NATIONAL EXAMINATIONS

December 2011

04-BS-7 MECHANICS OF FLUIDS

Three (3) hours duration

Notes to Candidates

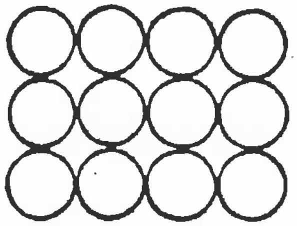
1. This is a **Closed Book** examination.
2. Exam consists of two Sections. **Section A is Calculative (9 questions)** and **Section B is Analytical (4 questions).**
3. **Do seven (7) questions from Section A (Calculative) and three (3) questions from Section B (Analytical).** Note that the Analytical 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 7 and 8. **These pages are to be returned with the Answer Booklet.**
9. **Constants** are given on page 9.
10. **Reference Equations** are given on pages 10 to 13.

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.



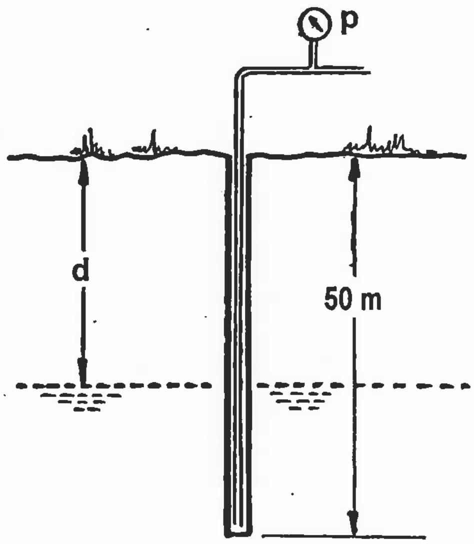
(5 marks)

QUESTION 2

For a borehole to supply an adequate amount of water it must be drilled far enough below the water table to ensure proper seepage of water from the surrounding soil. In order to check the height of the water table in a borehole 50 m deep a plastic tube is inserted to the very bottom of the borehole as shown in the adjacent sketch and a small flow of air pumped down the pipe from the top. After some time a pressure gauge fitted to the top of the pipe gives a steady reading of 1.96 kPa gauge.

(a) Determine the depth d of the water table below the surface of the ground.

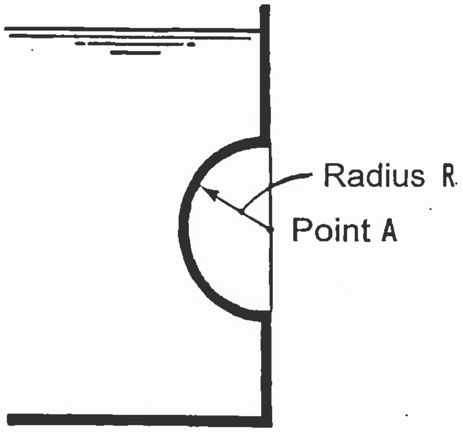
(b) Sketch the water table surface when water is being pumped from the well.



(5 marks)

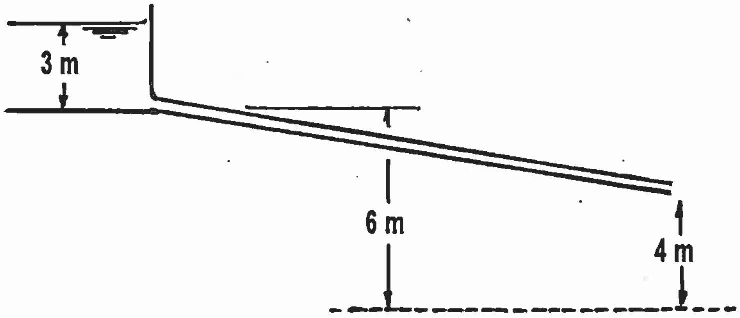
QUESTION 3

Refer to the adjacent figure. The hemispherical body shown in the figure projects into a tank. Find the horizontal and vertical forces acting on the hemispherical projection for the case when the tank is full of water with the free surface 2.5 m above the centre of the hemisphere (Point A). The radius of the hemisphere is 1 m.



(5 marks)

QUESTION 4



In an experiment to determine the head loss in a pipe system, one end of a pipe at an elevation of 6 m was connected to a reservoir of water while the other end at an elevation of 4 m was left open to the atmosphere as shown above. The pipe was 50 mm in diameter with a total length of 120 m. The reservoir contained water to a level 3 m above the pipe connection. If the measured flow rate was 6 litre/s determine the total head loss in the system. Assume that the pipe has a smooth entrance with no loss.

(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.

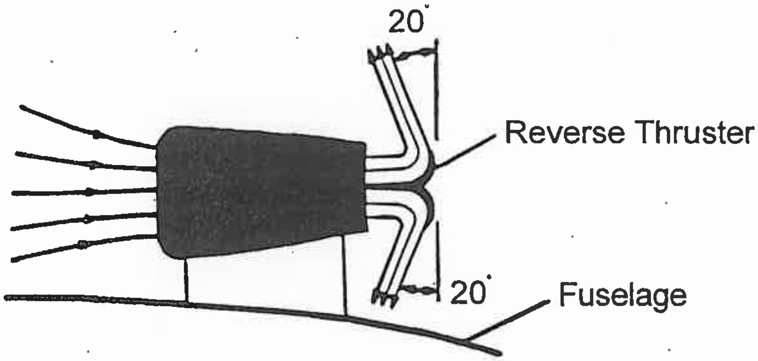
(5 marks)

QUESTION 6

A metal can containing pure unsweetened apple juice is 103 mm in diameter and 166 mm in height. To drain the can a hole 3 mm in diameter is punched in the top as well as in the bottom of the can using a sharp pointed device. The can is held vertically. Determine the flow rate out of the can at the point in time when it contains exactly 1 litre of juice. Assume that the bottom hole is similar to a Borda tube having a coefficient of velocity of $C_v = 0.98$ and a coefficient of contraction of $C_c = 0.52$. Assume also that the difference in pressure between the air in the can and the atmosphere is negligible.

(5 marks)

QUESTION 7



Boeing 727 and Boeing 737 as well as McDonnell Douglas DC-9 aircraft make use of Pratt and Whitney JT8D engines. The air flow rate through these engines is 143 kg/s. The inlet velocity is 220 m/s and the exhaust velocity is 650 m/s. After the aircraft touches down vanes are actuated to produce reverse thrust to aid deceleration and hence shorten the landing distance as shown in the sketch above. Determine the following for each engine:

(a) Forward thrust on aircraft during normal operation (reverse thruster not actuated).

(b) Reverse thrust on aircraft with reverse thruster deployed (actuated).

(c) If the reverse thruster did not turn the exhaust stream to be 20° forward but discharged the exhaust at right angles to the initial direction (20° becomes 0°), state whether there would still be reverse thrust. Explain or show by calculation the reason for your answer.

(5 marks)

QUESTION 8

Refer to the Examination Paper Attachments Page 7 **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.

(5 marks)

QUESTION 9

Refer to the Examination Paper Attachments Page 8 **Drag on Solid Bodies**

A slurry of fine sand and water is used for coal separation. The sand is kept in suspension by agitation of the mixture and the resultant average specific gravity 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 sand in the water. The sand particles are 500 μm in diameter and have a specific gravity of 2.6.

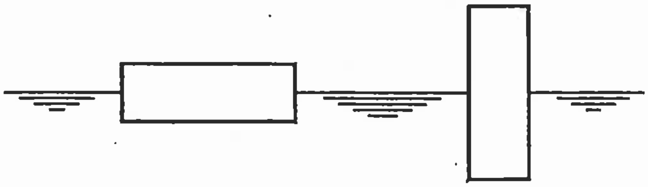
Show on the diagram where values have been plotted and read.

(5 marks)

SECTION A 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

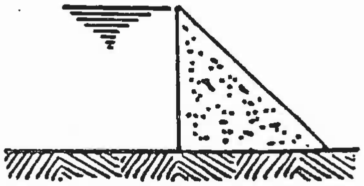


Horizontal Vertical

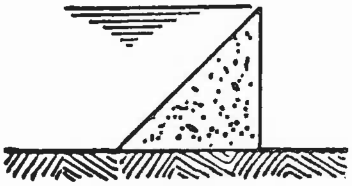
A bar of square cross section with density half that of water will float half submerged as shown in the sketch above. State which orientation will be stable - horizontal or vertical. Explain why the chosen orientation is stable and how this can be proven.

(5 marks)

QUESTION 11



Dam A

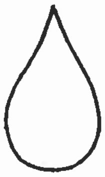


Dam B

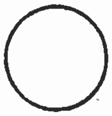
Two small triangular dams are built on a firm flat surface as shown above. Assuming that there is no seepage under the wall but that sliding can occur, state which dam - Dam A or Dam B - will be most likely to slide. Explain fully why one will be more likely to slide than the other.

(5 marks)

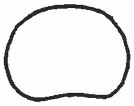
QUESTION 12



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.

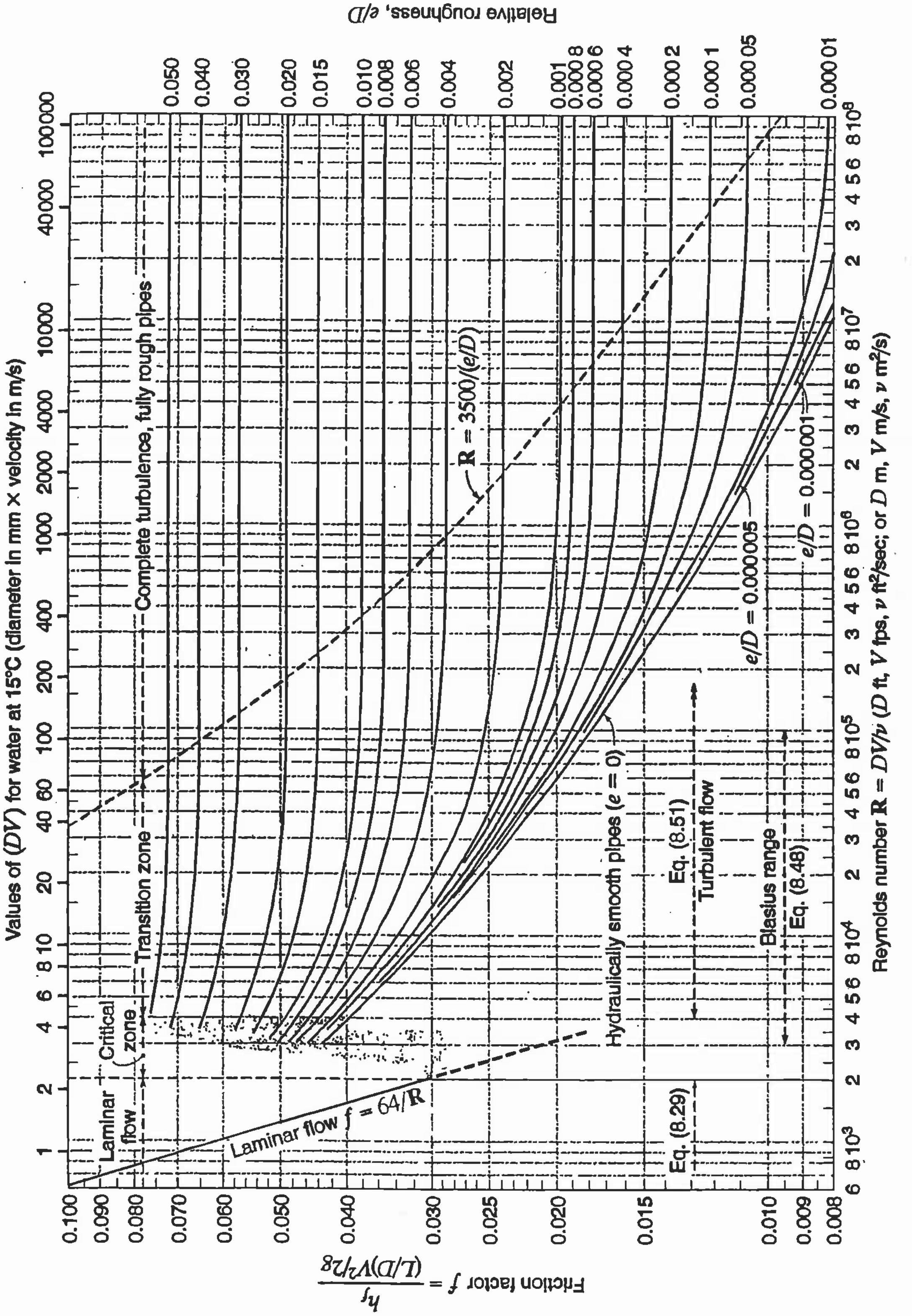
(5 marks)

QUESTION 13

An oil lamp used for illumination has a wick which feeds oil from the reservoir to the flame some distance above the oil surface. Explain how the oil rises against the force of gravity and state what design features are required in the wick and what fluid properties the oil should have to make this possible.

(5 marks)

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



Moody chart for pipe friction factor (Stanton diagram).

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

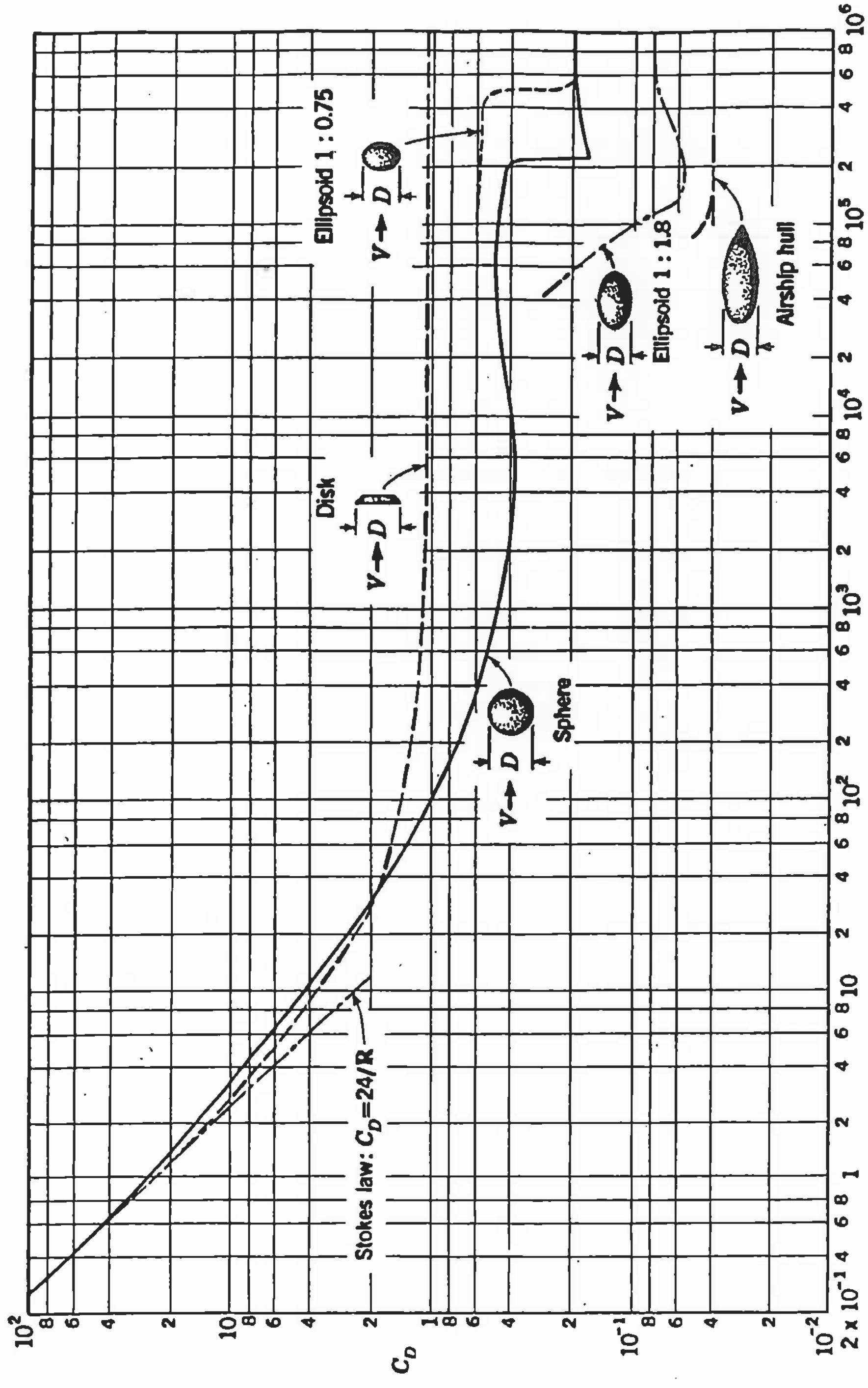


Figure 10.10 Drag coefficient for bodies of revolution. (Adapted from L. Prandtl, "Ergebnisse der aerodynamischen Versuchsanstalt zu Göttingen," p. 29, R. Oldenbourg, Munich and Berlin, 1923; and F. Eisner, "Das Widerstandsproblem," *Proc. 3d Internatn. Congr. Appl. Mech., p. 32, 1930.*)

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 $\rho = 1000\ kg/m^3$
Density of Sea Water $\rho = 1025\ kg/m^3$
Density of Concrete $\rho = 2400\ kg/m^3$
Density of Air $\rho = 1.19\ kg/m^3$ (at 20°C), $\rho = 1.21\ kg/m^3$ (at 15°C)
Absolute Viscosity of Water $\mu = 1.0 \times 10^{-3}\ Ns/m^2$
Absolute Viscosity of Air $\mu = 1.8 \times 10^{-5}\ Ns/m^2$
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: $P = ½ \rho Q V^2$
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

$P_{total} = \frac{1}{2}\ \rho\ A_T\ V_1^3$
$P_{max} = 8/27\ \rho\ A_T\ V_1^3$
$\eta_{max} = P_{max} / P_{total} = 16/27$

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

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