NATIONAL EXAMINATIONS

May 2012

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 to 9. **These pages are to be returned with the Answer Booklet.**
9. **Constants** are given on page 10.
10. **Reference Equations** are given on pages 11 to 14.

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

Calculate the capillary rise of water in contact with air in a clean glass channel of rectangular cross section 1 mm x 2 mm. The surface tension of water $\sigma = 0.073$ N/m and the contact angle $\theta = 0°$

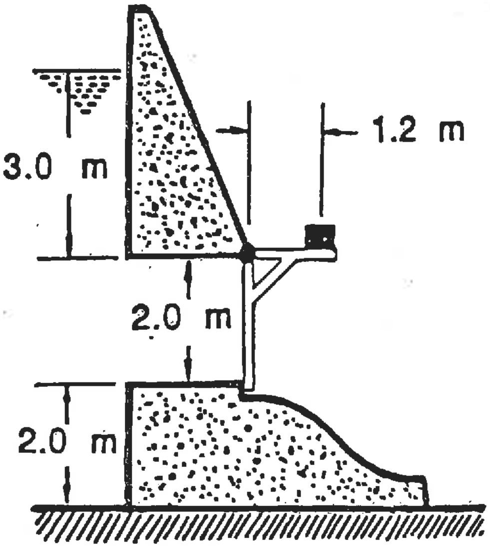
(5 marks)

QUESTION 2

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 of a Rectangle about its centroid is $I_c = (bh^3/12)$

(5 marks)



QUESTION 3

Suppose that, in determining the purity of the gold crown belonging to the tyrant of Syracuse who suspected that it was not pure, Archimedes found that it displaced 0.33 L of water when submerged while an equivalent mass of pure gold displaced 0.22 L of water when submerged. If some gold could have been replaced with silver, what would the purity (% gold) by weight have been. The specific gravity of gold is 19.32 and that of silver is 10.50.

(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 4.8 km 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 2.32 MPa 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

A pump lifts water at the rate of 6.0 m^3/s to a height of 120 m over a distance of 200 m. The friction head loss in the discharge pipe is 30 m and that in the inlet pipe negligible. Calculate the power (kW) required if the pump efficiency is 90 percent.

(5 marks)

QUESTION 6

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

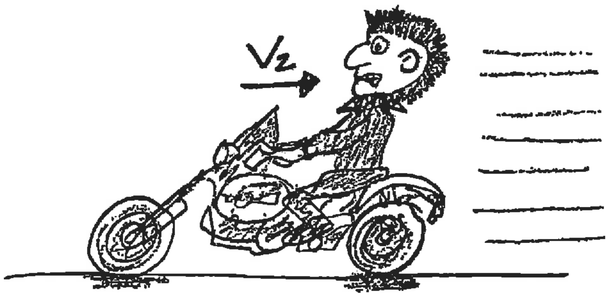
A domestic heat recovery air exchanger draws fresh air into a house and rejects stale air to the atmosphere. Air is distributed and collected through corrugated aluminum pipes 150 mm in diameter. The corrugations to permit easy bending for installation are 3 mm in height. The air flow through each pipe is 0.08 m^3/s. Determine the pressure drop per 100 m of straight pipe for the corrugated aluminum lines (before bending to the required configuration).

(5 marks)

QUESTION 7

A motor cyclist without a face mask has his mouth facing directly forward and hence breathes in and out at the stagnation point. Determine at what speed the stagnation pressure would be so great as to prevent the rider from exhaling (and possibly suffocating). Assume that his maximum breathing out pressure is equivalent to 100 mm water gauge. Hint: Use Energy Equation.

(5 marks)



Drawn by Daniel LeBlanc Second Year Student 2003

QUESTION 8

Refer to the Examination Paper Attachments **Absolute Viscosity** to obtain viscosities

Consider a cylindrical tank 300 mm in diameter and 500 mm in height. Either gasoline (specific gravity S = 0.716) or lubricating oil (SAE 30 Eastern) at 20°C flows into the tank at a constant rate of 0.20 L/s. The contents are discharged through a fixed orifice of 10 mm diameter having a discharge coefficient C_d for gasoline of 0.90 and a discharge coefficient C_d for oil of 0.75.

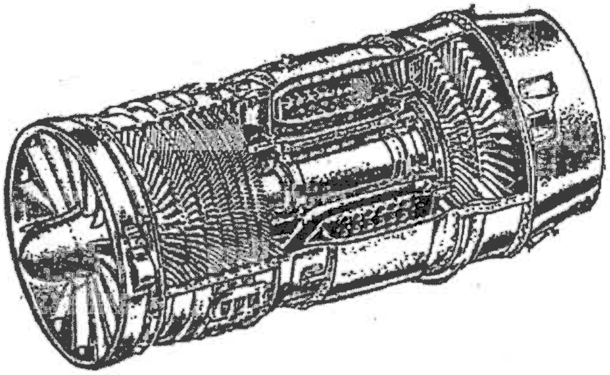
(a) Determine the viscosities of the gasoline and the oil
(b) Calculate the equilibrium level of gasoline in the tank
(c) Calculate the equilibrium level of lubricating oil in the tank
(d) Comment on any differences or observations arising from (b) and (c) above

(5 marks)

QUESTION 9

The adjoining figure shows a typical turbojet aircraft engine without an exhaust nozzle. 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



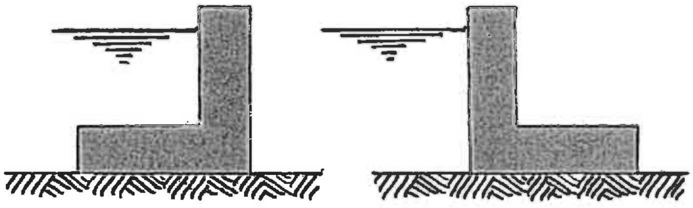
Assume that the exhaust gas pressure is the same as the inlet air pressure. Assume also that the inlet air velocity is equal to the aircraft velocity. Neglect the mass flow of the fuel. Note that the inlet flow area must be calculated to give an inlet air velocity equal to the aircraft velocity.

(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



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

The Moody Diagram (see page 7) gives the pipe friction factor as a function of Reynolds number. Explain why there is a discontinuity in the curve and a sudden increase in the friction factor when the flow changes from laminar to turbulent. Explain also why a rough pipe ($\varepsilon/D \approx 0.0001$) behaves as a rough pipe at high Reynolds numbers but as a smooth pipe at low Reynolds numbers

(5 marks)

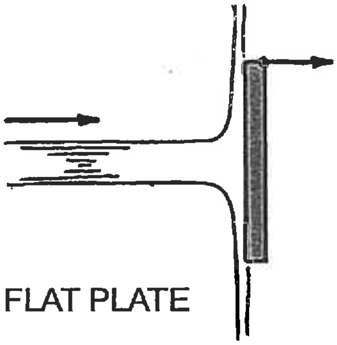
QUESTION 12

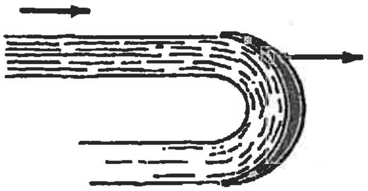
Refer to the Examination Paper Attachments **Aircraft Wing**

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.

(5 marks)

QUESTION 13


FLAT PLATE

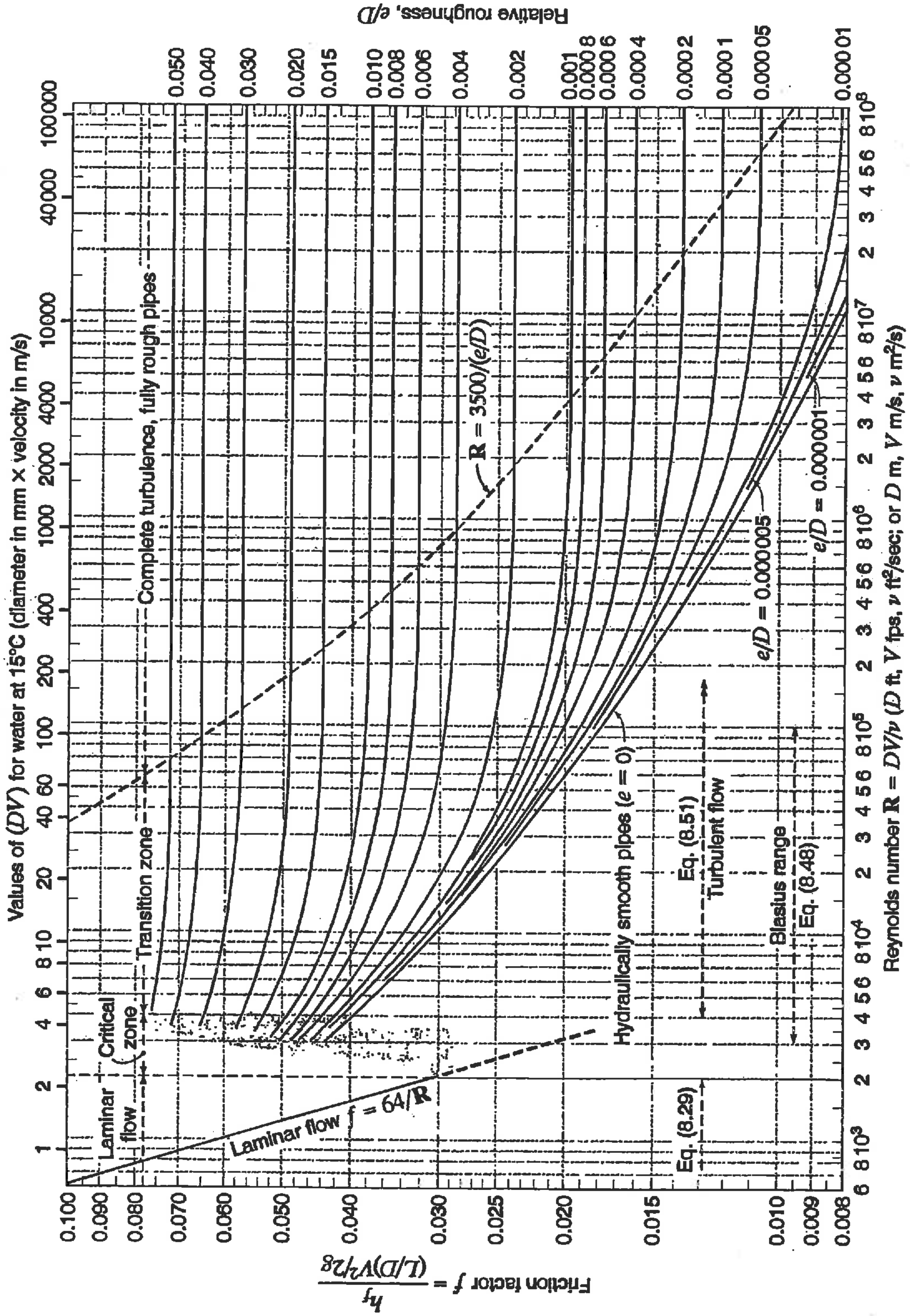

CURVED PLATE

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) and explain from an energy aspect the reason for you answer.

(5 marks)

EXAMINATION PAPER ATTACHMENTS

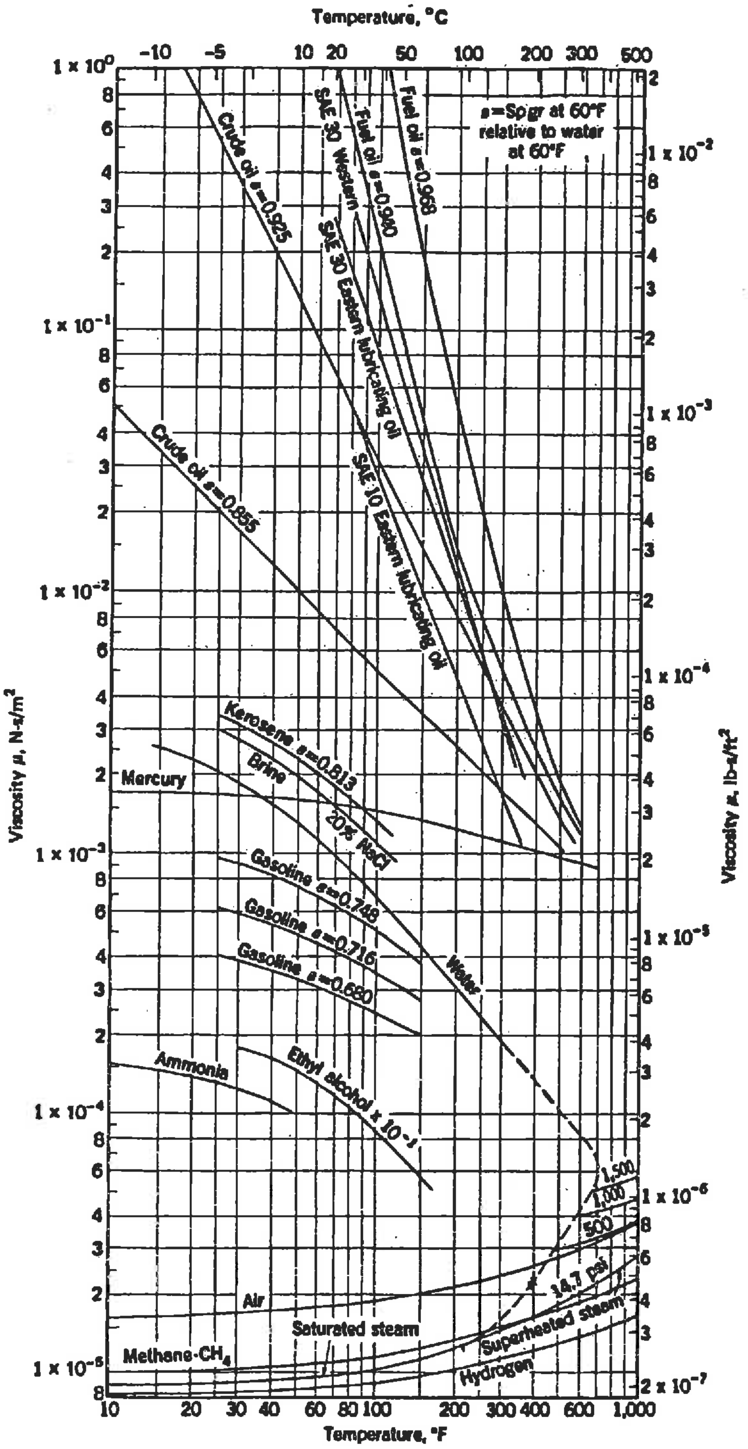
QUESTION 6 MOODY DIAGRAM **NAME** ....



Moody chart for pipe friction factor (Stanton diagram).

EXAMINATION PAPER ATTACHMENTS

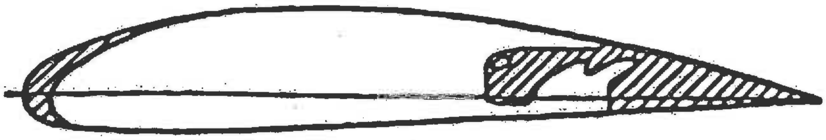
QUESTION 8 ABSOLUTE VISCOSITY **NAME ....**



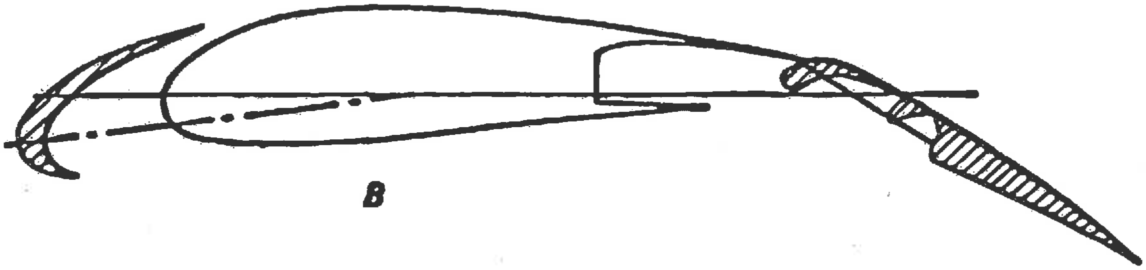
Absolute viscosity μ of fluids.

EXAMINATION PAPER ATTACHMENTS

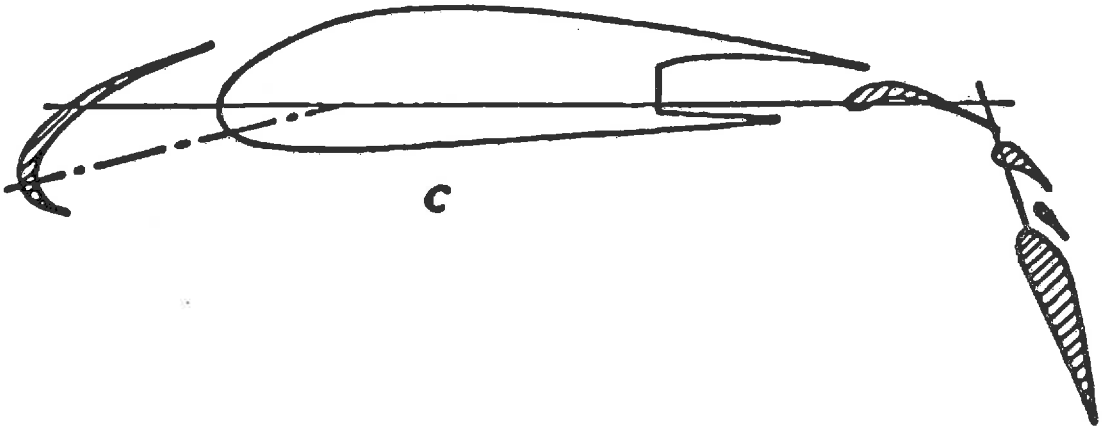
QUESTION 13 AIRCRAFT WING **NAME ....**



A



B



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 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

$$p\,v = R\,T$$
$$p = \rho\,R T$$

Universal Gas Law

$$p\,v^n = \text{constant}$$

Compressibility

$$\beta = -\Delta / V\,\Delta p$$

Viscous Force and Viscosity

$$F = \mu\,A\,du / dy$$
$$\tau = \mu\,du / dy$$
$$\nu = \mu / \rho$$

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

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

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

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

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

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

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