NATIONAL EXAMINATIONS

May 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.

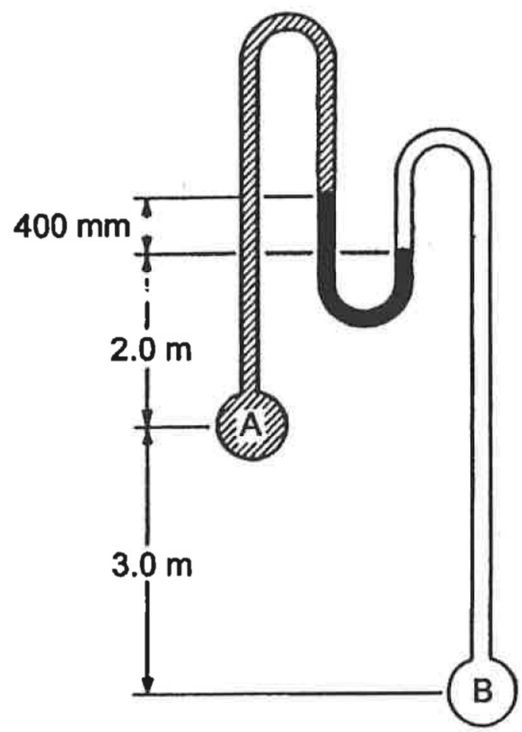
SECTION A CALCULATIVE QUESTIONS

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 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 12 for specific gravities.



(5 marks)

QUESTION 2

A pitot-static tube is used for measuring the air flow in a duct. A differential manometer containing water is connected between the dynamic and static measuring points of the pitot-static tube. The ambient temperature is 20°.

(a) Sketch the pitot-static together with the differential manometer and show clearly the connections to the pipe.

(b) If the reading on the manometer is 24 mm, determine the air velocity in the duct.

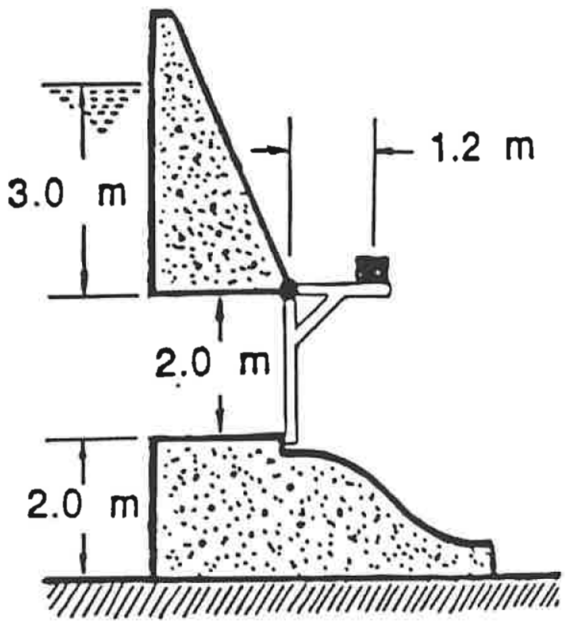
(c) If the same air velocity were measured using a differential pressure gauge instead of a manometer, determine the differential pressure reading on the gauge in kPa.

(5 marks)

QUESTION 3

The adjoining sketch shows a hinged gate in the wall of a dam. The gate is rectangular being 1.5 m wide and 2.0 m high. It is located so that the top of the gate is 3.0 m below the normal water level. It is held closed by a weight located 1.2 m from the hinge. Calculate the required mass for the weight such that the gate will begin to open on rising water level. Neglect the mass of the gate.

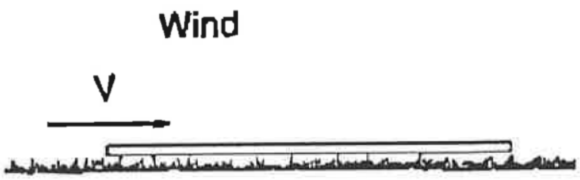
Note: Moment of Inertia Ic of a rectangle about its centroid is $I_c = (bh^3/12)$ where b is width and h is height



(5 marks)

QUESTION 4

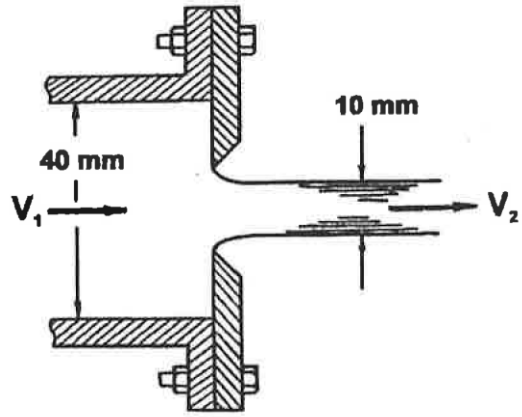
Preformed fibre insulation panels 2.438 m x 1.219 m x 25 mm are used to insulate a building. During construction some are left lying flat on grass as shown in the adjoining sketch. If the density of a panel is 100 kg/m^3 calculate the minimum wind velocity (in km/hr) at ground level which will lift the panel and blow it away. Note that the grass under the panel reduces the air velocity to stagnation conditions. Assume an air temperature of 20°C



(5 marks)

QUESTION 5

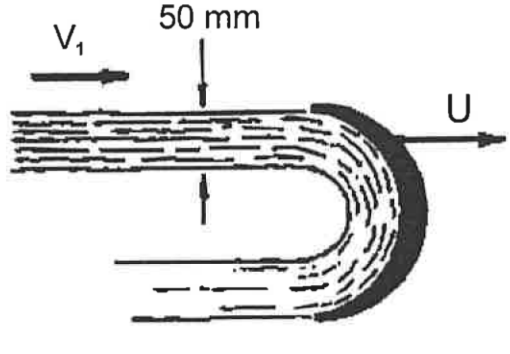
A high velocity water jet is created by attaching a plate with a sharp edged orifice to the end of a pipe 40 mm in diameter. The pressure in the pipe is 3 MPa gauge. Calculate the velocity in the pipe and in the 10 mm diameter jet so created and hence the flow rate from the nozzle. Assume ideal flow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



(5 marks)

QUESTION 6

A jet of water with a diameter of 50 mm and a velocity V_1 of 30 m/s strikes a curved plate and is turned completely through 180° without friction loss. The plate is driven by the jet and in the same direction as the jet.



(a) Calculate the force exerted on the plate when the plate is moving at a speed U of 10 m/s.

(b) Calculate the power developed by the plate when moving at 10 m/s.

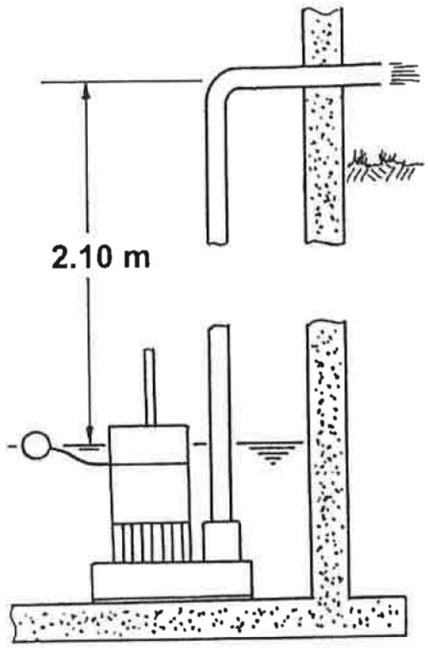
(c) Calculate the efficiency of energy transfer between the jet and the plate.

(d) Determine the speed of the plate U that will give the maximum efficiency and state with a reason why this speed gives the best efficiency.

(5 marks)

QUESTION 7

During an actual test of a ¼ HP Mastercraft submersible sump pump, shown in the adjoining diagram, the pump discharged water at a rate of 96 litres/minute. The difference in height between the water surface in the sump and the point of discharge was 2.10 m. The head loss in the discharge pipe was 1.03 m. Assume that the input to the pump is 186 W (¼ HP).



(a) Calculate the efficiency of the pump.

(b) Comment on the value of the efficiency as calculated in (a) above. State what factors could affect the calculation of efficiency or the efficiency of the pump.

(5 marks)

QUESTION 8

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

The discharge pipe for the ¼ HP Mastercraft submersible sump pump, as shown in the diagram for Question 7 above, is a flexible corrugated plastic pipe as shown in the adjoining picture. The dimensions for this pipe are as follows:

Inside diameter	32 mm
Outside diameter	38 mm
Overall length	2.85 m

Neglect the thickness of the plastic wall of the pipe and ignore the effect of any bends.

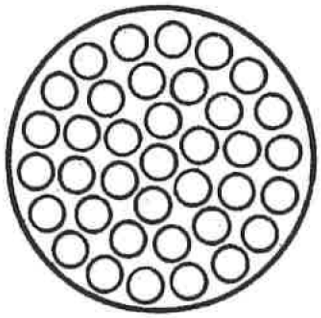
Calculate the head loss over the length of the pipe with a flow of 96 litres/minute.

Note: Return page 9 with your answer booklet and with your name on it.

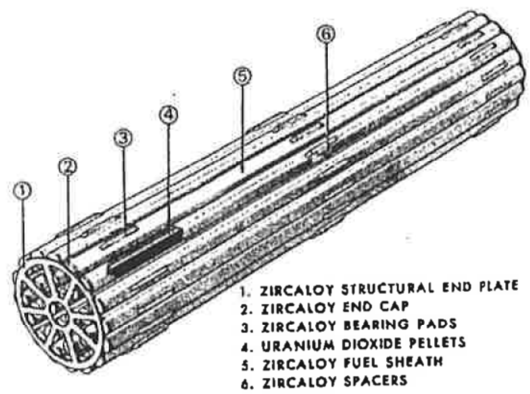
(5 marks)

QUESTION 9

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



END VIEW INSIDE PRESSURE TUBE



The diagram on the right above shows a fuel bundle as used in a CANDU nuclear reactor. A typical reactor has a dozen such bundles in several hundred pressure tubes through which coolant (heavy water) flows to remove the heat generated in the fuel. The diagram on the left above shows the flow cross section with the fuel rods which hold the fuel pellets. The rods are surrounded by coolant which in turn flows within the larger pressure tube.

Calculate the pressure drop in kPa within the pressure tube over the length of one of the bundles assuming the following specified and operational parameters:

Internal diameter of pressure tube	104.0 mm	
External diameter of fuel rods	13.1 mm	
Number of fuel rods	37	
Length of fuel bundle	495 mm	
Density of water	712 kg/m^3	at ~300°C
Viscosity of water	9.0 x 10^{-5} Ns/m^2	at ~300°C
Coolant flow rate	24 kg/s	

Neglect the effect of the spacers between the fuel rods and the end plates as well as entrance and exit losses.

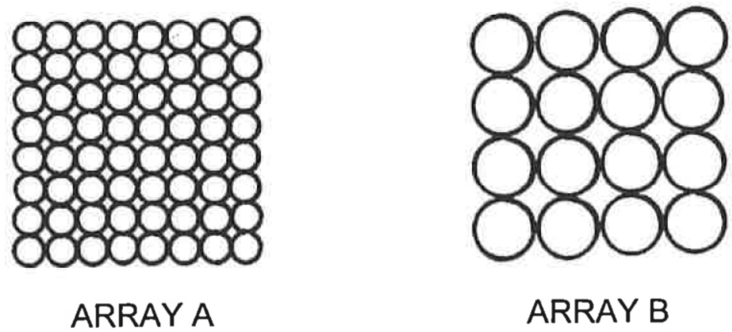
Note: Return page 10 with your answer booklet and with your name on it.

(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.**

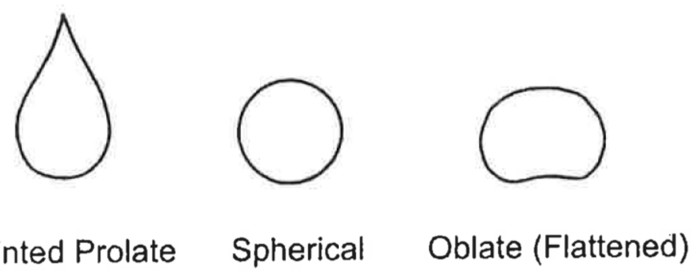
QUESTION 10



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 11

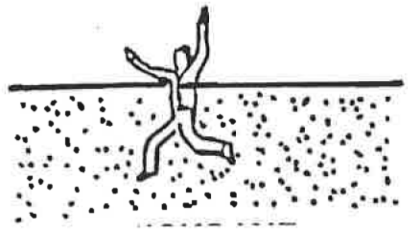


With reference to the sketches above state what shape a very large rain drop falling through the atmosphere is likely to assume - prolate, spherical or oblate. Explain why it would assume the chosen shape and compare this shape with the likely shape of a very small raindrop.

(5 marks)

QUESTION 12

Light Oil



Quicksand

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 more deeply. Give a full explanation for your answer.

(5 marks)

QUESTION 13

Refer to the Examination Paper Attachments Page 11 **Aircraft Wing**

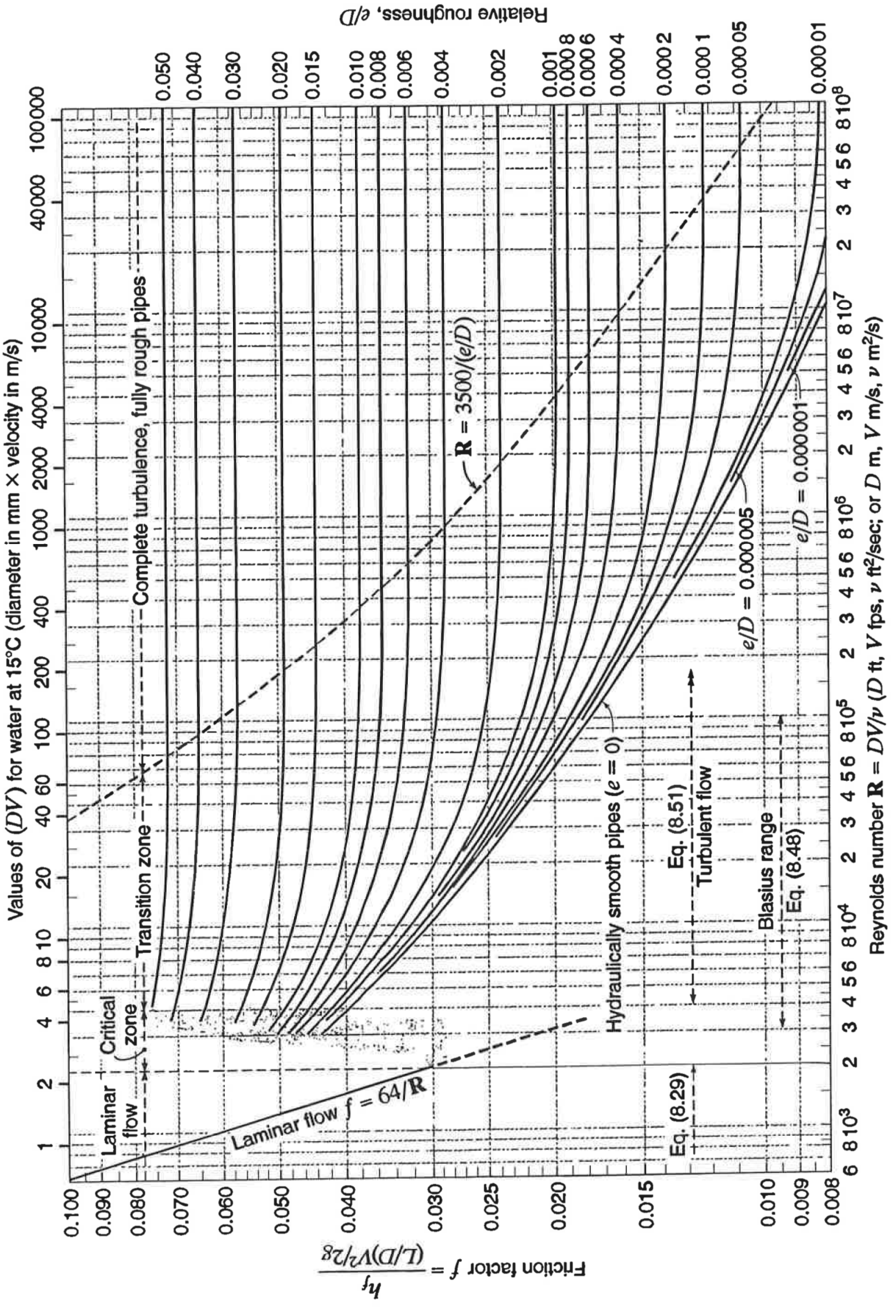
The attached diagram shows an aircraft wing in different configurations. State when and why these different configurations (A, B, C) are used. Explain the physical phenomena contributing to high lift conditions and drag effects.

(5 marks)

EXAMINATION PAPER ATTACHMENTS

QUESTION 8 MOODY DIAGRAM

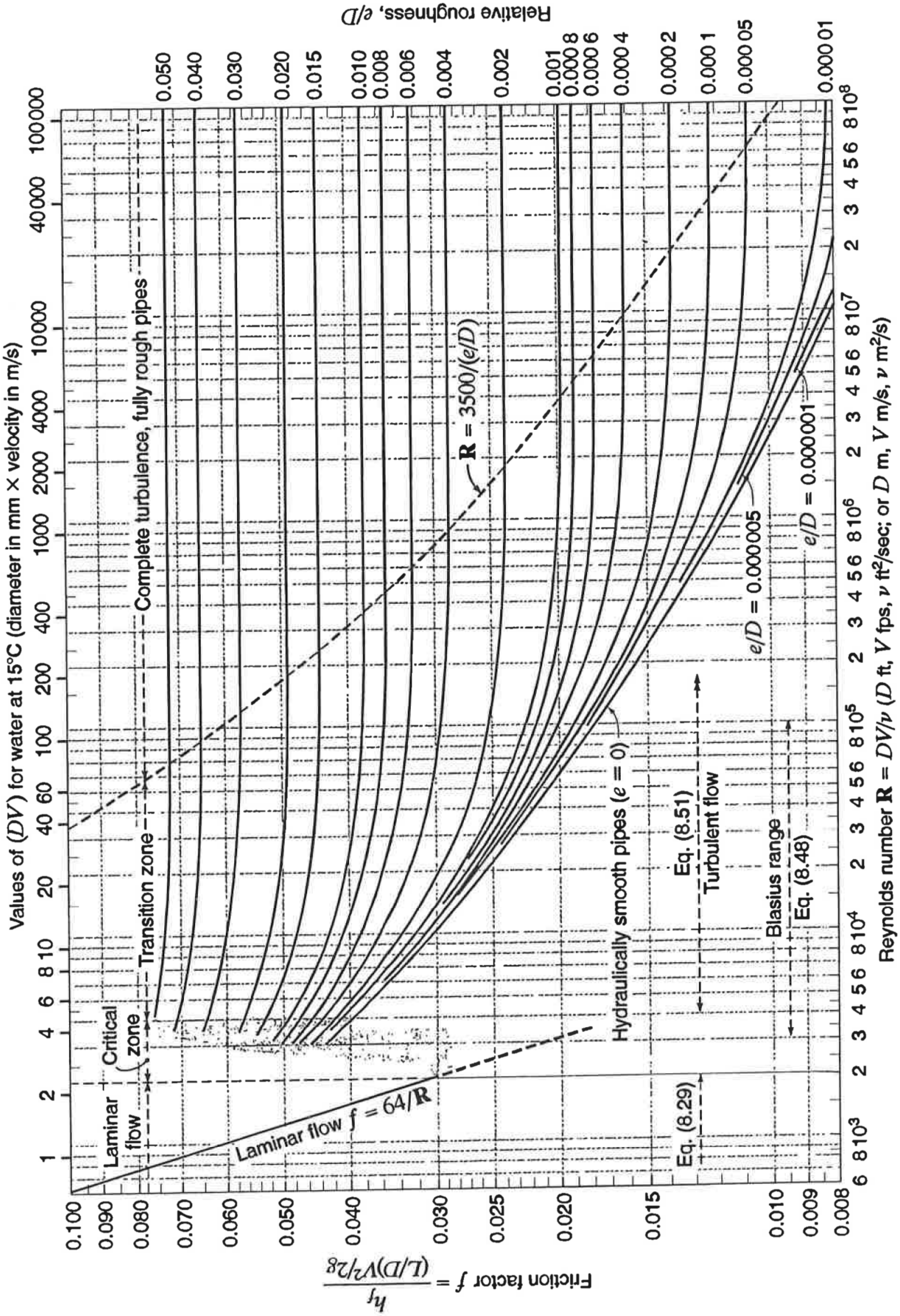
NAME ....



Moody chart for pipe friction factor (Stanton diagram).

EXAMINATION PAPER ATTACHMENTS

QUESTION 9 MOODY DIAGRAM NAME ....

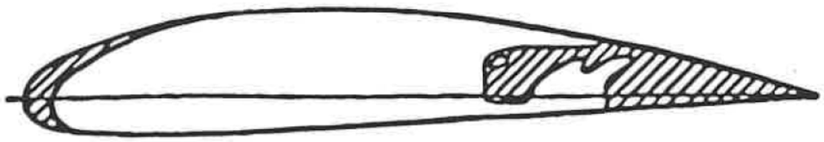


Moody chart for pipe friction factor (Stanton diagram).

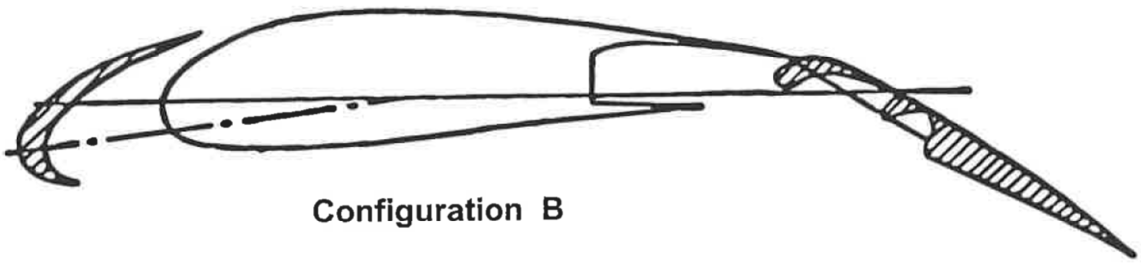
EXAMINATION PAPER ATTACHMENTS

NAME ....

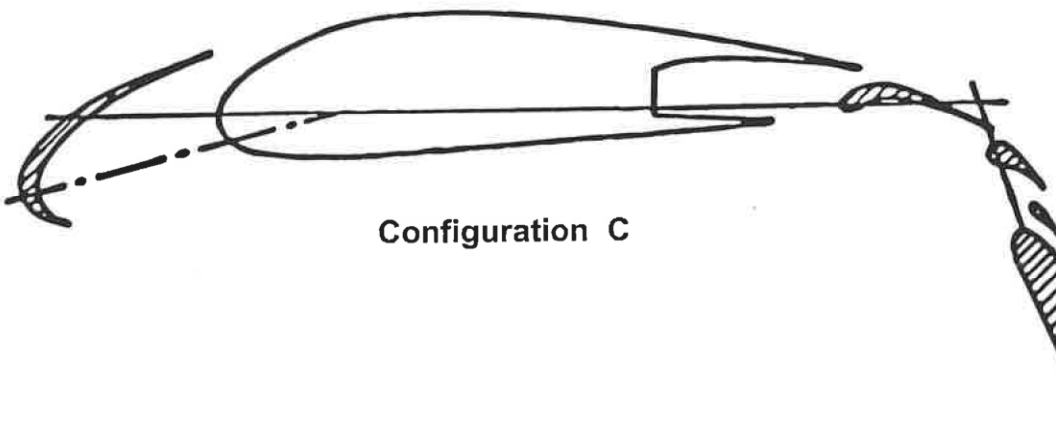
QUESTION 13 AIRCRAFT WING



Configuration A



Configuration B



Configuration C

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

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