NATIONAL EXAMINATIONS

May 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. Candidates may use one of the approved **Casio** or **Sharp** calculators.

8. **Reference information** for particular questions is given on pages 7 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.**

9. **Constants** are given on page 11.

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

SECTION A CALCULATIVE QUESTIONS

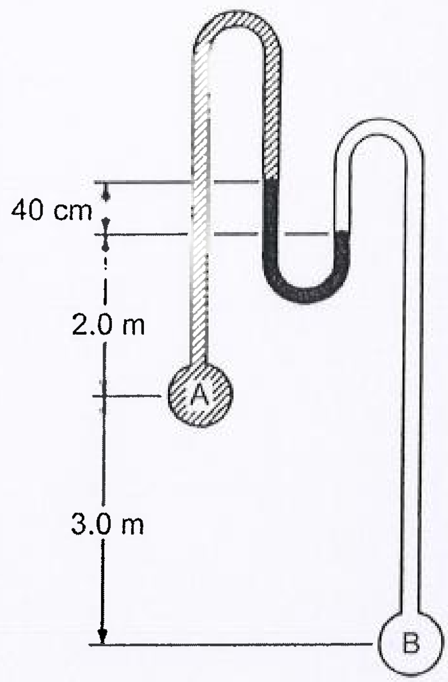
<u>Do seven of nine questions</u>. Solutions to these questions must be set out logically with all intermediate answers and units given.

QUESTION 1

Refer to the adjoining illustration. Use the differential elevations in metres and centimetres 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.

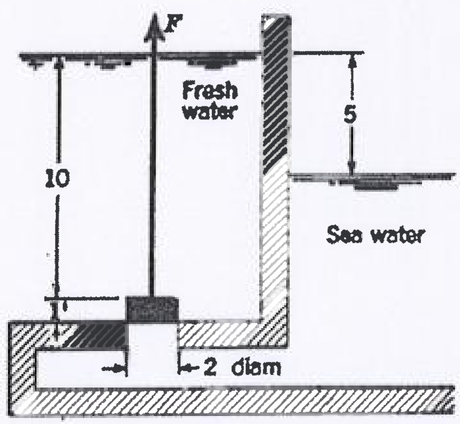
(5 marks)



QUESTION 2

Refer to the adjoining sketch. For the conditions shown in the figure, find the force *F* required to lift the concrete-block gate if the concrete density is 2400 kg/m^3. The density of sea water is 1025 kg/m^3. All dimensions are in metres.

(5 marks)



QUESTION 3

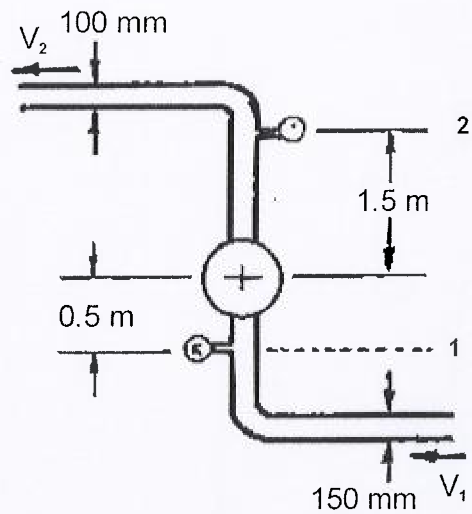
Refer to the Examination Paper Attachments Page 7 **Jounama Dam**.

This drawing shows an elevation and cross section of the spillway for the dam. Calculate the total horizontal force on the pivots of each radial gate when the dam is at its full supply level.

(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 a pressure of 150 kPa and the suction gauge reads a vacuum of 30 kPa (negative gauge pressure) 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)

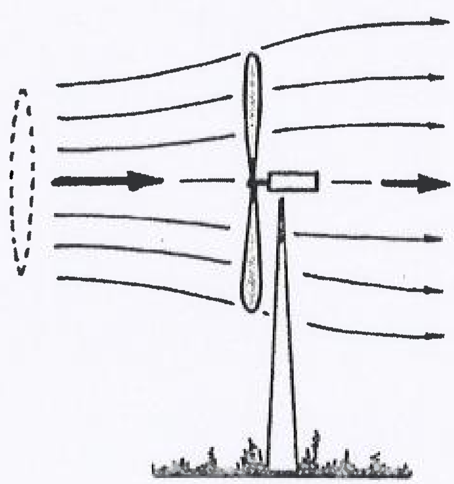
QUESTION 5

A 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. If the reading on the manometer is 24 mm, determine the air velocity in the duct. 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 6

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 7

Refer to the Examination Paper Attachments Page 8 **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.

Show on the diagram where values have been plotted and read.

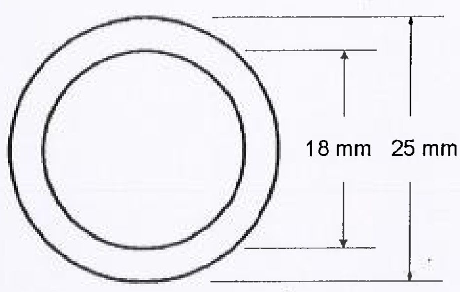
Hint: Guess velocities and plot corresponding friction factor versus Reynolds number on Moody diagram for each chosen velocity.

(5 marks)

QUESTION 8

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

Determine the head loss in an annular duct of length 5 m where the annulus has an outer diameter of 25 mm and an inner diameter of 18 mm and water flows within the annulus (between the inner and outer diameters) at a rate of 0.5 litres/s. The duct is made of copper drawn tubing.



Show on the diagram where values have been plotted and read.

(5 marks)

QUESTION 9

Refer to the Examination Paper Attachments Page 10 **Drag Coefficients of Cyclists.**

The chart shows drag coefficients of cyclists in different configurations. Determine the maximum speed in km/h that a regular cyclist should be able to maintain on a standard (no aerodynamic components) racing bicycle during a two hour cycling race. Neglect rolling resistance. Note that the drag force has to be calculated since that given in the table is only at a speed of 20 mph (8.9 m/s or 32 km/h) and will be different for the speed to be calculated.

Human generated power can be determined from the following equation which gives average power in kW over a given period of time where t is in minutes.

$$P = 0.373 - 0.097 \log_{10} t \qquad \text{for healthy young men}$$

(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.***

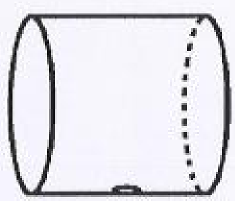
QUESTION 10

Explain how pipe roughness (assuming surface roughness height ϵ >> laminar sublayer thickness δ) affects the velocity profile in a pipe. Sketch typical velocity profiles for pipes of different roughness assuming fully developed turbulent flow. Assume that the flow rate is the same in each case.

(5 marks)

QUESTION 11

Axis Vertical



Axis Horizontal

A cylindrical drum with a height equal to its diameter can either be stood on its end (axis vertical) or put on its side (axis horizontal) to drain water through a hole at its lowest point. Determine with explanations the following:

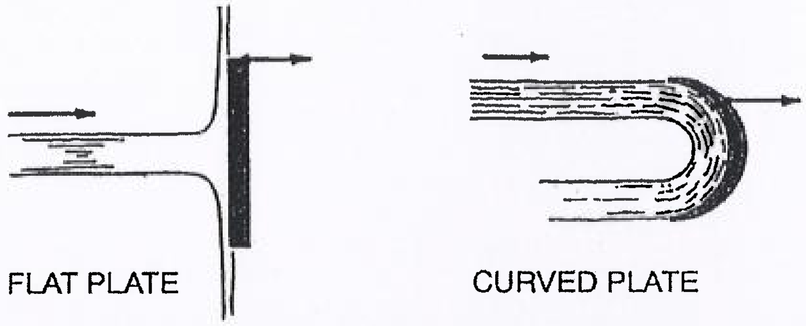
(a) The orientation in which the drum will drain more quickly.

(b) The reason why one orientation gives a shorter time to drain than the other.

(c) An alternative orientation which will give a shorter draining time than either of the given orientations.

(5 marks)

QUESTION 12



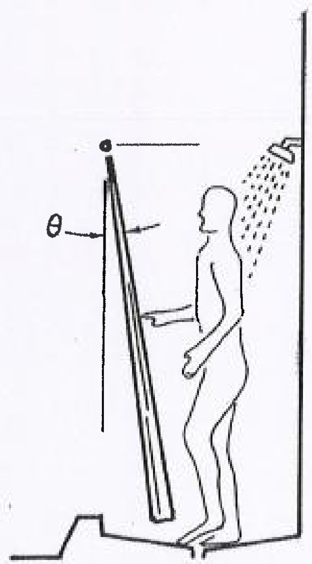
A flat plate and curved plate are subject to horizontal jets having the same flow rate and velocity. State which will be subject to the greater force when stationary and explain why this would be the case. When moving in the same direction as the jet state which plate will give the best transfer of energy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

(5 marks)

QUESTION 13

Consider a closed shower cubical, square in plan view, which is closed by drawing a curtain across the open side. When taking a hot shower with the curtain closed the curtain tends to blow inwards. Explain why this is so and state the fundamental fluid mechanics principles that create this phenomenon. Hence suggest how one could calculate the angle of the curtain θ clarifying what basic parameters would be required.

(5 marks)

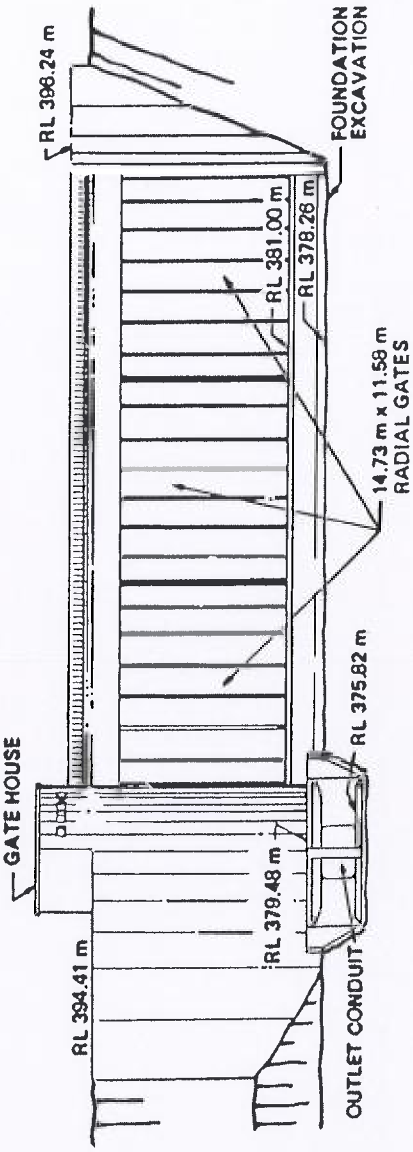


EXAMINATION PAPER ATTACHMENTS

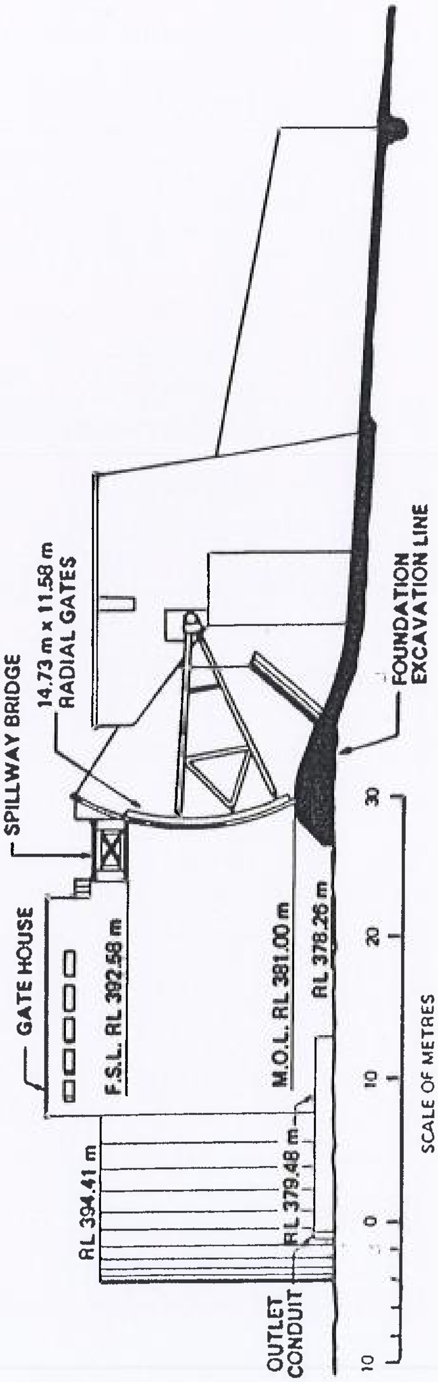
NAME ....

PROBLEM 3.13 JOUNAMA DAM

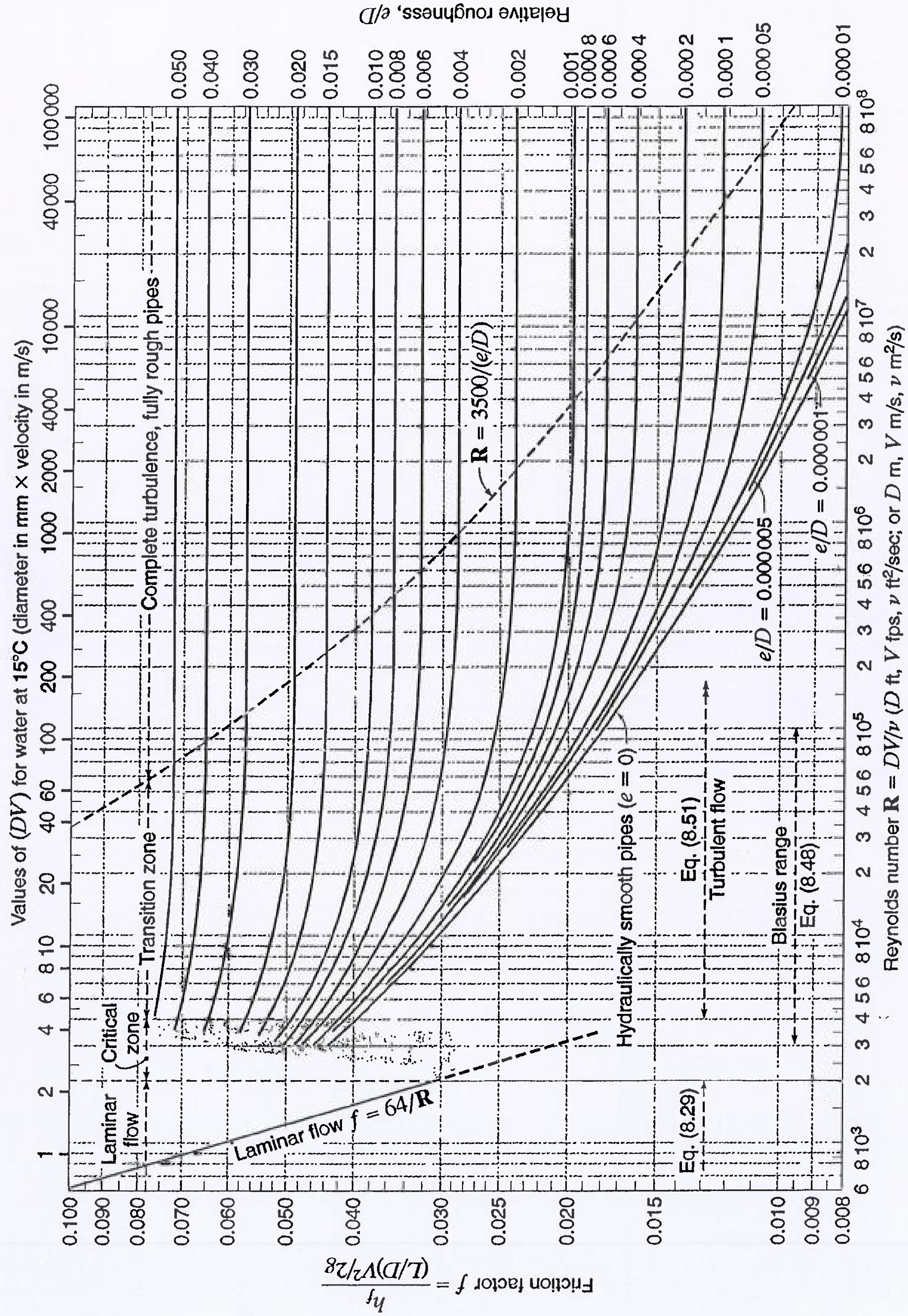
Upstream Elevation of Jounama Dam Spillway



Section along Jounama Dam Spillway

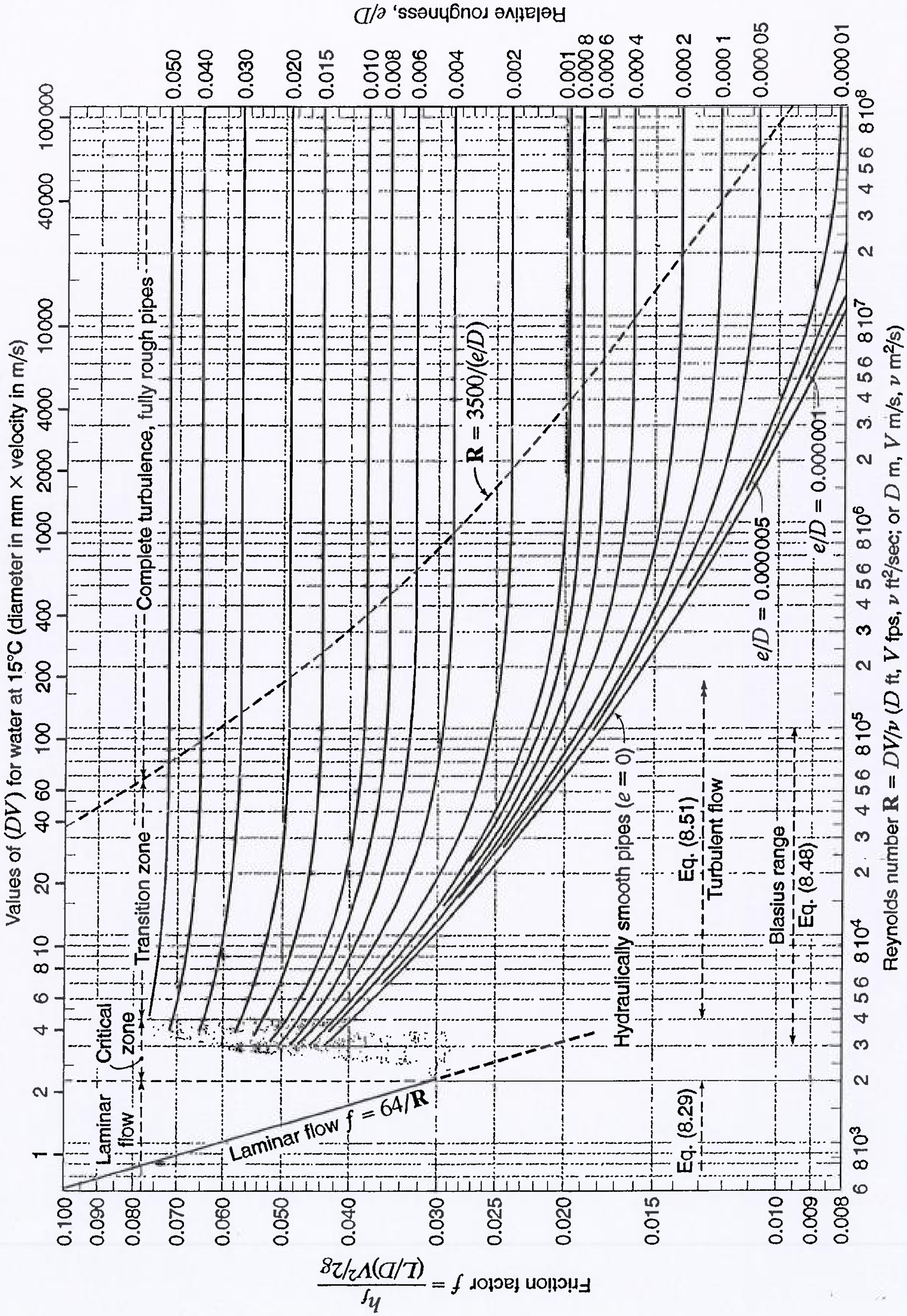


QUESTION 7 MOODY DIAGRAM **NAME** ....



Moody chart for pipe friction factor (Stanton diagram).

QUESTION 8 MOODY DIAGRAM NAME ....

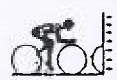


Moody chart for pipe friction factor (Stanton diagram).

QUESTION 9 DRAG COEFFICIENTS OF CYCLISTS

Applications to Ground Vehicles

TABLE 6.1 Aerodynamic and rolling resistance data for several bicycle-rider configurations travelling at a speed of 20 mph (8.9 m/s)

Configuration			D_f Drag Force		Rolling Resistance		Drag Coefficient	Frontal Area A	
			lbf	N	lbf	N	$C_D = \frac{D_f}{\frac{1}{2}\rho U_\infty^2 A}$	ft²	m²
European Upright Commuter	*40-lb bike, 160-lb rider, tires: 27 in. dia., 40 psi*		6.14	27.3	1.20	5.34	1.1	5.5	0.51
Touring (Arms Straight)	*25-lb bike, 160-lb rider, tires: 27 in. dia., 90 psi*		4.40	19.6	0.83	3.69	1.0	4.3	0.40
Racing (Fully Crouched)	*20-lb bike, 160-lb rider, tires: 27 in. dia., 105 psi*		3.48	15.5	0.54	2.4	0.88	3.9	0.36
Aerodynamic Components (Fully Crouched)	*20-lb bike, 160-lb rider, tires: 27 in. dia., 105 psi*		3.27	14.5	0.54	2.4	0.83	3.9	0.36
Partial fairing (Zzipper, Crouched)	*21-lb bike, 160-lb rider, tires: 27 in. dia., 105 psi*		2.97	13.2	0.54	2.4	0.70	4.1	0.38
Recumbent (Easy Racer)	*27-lb bike, 160-lb rider, tires: 20 in. front, 27 in. rear, 90 psi*		2.97	13.2	0.94	4.2	0.77	3.8	0.35
Drafting (Closely Following Another Bicycle)	*20-lb bike, 160-lb rider, tires: 27 in. dia., 105 psi*		1.94	8.63	0.54	2.4	0.50	3.9	0.36
Blue Bell (Two Wheels, One Rider)	*40-lb bike, 160-lb rider, tires: 20 in. front, 27 in. rear, 105 psi*		0.61	2.7	0.8	4	0.12	5.0	0.46
Vector Single (Three Wheels)	*68-lb bike, 160-lb rider, tires: 24 in. front, 27 in. rear*		0.51	2.3	1.02	4.54	0.11	4.56	0.424

Modified from "The Aerodynamics of Human Powered Land Vehicles" by A. C. Gross, C. R. Kyle, and D. J. Malewicki, *Scientific American*, vol. 249, no. 6, December 1983, pp. 142–152. With permission from the publisher.

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 $Re \sim 10^4$

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

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