NATIONAL EXAMINATIONS

May 2018

04-BS-7 MECHANICS OF FLUIDS

Three (3) hours duration

Notes to Candidates

1. This is a **Closed Book** examination.

2. Exam consists of two Sections. **Section A is Calculative (9 questions)** and **Section B is Analytical (4 questions)**.

3. **Do seven (7) questions from Section A (Calculative) and three (3) questions from Section B (Analytical)**. Note that the Analytical Questions do not require detailed calculations but do require full explanations.

4. **Ten (10) questions constitute a complete paper.** (Total 50 marks).

5. **All questions are of equal value.** (Each 5 marks).

6. 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.

7. **Read the entire question before commencing** the calculations and **take note of hints or recommendations** given.

8. Either one of the approved **Casio** or **Sharp** calculators may be used.

9. **Reference information** for particular questions is given on pages 8 to 10. **All pages of questions attempted are to be returned with the Answer Booklet, showing diagrams generated or where readings were taken and which data was used. Candidates must write their names on these pages.**

10. **Constants** are given on page 11.

11. **Nomenclature** and **Reference Equations** are given on pages 12 to 15.

SECTION A CALCULATIVE QUESTIONS

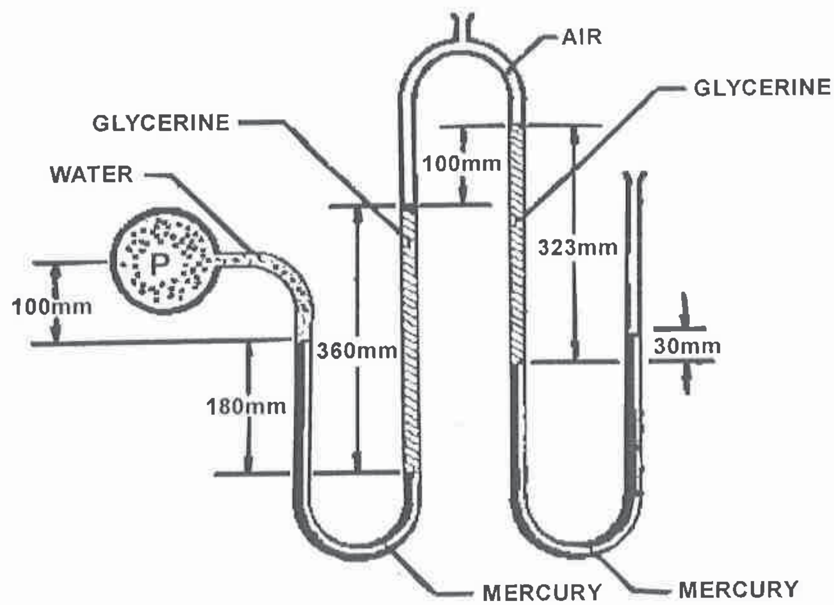
***Do seven of nine questions**. Solutions to these questions must be set out logically with equations and calculation steps shown. All intermediate answers and units must be given.*

QUESTION 1

Refer to the diagram below which shows a horizontal pipe to which a manometer is connected. The manometer has two openings to the atmosphere.

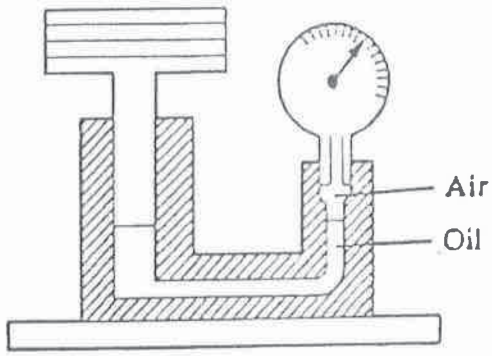
Determine the absolute pressure P in the pipe in kPa when the manometer readings are as shown in the diagram. Refer to the **Constants** on Page 11 for the specific gravities of the relevant fluids.

The pipe carries water and those manometer tubes which are open to atmosphere are subject to an atmospheric pressure head equal to 10 m of water.



(5 marks)

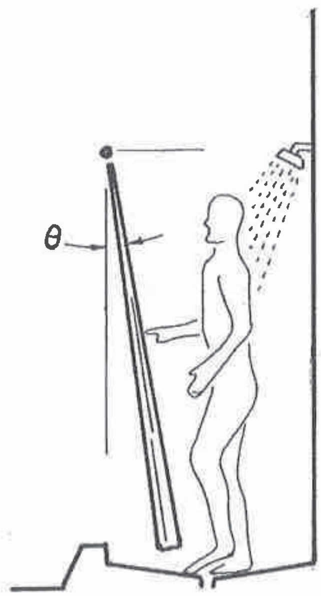
QUESTION 2



The Crosby gauge tester shown in the figure is used to calibrate or to test pressure gauges by applying weights to the piston. The piston diameter is 25 mm. When the total mass of the weights and the piston is 9 kg, calculate the pressure at the gauge. If the gauge being tested indicates 179 kPa, determine the percent error in the gauge.

(5 marks)

QUESTION 3



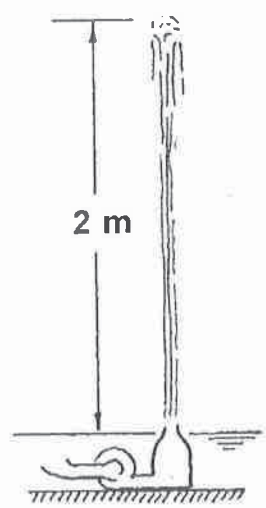
An annoying feature of a shower curtain is that it blows inwards when one is taking a hot shower. If the temperature <u>within</u> the shower cubicle is 30°C and the general air temperature in the bathroom is 15°C, calculate the angle θ it would reach when blowing inwards. The shower cubicle is 1 m square in plan and 2 m in height. The effective width of the shower curtain is thus 1 m and its length 2 m. The mass of the curtain is 400 g.

Assume that the temperature everywhere within the shower cubicle (below the level of the curtain support rod) is the same and neglect any effect of the water spray or the person or any deflection of the curtain. Assume also that the air temperature <u>above</u> the shower cubicle is the same as that in the bathroom, that is, it has no influence.

Hint: Calculate forces at mid-point of curtain.

(5 marks)

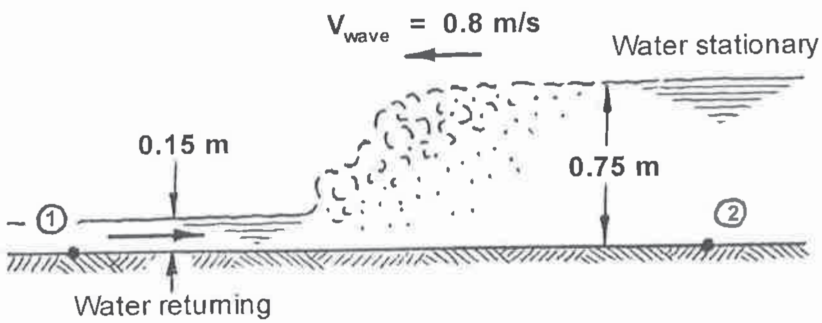
QUESTION 4



A submersible package fountain (motor, pump and jet in a single unit) is required for a garden pond. The jet is to be 20 mm in diameter and is to shoot the water to a height of 2 m. When submersed the nozzle is just above the water surface. Assuming that the pump and hydraulic components have an overall efficiency of 65%, determine the power required to run the fountain.

(5 marks)

QUESTION 5



While spending the summer at a beach, some engineering students exercised their minds by pondering the energy available in the waves. Some simple measurements and observations indicated that the turbulent waves were some 20 m apart and passed a given point every 25 seconds. The depth of water in front of the wave was 0.15 m and behind the wave 0.75 m. Immediately after the wave had passed, the water was stationary for a short while before flowing back into the sea with increasing velocity and reducing depth. By considering the wave as an hydraulic jump, estimate the dissipation of energy per unit time (power) in each wave over the entire width of the beach, that is, 1 km.

Hint: Change the point of reference such that the wave is stationary and that the water is flowing towards and away from it (observer travelling with the wave).

(5 marks)

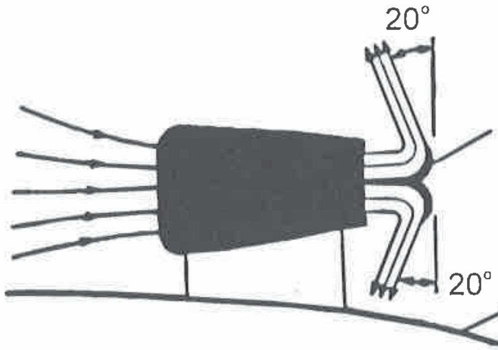
QUESTION 6

Refer to the Examination Paper Attachments Page 8 **Moody Diagram**

A domestic heat recovery air exchanger draws fresh air into a house and rejects stale air to the atmosphere. Air is distributed and collected through corrugated aluminum pipes 150 mm in diameter. The corrugations to permit easy bending for installation are 3 mm in height. The air flow through each pipe is 0.08 m^3/s. Determine the pressure drop per 100 m of straight pipe for the corrugated aluminum lines (before bending to the required configuration).

(5 marks)

QUESTION 7



Boeing 727 and Boeing 737, as well as McDonnell Douglas DC-9 aircraft, made use of Pratt and Whitney JT8D engines. The air flow rate through these engines is 143 kg/s. The inlet velocity is 220 m/s and the exhaust velocity is 650 m/s. After the aircraft touches down, vanes are actuated to produce reverse thrust to aid deceleration and hence shorten the landing distance as shown in the sketch above. Determine the following for each engine:

(a) Forward thrust on aircraft during normal operation (reverse thruster not actuated).

(b) Reverse thrust on aircraft with reverse thruster deployed (actuated).

(c) If the reverse thruster did not turn the exhaust stream to be 20° forward but discharged the exhaust at right angles to the initial direction (20° becomes 0°), state whether there would still be reverse thrust. Give a reason for your answer.

(5 marks)

QUESTION 8

Refer to the Examination Paper Attachments Page 9 **Drag Diagram**

A standard table tennis ball is 40 mm in diameter and has a mass of 3 g. Determine its terminal velocity when falling in air at 15°C.

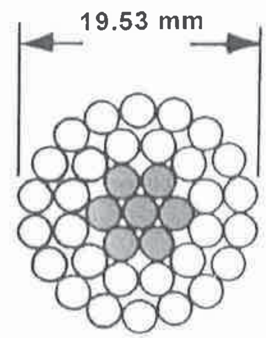
Recommended Method: Set up equations of C_D and Re in terms of ball velocity V. Guess two or three velocities V and plot points (C_D versus Re) for these values on the diagram. Draw a line through these points and, from the point where this line crosses the drag characteristic line, obtain the answer.

<u>*Return the diagram with your answer booklet to show your working.*</u>

(5 marks)

QUESTION 9

Refer to the Examination Paper Attachments Page 10 **Drag Diagram**



Power transmission lines supported by pylons are subject to wind and gravitational forces, and the supporting insulators holding the power lines must be designed accordingly. The cross section and diameter of one conducting cable is shown in the adjoining diagram. The conducting cable consists of a central core of steel wires surrounded by an annular bundle of aluminum wires. All wires are 2.79 mm in diameter.

(a) Determine the horizontal force per metre length of one conducting cable when subject to a wind speed of 90 km/hr with an air temperature of 15°C. Since the cable is impregnated and coated with grease, assume that the surface is a smooth infinite cylinder.

(b) Determine the vertical force per metre length due to gravity. Neglect the weight of the grease. Compare the value of this vertical force with the horizontal force obtained in (a) above.

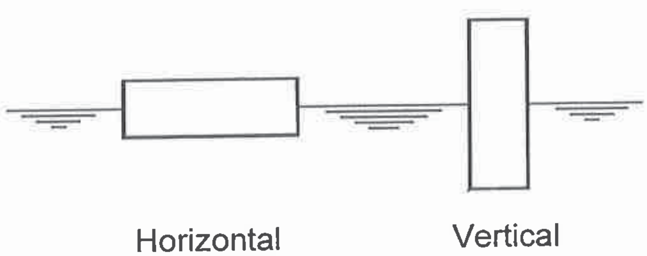
Refer to the **Constants** on Page 11 for the densities of steel and aluminum.

(5 marks)

SECTION B GRAPHICAL AND ANALYTICAL QUESTIONS

<u>Do three of four questions</u>. These questions do not require detailed calculations but complete written explanations must be given to support the answers where descriptive answers are required.

QUESTION 10



A bar of square cross section with density half that of water will float half submerged as shown in the sketch above. State which orientation will be stable - horizontal or vertical. Explain why the chosen orientation is stable and how this can be proven.

(5 marks)

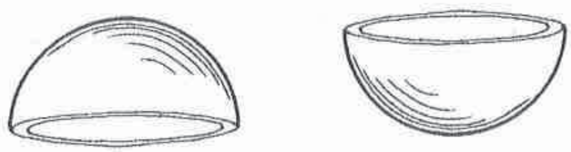
QUESTION 11

Refer to the Examination Paper Attachments Page 8 **Moody Diagram.**

In Mechanics of Fluids most transitions occur in a progressive or continuous manner (as in the Drag Coefficient Diagram on Page 9). However in the Moody Diagram on Page 8 the friction factor f jumps to nearly double its value when the flow changes from laminar to turbulent. Explain what implications this has on flow in a pipe assuming the same flow rate for both conditions. Explain fully the fundamental cause of this jump with respect to energy in the system.

(5 marks)

QUESTION 12



Orientation A Orientation B

Two light hemispheres are dropped in the atmosphere over some distance. State which orientation A or B will be most likely when falling freely in air. Explain why the chosen orientation will result. Support your explanation by sketching the objects in both orientations with streamlines around them.

(5 marks)

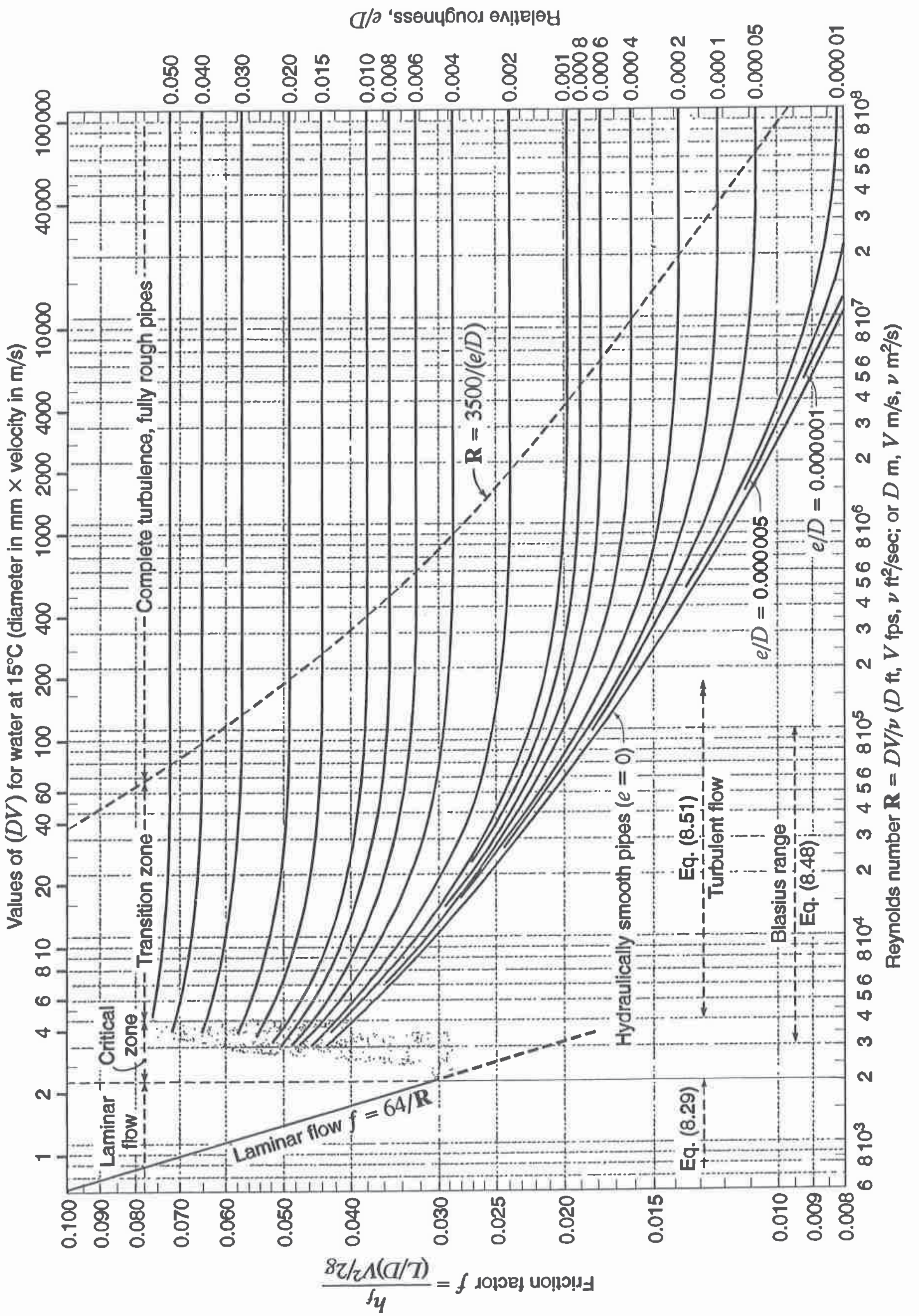
QUESTION 13

Table tennis players often hit the ball with a high degree of top spin to induce the ball to curve down onto the table beyond the net more quickly than it would by gravity alone. Explain how and why this occurs. Support your explanation by sketching stream lines around the ball and showing appropriate pressure variations.

Hint: Change the point of reference such that the ball is stationary but spinning and that the air is flowing past it (observer travelling with the ball).

(5 marks)

QUESTION 6 MOODY DIAGRAM NAME ....



Moody chart for pipe friction factor (Stanton diagram).

EXAMINATION PAPER ATTACHMENTS

QUESTION 8 DRAG DIAGRAM NAME ....

Forces on Immersed Bodies

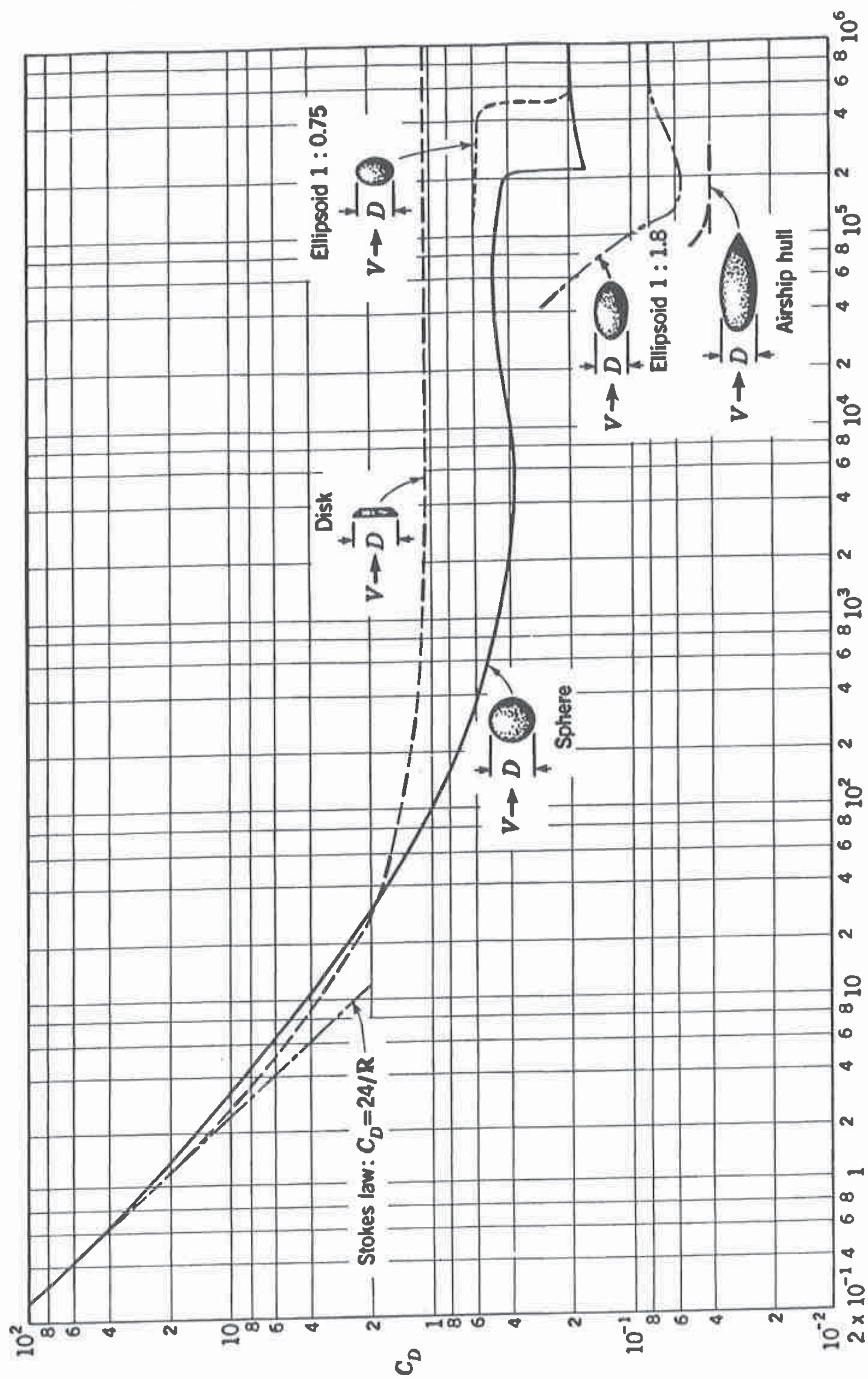


Figure Drag coefficient for bodies of revolution. (Adapted from L. Prandtl, "Ergebnisse der aerodynamischen Versuchsanstalt zu Göttingen," p. 29, R. Oldenbourg, Munich and Berlin, 1923; and F. Eisner, "Das Widerstandsproblem," *Proc. 3d Internatn. Congr. Appl. Mech., p. 32, 1930.*)

EXAMINATION PAPER ATTACHMENTS

QUESTION 9 DRAG DIAGRAM **NAME** ....

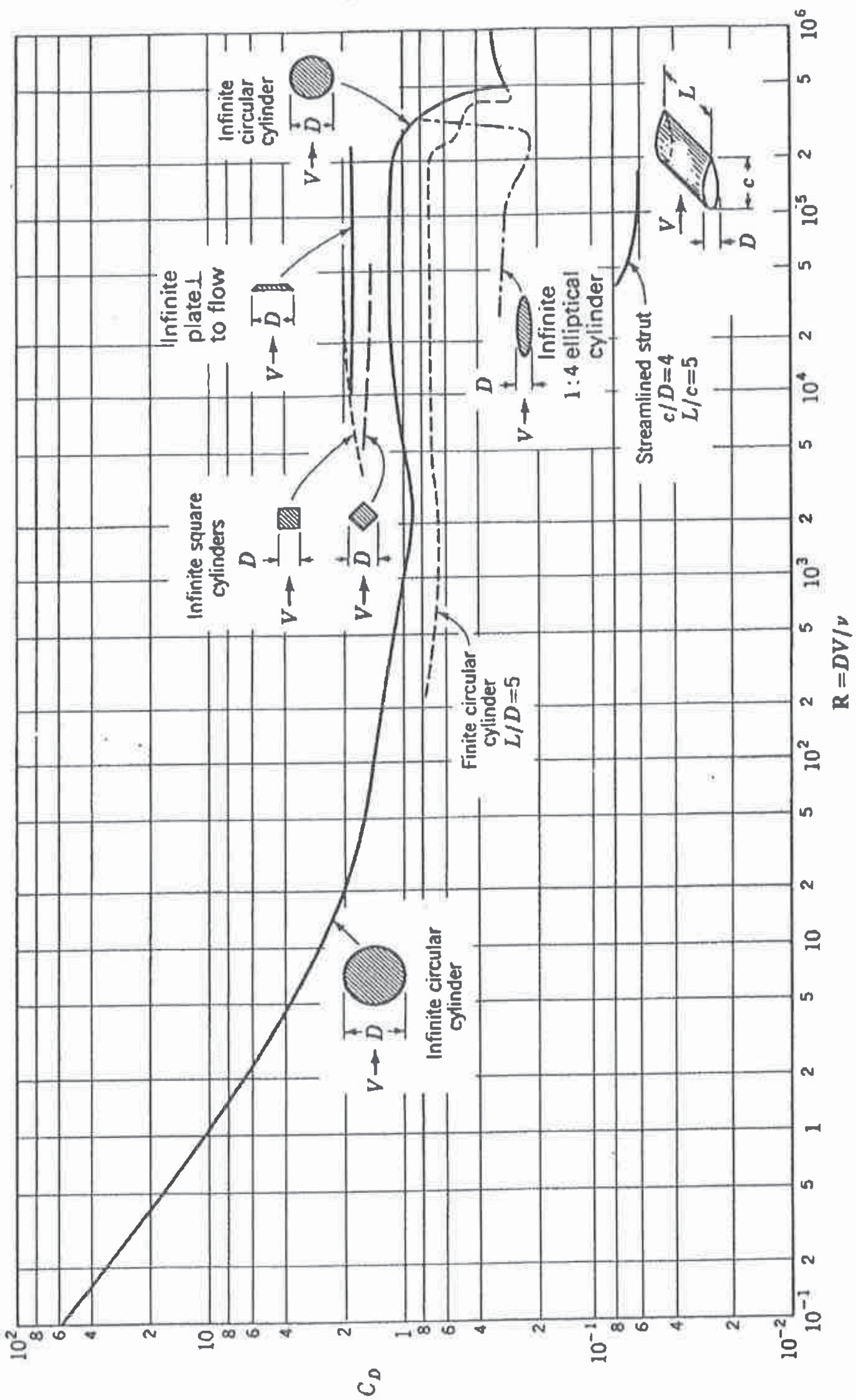


Figure Drag coefficient for two-dimensional bodies. (Adapted from L. Prandtl, "Ergebnisse der aerodynamischen Versuchsanstalt zu Göttingen," p. 24, R. Oldenbourg, Munich and Berlin, 1923; F. Eisner, "Das Widerstandsproblem," *Proc. 3d Internatn. Congr. Appl. Mech.*, p. 32, 1930; A. F. Zahm, R. H. Smith, and G. C. Hill, "Point Drag and Total Drag of Navy Struts No. 1 Modified," *NACA Rept. 137*, p. 14, 1972; and W. F. Lindsey, "Drag of Cylinders of Simple Shapes," *NACA Rept. 619*, pp. 4–5, 1938.)

04-BS-7 MECHANICS OF FLUIDS

GENERAL REFERENCE INFORMATION

CONSTANTS

In engineering calculations a high degree of accuracy is seldom attained due to the neglect of minor influences or the inaccuracy of available data. For consistency in calculations however the following reasonably accurate constants should be used:

Atmospheric Pressure p_o = 100 kPa
Gravitational Acceleration g = 9.81 m/s^2
Specific Gravity of Water = 1.00
Specific Gravity of Glycerine = 1.26
Specific Gravity of Mercury = 13.56
Specific Gravity of Benzene = 0.90
Specific Gravity of Carbon Tetrachloride = 1.59
Density of Water ρ = 1000 kg/m^3
Density of Sea Water ρ = 1025 kg/m^3
Density of Gasoline ρ = 750 kg/m^3
Density of Aluminum ρ = 2700 kg/m^3
Density of Steel ρ = 7780 kg/m^3
Density of Concrete ρ = 2400 kg/m^3
Density of Air ρ = 1.19 kg/m^3 (at 20°C), ρ = 1.21 kg/m^3 (at 15°C)
Absolute Viscosity of Water μ = 1.0 x 10^{-3} Ns/m^2
Absolute Viscosity of Air μ = 1.8 x 10^{-5} Ns/m^2
Surface Tension of Water σ = 0.0728 N/m (at 20°C)
Specific Heat of Water c_p = 4.19 kJ/kg°C
Specific Heat of Air c_p = 1005 J/kg°C
Specific Heat of Air c_v = 718 J/kg°C
Gas Constant for Air R = 287 J/kg°K
Gas Constant for Helium R = 2077 J/kg°K
Gas Constant for Hydrogen R = 4120 J/kg°K

NOMENCLATURE FOR REFERENCE EQUATIONS (SI UNITS)

a	Width	m
A	Flow area, Surface area	m^2
CV	Calorific value	J/kg
c_p	Specific heat at constant pressure	J/kg°C
b	Width	m
D	Diameter	m
E	Energy	J
F	Force	N
g	Gravitational acceleration	m/s^2
h	System head	m
h_L	Head loss	m
H	Pump or turbine head	m
I	Moment of inertia	m^4
k	Ratio of specific heats	
k	Loss coefficient	
K	Constant	
L	Length	m
m	Mass	kg
M	Mass flow rate	kg/s
N	Rotational speed	rev/s
p	Pressure	Pa (N/m^2)
P	Power	W (J/s)
q	Specific heat	J/kg
Q	Flow rate	m^3/s
r	Radius	m
R	Specific gas constant	J/kg K
T	Temperature	K
U	Blade velocity	m/s
v	Specific volume	m^3/kg
V	Velocity	m/s
V	Volume	m^3
w	Specific work	J/kg
W	Work	J
y	Depth	m
z	Elevation	m
η	Efficiency	
μ	Dynamic viscosity	Ns/m^2
ν	Kinematic viscosity	m^2/s
ρ	Density	kg/m^3
σ	Surface tension	N/m
τ	Thrust	N
τ	Shear stress	N/m^2

REFERENCE EQUATIONS

Equation of State

$p\ v = R\ T$

$p = \rho RT$

Universal Gas Law

$p\ v^n = \text{constant}$

Compressibility

$\beta = - \Delta / V\ \Delta p$

Viscous Force and Viscosity

$F = \mu A\ du/dy$

$\mu = \tau / (du/dy)$

$\nu = \mu / \rho$

Capillary Rise and Internal Pressure due to Surface Tension

$h = (\sigma \cos\theta / \rho g) \times (\text{perimeter} / \text{area})$

$p = 2\sigma / r$

Pressure at a Point

$p = \rho g h$

Forces on Plane Areas and Centre of Pressure

$F = \rho g y_c A$

$y_p = y_c + I_c / y_c A$

Moments of Inertia

Rectangle: $I_c = b h^3 / 12$

Triangle: $I_c = b h^3 / 36$

Circle: $I_c = \pi D^4 / 64$

Surface Area of Solids

Sphere: $A = \pi D^2$

Volumes of Solids

Sphere: $V = \pi D^3 / 6$

Cone: $V = \pi D^2 h / 12$

Spherical Segment: $V = (3 a^2 + 3 b^2 + 4 h^2) \pi h / 2 g$

Continuity Equation

$$\rho_1 V_1 A_1 = \rho_2 V_2 A_2 = M$$

General Energy Equation

$$p_1 / \rho_1 g + z_1 + V_1^2 / 2 g + q_{in} / g + w_{in} / g$$
$$= p_2 / \rho_2 g + z_2 + V_2^2 / 2 g + h_L + q_{out} / g + w_{out} / g$$

Bernoulli Equation

$$p_1 / \rho g + z_1 + V_1^2 / 2 g = p_2 / \rho g + z_2 + V_2^2 / 2 g$$

Momentum Equation

Conduit: $F_R = p_1 A - p_2 A - M (V_2 - V_1)$

Free Jet: $F_R = - \rho Q (V_2 - V_1)$

Flow Measurement

Venturi Tube: $Q = [C A_2 / \{1 - (D_2 / D_1)^4\}^{1/2}][2 g \Delta h]^{1/2}$

Flow Nozzle: $Q = K A_2 [2 g \Delta h]^{1/2}$

Orifice Meter: $Q = K A_o [2 g \Delta h]^{1/2}$

Flow over Weirs

Rectangular Weir: $Q = C_d (2 / 3) [2 g]^{1/2} L H^{3/2}$

Power

Turbomachine: $P = \rho g Q H$

Free Jet: $P = ½ \rho Q V^2$

Moving Blades: $P = M \Delta V U$

Aircraft Propulsion

$F_{thrust} = M (V_{jet} - V_{aircraft})$

$P_{thrust} = M (V_{jet} - V_{aircraft}) V_{aircraft}$

$E_{jet} = ½ (V_{jet}^2 - V_{aircraft}^2)$

$P_{jet} = ½ M (V_{jet}^2 - V_{aircraft}^2)$

$E_{fuel} = CV_{fuel}$
$P_{fuel} = M_{fuel}\ CV_{fuel}$
$\eta_{thermal} = P_{jet} / P_{fuel}$
$\eta_{propulsion} = P_{thrust} / P_{jet} = 2\ V_{aircraft} / (V_{jet} + V_{aircraft})$
$\eta_{overall} = \eta_{thermal} \times \eta_{propulsion}$

Wind Power

$P_{total} = ½\ \rho\ A_T\ V_1^3$
$P_{max} = 8/27\ \rho\ A_T\ V_1^3$
$H_{max} = P_{max} / P_{total} = 16/27$

Reynolds Number

$Re = d\ V\ \rho / \mu$

Flow in Pipes

$h_L = f\ (L / D)\ (V^2 / 2\ g)$
$D_e = 4$ (flow area) / (wetted perimeter)
$D = D_e$ for non-circular pipes
$L = L_{total} + L_e$ for non-linear pipes
$(L / D) = 35\ k$ for $Re \sim 10^4$

Drag on Immersed Bodies

Friction Drag: $F_f = C_f\ ½\ \rho\ V^2\ B\ L$ $(B = \pi\ D)$
Pressure Drag: $F_p = C_p\ ½\ \rho\ V^2\ A$
Total Drag: $F_D = C_D\ ½\ \rho\ V^2\ \mathbf{A}$

Aircraft Wing: $F_L = C_L\ ½\ \rho\ V^2\ A_{wing}$
Aircraft Wing: $F_D = C_D\ ½\ \rho\ V^2\ A_{wing}$

Karmen Vortex Frequency

$f \approx 0.20\ (V / D)\ (1 - 20 / Re)$