A_M : midship sectional area f model

A : tank cross sectional area

∇ : model volume displacement

L : model length

V : model speed before correction

Schuster Blockage correction

$$\frac{\Delta V}{V} = \frac{m_1}{1 - m_1 - F_{nh}^2} + \left(1 - \frac{R_V}{R_T} \right) \cdot \frac{2}{3} \cdot F_{nh}^{10}$$

$$m_1 = \frac{A_M}{A_T}$$

where A_M is the maximum sectional area of the model and A_T is the maximum sectional area of the full scale vessel.

Ship Flow of Transmission of Power

$$P_E = R_T V_S$$

$$P_T = T \cdot V_A$$

$$K_T = \frac{T}{\rho n^2 D^4}$$

$$K_Q = \frac{Q}{\rho n^2 D^5}$$

$$J = \frac{V_A}{nD}$$

$$\eta_O = \frac{K_T}{K_Q} \cdot \frac{J}{2\pi}$$

$$\eta_H = \frac{P_E}{P_T} = \frac{R_T \cdot V_S}{T \cdot V_A}$$

$$\eta_B = \frac{P_T}{P_D}$$

$$\eta_D = QPC = \frac{P_E}{P_D} = \eta_R \eta_O \eta_H = \frac{(1-t)}{(1-w)} \eta_B$$

$$\text{Propeller Torque } Q = \frac{P_D}{2\pi n}$$

Propeller Thrust $T = \frac{P_T}{V_A}$

$$\eta_R = \frac{\eta_B}{\eta_O} = \frac{P_T}{P_D} \cdot \frac{P_{DO}}{P_{TO}}$$

Thrust identity; $P_T = P_{TO}; \therefore \eta_R = \frac{P_{DO}}{P_D}$

Torque identity; $P_D = P_{DO}; \therefore \eta_R = \frac{P_T}{P_{TO}}$

$$\frac{P_E}{P_B} = \eta_S \eta_R \eta_O \eta_H$$

$$t = \frac{T - R_T}{T} \text{ or } \frac{R_T}{T} = 1 - t$$

$$\omega = \frac{V_S - V_A}{V_S} \text{ or } \frac{V_A}{V_S} = 1 - \omega$$

Apparent Slip $= \left(1 - \frac{V}{Pn}\right)$

True Propeller Slip $= \left(1 - \frac{V_A}{Pn}\right)$

Propeller Design using Charts and Polynomials

Known power, RPM and advance velocity

$$\frac{K_Q}{J^5} = \frac{Q}{\rho n^2 D^5} \left(\frac{nD}{V_A}\right)^5 = \frac{Qn^3}{\rho V_A^5}$$

Known power, diameter and advance velocity

$$\frac{K_Q}{J^3} = \frac{Q}{\rho n^2 D^5} \left(\frac{nD}{V_A}\right)^3 = \frac{Qn}{\rho D^2 V_A^3} = \frac{P_D}{2\pi \rho D^2 V_A^3}$$

Known thrust, diameter and advance velocity

$$\frac{K_T}{J^2} = \frac{T}{\rho n^2 D^4} \left(\frac{nD}{V_A}\right)^2 = \frac{T}{\rho V_A^2 D^2}$$

Known thrust, RPM and advance velocity

$$\frac{K_T}{J^4} = \frac{T}{\rho n^2 D^4} \left(\frac{nD}{V_A}\right)^4 = \frac{Tn^2}{\rho V_A^4}$$

Cavitation Considerations

Burrill's Method

$$V_R = \left[(0.7\pi n D)^2 + V_A^2 \right]^{\frac{1}{2}}$$

$$P_O = P_{atm} + \rho g h$$

Atmospheric pressure

$$P_{atm} = 101300 \text{ N/m}^2$$

Vapour pressure of water

$$P_V = 1700 \text{ N/m}^2 \text{ at } 15^\circ\text{C}$$

$$\sigma = \frac{P_O - P_V}{q_T}$$

$$q_T = 0.5 \rho V_R^2$$

$$\frac{A_P}{A_D} = \left[1.067 - 0.229 \frac{P}{D} \right]$$

$$\tau_C = \frac{T}{\frac{1}{2} \rho A_P V_{R(0.7)}^2}$$

Keller's method

$$\frac{A_E}{A_O} = \frac{(1.3 + 0.3Z)T}{(P_O - P_V)D^2} + K$$

Propeller Lifting Line Theory

$$\tan\beta = \frac{V_A}{2\pi r} = \frac{J}{\pi x}$$

$$\eta_i = \frac{\tan\beta}{\tan\beta_i}$$

$$\therefore \tan\beta_i = \frac{\tan\beta}{\eta_i}$$

$$a' = \frac{\tan^2\beta_i(1-\eta_i)}{1+\tan^2\beta_i}$$

$$k'T_i = \pi^3 k x^3 a'(1-a')$$

$$k'Q_i = k'T_i \frac{\lambda_i}{2}$$

$$K'T = k'T_i(1-\varepsilon \tan\beta_i)$$

Wake fraction integration

$$w_T = \frac{\int_{r_B}^R w'_T \cdot 2\pi r \cdot dr}{\int_{r_B}^R 2\pi r \cdot dr} = \frac{\int_{r_B}^R w'_T \cdot r \cdot dr}{\frac{1}{2}(R^2 - r_B^2)}$$

where;

$$w'_T = \frac{1}{2\pi} \int_0^{2\pi} w''_T \cdot d\theta$$

and R is the propeller radius and r_B is the boss radius.