NATIONAL EXAMINATIONS

May 2013

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. Candidates may use one of the approved **Casio** or **Sharp** calculators.
8. **Reference data** for particular questions are given on pages 8 and 9. **All pages of questions attempted are to be returned with the Answer Booklet showing where readings were taken and which data was used. Candidates must write their names on these pages.**
9. **Constants** are given on page 10.
10. **Reference Equations** are given on pages 11 to 14.

SECTION A CALCULATIVE QUESTIONS

Do seven of nine questions. Solutions to these questions must be set out logically with all intermediate answers and units given.

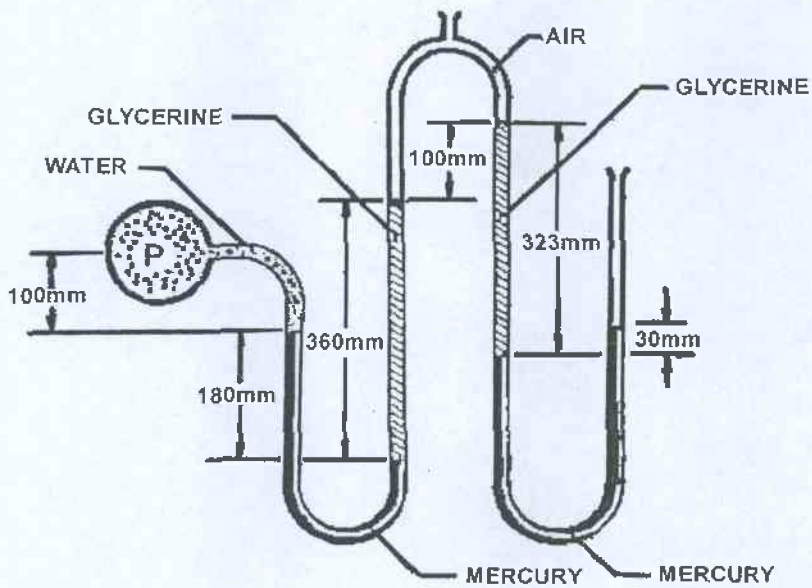
QUESTION 1

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 10 for the specific gravities of the relevant fluids.

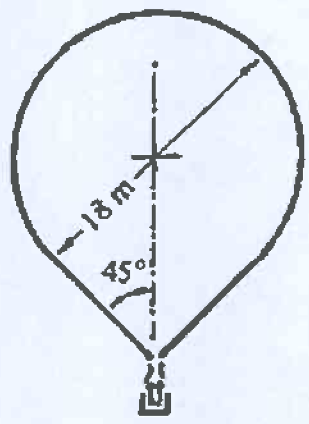
The pipe carries water and those manometer tubes which are open to atmosphere are subject to an atmospheric pressure head equal to 10 m of water.

(5 marks)



QUESTION 2

A hot air balloon as shown in the adjacent sketch is made in the shape of a sphere with a cone at the bottom. The diameter of the sphere is 18 m and the side of the cone is at an angle of 45° to the vertical axis. This gives the balloon a total volume of 3147 m^3. The total mass is made up as follows:



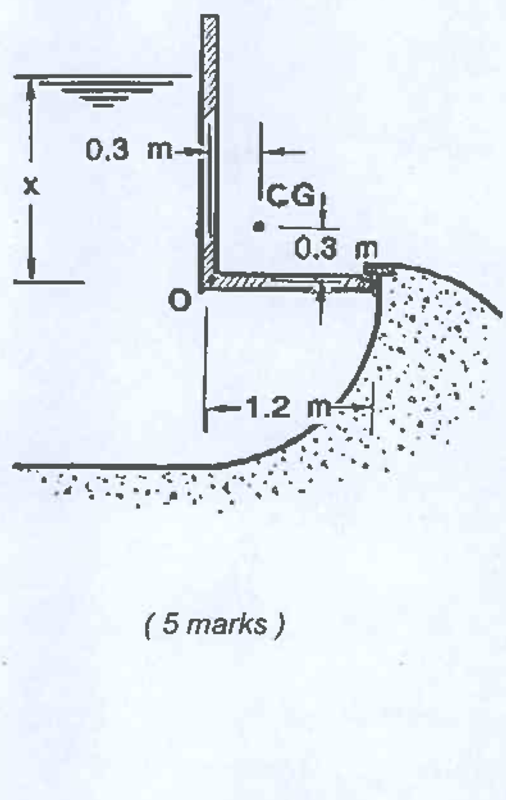
Envelope	100 kg
Basket	60 kg
Fuel Tanks	110 kg
Burners	50 kg
Two People	160 kg

Determine the temperature of the hot air inside the balloon envelope to establish neutral buoyancy (equilibrium) in the atmosphere. The ambient atmospheric conditions are 100 kPa and 15°C.

(5 marks)

QUESTION 3

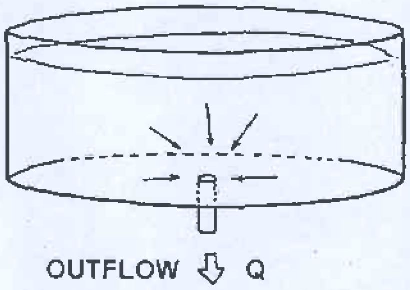
Refer to the illustration alongside. The angle of the gate is 90° as shown, the mass of the gate is 400 kg, the horizontal width of the gate 1.0 m, the length of the small arm 1.2 m, and the centre of gravity 0.3 m to right of and 0.3 m above pivot O. Neglect friction at the pivot and thickness of the gate. If the depth of water x above the pivot is 2 m, state whether the gate will open or remain closed.



(5 marks)

QUESTION 4

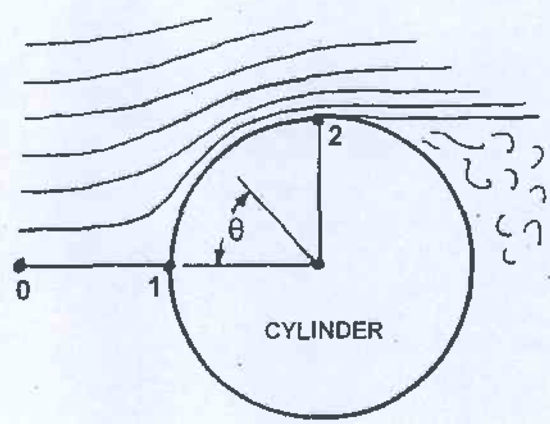
Water flows at a rate of 0.300 L/s through a small circular hole in the bottom of a large tank. Assuming the water in the tank approaches the hole <u>radially</u>, calculate the velocity in the tank at a distance of 100 mm from the hole.



(5 marks)

QUESTION 5

For ideal flow (no friction) the velocity V_1 around the surface of a long cylinder is given by $V_1 = 2\ V_0 \sin\theta$ where V_0 is the free stream velocity and θ the angular location around the cylinder measured from the front (stagnation point). Consider a concrete chimney 20 m in diameter and 275 m in height subject to a wind velocity of 100 km/hr. Determine the velocity and pressure of the air on the front (stagnation point – point 1) and sides (90° from stagnation point – point 2) of the chimney. Express the pressure relative to atmospheric pressure (gauge pressure).



(5 marks)

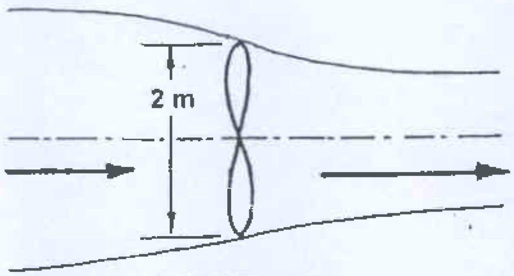
QUESTION 6

Preformed fibre insulation panels 2.438 m x 1.219 m x 25 mm are used to insulate a building. During construction some are left lying flat on grass as shown in the adjoining sketch. If the density of a panel is 100 kg/m^3 calculate the minimum wind velocity (in km/hr) at ground level which will lift the panel and blow it away. Note that the grass under the panel reduces the air velocity to stagnation conditions.

(5 marks)

QUESTION 7

A propeller of 2 m in diameter is mounted on an aircraft travelling at 500 km/hr. The airstream leaves the propeller with a velocity of 650 km/hr. Assume that the pressure upstream and downstream of the propeller is equal to atmospheric pressure and that the flow converges as the velocity increases. Determine the thrust developed by the propeller.



PROPELLER

(5 marks)

QUESTION 8

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

A 2.0 m diameter concrete pipe of length 1560 m, for which the roughness is 1.5 mm, conveys water between two reservoirs at a rate of 8.0 m^3/s. Determine the required difference in water surface elevation between the two reservoirs. Use the attached Moody diagram to obtain the friction factor.

Return the diagram with your answer booklet to show your readings.

(5 marks)

QUESTION 9

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

A meteorological balloon filled with hydrogen may be used for tracking wind directions in the atmosphere. If such a balloon is 600 mm in diameter when filled and has negligible mass determine its rate of rise through the lower atmosphere. Assume that the internal pressure is the same as that of the atmosphere and that it is spherical in shape. Assume constant diameter and constant densities while in the lower atmosphere. Obtain the answer by plotting on the attached Drag Coefficient Diagram and drawing a line through the plotted point.

Return the diagram with your answer booklet to show your working.

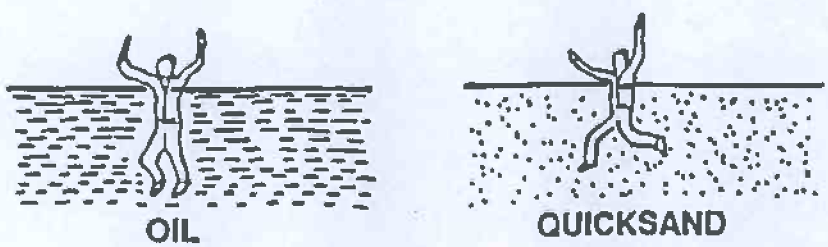
Hint: Set up equations of C_D and Re in terms of balloon velocity V and plot points for various guessed values of V on the chart.

(5 marks)

DESCRIPTIVE QUESTIONS

***Do three of four questions*. These questions do not require detailed calculations but complete written explanations must be given to support the answers.**

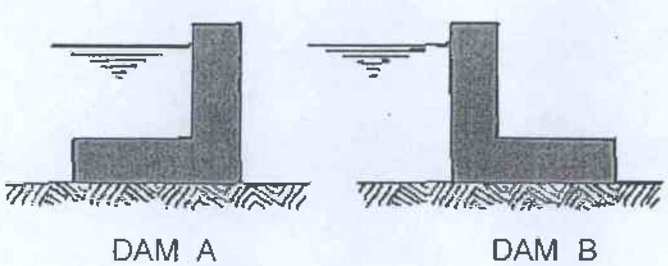
QUESTION 10



Two ponds contain light oil and quicksand (a slurry of fine sand and water in suspension) as shown above. State in which humans are more likely to sink. Give a full explanation for your answer.

(5 marks)

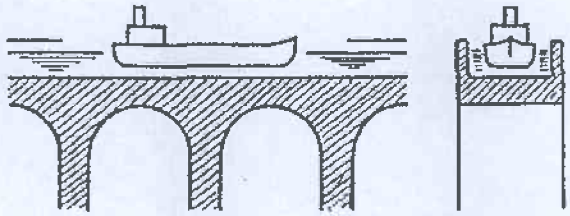
QUESTION 11



Two small L-shaped dams are built on a firm flat surface as shown above. Assuming that there is no seepage under the wall but that sliding can occur, state which dam - Dam A or Dam B - will be most likely to slide. Explain fully why one will be more likely to slide than the other.

(5 marks)

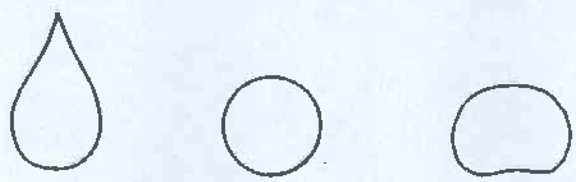
QUESTION 12



A barge 15 m long and 3 m wide is loaded such that its draught (depth of bottom below water surface) is 1.2 m. It sails in a long canal 5 m wide and 2 m deep. At one point the canal is taken across a valley by an aqueduct as shown in the sketch above. Determine the change in compressive force on the aqueduct pillars as the barge passes over them. Give a full explanation of your answer.

(5 marks)

QUESTION 13

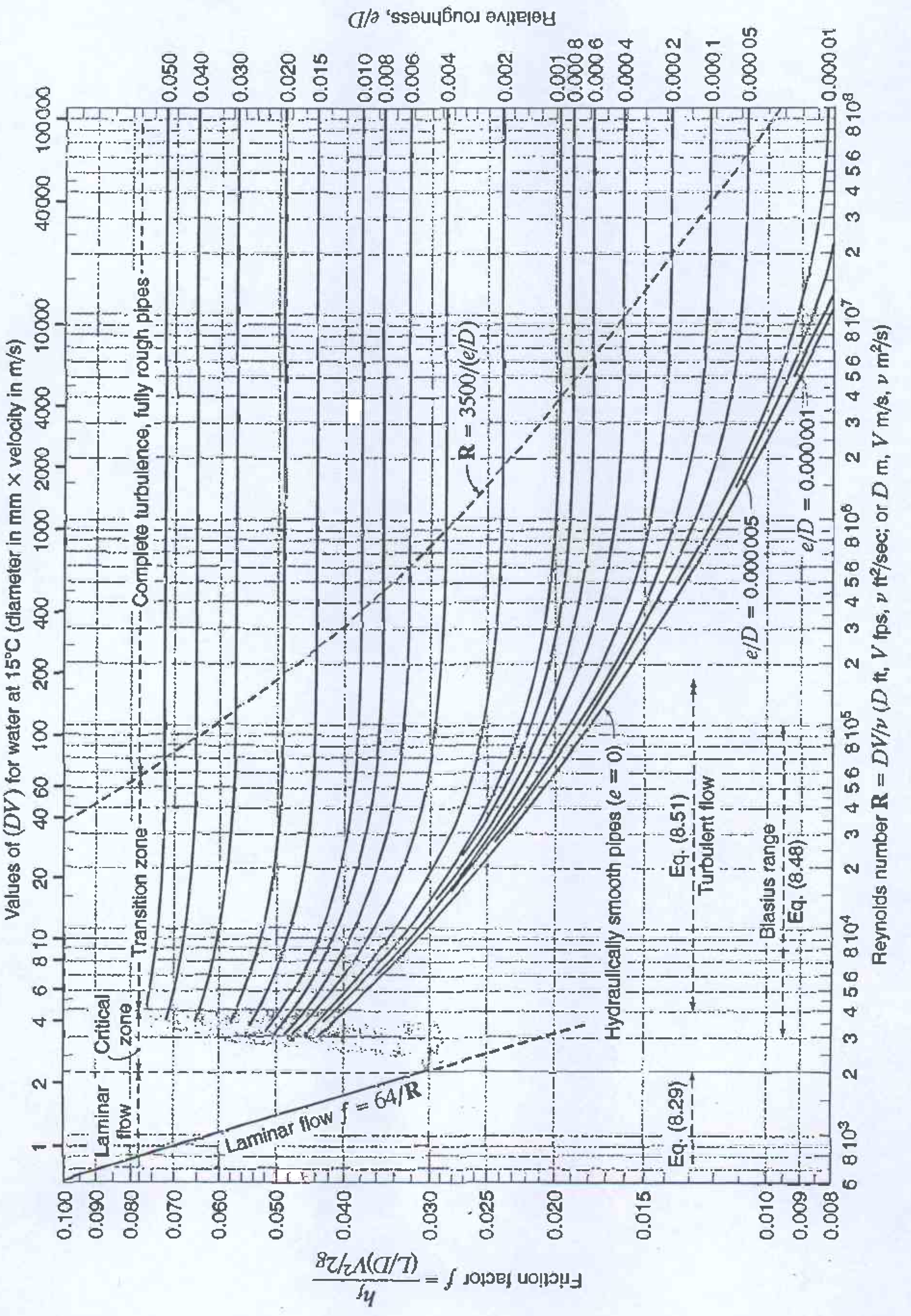


Pointed Prolate   Spherical   Oblate (Flattened)

With reference to the sketches above state what shape a very large rain drop falling through the atmosphere is likely to assume - prolate, spherical or oblate. Explain fully why it would assume the chosen shape and compare this shape with the likely shape of a very small raindrop.

(5 marks)

QUESTION 8 MOODY DIAGRAM **NAME** ....



Moody chart for pipe friction factor (Stanton diagram).

QUESTION 9 DRAG DIAGRAM FOR SOLID BODIES NAME ....

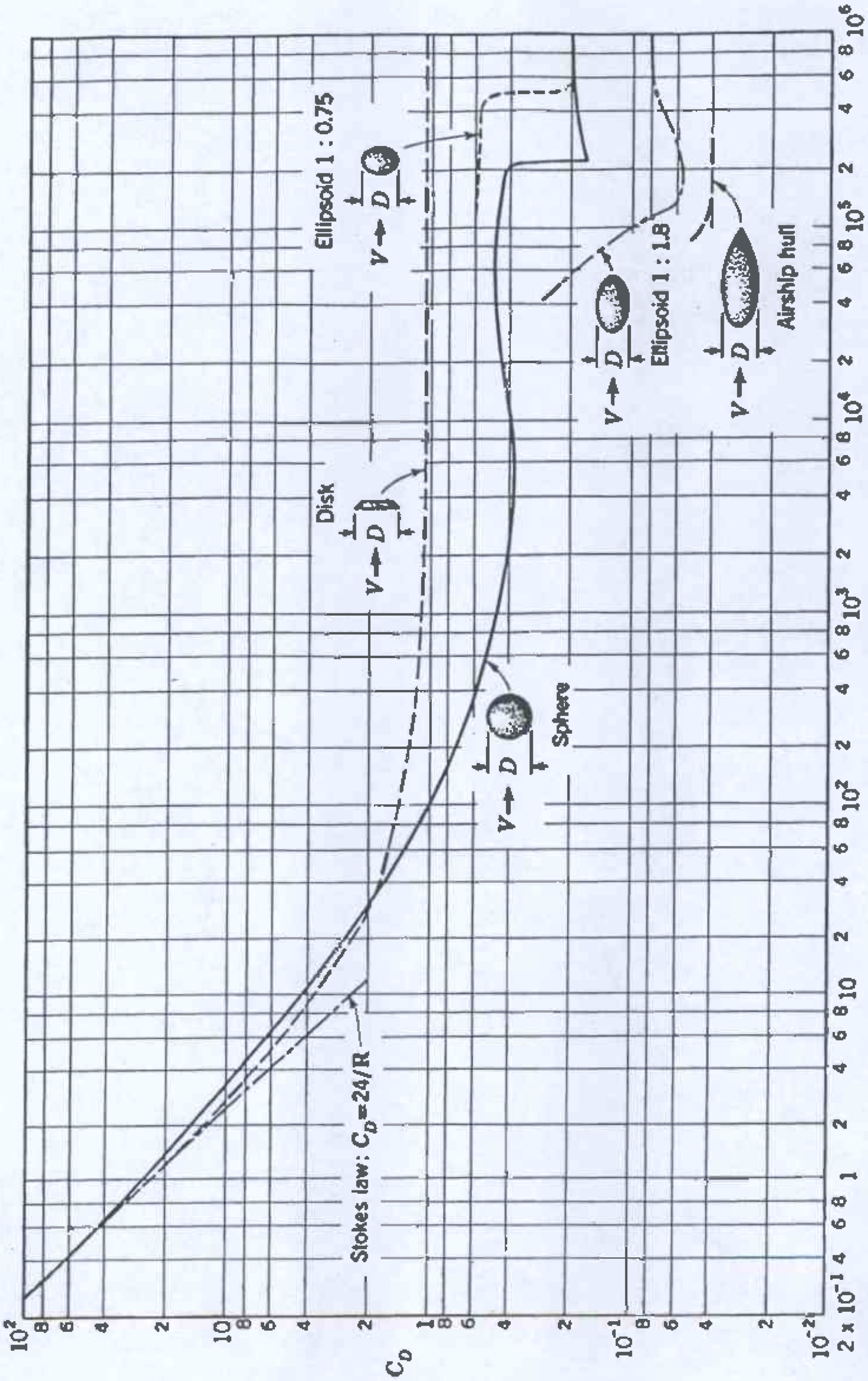


Figure 10.10 Drag coefficient for bodies of revolution. (Adapted from L. Prandtl, "Ergebnisse der aerodynamischen Versuchsanstalt zu Göttingen," p. 29, R. Oldenbourg, Munich and Berlin, 1923; and F. Eisner, "Das Widerstandsproblem," *Proc. 3d Internatn. Congr. Appl. Mech., p. 32, 1930.*)

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 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_p = 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: $I_c = \pi\,D^4 / 64$

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: $F_D = C_D\ ½\ \rho\ V^2\ A$

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

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