NATIONAL EXAMINATIONS

December 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 to 10. **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 11.

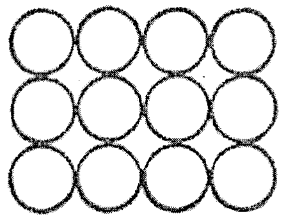
10. **Reference Equations** are given on pages 12 to 15.

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

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 $\sigma = 0.073$ N/m and the wetting angle $\theta = 0°$. Calculate the height above the free water surface to which the water will rise under these conditions.



(5 marks)

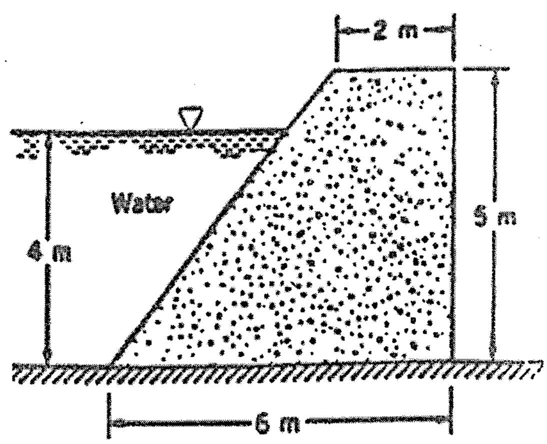
QUESTION 2

A Chrysler 2.2 litre engine has five main bearings supporting the crankshaft. The shaft is 60.000 mm in diameter while the bearing is 60.100 mm in diameter and 22.5 mm long. The clearance space (assumed to be uniform) is filled with SAE 30 western lubricating oil at 40°C. The absolute or dynamic viscosity μ at this temperature is 0.1 Ns/m^2. Calculate the rate at which heat is generated and dissipated in the bearings when the shaft turns at 2800 rpm (equivalent to a road speed of 100 km/hr). Express the answer in J/s.

(5 marks)

QUESTION 3

The concrete dam shown in the adjoining figure has a density of 2400 kg/m^3 and rests on a solid foundation. Determine the minimum coefficient of friction between the dam and the foundation required to keep the dam from sliding at the water depth shown. Assume no fluid uplift pressure along the base. Base your analysis on a unit length of the dam.



(5 marks)

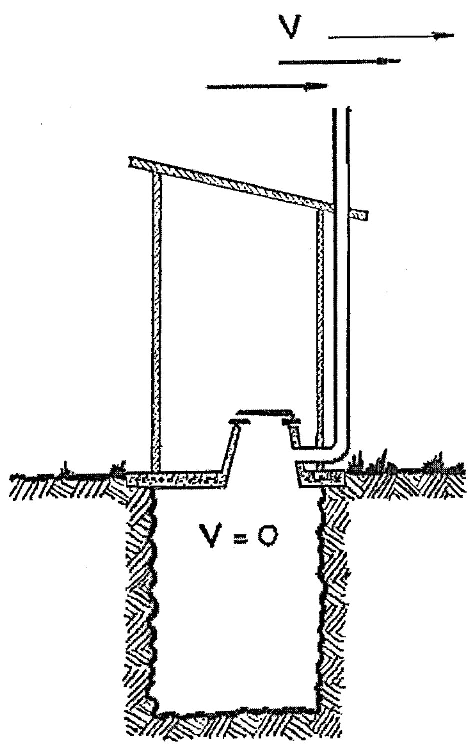
QUESTION 4

Water is pumped through a pipeline to supply the needs of a certain community. The pipe is 400 mm in diameter and 4800 m long. The flow rate is 0.36 m^3/s. It is suspected that corrosion in the pipe has caused excessive head loss so measurements are made at each end of the pipe. Near the pump the pressure is 2320 kPa and the elevation 84 m. Near the discharge the pressure is 120 kPa and the elevation 166 m. Calculate the head loss in the pipe.

(5 marks)

QUESTION 5

Outhouses as used by our predecessors particularly in rural areas were not much more than a hole in the ground with a seat on top. They were rather unpleasant to use until redesigned by someone with a knowledge of Bernoulli's theorem to extract the odours. By installing a simple vent pipe, air can be extracted from the top of the pit thereby minimizing its percolation into the outhouse structure. For a wind speed of 25 km/hr and an air temperature of 20°C, determine the differential pressure between the outside atmosphere and the pit to promote continuous air removal.



(5 marks)

QUESTION 6

A submersible package fountain (motor, pump and jet in a single unit) is required for a garden pond. The jet is to be 20 mm in diameter and is to shoot the water to a height of 2 m. When submersed the nozzle is just above the water surface. Assuming that the pump and hydraulic components have an overall efficiency of 65%, determine the power required to run the fountain.

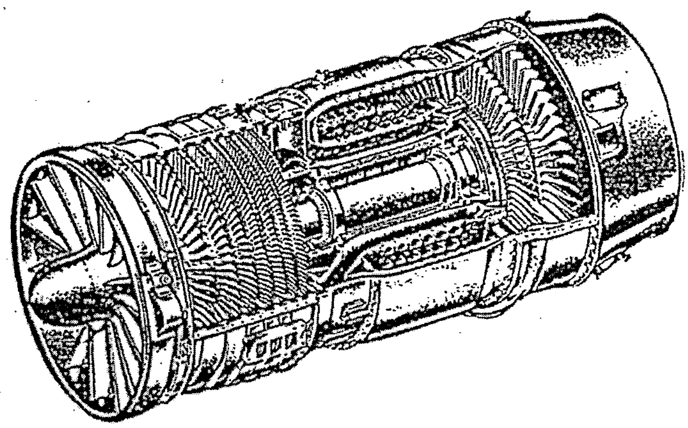
(5 marks)

QUESTION 7

The figure below 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 8 **Moody Diagram**

A commercial steel pipeline is required to convey water from a storage reservoir to a local supply head tank. The length of the pipeline is 5 km and the difference in head is 120 m. Select a suitable pipe diameter to give a flow rate of 1 m^3/s.

Return the diagram with your answer booklet to show your 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 in the range of 0.5 m to 0.7 m that will give points on the chart and plot these points. From a line through these points determine the pipe diameter.

(5 marks)

QUESTION 9

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

Consider a slurry of fine magnetite and water as is used for coal separation from rock. The magnetite is kept in suspension by agitation of the mixture and the resultant specific gravity of the slurry (about 1.5) is substantially higher than that of water. Coal will float in such a slurry but rock will sink. If agitation is stopped determine the rate of settling of the magnetite in the water. The magnetite particles are 50 μm in diameter and have a specific gravity of 5.0.

Since the particles are very small, assume Stokes' Law but determine, from the empirical curve, whether using Stoke's Law was a good assumption.

(5 marks)

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.**

QUESTION 10

Refer to the Examination Paper Attachments Page 10 **Dam Spillway.**

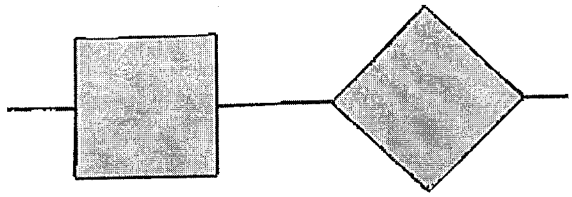
A small dam has a spillway over which water is discharged into a downstream channel. The water accelerates down the spillway and decelerates in an hydraulic jump in the channel.

(a) On the diagram sketch the profile of the water surface. Show clearly two or three representative streamlines and any zones of turbulence.

(b) Sketch the energy grade line and hydraulic grade line over the full extent of the flow disturbance caused by the spillway and hydraulic jump. Show clearly the relative magnitude of friction losses and velocity head.

(5 marks)

QUESTION 11



A B

A long bar of square cross section floats on water. If its specific gravity is one half that of water, determine its stable orientation (one flat side upwards as in **A** or edge between two flat sides upward as in **B**). For each of the two extreme conditions, determine the depth of the centre of buoyancy in terms of the dimension of the side of the square. Explain how the depth of the centre of buoyancy can be expected to determine the most stable orientation.

(5 marks)

QUESTION 12

NORMAL CONDITIONS FLOOD CONDITIONS

A wide shallow river of uniform depth and constant slope caries water at a certain flow rate. Under flood conditions the water depth is twice the normal depth. Assume that the river banks are high enough to prevent the river from increasing in width as the level rises.

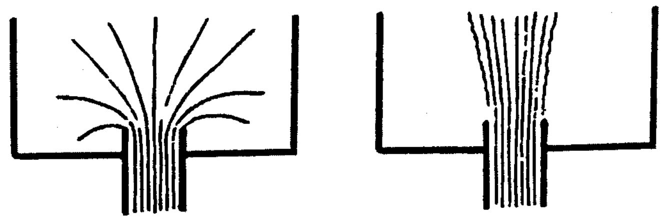
(a) State whether the velocity under flood conditions will be ***less than / the same as / greater than*** the normal flow velocity.

(b) State whether the flow rate will be ***less than / the same as / between one and two times / two times / greater than two times*** the normal flow rate.

Justify your answer with reference to the applicable theoretical relations.

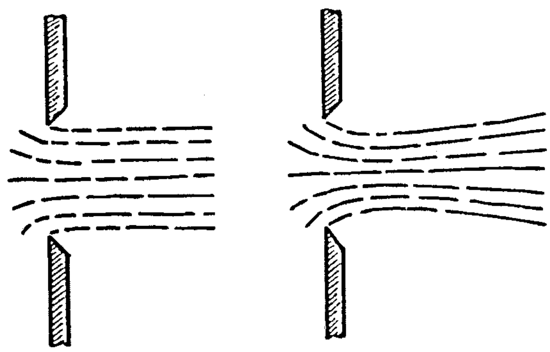
(5 marks)

QUESTION 13 FLOW CHARACTERISTICS



A B

(a) The two sketches **A** and **B** above show streamlines of flow entering or leaving a tank through a pipe in the bottom. State which tank has the flow entering and which has the flow leaving. Give a full explanation for your answer, clarifying what fluid characteristic determines the flow in each case.

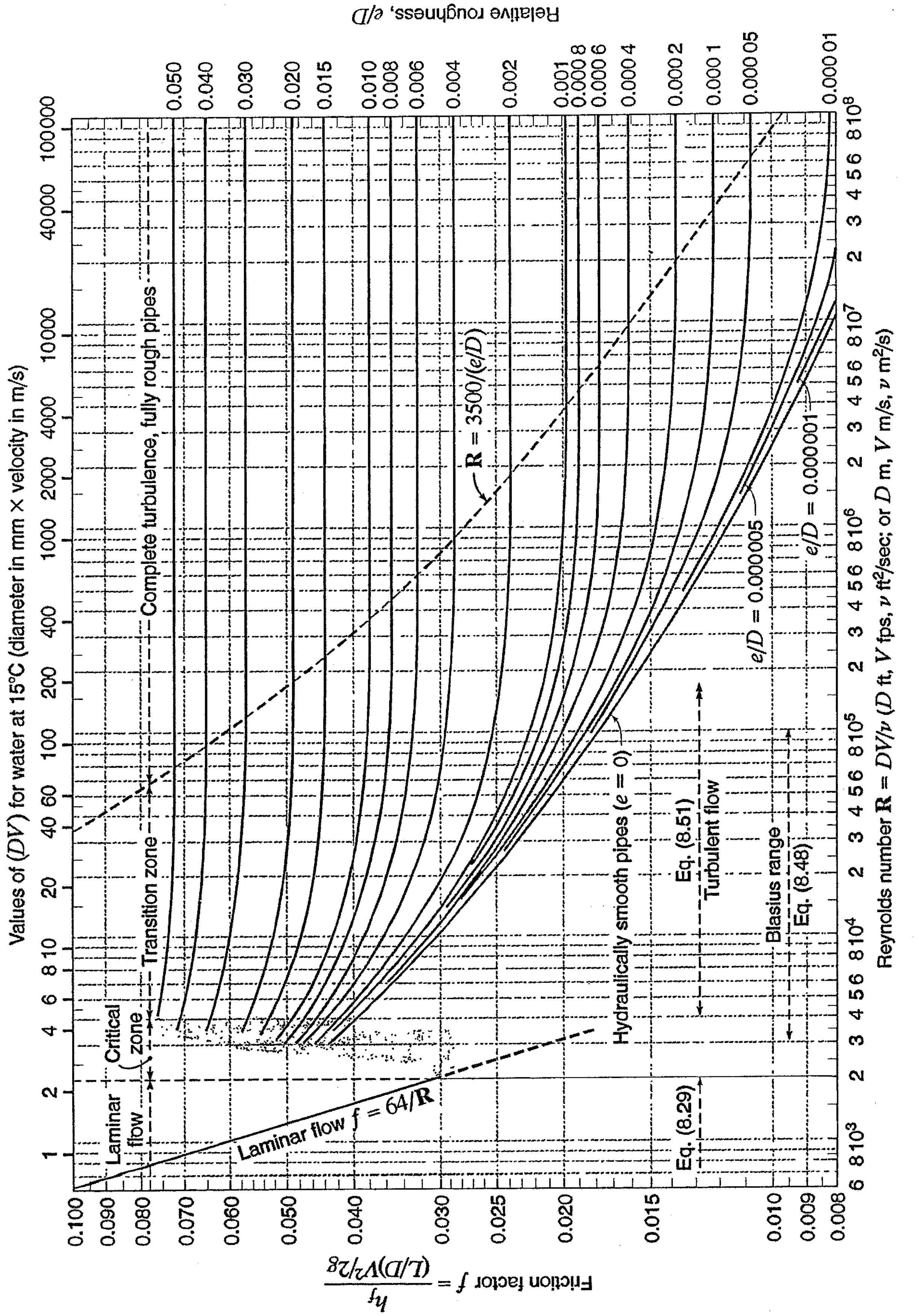


A B

(b) The two sketches **A** and **B** above show water being discharged through sharp edged orifices under different conditions. State which one has the greater Reynolds number. Give a full explanation for your answer, clarifying what fluid characteristics determine the change in shape of the jet.

(5 marks)

QUESTION 8 MOODY DIAGRAM NAME ....



Moody chart for pipe friction factor (Stanton diagram).

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

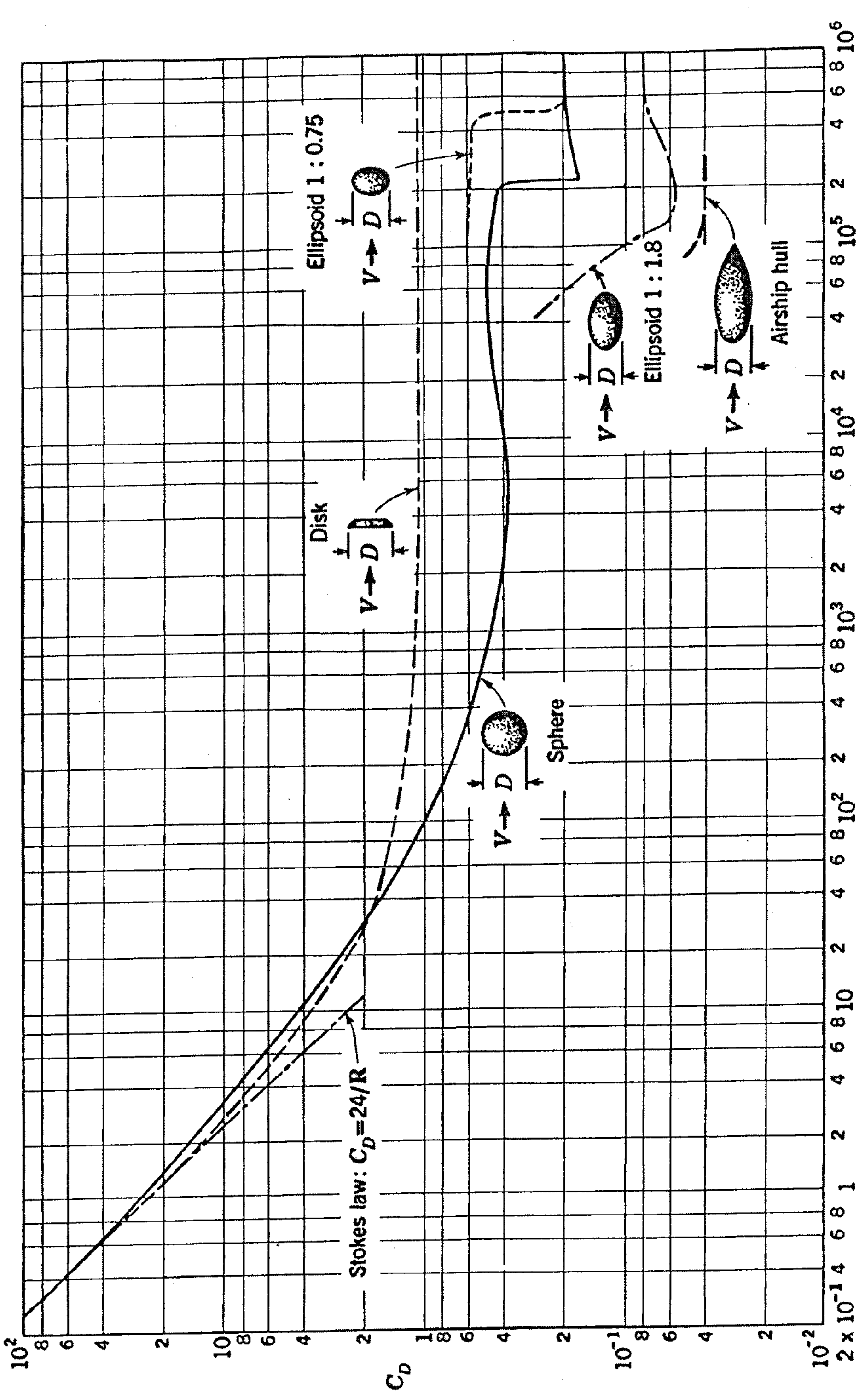
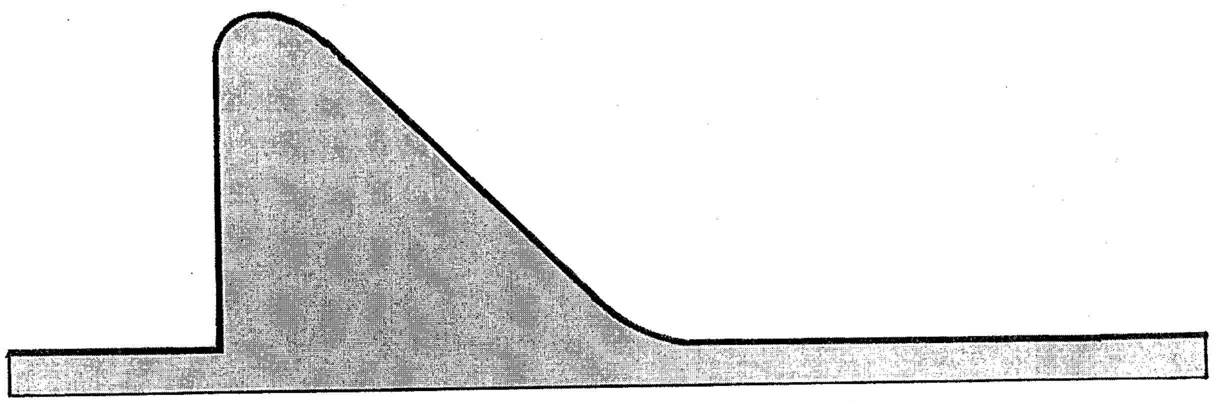


Figure 10.10 Drag coefficient for bodies of revolution. (Adapted from L. Prandtl, "Ergebnisse der aerodynamischen Versuchsanstalt zu Göttingen," p. 29, R. Oldenbourg, Munich and Berlin, 1923; and F. Eisner, "Das Widerstandsproblem," *Proc. 3d Internatn. Congr. Appl. Mech., p. 32, 1930*.)

EXAMINATION PAPER ATTACHMENTS

NAME ....

QUESTION 10 DAM SPILLWAY



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: $P = \frac{1}{2} \rho Q V^2$
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

$P_{total} = ½\, \rho\, A_T\, V_1^3$
$P_{max} = 8/27\, \rho\, A_T\, V_1^3$
$H_{max} = P_{max} / P_{total} = 16/27$

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

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