NATIONAL EXAMINATIONS

May 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 Analytical (4 questions)** and **Section B is Calculative (9 questions).**

3. **Do three (3) questions from Section A (Analytical) and seven (7) questions from Section B (Calculative).** Note that the Analytical Questions do not require detailed calculations.

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 9 to 12. **These pages must show where data was obtained and are to be returned with the Answer Booklet.**

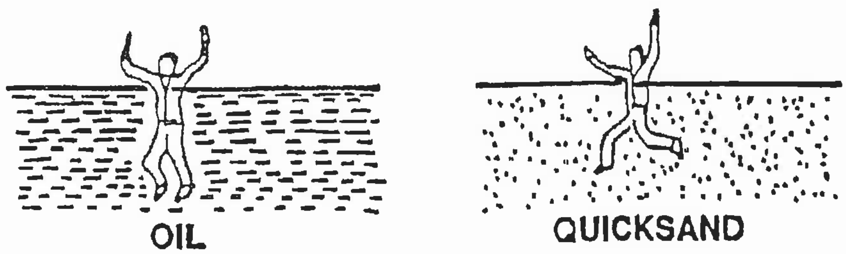
9. **Constants** are given on page 13.

10. **Reference Equations** are given on pages 14 to 17.

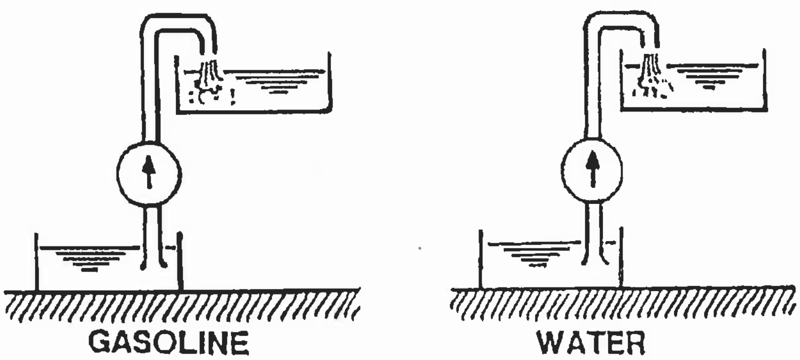
SECTION A ANALYTICAL QUESTIONS

Do three of four questions. These questions do not require detailed calculations but complete written explanations must be given to support the answers. Where appropriate mathematical derivations or calculations should be given to justify the conclusions.

QUESTION 1 FLUID DENSITY



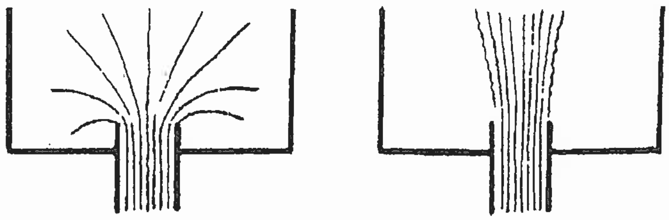
(a) Two ponds, one contains light oil and the other quicksand (a slurry of find sand and water in suspension) as shown above. State in which pond a person is more likely to fully sink. Give a full explanation for your answer.



(b) Two identical pumps pump the same volume per second of either gasoline or water as shown above. State which pump will require the greater power. Give a full explanation for your answer with equations if appropriate.

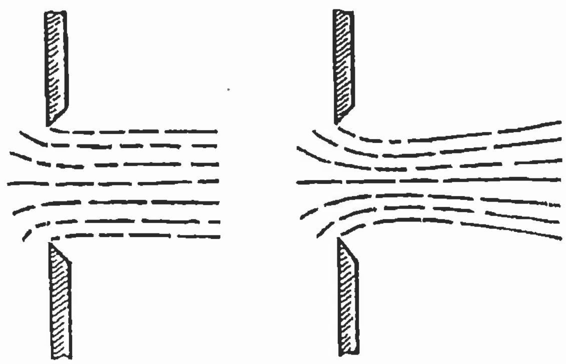
(5 marks)

QUESTION 2 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.



C D

(b) The two sketches C and D 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 3 BOUNDARY LAYER EFFECTS

With respect to flow separation and the influence of laminar or turbulent boundary layers, explain why a golf ball has dimples on its surface.

(5 marks)

QUESTION 4 PUMP SUCTION HEAD

Explain what is meant by Net Positive Suction Head (NPSH) and how this affects the setting (elevation) of a centrifugal pump. In particular explain what effect the following parameters have on the NPSH:

~ elevation above reservoir
~ head loss in inlet pipe
~ temperature of liquid
~ design of pump (specific speed)

(5 marks)

SECTION B CALCULATIVE QUESTIONS

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

QUESTION 5 FLUID VISCOSITY

Refer to Examination Paper Attachments Page 9 **Absolute Viscosities**

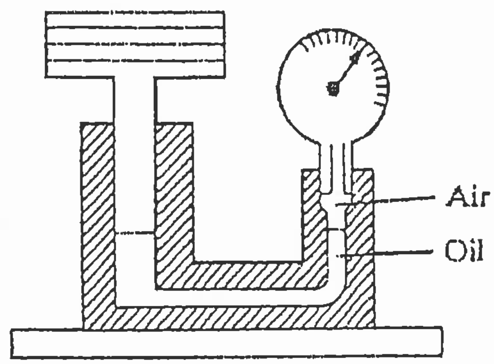
A journal bearing consists of an 80.0 mm shaft in an 80.3 mm sleeve 100 mm long. The clearance space (assumed to be uniform) is filled with SAE 30 western lubricating oil at 40°C The absolute or dynamic viscosity μ is to be obtained from the attached chart. Calculate the rate at which heat is generated at the bearing when the shaft turns at 120 rpm. Express your answer in J/s.

(5 marks)

QUESTION 6 FLUID PRESSURE

The Crosby gauge tester shown in the figure is used to calibrate or to test pressure gauges. When the total mass of the weights and the piston is 9 kg, the gauge being tested indicates 179 kPa. If the piston diameter is 25 mm, determine the percent error in the gauge.

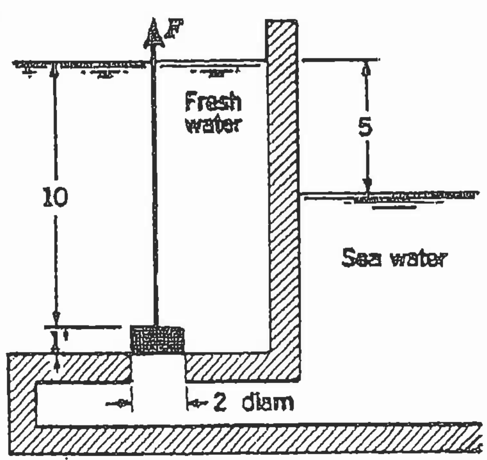
(5 marks)



QUESTION 7 STATIC PRESSURE

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 8

Refer to the Examination Paper Attachments Page 10 **Jurumirim Hydro Power Plant**.

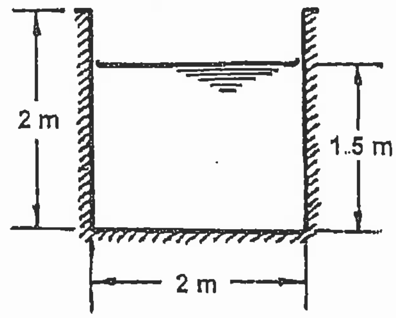
The attached figure shows a cross section of the plant in Brazil. By taking dimensions from this figure determine the water flow rate through the turbine and the corresponding water velocity in the penstock for the maximum power output of 50 MW. Note that the Penstock is circular in cross section. The levels on the drawing are in metres

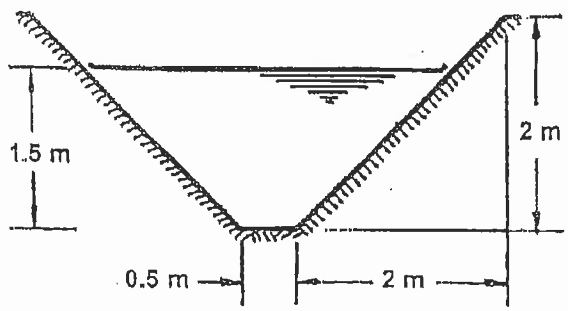
(5 marks)

QUESTION 9

Consider two concrete irrigation canals with cross sections as shown. One is square 2 m wide by 2 m deep and the other trapezoidal 4.5 m wide by 2 m deep with 45° sides and 0.5 m wide bottom. Both have water flowing 1.5 m deep at a flow rate of 3 m^3/s. Determine from general pipe flow relations the slope required by each. Hence determine which will carry water the furthest for a given difference in elevation.

(5 marks)

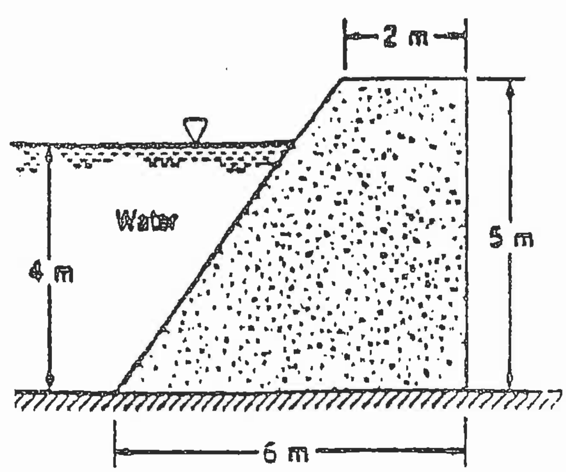




QUESTION 10

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.

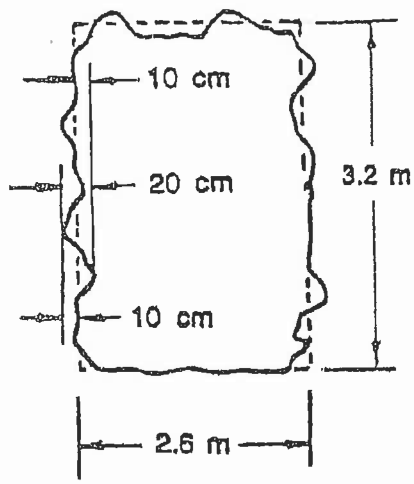
(5 marks)



QUESTION 11

A sloping underground tunnel provides ventilation to the working face of a coal mine. The tunnel is 2.6 m wide and 3.2 m high and slopes from the surface to the mining area over a distance of 1.5 km. The tunnel is unlined and the surface has an irregular profile with rock projections and depressions of 10 cm on either side of the nominal profile. Air at a temperature of 15°C flows through the tunnel at a mean velocity of 8 m/s. Determine the pressure drop in the tunnel.

Refer to the Examination Paper Attachments page 11 for **Moody Diagram**.



(5 marks)

QUESTION 12

Assume that a centrifugal pump and flow system can be mathematically modelled as follows:

Pump:	H	=	$A N^2 - B Q^2$
System:	H	=	$C + D Q^2$

where the constants and variables are as follows:

H	=	Head (m)
Q	=	Flow (m^3/s)
N	=	Pump Speed (rev/min)
A	=	0.000 060
B	=	1.6
C	=	Static Head (m)
D	=	10

For a pump speed of 900 rev/min and a static head of 20 m determine the operating point in terms of flow Q and head H. Show the pump and system characteristics as well as the operating point in a sketch.

(5 marks)

QUESTION 13

Refer to the Examination Paper Attachments Page 12 **Drag on Boeing 747.**

The diagram gives the drag coefficient C_D which corresponds with the lift coefficient C_L of a Boeing 747. These coefficients are based on the wing area which is 511 m^2. If the total weight of a fully loaded Boeing 747-400 (extended cab) on reaching its cruising altitude is 320 tonnes and its speed is Mach 0.89 determine:

(a) The coefficient of lift when flying at an altitude of 10 000 m where the air temperature and pressure are -50°C and 26 kPa respectively.

(b) The coefficient of drag corresponding with the coefficient of lift at the conditions in (a) above.

(c) The thrust power required to maintain the speed of the aircraft.

Note that the Mach number is the speed of the aircraft divided by the speed of sound. The velocity of sound *a* is given by $a = (kRT)^{1/2}$ where k for air is 1.4. Show on the diagram where values were plotted and read.

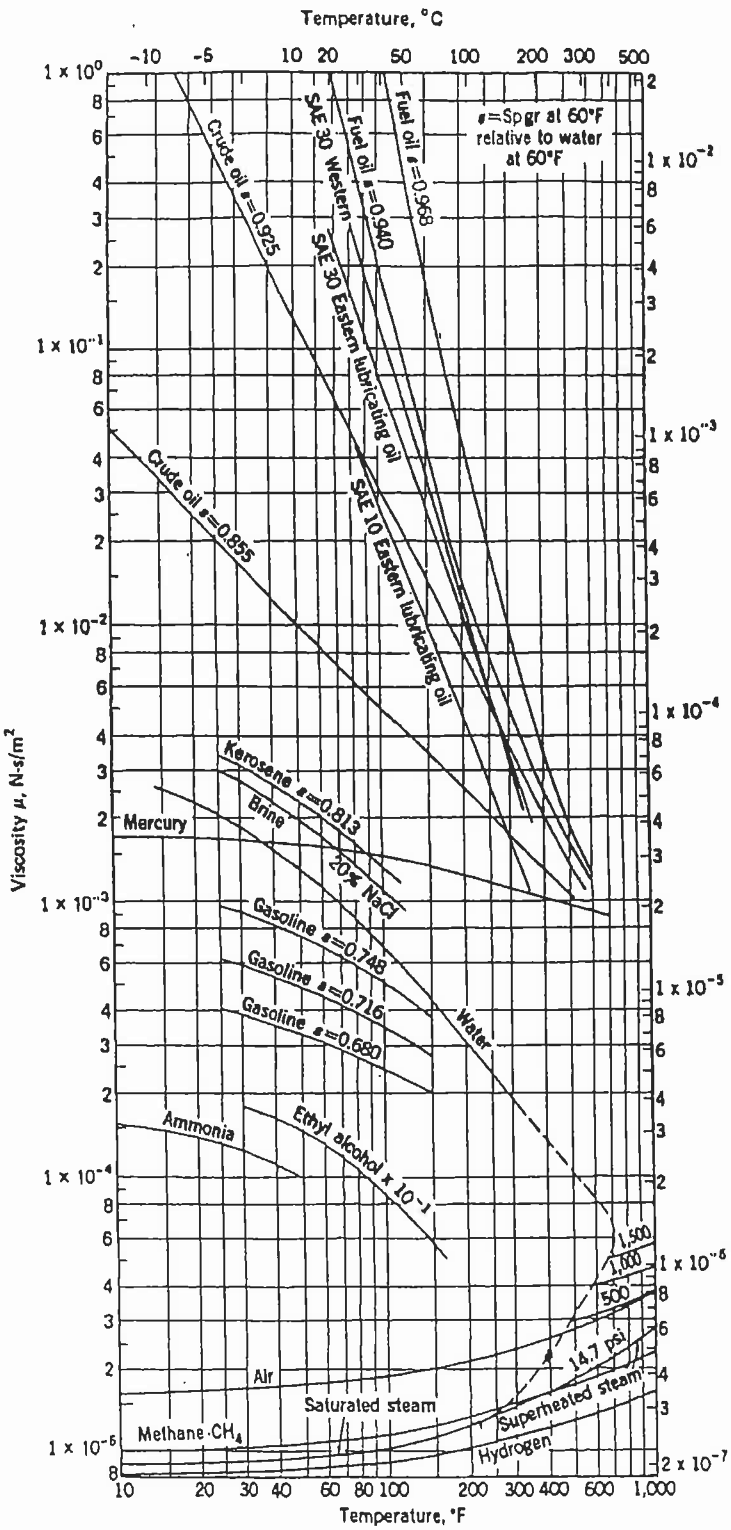
(5 marks)

04-BS-7 May 2011

EXAMINATION PAPER ATTACHMENTS

MECHANICS OF FLUIDS NAME ....

QUESTION 5 ABSOLUTE VISCOSITIES



QUESTION 8 JURUMIRIM HYDRO POWER PLANT

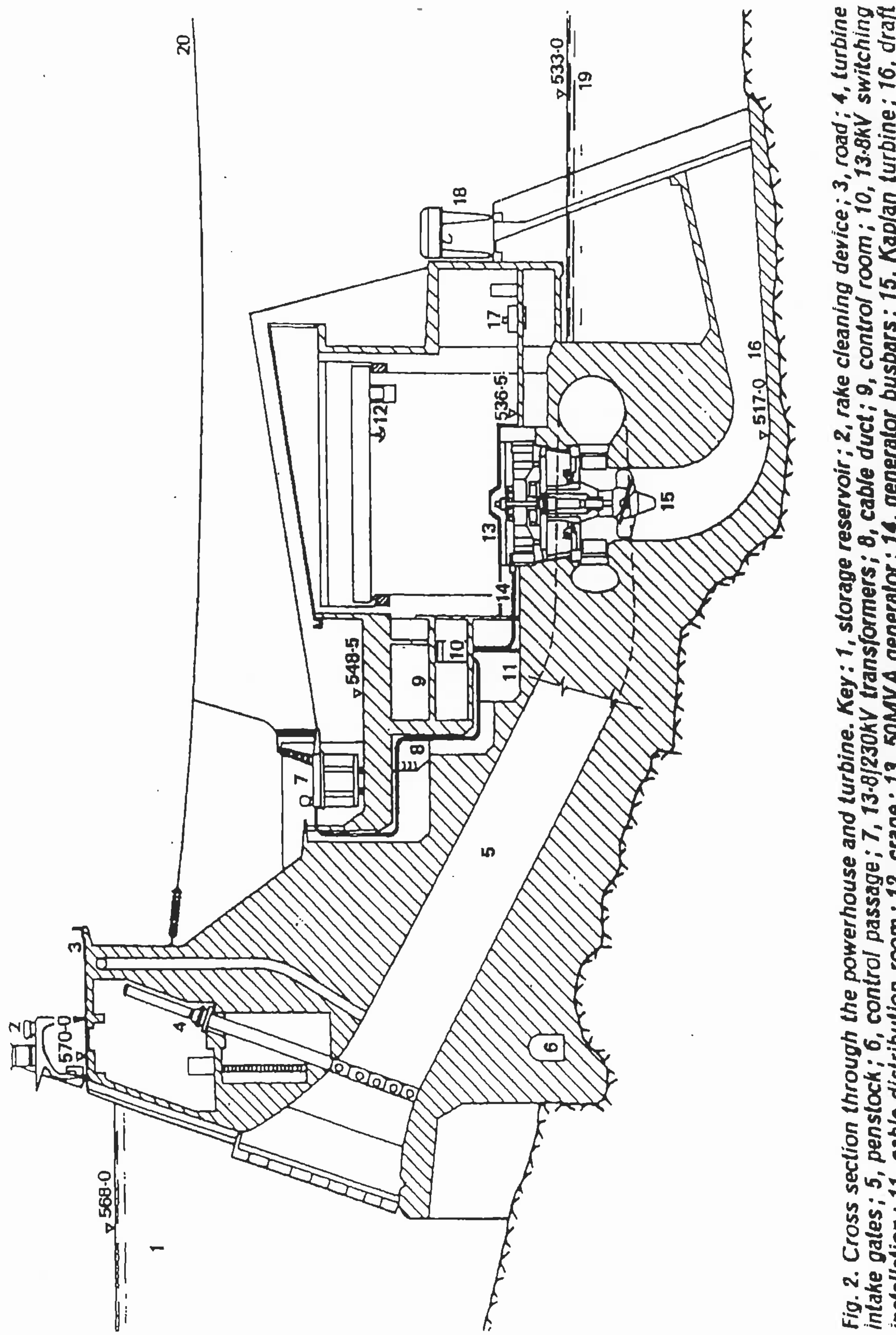


Fig. 2. Cross section through the powerhouse and turbine. Key: 1, storage reservoir; 2, rake cleaning device; 3, road; 4, turbine intake gates; 5, penstock; 6, control passage; 7, 13·8/230kV transformers; 8, cable duct; 9, control room; 10, 13·8kV switching installation; 11, cable distribution room; 12, crane; 13, 50MVA generator; 14, generator busbars; 15, Kaplan turbine; 16, draft tube; 17, turbine regulator; 18, crane for shut-off device; 19, downstream side; and 20, 230kV overhead line

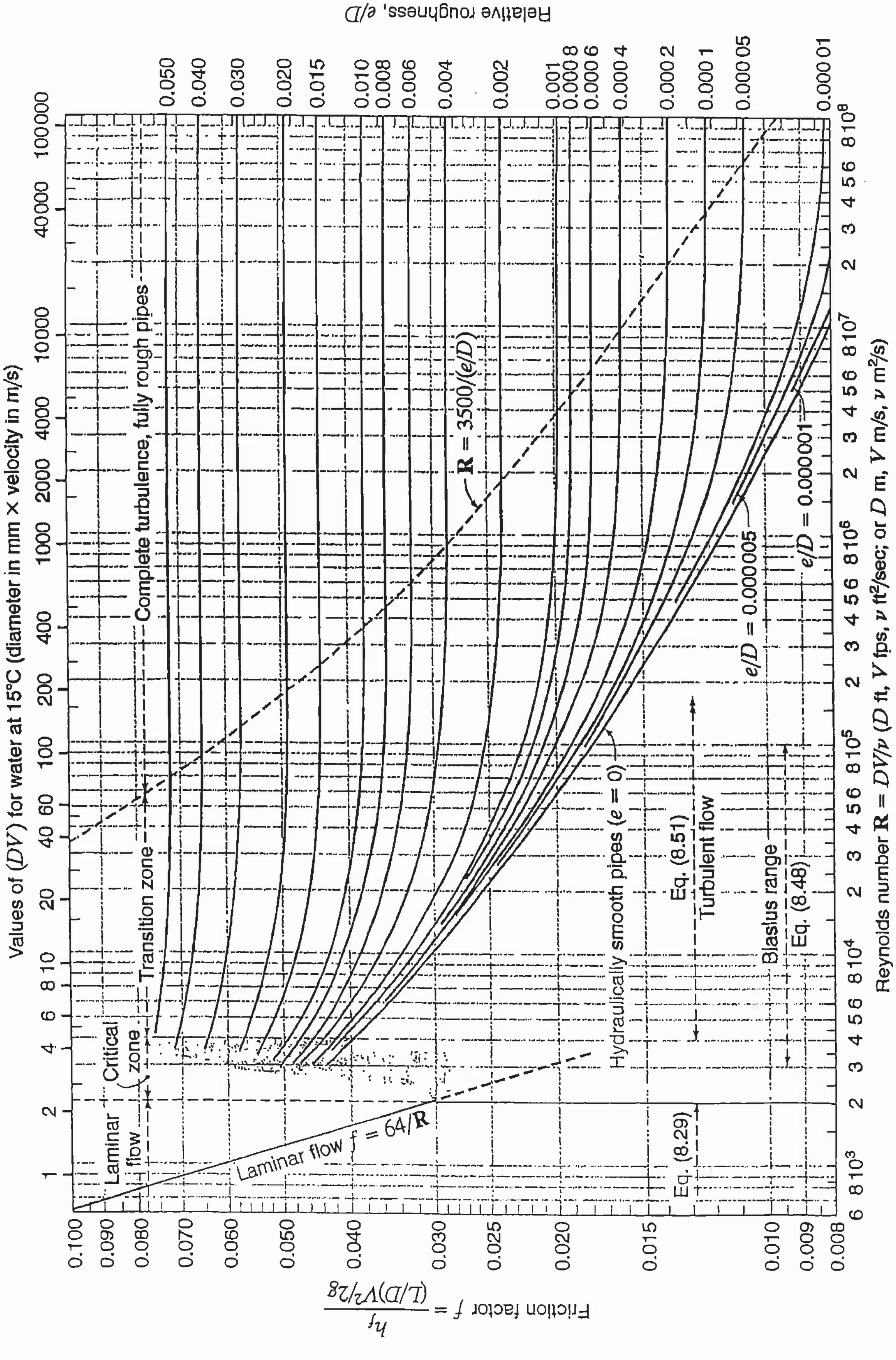


Figure 8.11
Moody chart for pipe friction factor (Stanton diagram).

QUESTION 13 DRAG ON BOEING 747

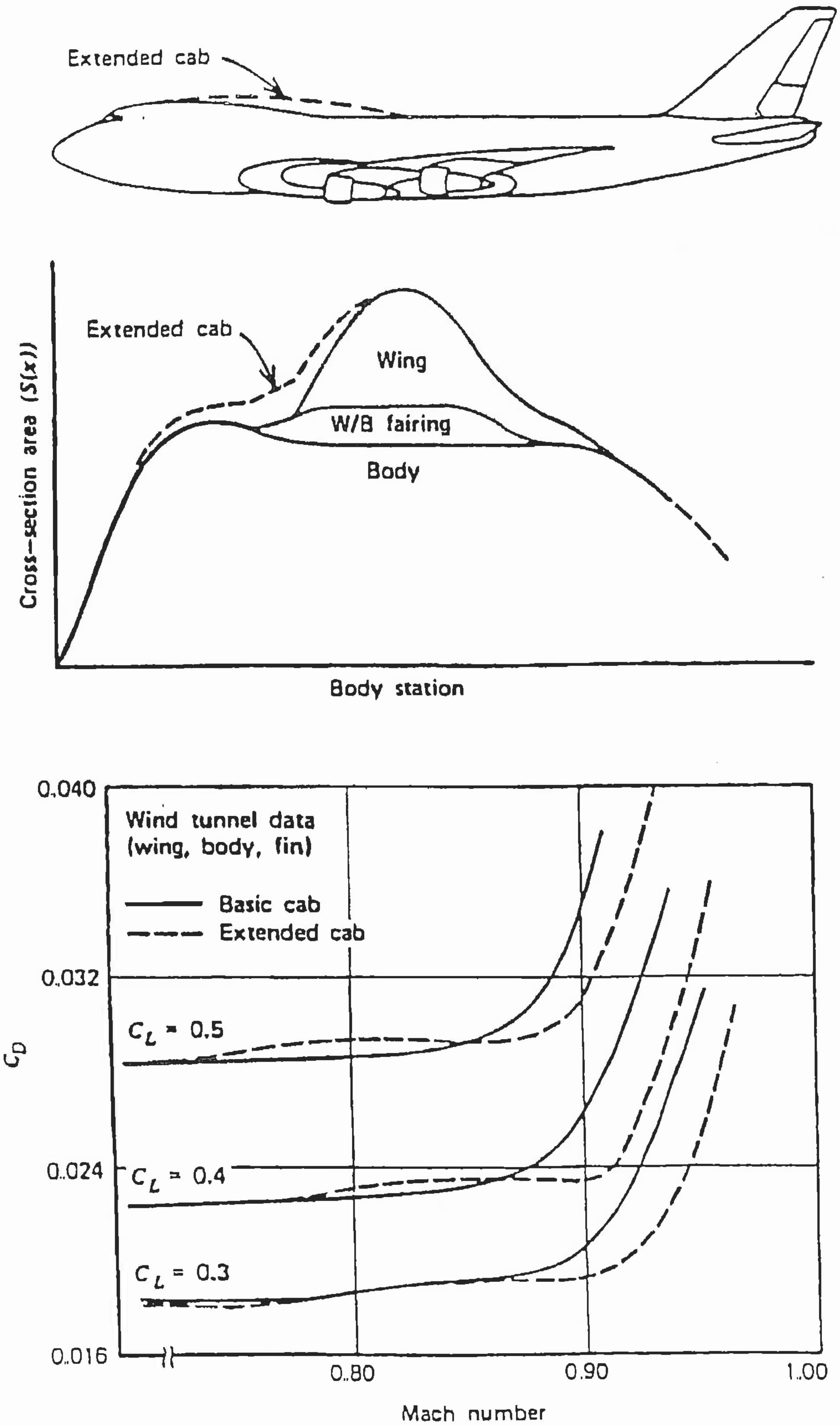


Fig. 9. Effect on $S(x)$ and on measured drag of Boeing 747 due to fuselage modificat:
(Goodmanson and Gratzer, 1973. *Courtesy of the Boeing Company*)

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
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
Gravitational Acceleration g = 9.81 m/s^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

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: $P = M \Delta V U$
Steam Turbine: $P = M (V_{SI} \cos \theta - V_{S2} \cos \delta) U$

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 $Re \sim 10^4$

Pump Specific Speed and Net Positive Suction Head

$N_s = \omega Q^{1/2} / (g H)^{3/4}$
$u_2 = \phi (2 g H)^{1/2}$
$u_2 = \pi D N / 60$
$\sigma_c = NPSH_{required} / H$
$NPSH_{available} = (p_{atmosphere} - p_{vapour}) / (\rho g) - z - h_L$

Drag on Immersed Bodies

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

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