NATIONAL EXAMINATIONS

December 2015

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 7 to 11. **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 12.

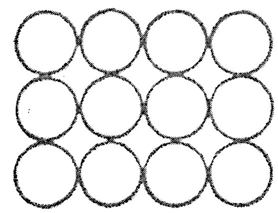
11. **Reference Equations** are given on pages 13 to 16.

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

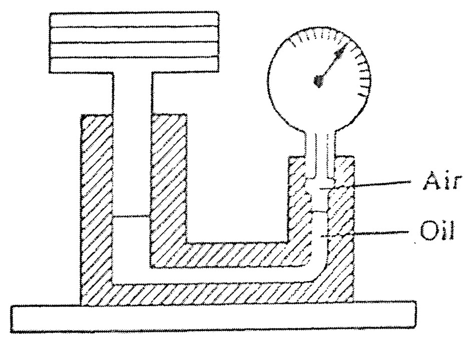
Water rises, due to capillarity, between closely packed vertical glass rods. The rods are 1 mm in diameter and set on a square array when viewed from above as shown in the adjoining sketch. The surface tension of water σ = 0.073 N/m and the wetting angle θ = 0°. Calculate the height above the free water surface to which the water will rise under these conditions.



(5 marks)

QUESTION 2

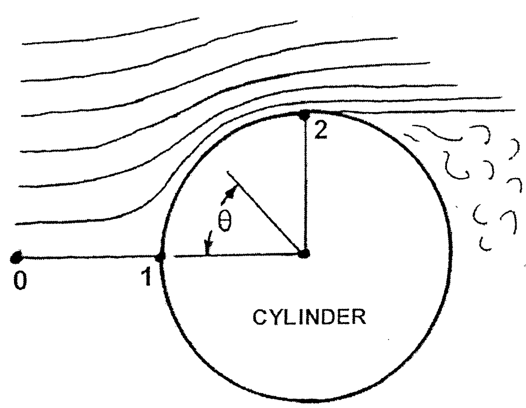
The Crosby gauge tester shown in the figure is used to calibrate or to test pressure gauges. When the total mass of the weights and the piston is 9 kg, the gauge being tested indicates 179 kPa. If the piston diameter is 25 mm, determine the percent error in the gauge.



(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 100 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 pressure relative to atmospheric pressure (gauge pressure).



(5 marks)

QUESTION 4

Refer to the Examination Paper Attachments Page 7 **Island Bend Dam.**

(a) Determine the discharge flow rate over the crest of the dam or spillway from one open gate, if the dam is at its full supply level F.S.L. and that radial gate is fully opened by lifting it above the full supply level F.S.L. Take 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).

(5 marks)

QUESTION 5

Refer to the Examination Paper Attachments Page 8 **Absolute Viscosity.**

Consider a cylindrical tank 300 mm in diameter and 500 mm in height. Either gasoline (s = 0.716) or lubricating oil (SAE 30 Eastern) at 20°C flows into the tank at a constant rate of 0.20 litre/s. The contents are discharged through a fixed orifice of 10 mm diameter having a discharge coefficient C_d for gasoline of 0.90 and a discharge coefficient C_d for oil of 0.75.

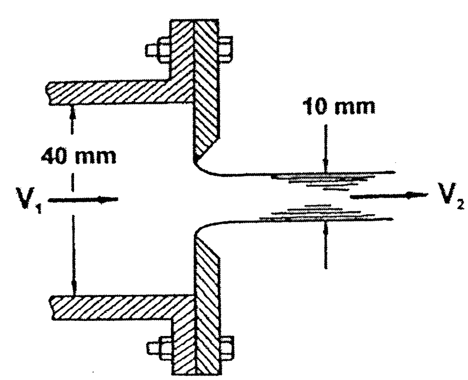
(a) Determine the viscosities of the gasoline and the oil.
(b) Calculate the equilibrium level of gasoline in the tank.
(c) Calculate the equilibrium level of lubricating oil in the tank.
(d) Comment on any differences or observations arising from (b) and (c) above.

Refer to the attached chart Page 8 **Absolute Viscosity** to obtain viscosities.

(5 marks)

QUESTION 6

A high velocity water jet is created by attaching a plate with a sharp edged orifice to the end of a pipe 40 mm in diameter. The pressure in the pipe is 3 MPa gauge. Calculate the velocity in the pipe and in the 10 mm diameter jet so created and hence the flow rate from the nozzle. Assume ideal flow conditions, that is, no fluid friction.

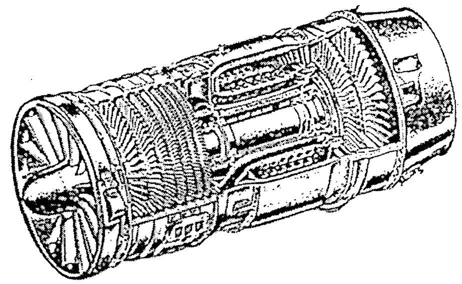


(5 marks)

QUESTION 7

The figure alongside shows a typical turbojet aircraft engine. Calculate the thrust from this engine when operating under the following conditions:

Ambient air pressure	100 kPa
Inlet air temperature	20°C
Exhaust gas temperature	700°C
Exhaust gas velocity	900 m/s
Aircraft velocity	900 km/hr
Exhaust flow area	0.3 m^2



Assume that the exhaust gas pressure is the same as the inlet air pressure. Assume also that the inlet air velocity is equal to the aircraft velocity. Neglect the mass flow of the fuel. Calculate the inlet flow area to give an inlet air velocity equal to the aircraft velocity and the exhaust nozzle area to give the required exit gas velocity.

(5 marks)

QUESTION 8

Refer to the Examination Paper Attachments Page 9 **Drag Diagram for Solid Bodies.**

A meteorological balloon filled with helium may be used for tracking wind directions and estimating cloud ceiling in the atmosphere after release from ground level. If such a balloon is 600 mm in diameter when filled and has a mass of 80 g determine its rate of rise through the lower atmosphere with an ambient temperature of 15°C. 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.

Recommended Method: Set up equations of C_D and Re in terms of balloon 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 **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 rate 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)

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

Refer to the Examination Paper Attachments Page 11 **Island Bend Dam.**

If the dam is at its full supply level F.S.L. and one radial gate is fully opened by lifting it above the full supply level F.S.L., draw, on the attached diagram, the following:

(a) The water level surfaces from upstream of the dam to well downstream of the end of the spillway.

(b) The hydraulic grade line HGL over the full extent of the drawing.

(c) The energy grade line EGL over the full extent of the drawing.

(d) Explain why the water profile over the full extent of the drawing changes in the way that it does at each stage where there is a velocity or directional change.

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

(5 marks)

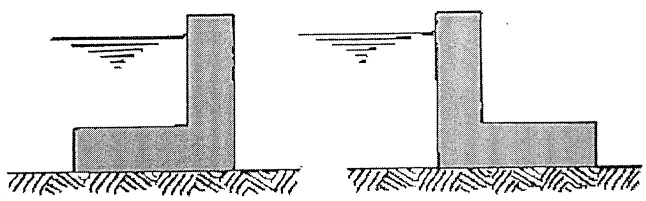
QUESTION 11

Refer to the Examination Paper Attachments Page 10 **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 10 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 and account for any energy gains or losses in the overall system.

(5 marks)

QUESTION 12

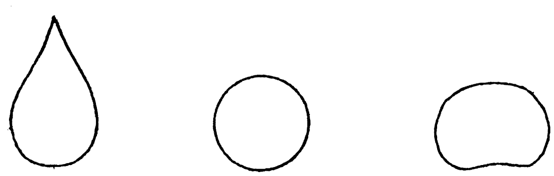


DAM A DAM B

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 13



Pointed Prolate Spherical Oblate (Flattened)

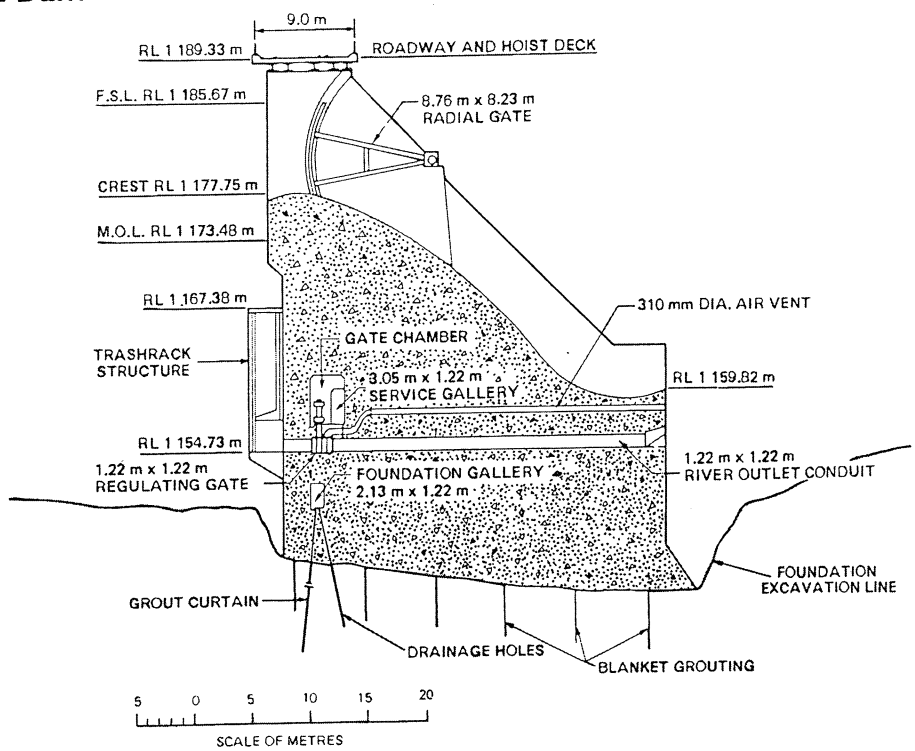
With reference to the sketches above state what shape a very large rain drop falling through the atmosphere is likely to assume - prolate, spherical or oblate. Explain fully why it would assume the chosen shape and compare this shape with the likely shape of a very small raindrop.

(5 marks)

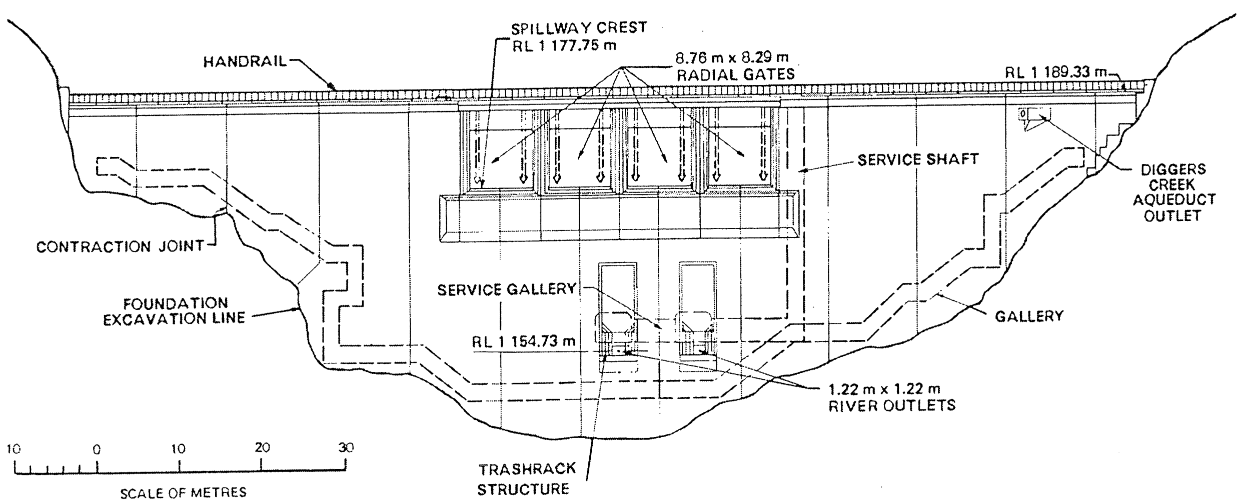
EXAMINATION PAPER ATTACHMENTS

QUESTION 4 ISLAND BEND DAM

Section through Island Bend Dam

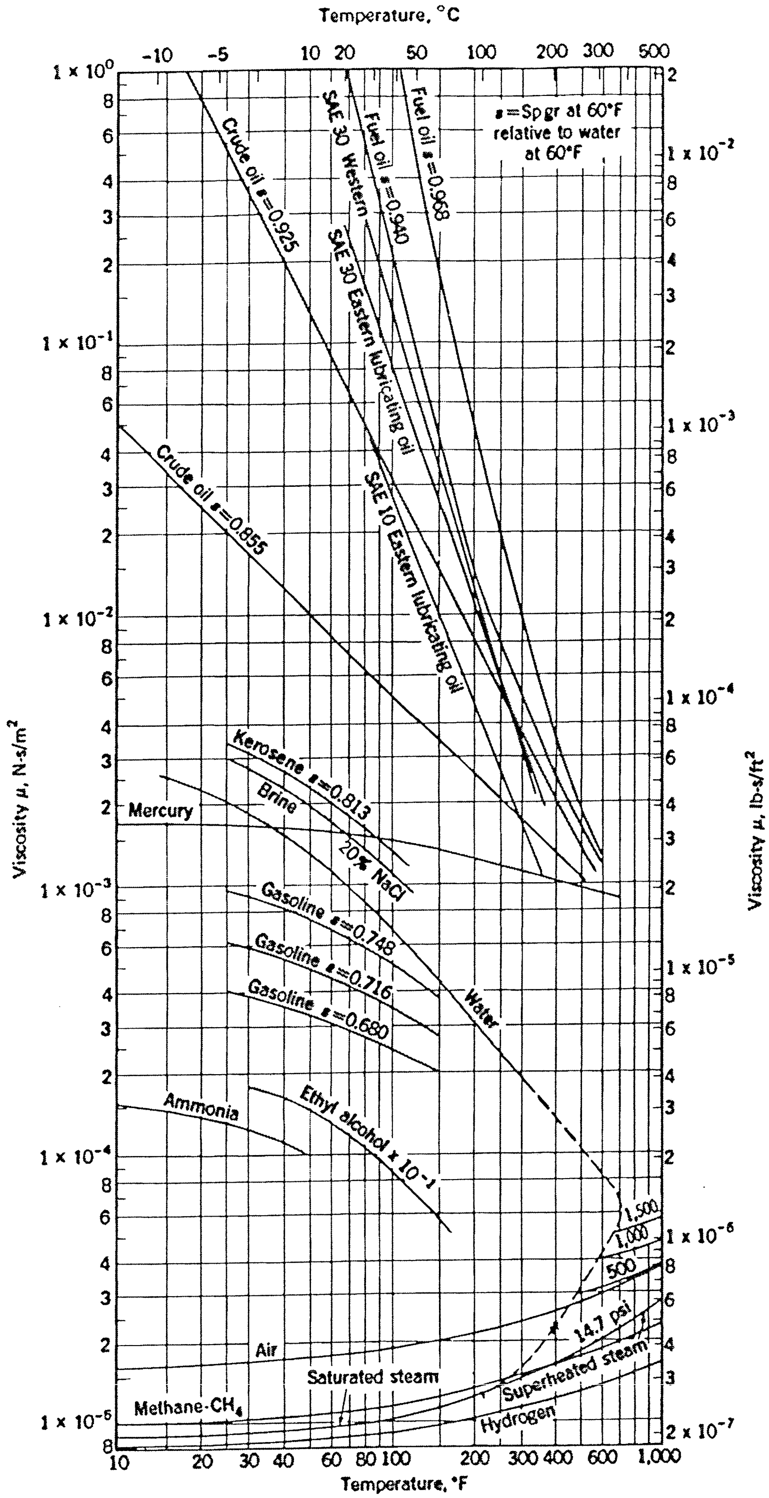


Upstream Elevation of Island Bend Dam



EXAMINATION PAPER ATTACHMENTS

QUESTION 5 ABSOLUTE VISCOSITY NAME ....



Absolute viscosity μ of fluids.

QUESTION 8 DRAG DIAGRAM FOR SOLID BODIES NAME ....

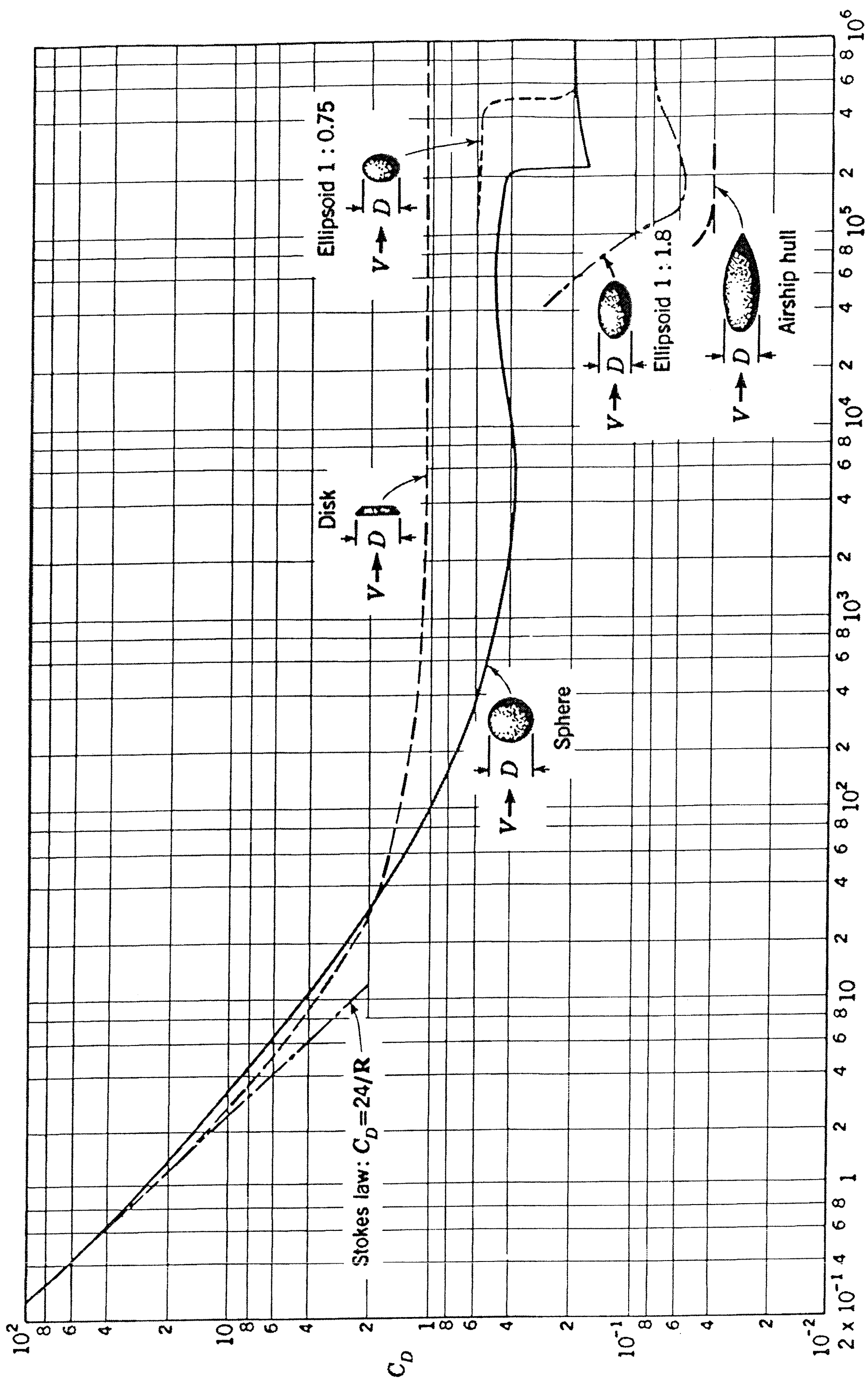
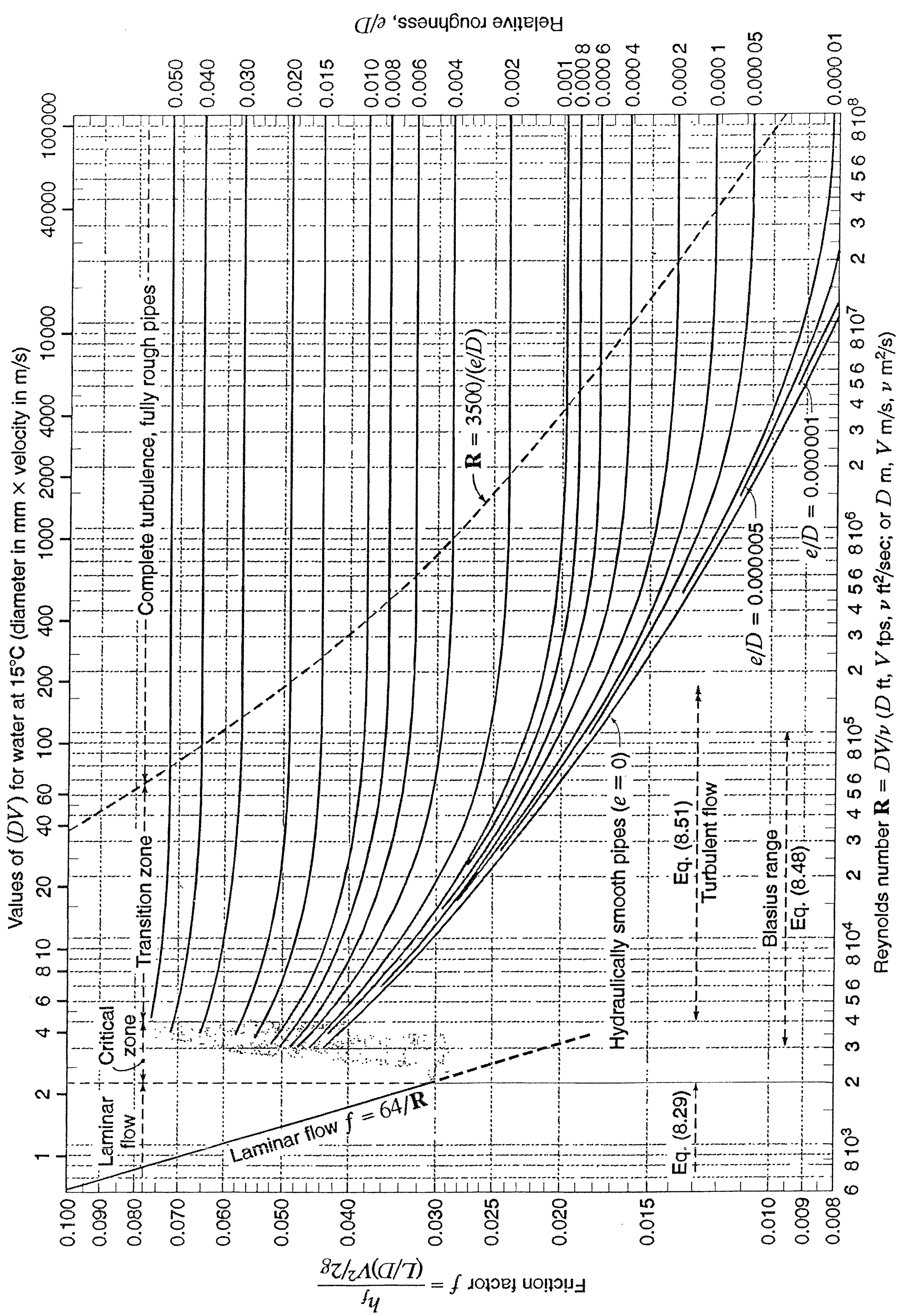


Figure 10.10 Drag coefficient for bodies of revolution. (Adapted from L. Prandtl, "Ergebnisse der aerodynamischen Versuchsanstalt zu Göttingen," p. 29, R. Oldenbourg, Munich and Berlin, 1923; and F. Eisner, "Das Widerstandsproblem," *Proc. 3d Internatn. Congr. Appl. Mech., p. 32, 1930.*)

QUESTION 9 & QUESTION 11 MOODY DIAGRAM

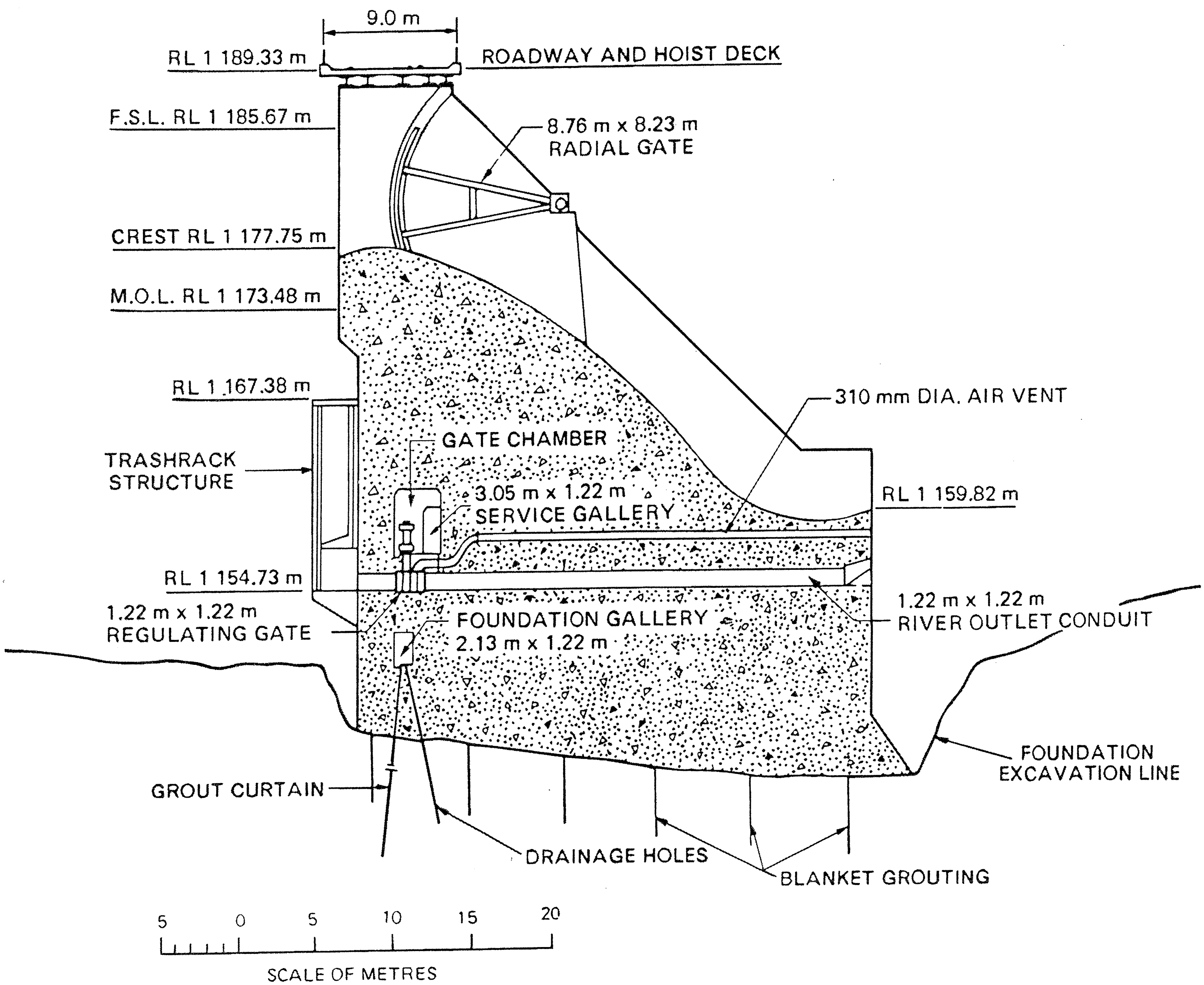
NAME ....



Moody chart for pipe friction factor (Stanton diagram).

QUESTION 10 ISLAND BEND DAM NAME ....

Section through Island Bend Dam



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

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 ~ 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

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