NATIONAL EXAMINATIONS

December 2017

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

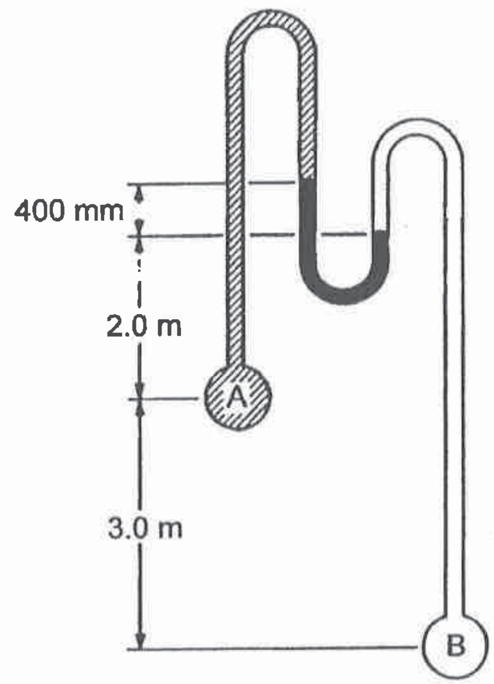
***Do seven of nine questions.* Solutions to these questions must be set out logically with all intermediate answers and units given.**

QUESTION 1

Refer to the adjoining illustration. Use the differential elevations in metres and the manometer reading in millimetres as given in the figure. Pipe A contains benzene and pipe B contains carbon tetrachloride while the U-tube contains mercury. Determine the pressure in pipe A if the pressure in pipe B is 200 kPa.

Refer to Constants on Page 11 for specific gravities.

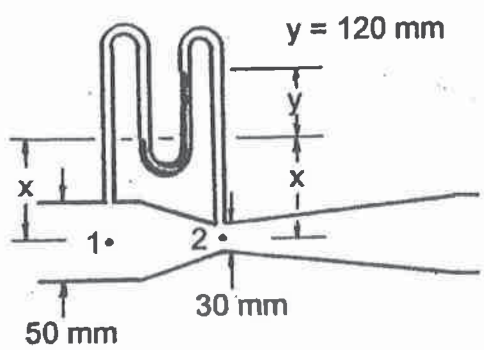
(5 marks)



QUESTION 2

A horizontal venturi tube is used for the measurement of the flow of gasoline with specific gravity 0.72. The pipe diameter is 50 mm and the venturi throat 30 mm. A mercury manometer connected to the inlet and throat of the venturi gives a reading of 120 mm. Determine the following:

(a) Velocity in the pipe
(b) Mass flow rate

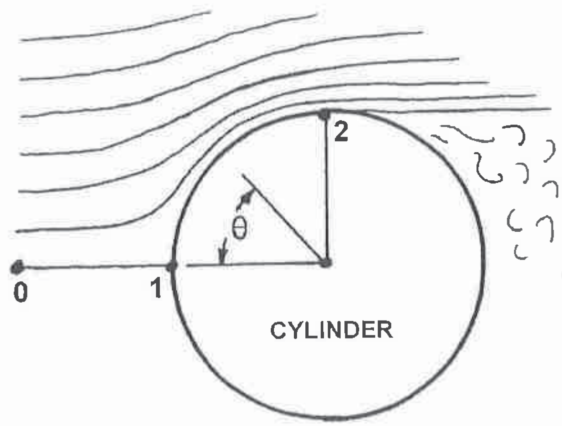


Assume ideal flow conditions (left to right) that is, a discharge coefficient of unity.

(5 marks)

QUESTION 3

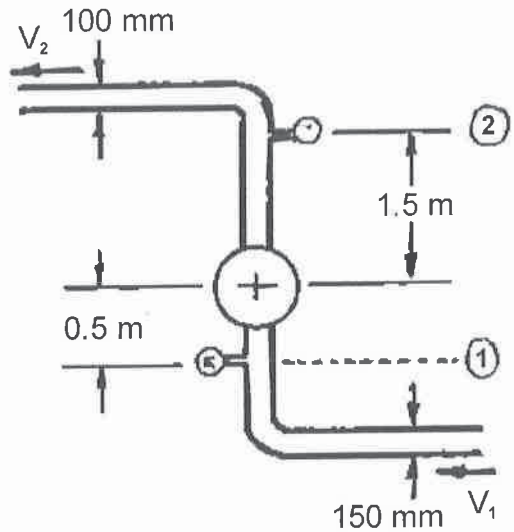
For ideal flow (no friction) the velocity V_1 around the surface of a long cylinder is given by $V_1 = 2\ V_0 \sin\theta$ where V_0 is the free stream velocity and θ the angular location around the cylinder measured from the front (stagnation point). Consider a concrete chimney 20 m in diameter and 275 m in height subject to a wind velocity of 160 km/h. 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 pressures relative to atmospheric pressure (gauge pressure).



(5 marks)

QUESTION 4

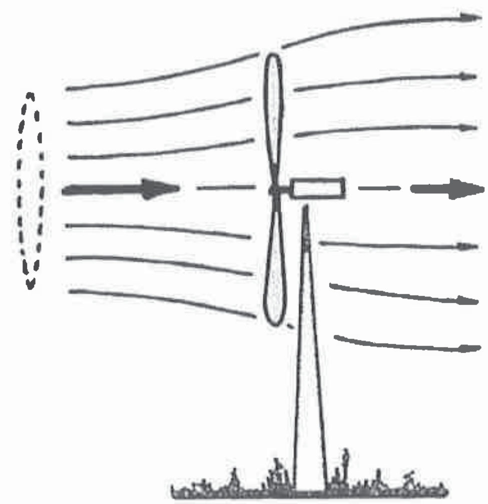
The diameters of the suction and discharge pipes of a pump are 150 mm and 100 mm, respectively. The discharge pressure is read by a gauge at a point 1.5 m above the center line of the pump, and the suction pressure is read by a gauge 0.5 m below the center line. The pressure gauge reads 150 kPa and the suction gauge reads a vacuum of 30 kPa when gasoline having a specific gravity of 0.75 is pumped at the rate of 0.035 m^3/s. Calculate the electrical power required to pump the fluid if the pump efficiency is 75%.



(5 marks)

QUESTION 5

A wind turbine is operating in a wind of 10 m/s that has a density of 1.2 kg/m^3. The diameter of the windmill is 4 m. The constant pressure (atmospheric) streamline passing the turbine blade tip has a diameter of 3 m upstream of the wind turbine and 4.5 downstream. Assume that the velocity distributions are uniform and the air is incompressible. Determine the thrust due to the wind on the wind turbine.



(5 marks)

QUESTION 6

Refer to the Examination Paper Attachments Page 8 **Island Bend Dam.**

(a) Determine the discharge flow rate over the crest of the dam and down the spillway from one open gate, if the dam is at its full supply level F.S.L. and that the radial gate is fully opened by lifting it above the full supply level F.S.L. Obtain dimensions from the drawing. Assume that for this spillway (weir) the discharge coefficient C_d is 0.80. Note that the width of each gate is slightly greater than its height (not specifically stated on the drawing).

(b) Determine the horizontal force due to water pressure on one radial gate if the dam is at its full supply level F.S.L and all radial gates are fully closed. Note that the width of each gate is slightly greater than its height (not specifically stated on the drawing) and that the top of the gate is higher than the full supply level F.S.L. (also not obvious from the drawing).

(5 marks)

QUESTION 7

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

A commercial steel pipe with a roughness of 0.06 mm and a length of 500 m is to convey oil with a density of 800 kg/m^3 and a viscosity of 0.048 Ns/m^2 at a rate of 0.3 m^3/s from a reservoir of surface elevation 190 m to one of surface elevation 120 m. Select a suitable pipe diameter by plotting on the attached Moody Diagram.

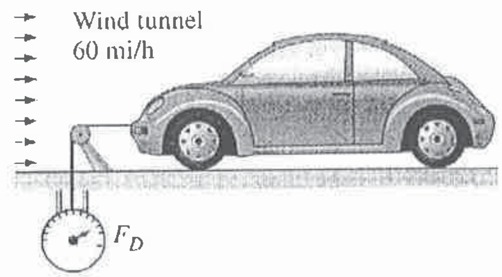
Return the diagram with your answer booklet to show your plotting and readings.

Hint: Set up equations of friction factor f and Reynolds number Re in terms of pipe diameter D. Guess two or more values of D within the range of 0.2 m to 0.4 m that will give points on the chart and plot these points. Draw a straight line through these points. Hence determine the pipe diameter.

(5 marks)

QUESTION 8

The drag coefficient of a car is to be determined experimentally with a full scale test in a large wind tunnel. The wind speed is 100 km/h (60 mi/h) and the drag force measured on a scale as shown in the adjacent drawing is 302 N (68 lbf). The frontal area of the car is 2.068 m^2 (22.26 ft^2). Neglect any ground effect due to the floor not moving relative to the car.



(a) Calculate the drag coefficient of the car. Assume an air temperature of 20°C.

(b) Calculate the equivalent power required to overcome wind resistance at this speed (100 km/h) on the open road. Neglect rolling resistance.

(c) If the overall engine and transmission efficiency is 30% estimate the fuel consumption of the car in litres per 100 km at 100 km/h due to wind resistance only. Use the answer from (b) above and assume a calorific value of 40 000 kJ/kg for the fuel.

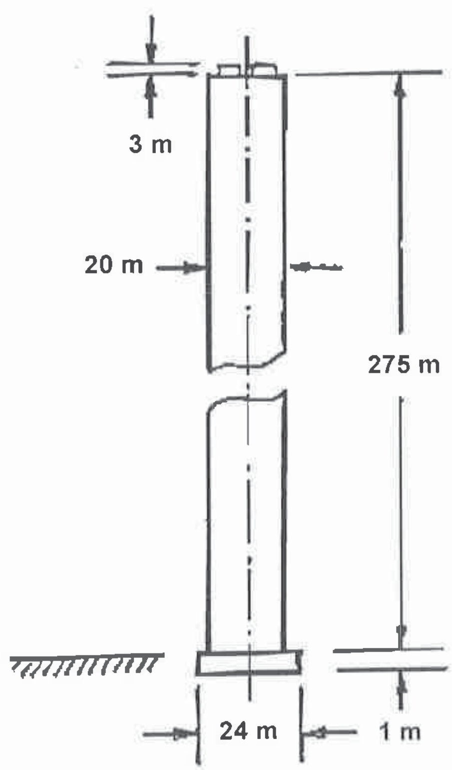
(5 marks)

QUESTION 9

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

The adjoining diagram shows a multi-flue chimney for a coal fired power plant. It is to be checked for wind loading. The chimney consists of a cylindrical concrete wind shield containing three fire-brick flues for the exhaust gases from three boilers. The wind shield is fixed to a circular concrete slab below ground level which serves as the foundation.

The wind shield of the chimney is 20 m in diameter and 275 m in height. Neglect the protrusion of the flues above the windshield.



(a) From the attached diagram determine the coefficient of drag on the chimney at a wind speed of 160 km/h assuming it to be an infinite cylinder.

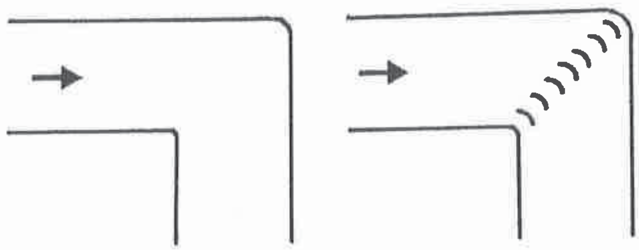
(b) Estimate the total horizontal force on the chimney due to a wind velocity of 160 km/h assuming that the wind speed is the same over the whole height of the wind shield.

(5 marks)

SECTION B GRAPHICAL AND ANALYTICAL QUESTIONS

***Do three of four questions*. 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

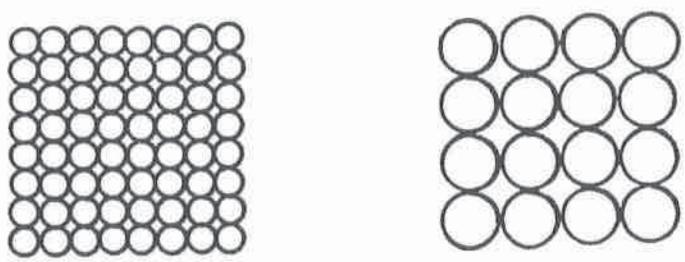


DUCT A DUCT B

A large duct carrying air at a high velocity has a 90° bend as shown in the diagram above. Duct A has no inserts. Duct B has curved vanes at the bend as shown. State which bend will have the lesser head loss. Explain why the selected duct has less head loss. Sketch the flow pattern in each duct to justify your explanation

(5 marks)

QUESTION 11

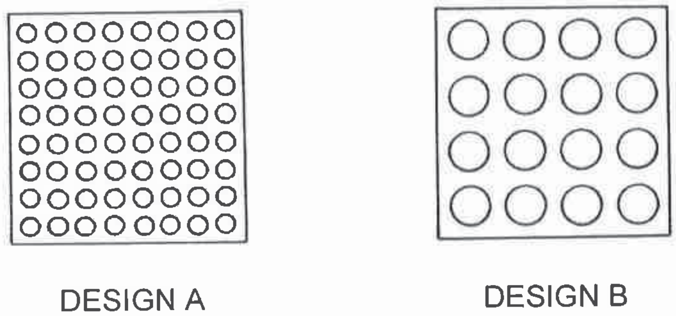


ARRAY A ARRAY B

The diagrams above show glass rods of two different diameters packed in a square array. Array A has small diameter rods. Array B has large diameter rods (double the size of the small rods). If each of these bundles is dipped vertically into a shallow tray of water state which bundle will have the greater rise of water between the rods. Explain your answer. Justify your answer by means of mathematical equations.

(5 marks)

QUESTION 12



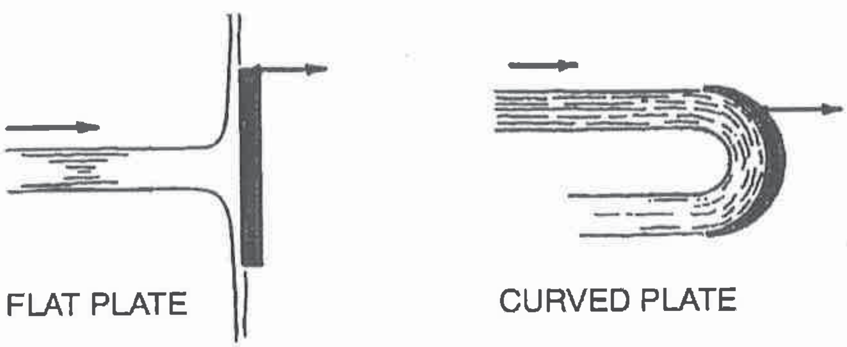
A steam condenser generally consists of an array of tubes surrounded by steam on the outside and having cooling water flowing through the inside of the tubes. Condenser design A has small tubes. Condenser design B has large tubes (double the size of those in Design A). The total flow area and total flow rate are the same in each case.

(a) State which design will have the lesser fluid pressure drop in the cooling water due to fluid friction. Explain your answer. Justify the explanation using suitable mathematical relations.

(b) State which design will have the better heat transfer capabilities for similar temperature conditions of the steam and water. Explain your answer.

(5 marks)

QUESTION 13



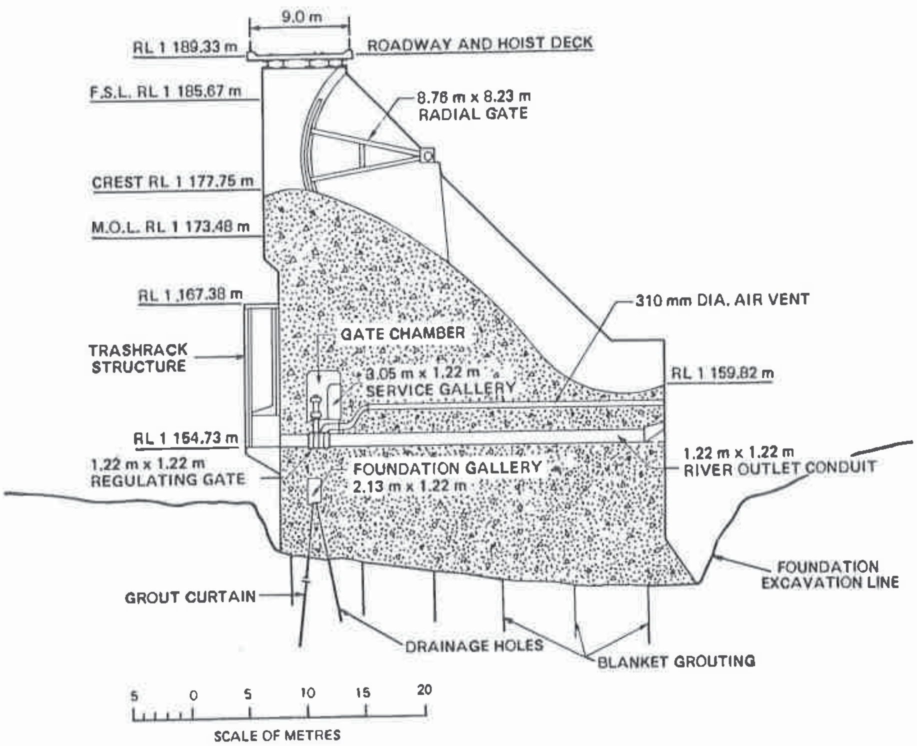
A flat plate and curved plate are subject to horizontal jets having the same flow rate and velocity. State which will be subject to the greater force when stationary and explain why this would be the case. When moving in the same direction as the jet state which plate will give the best transfer of energy (from jet to plate). Explain from an energy aspect the reason for you answer.

(5 marks)

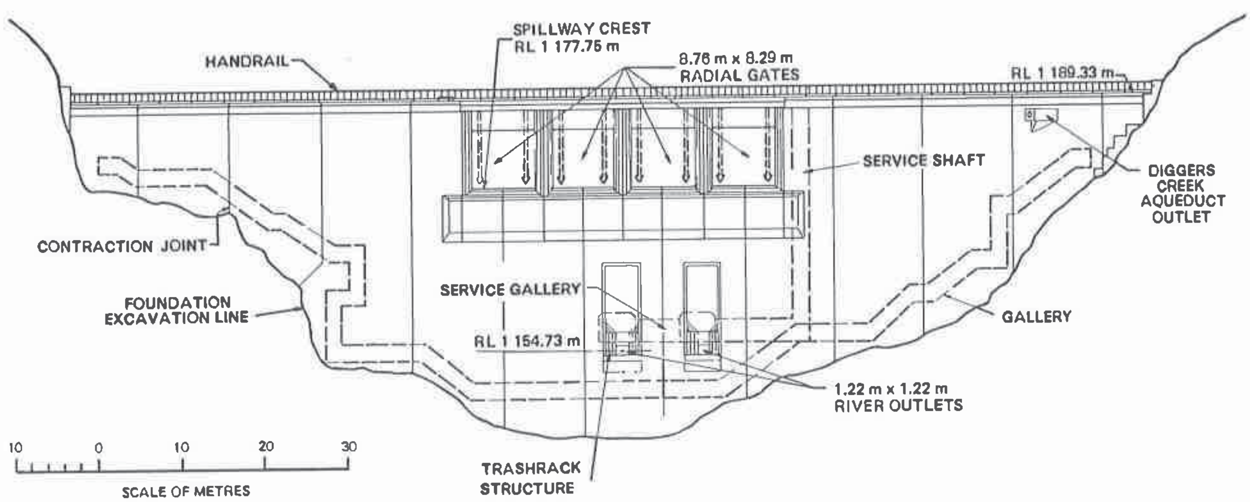
EXAMINATION PAPER ATTACHMENTS

QUESTION 6 ISLAND BEND DAM

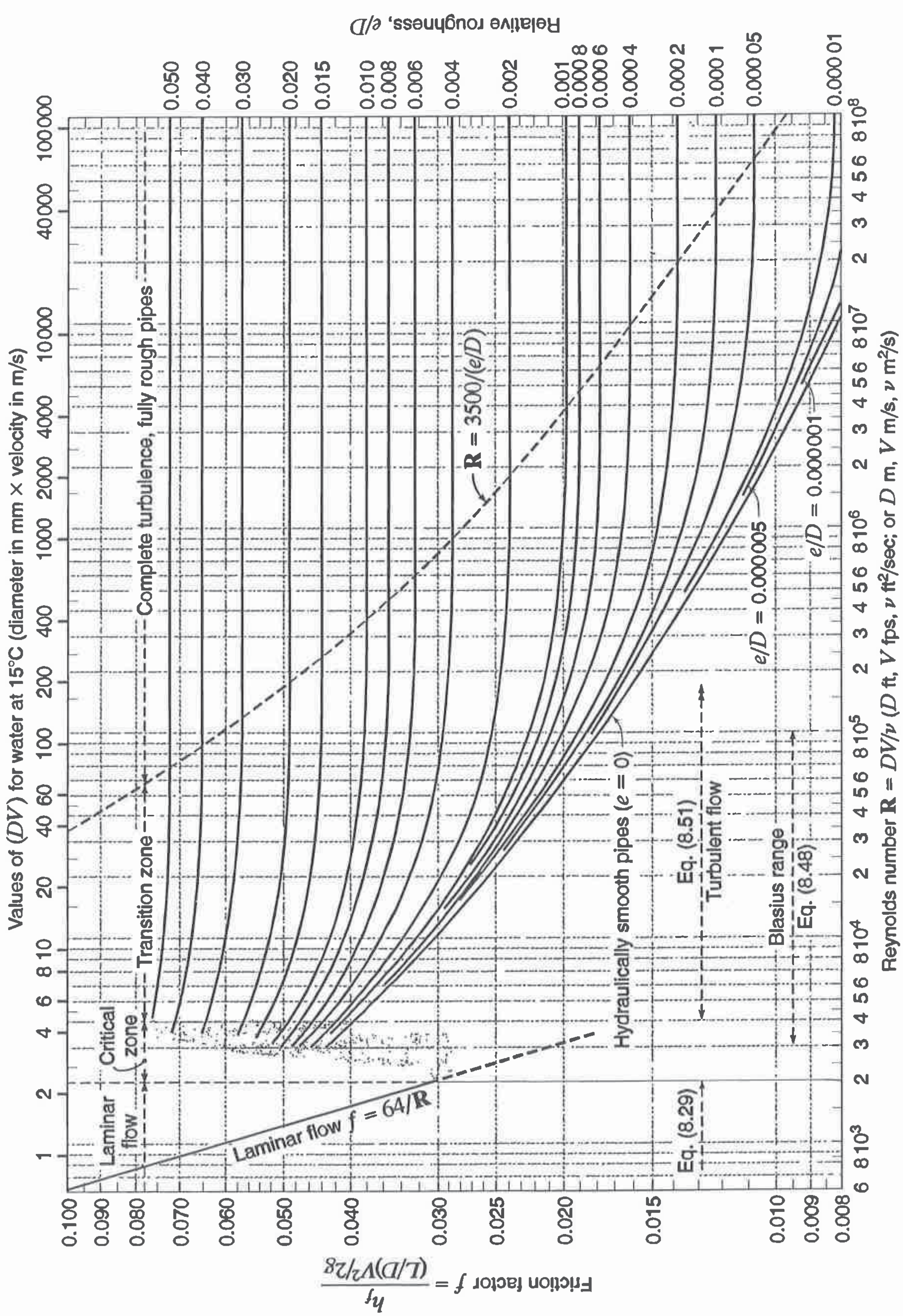
Section through Island Bend Dam



Upstream Elevation of Island Bend Dam



QUESTION 7 MOODY DIAGRAM NAME ....



Moody chart for pipe friction factor (Stanton diagram).

EXAMINATION PAPER ATTACHMENTS

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

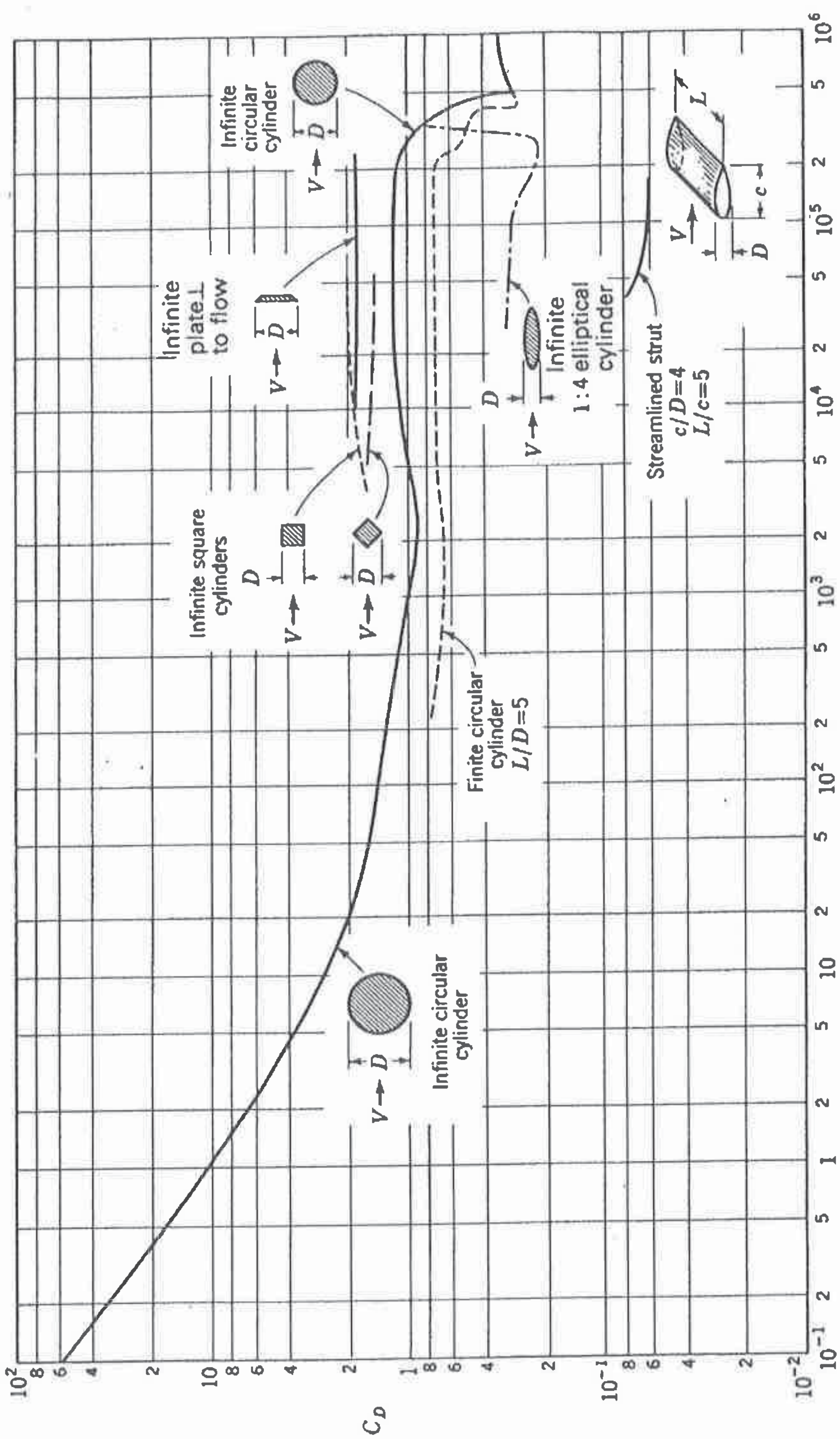


Figure Drag coefficient for two-dimensional bodies. (Adapted from L. Prandtl, "Ergebnisse der aerodynamischen Versuchsanstalt zu Göttingen," p. 24, R. Oldenbourg, Munich and Berlin, 1923; F. Eisner, "Das Widerstandsproblem," *Proc. 3d Internatn. Congr. Appl. Mech.*, p. 32, 1930; A. F. Zahm, R. H. Smith, 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 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: $F_f = C_f\ ½\ \rho\ V^2\ B\ L \quad (B = \pi\ D)$
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

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