NATIONAL EXAMINATIONS

December 2019

04-BS-7 MECHANICS OF FLUIDS

Three (3) hours duration

Notes to Candidates

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

2. The examination 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 9 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. **Nomenclature** and **Reference Equations** are given on pages 13 to 16.

SECTION A CALCULATIVE QUESTIONS

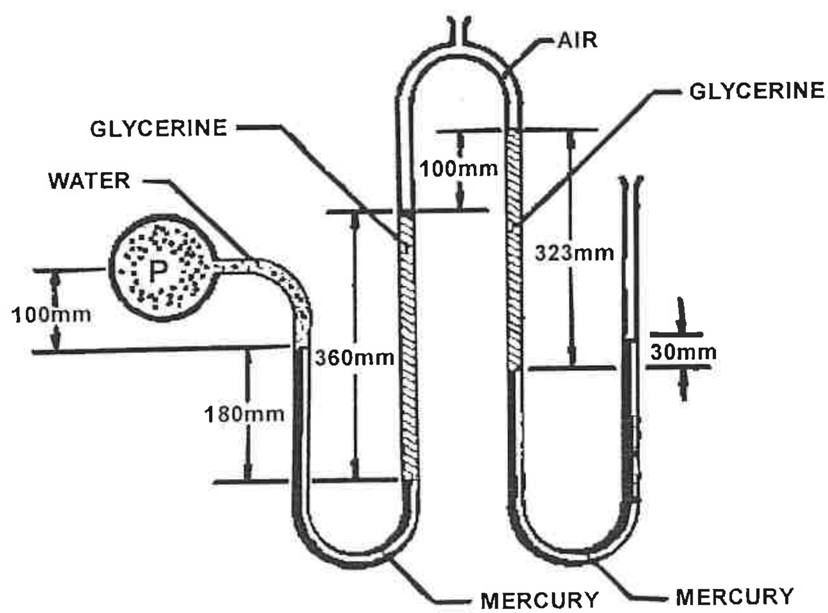
Do seven of nine questions. ***Solutions to these questions must be set out logically with equations and calculation steps shown. All intermediate answers and units must be given.***

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 12 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.

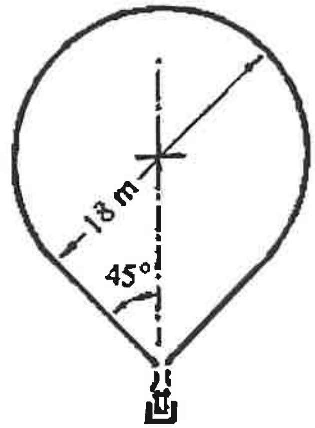


(5 marks)

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.

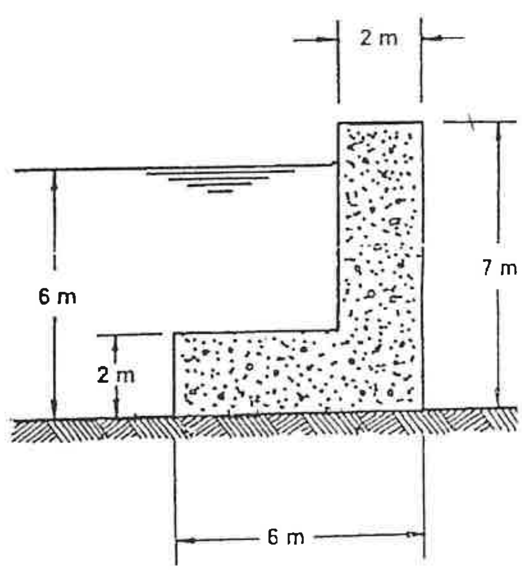
(5 marks)

QUESTION 3

A concrete canal wall designed to minimize land usage has dimensions as indicated in the adjoining sketch. Determine whether or not this design will ensure that the entire base in contact with the ground is under compressive stress, that is, that the resultant force passes through the middle third of the base. Show clearly on a sketch all the forces to be considered as well as the point about which moments are taken. Refer to the **Constants** on Page 12 for the density of concrete.

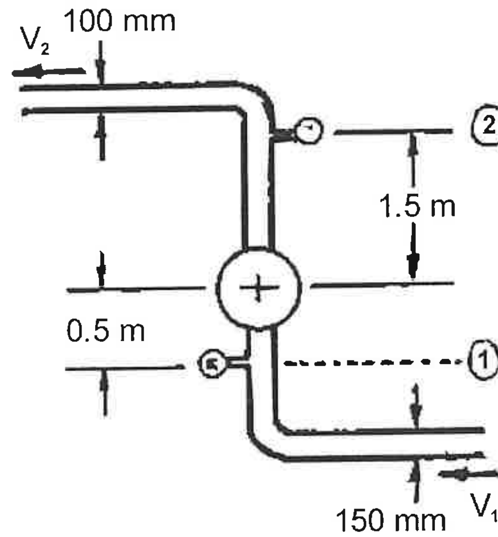
Note: The middle third is the centre part of the base that is 2 m from each side of the base.

Hint: Consider the moments of the forces about a point at the extreme right hand side of the base.



(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

Assume that a centrifugal pump and flow system can be mathematically modelled as follows:

Pump:	H	=	$A N^2 - B Q^2$
System:	H	=	$C + D Q^2$

where the constants and variables are as follows:

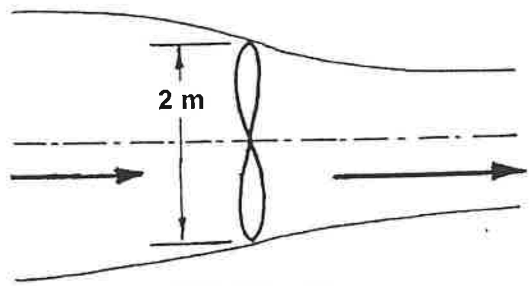
H	=	Head (m)
Q	=	Flow (m^3/s)
N	=	Pump Speed (rev/min)
A	=	0.000 060
B	=	1.6
C	=	Static Head (m)
D	=	10

For a pump speed of 900 rev/min and a static head of 20 m determine the operating point in terms of flow Q and head H. Show, in a sketch, the pump and system characteristics as well as the operating point.

(5 marks)

QUESTION 6

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.

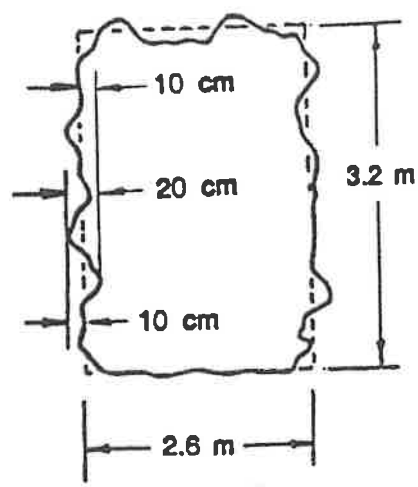


(5 marks)

QUESTION 7

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

A sloping underground tunnel provides ventilation to the working face of a coal mine. The tunnel is 2.6 m wide and 3.2 m high and slopes from the surface to the mining area over a distance of 1.5 km. The tunnel is unlined and the surface has an irregular profile with rock projections and depressions of 10 cm on either side of the nominal profile. Air at a temperature of 15°C flows through the tunnel at a mean velocity of 8 m/s. Determine the pressure drop in the tunnel.



(5 marks)

QUESTION 8

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

A concrete water supply pipeline of 1 m diameter is laid over a distance of 10 km. The outlet of the pipe is 40 m lower than the inlet. Determine the flow rate in the pipe. Neglect entrance and exit losses. Assume an absolute roughness of 1 mm.

Hint: Develop equations for friction factor and Reynold number in terms of velocity. Guess two or more velocities and plot the corresponding friction factor versus Reynolds number on the Moody diagram for each chosen velocity. Draw a line through these points and read the answer from the diagram. Return the diagram showing the result.

(5 marks)

QUESTION 9

Refer to the Examination Paper Attachments Page 11 **Drag on Boeing 747.**

The diagram gives the drag coefficient C_D which corresponds with the lift coefficient C_L of a Boeing 747. These coefficients are based on the wing area which is 511 m^2. If the total weight of a fully loaded Boeing 747-400 (extended cab) on reaching its cruising altitude is 320 Mg (tonnes) and its speed is Mach 0.89 determine:

(a) The coefficient of lift when flying at an altitude of 10 km where the air temperature and pressure are -50°C and 26 kPa respectively.

(b) The coefficient of drag corresponding with the coefficient of lift at the conditions in (a) above.

(c) The thrust power required to maintain the speed of the aircraft.

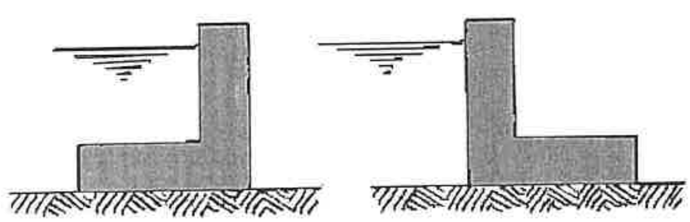
Note that the Mach number is the speed of the aircraft divided by the speed of sound. The velocity of sound a is given by $a = (kRT)^{1/2}$ where k for air is 1.4. Show on the diagram where values were plotted and read. *Return the diagram with your answer booklet.*

(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

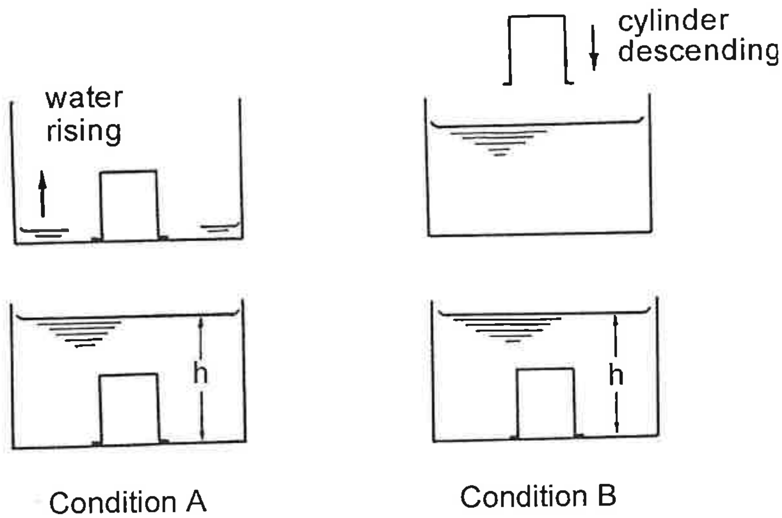


DAM A DAM B

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 11



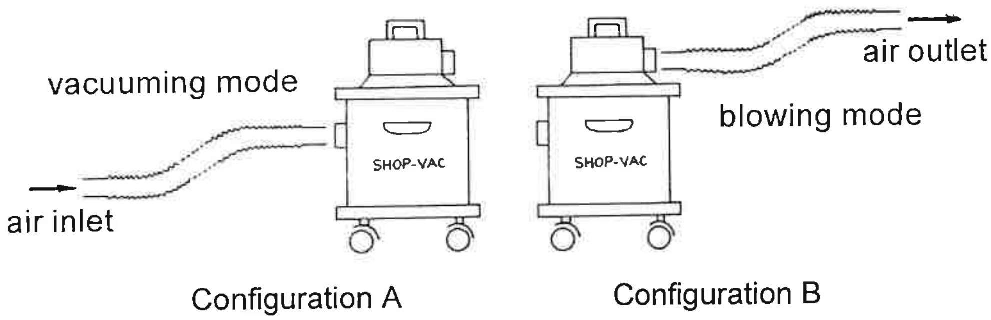
A vertical cylinder, open at the bottom and closed at the top, is immersed in water in a tank. The bottom rim of the cylinder has a seal to prevent any leakage when the cylinder is seated on the bottom of the tank.

In Condition A the cylinder is first seated on the bottom of the tank and the tank then filled with water. In Condition B the tank is initially filled with water and the cylinder then immersed, in a vertical orientation, until seated on the bottom of the tank. The top diagrams show the initial process and the bottom diagrams the final position.

When the cylinder is fully immersed the depth of the water h in both A and B is the same. State whether the air pressure inside the cylinder in B will be less than / equal to / greater than that in cylinder in A. Explain your answer fully and say how the pressure in each could be determined.

(5 marks)

QUESTION 12

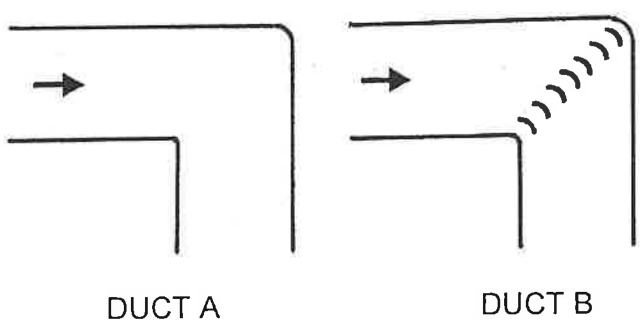


Consider a workshop vacuum cleaner used for clearing away sawdust in a carpentry shop. The flexible hose can be connected to the inlet, as in Configuration A, to suck up and collect sawdust from the floor, or to the outlet, as in Configuration B, to blow away sawdust from machine parts. In the vacuuming mode the nozzle has to be held very close to the surface in order to be effective in collecting the sawdust, but in the blowing mode it can be held quite far away and still clear the sawdust away.

Explain why this is the case. Clarify your explanation with diagrams in the answer booklet showing air flow streamlines at both the inlet and outlet nozzles. In both cases the flexible hose and nozzle are the same dimensions and the air flow the same magnitude.

(5 marks)

QUESTION 13

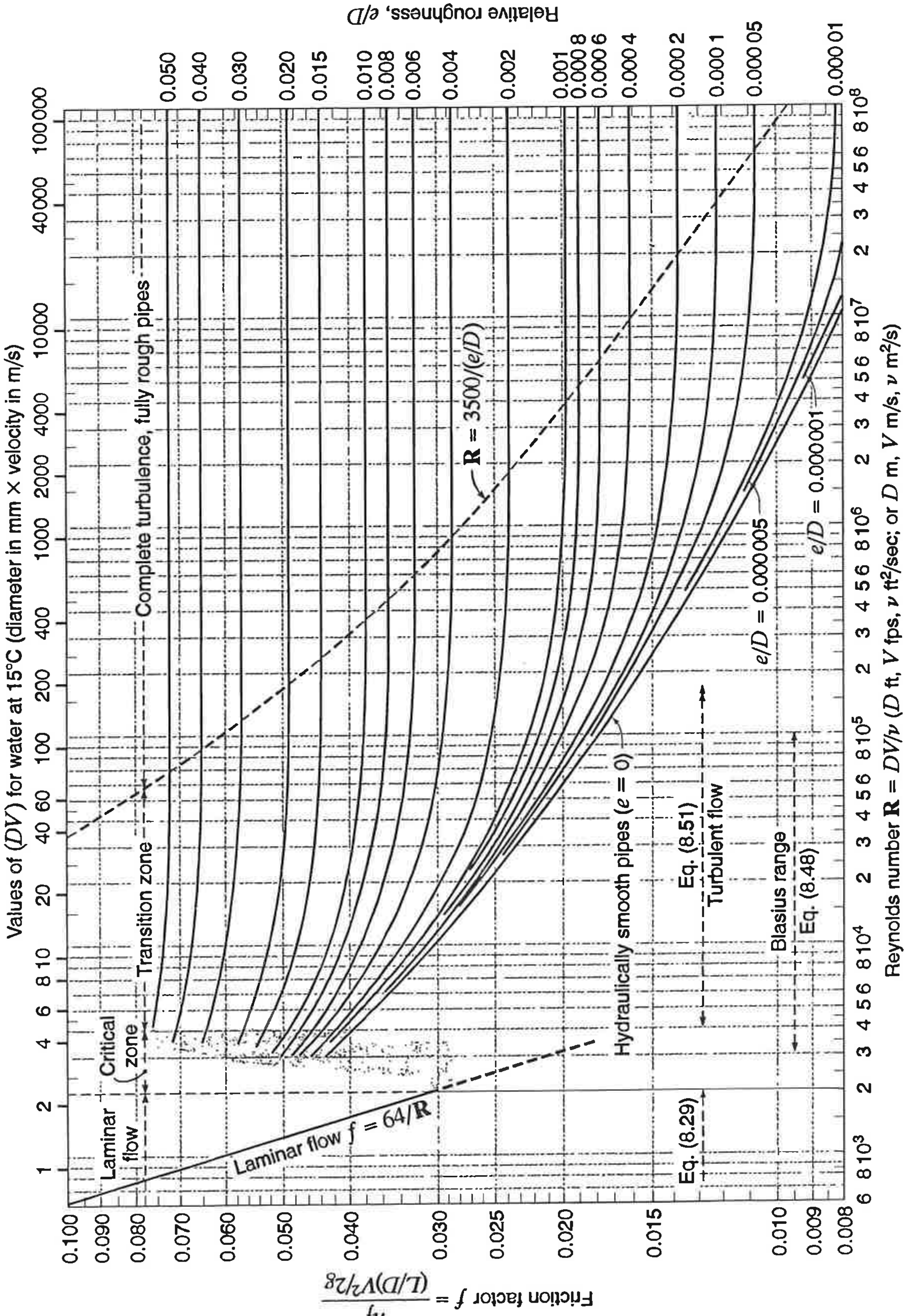


A large duct carrying air at a high velocity has a 90° bend as shown in the diagram above. Duct A has no inserts. Duct B has curved vanes at the bend as shown. State which bend will have the lesser head loss. Explain why the selected duct has less head loss. Sketch, in the answer booklet, the flow pattern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

(5 marks)

EXAMINATION PAPER ATTACHMENTS

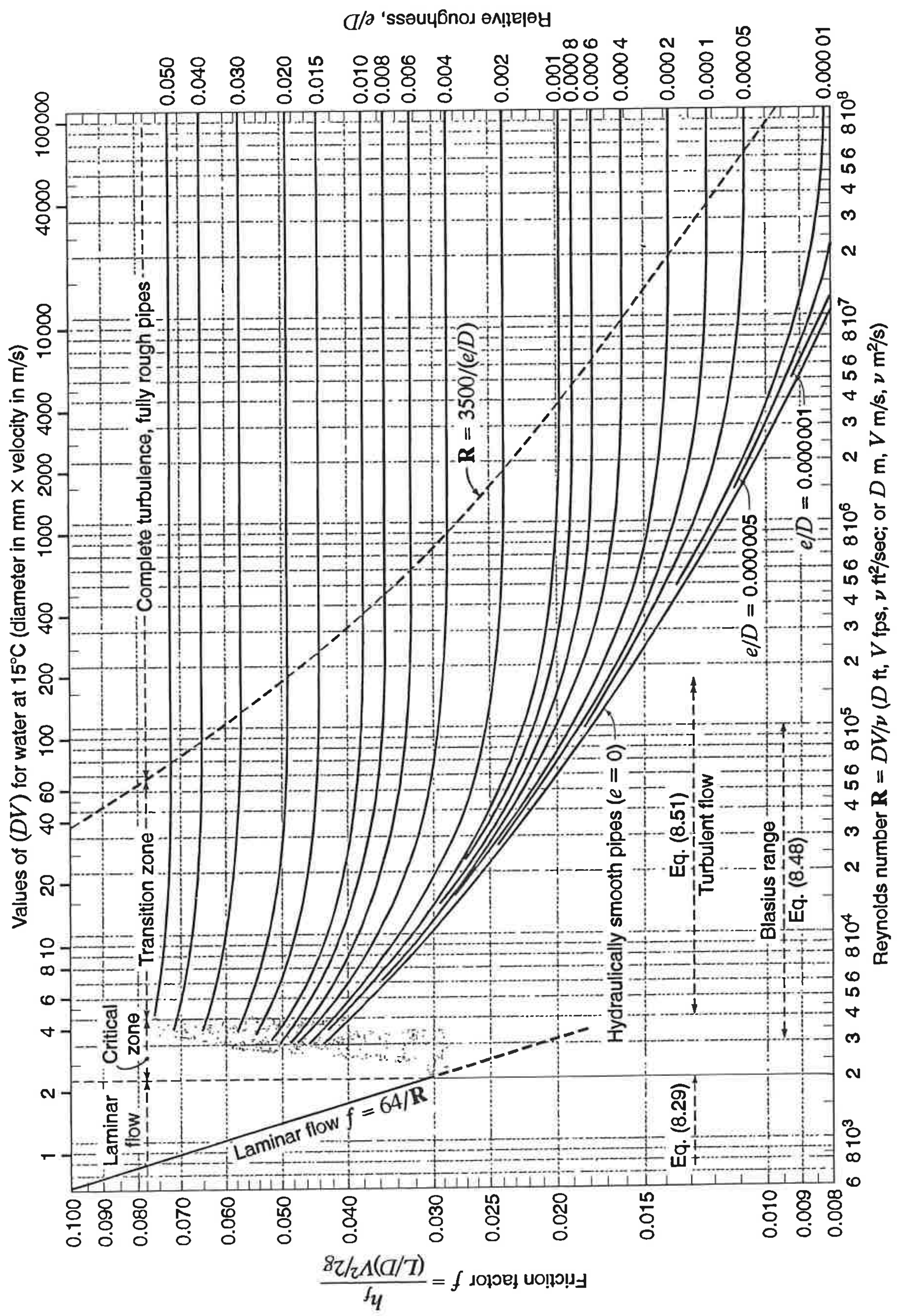
QUESTION 7 MOODY DIAGRAM **NAME ....**



Moody chart for pipe friction factor (Stanton diagram).

EXAMINATION PAPER ATTACHMENTS

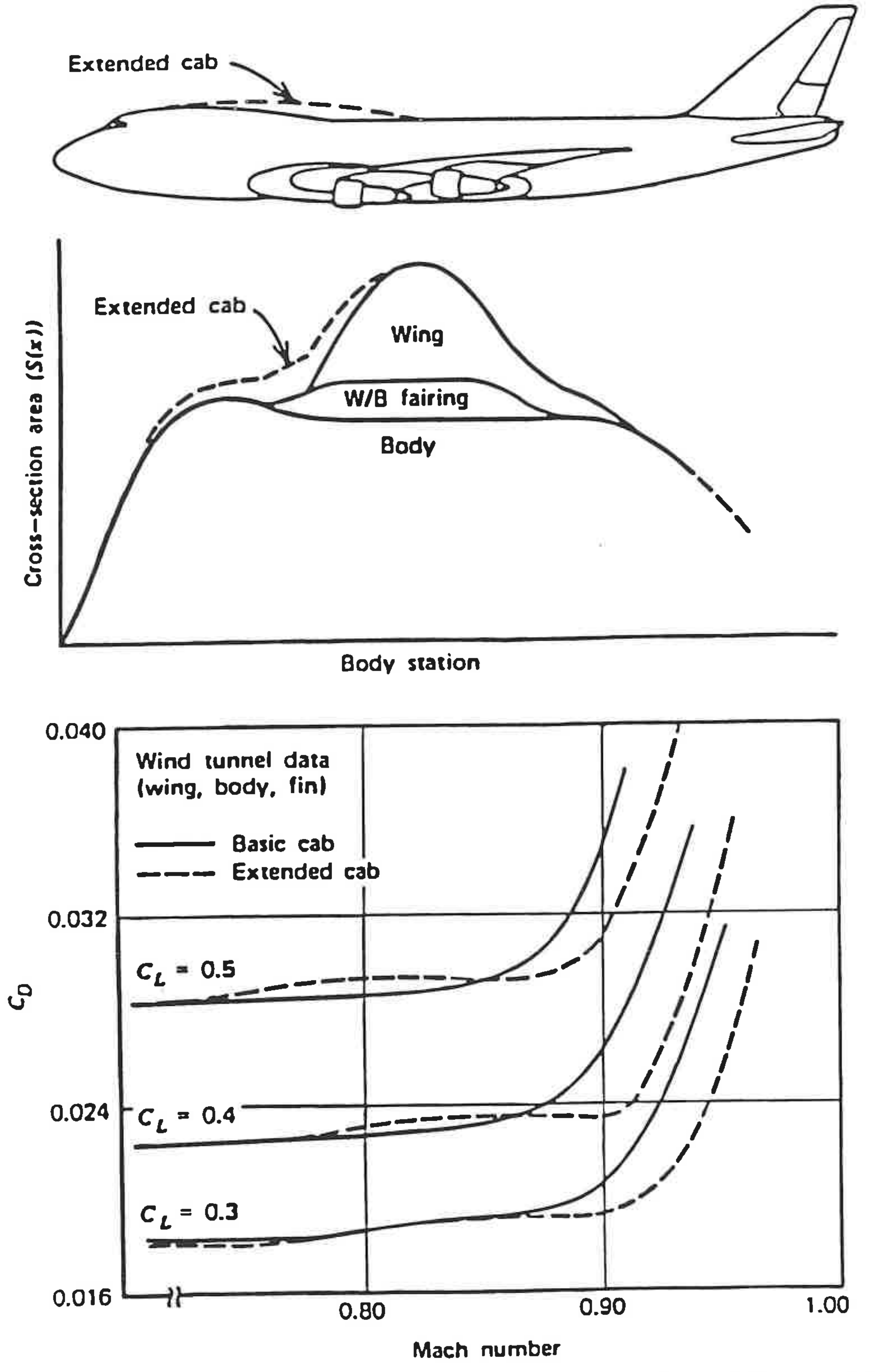
QUESTION 8 MOODY DIAGRAM **NAME ....**



Moody chart for pipe friction factor (Stanton diagram).

EXAMINATION PAPER ATTACHMENTS

QUESTION 9 DRAG ON BOEING 747 NAME ....



Effect of cross sectional area S(x) on measured drag of Boeing 747 due to fuselage modification

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

Closed Conduit: $F_R = p_1 A_1 - p_2 A_2 - M (V_2 - V_1)$
Open Channel: $F_R = p_1 A_1 - p_2 A_2 - M (V_2 - V_1)$
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: $P = \frac{1}{2} \rho Q V^2$
Moving Blades: $P = M \Delta V U$

Aircraft Propulsion

$F_{thrust} = M (V_{jet} - V_{aircraft})$
$P_{thrust} = M (V_{jet} - V_{aircraft}) V_{aircraft}$
$E_{jet} = \frac{1}{2} (V_{jet}^2 - V_{aircraft}^2)$

$P_{jet} = \frac{1}{2} M (V_{jet}^2 - V_{aircraft}^2)$

$E_{fuel} = CV_{fuel}$

$P_{fuel} = M_{fuel} CV_{fuel}$

$\eta_{thermal} = P_{jet} / P_{fuel}$

$\eta_{propulsion} = P_{thrust} / P_{jet} = 2 V_{aircraft} / (V_{jet} + V_{aircraft})$

$\eta_{overall} = \eta_{thermal} \times \eta_{propulsion}$

Wind Power

$P_{total} = \frac{1}{2} \rho A_T V_1^3$

$P_{max} = 8/27 \rho A_T V_1^3$

$H_{max} = P_{max} / P_{total} = 16/27$

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: $F_f = C_f \frac{1}{2} \rho V^2 B L$ $(B = \pi D)$

Pressure Drag: $F_p = C_p \frac{1}{2} \rho V^2 A$

Total Drag: $F_D = C_D \frac{1}{2} \rho V^2 \mathbf{A}$

Aircraft Wing: $F_L = C_L \frac{1}{2} \rho V^2 A_{wing}$

Aircraft Wing: $F_D = C_D \frac{1}{2} \rho V^2 A_{wing}$

Karmen Vortex Frequency

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