

NAME: _____ STUDENT NUMBER: _____

SECTION: B __, C __, D __, F __

CARLETON UNIVERSITY

MAAE 2300
MID-TERM EXAMINATION
24 February 2015

DURATION: 1.3 HOURS

No. of Students: **412**

Department Name: Mechanical and Aerospace Engineering

Course Number: **MAAE 2300 Fluid Mechanics I**

Instructors: Daniel Feszty (Section B), Fred Nitzsche (Section C), Steve Ulrich (Section D), Vinh Tang (Section F)

AUTHORIZED MEMORANDA

- The mid-term exam is closed textbook.
- 1 handwritten formula sheet are allowed (8-1/2"x11" **double** sided).
- Photocopies are not permitted.
- Any brand of calculator is permissible.

Students **MUST** count the number of pages in this examination question paper **before** beginning to write, and report any discrepancy immediately to a proctor. This question paper has **18** pages (including cover). Note: The pages are double-sided.

This examination question paper **MAY NOT** be taken from the examination room.

In addition to this question paper, students require: an examination booklet: yes ___ no X
a Scantron sheet yes X no ___

NAME: _____ STUDENT NUMBER: _____

MULTIPLE CHOICE ANSWERS

- Please show your final answers on the Scantron sheet provided below.
- Only those answers will be accepted, which are shown on the Scantron sheet.
- No part marks will be given.

SECTION	Questions	Value of Each Question	Total
Section 1: multiple choice theoretical questions	1-14	1 marks	14 marks
Section 2: multiple choice numerical problems	15-21	2 or 3 marks (3 problems, each worth 6 marks)	18 marks
		TOTAL	32 marks

Detailed breakdown of question marks:

<u>Question no.:</u>	<u>Marks</u>
1 – 14	14 x 1
15, 16, 17	3 x 2
18 - 21	4 x 3
TOTAL MARKS:	32

Section 1: Multiple Choice Questions – Theoretical Questions
Please indicate your answer on the scantron sheet provided.

Q1. Incompressible fluid is defined as:

- a) fluid, in which pressure is constant everywhere in the fluid
- b) fluid, in which density is constant everywhere in the fluid
- c) fluid, in which pressure at a point does not change with time
- d) fluid, in which density at a point does not change with time
- e) both b) and d)

Q2. Let's assume that you are swimming in a swimming pool with your head just under the water surface. Later, you dive to the bottom of the pool where you feel more pressure on your ears than near the water surface. This is because:

- a) density is larger at the bottom than the top
- b) pressure is larger at the bottom than the top
- c) according to linear momentum theory, a force will be generated due to the fluid moving around your ears as you swim.
- d) both a) and b)
- e) both b) and c)

Q3. Fig. 1 shows the wake generated by a wind turbine. If this wake can be assumed to be a streamtube, which edges are formed by a streamline, and if air at these low speeds can be assumed to be incompressible, then which statement is true?

- a) Since air cannot pass through the streamtube walls, only those air particles which entered the streamtube through area A_1 will pass through the wind turbine's rotor disc (A) (Fig. 1a).
- b) Since conservation of mass has to be maintained, particles passing through the wind turbine's rotor disc (A) must enter through an equal area ($A_2 = A$) located at the streamtube entry plane (Fig. 1b).
- c) None of the above statements is true.

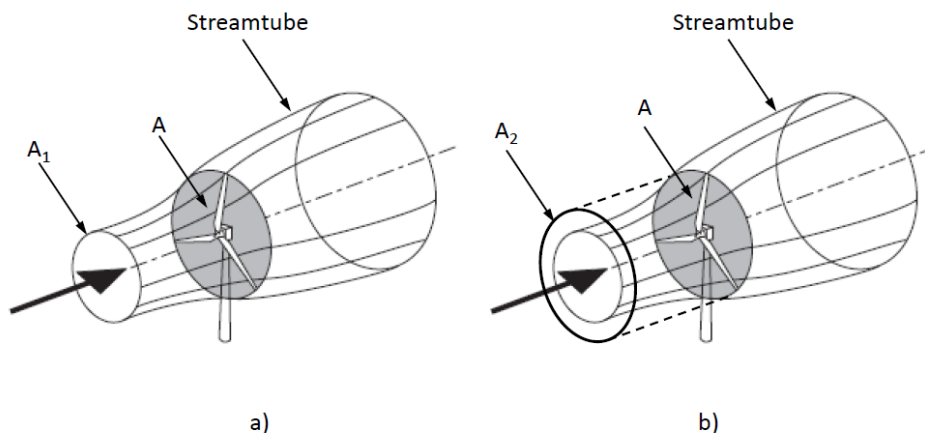


Fig. 1.

Q4. Consider a propeller surrounded by a Control Volume, as shown in Fig. 2. If we wish to calculate the thrust generated by the propeller by applying the Linear Momentum theorem, then we would need to know the following data:

- a) velocity, pressure and density at the propeller disc only
- b) the number and shape of propeller blades and the rotational frequency of the propeller
- c) velocity, pressure and density at the propeller disc as well as the number and shape of the propeller blades and the rotational frequency of the propeller
- d) velocity, pressure and density at the inlet (station 1) and outlet (station 2) of the Control Volume
- e) velocity, pressure and density at the inlet (station 1) and outlet (station 2) of the Control Volume as well as the number and shape of the propeller blades and the rotational frequency of the propeller.

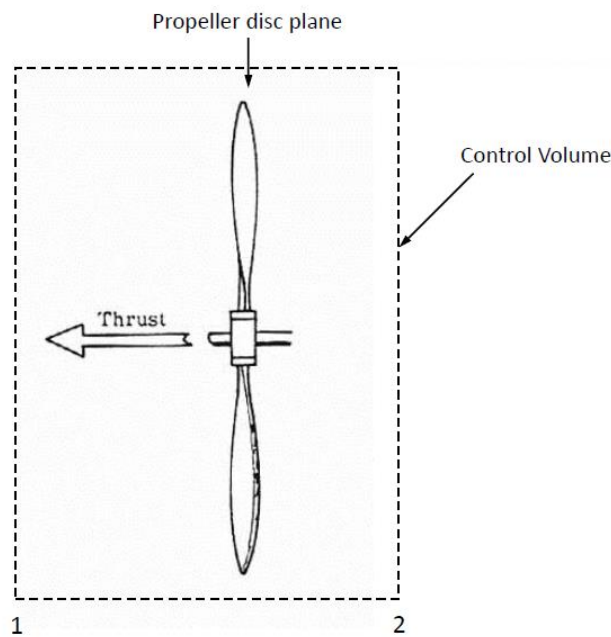


Fig. 2. Side view of a propeller.

Q5. In essence, the Control Volume approach of analyzing fluid flows builds upon

- a) the Lagrangian viewpoint of Fluid Mechanics
- b) the Eulerian viewpoint of Fluid Mechanics
- c) Pascal's law
- d) all of the above
- e) none of the above

Q6. If the reference pressure is defined as the ambient pressure in a given environment (i.e. 100,000 Pa on Earth or 0 Pa on Moon) then in your view, would it be possible to achieve -1,000 Pa of absolute pressure on either Earth or Moon?

- a) yes
- b) **no**
- c) yes, but only on the Moon
- d) yes, but only on the Earth

Q7. If the reference pressure is defined as the ambient pressure in a given environment (i.e. 100,000 Pa on Earth or 0 Pa on Moon) then in your view, would it be possible to achieve -1,000 Pa of gauge pressure on either Earth or Moon?

- a) yes
- b) no
- c) yes, but on the Moon only
- d) **yes, but on the Earth only**

Q8. Fig. 3 below shows a boundary layer. Note that the edge of the boundary layer is shown by the dashed line. In which portion of Fig. 3 is the flow uniform?

- a) **in the freestream only**
- b) in the boundary layer only
- c) in both the freestream and the boundary layer
- d) in neither the freestream or the boundary layer

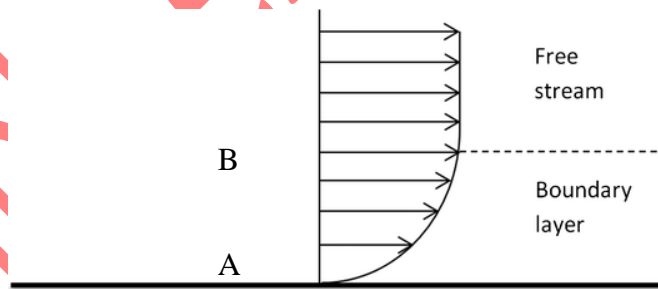


Fig. 3.

Q9. On Fig. 3, where does the no-slip condition occur?

- a) **at the wall (point A), since fluid particles do not move (or “slip”) at the the solid wall**
- b) at the edge of the boundary layer and the freestream (point B), since fluid particles move with the same speed, i.e. they don't slip relative to each other.
- c) at both points A and B
- d) at neither of points A and B.

Q10. Consider a bathtub, in which both the tap as well as the drainage are open. If the tap is set to 0.1 kg/s of mass flow rate, while the drainage capacity is 0.08 kg/s, then the net rate of outflow from the bathtub is:

- a) positive
- b) negative (i.e a net inflow)
- c) zero

Q11. Consider a water hose, from which a jet of water exits as shown in Fig. 4. The pressure inside the water jet – in terms of gauge pressure - just after leaving the hose (i.e. at point A) will be:

- a) positive
- b) negative
- c) zero

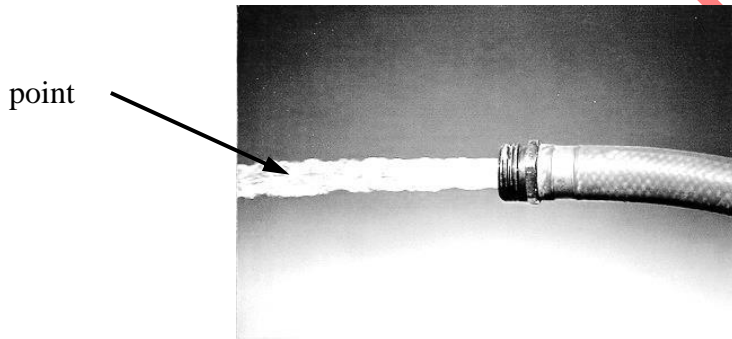


Fig. 4.

Q12. A Canadian flag on top of the Peace Tower of the Parliament building is blown by the wind as shown in Fig. 5. The wind speed is constant and uniform, but the flag is “waving”, i.e. it exhibits a wavy motion. As such, it essentially visualizes the flow behind the flag pole. In this case, the flow behind the flag pole is:

- a) steady
- b) unsteady
- c) steady and uniform
- d) unsteady and one-dimensional
- e) steady, non-uniform and three-dimensional

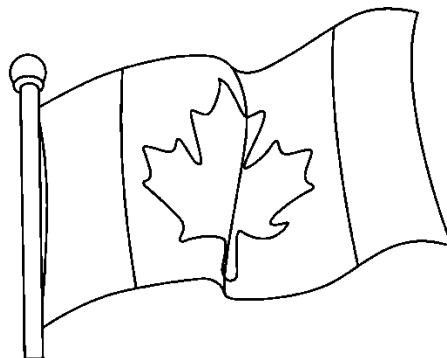


Fig. 5.

Q13. When solving fluid flow problems with the Linear Momentum theorem, the force terms calculated correspond to:

- a) the force that the fluid exerts on the object/machine inside the Control Volume
- b) the force that the object/machine exerts on the fluid passing around it
- c) can be either a) or b), it depends on our choice.

Q14. Consider the fluid having a uniform velocity V , flowing into the cylindrical tube with the cross section area A , as shown in Fig. 6. The volumetric flow rate (Q) inside the tube can be calculated from:

- a) $Q=V.A$
- b) $Q= V \cos(\theta).A$
- c) $Q= V \sin(\theta).A$
- d) $Q= V^2.A$

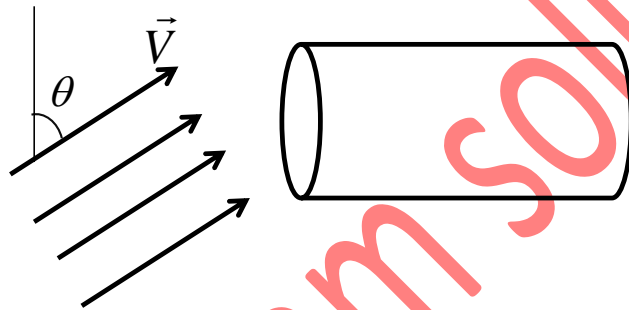


Fig. 6.

Section 2: Multiple Choice Questions – Numerical Problems

For Questions 15,16,17 please refer to the problem statement below. Please indicate your answers on the scantron sheet provided.

Problem Statement: The gardens of the Rideau Hall, where the Governor General of Canada resides, feature a fountain which has a “stretched surface” (Fig. 7). The cross-section of the fountain is shown in Fig. 8. Note that the water thickness over the lip (point A in Fig. 8) is 2 cm, while the velocity over the lip varies according to a parabolic function of the form $v = (ky)^{0.5}$. Your task is to design the fluid mechanics portion of this fountain in a way so that the water curtain around the perimeter of the lip is unbroken and starts from 2 cm height at the top. You may assume uniform inflow from the pump as well as steady flow and incompressible fluid throughout the fountain. Note that the density of water is $1,000 \text{ kg/m}^3$.

[Hint: $\int x^n dx = \frac{x^{n+1}}{n+1} + C$]



Fig. 7

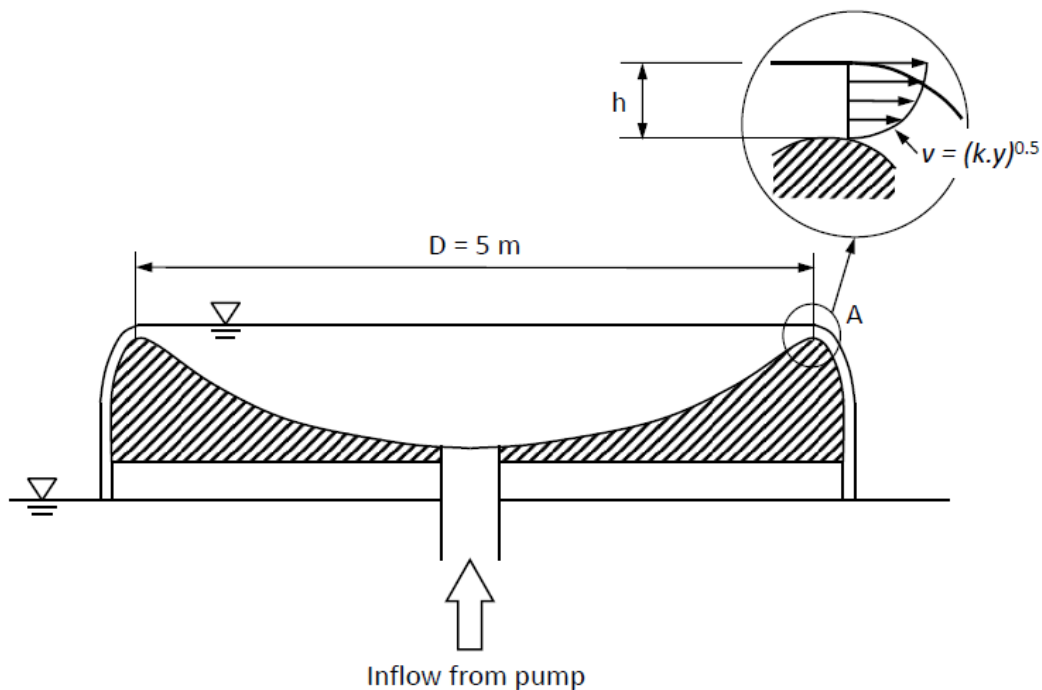


Fig. 8

Q15 [2 marks]: If the velocity on top of the lip (point A in the sketch) is 2.5 cm/s, then what would be the corresponding value of k in the expression for the parabolic velocity profile?

- a) 0.03125 m/s²
- b) 0.04580 m/s²
- c) 0.05561 m/s²
- d) 0.06250 m/s²

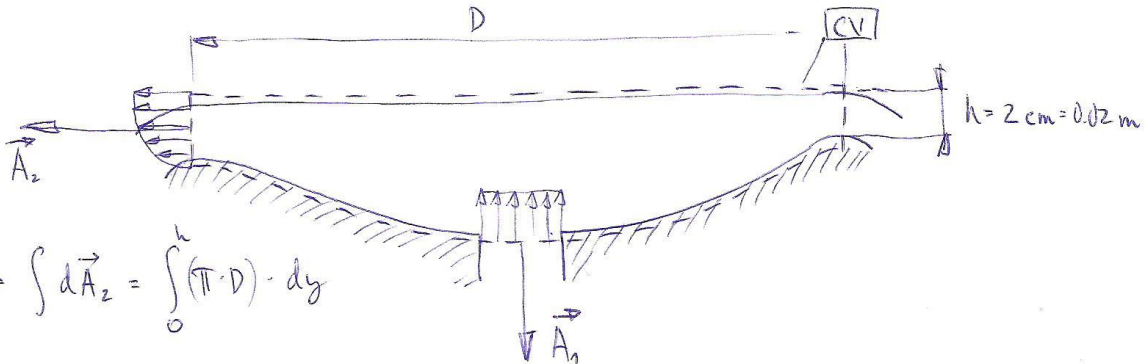
Q16 [2 marks]: For the conditions of Q15, what would be the average velocity over the lip?

- a) 1.25 cm/s
- b) 1.67 cm/s
- c) 2.04 cm/s
- d) 2.28 cm/s

Q17 [2 marks]: Independent of the answer in question Q1, let's assume that the velocity profile varies according to the formula $v = (0.0025y)^{0.5}$. In order to maintain a 2 cm thick water layer over the lip (point A on Fig. 9), what mass flow rate should the water pump deliver to the fountain?

- a) 1.206 kg/s
- b) 1.481 kg/s
- c) 1.887 kg/s
- d) 2.435 kg/s

Q3: if $v = (0.0025 \cdot y)^{\frac{1}{2}}$ and $h = 2 \text{ cm}$ then $Q_1 = ?$



$$\vec{A}_2 = \int d\vec{A}_2 = \int_0^h (\pi \cdot D) \cdot dy$$

Conservation of mass for CV:

$$\int_{CS} \rho \cdot \vec{v} \cdot d\vec{A} = - \frac{d}{dt} \int_{CV} \rho \cdot dV$$

\emptyset since steady flow ($\frac{d}{dt} = \emptyset$)

$$\int_{A_1} \rho_1 \cdot \vec{v}_1 \cdot d\vec{A}_1 + \int_{A_2} \rho_2 \cdot \vec{v}_2 \cdot d\vec{A}_2 = \emptyset$$

$$\rho_1 \cdot \vec{v}_1 \cdot \int_{A_1} d\vec{A}_1 + \rho_2 \cdot \int_{A_2} (0.0025 \cdot y)^{\frac{1}{2}} \cdot (\pi \cdot D \cdot dy) = \emptyset$$

$$\rho_1 \cdot v_1 \cdot (-A_1) + \rho_2 \cdot \int_0^h (0.0025 \cdot y)^{\frac{1}{2}} \cdot (\pi \cdot D) \cdot dy = \emptyset$$

$$-Q_1 + 0.0025^{\frac{1}{2}} \cdot \pi \cdot D \cdot \left[\frac{y^{\frac{3}{2}}}{\frac{3}{2}} \right]_0^h = \emptyset$$

$$Q_1 = 0.0025^{\frac{1}{2}} \cdot \pi \cdot 5 \cdot \frac{0.02^{1.5}}{1.5} = 1.481 \cdot 10^{-3} \frac{\text{m}^3}{\text{s}}$$

$$\underline{\underline{\dot{m}_1}} = \rho \cdot Q_1 = 1,000 \cdot 1.481 \cdot 10^{-3} = \underline{\underline{1.481 \frac{\text{kg}}{\text{s}}}}$$

For Questions 18,19 please refer to the problem statement below. Please indicate your answers on the scantron sheet provided.

Problem Statement: Consider the inverted manometer containing three types of fluid, as shown in Fig. 9. The water has the density of 1000 kg/m^3 , and the specific gravity (SG) for oil is 0.8 and for mercury is 13.6. The levels of the fluid interfaces are indicated as: $h_1 = 20 \text{ cm}$ and $h_2 = 15 \text{ cm}$. (Assuming $p_{atm} = 100 \text{ kPa}$ and $g = 9.81 \text{ m/s}^2$)

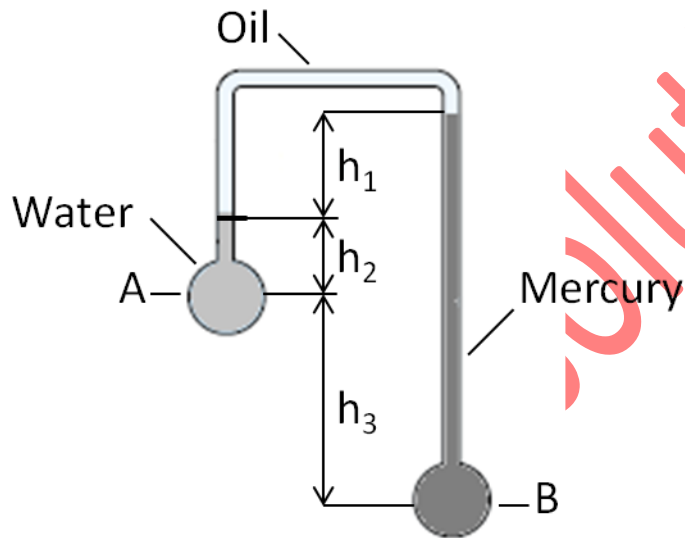


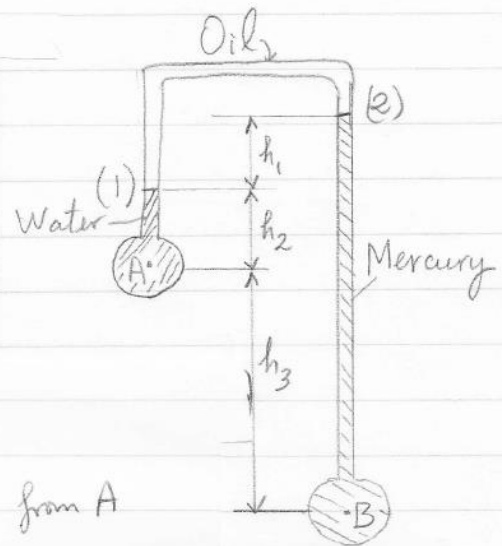
Fig. 9

Q18 [3 marks]: If the pressure at A is 20 kPa (gauge), then the absolute pressure at the interface between Oil and Mercury would be closest to:

- a) 214 kPa
- b) 92 kPa
- c) 146 kPa
- d) 117 kPa

Q19 [3 marks]: If the pressure at A is not available, but the the pressure difference between B and A is $p_B - p_A = 85 \text{ kPa}$, then the distance between A and B (measured by h_3) would be closest to:

- a) 30.9 cm
- b) 14.2 cm
- c) 38.4 cm
- d) 7.8 cm



a) Find P_2 (abs)

using up-down approach, starting from A

$$P_A - \rho_w g h_2 - \rho_{oil} g h_1 = P_2$$

$$\text{or } P_2 = (20,000 \text{ Pa} + 100,000 \text{ Pa}) - (1000 \frac{\text{kg}}{\text{m}^3})(9.81 \frac{\text{m}}{\text{s}^2})(0.15 \text{ m}) - (0.8)(1000 \frac{\text{kg}}{\text{m}^3})(9.81 \frac{\text{m}}{\text{s}^2})(0.2 \text{ m})$$

$$P_2 = 116,959 \text{ Pa} \approx \underline{\underline{117 \text{ kPa}}}$$

b) Find h_3

using up-down approach, starting from A

$$P_A - \rho_w g h_2 - \rho_{oil} g h_1 + \rho_M g (h_1 + h_2 + h_3) = P_B$$

$$\rho_M h_3 = \frac{P_B - P_A}{g} + \rho_w h_2 + \rho_{oil} h_1 - \rho_M (h_1 + h_2)$$

$$h_3 = \frac{1}{\rho_M} \left[\frac{P_B - P_A}{g} + \rho_w h_2 + \rho_{oil} h_1 - \rho_M (h_1 + h_2) \right]$$

$$= \frac{1}{(13.6)(1000 \frac{\text{kg}}{\text{m}^3})} \left[\frac{85,000 \text{ Pa}}{9.81 \frac{\text{m}}{\text{s}^2}} + (1000 \frac{\text{kg}}{\text{m}^3})(0.15 \text{ m}) + (0.8)(1000 \frac{\text{kg}}{\text{m}^3})(0.2 \text{ m}) - \right.$$

$$\left. (13.6)(1000 \frac{\text{kg}}{\text{m}^3})(0.2 + 0.15) \text{ m} \right]$$

$$h_3 = 0.31 \text{ m} = \underline{\underline{31 \text{ cm}}}$$

For Questions 20,21 please refer to the problem statement below. Please indicate your answers on the scantron sheet provided.

Problem Statement: An horizontal water jet ($\rho_{\text{water}} = 1000 \text{ kg/m}^3$) exits a nozzle with a uniform velocity V of 3 m/s, hits a vane, is turned through an angle of $\theta = 40 \text{ deg}$, and leaves the vane, as shown in Fig. 10 below. The cross-sectional area A of the flow is 0.006 m^2 . For this question, neglect gravity and friction effects.

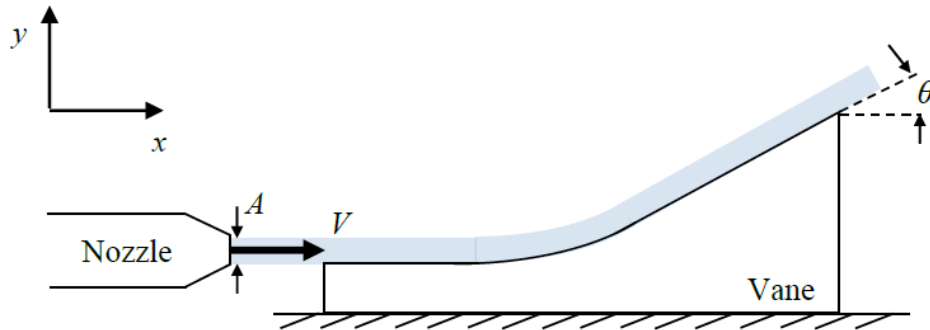


Fig. 10

Q20 [3 marks]: Determine the anchoring force along the x-axis required to hold the vane stationary.

- a) 22.3 N
- b) -22.3 N
- c) 12.6 N
- d) -12.6 N

Q21 [3 marks]: Determine the maximum velocity V that the vane can sustain in order to remain stationary if it is anchored by a mechanism that provides a force along the x-axis with a magnitude of 30 N.

- a) 21.4 m/s
- b) 7.1 m/s
- c) 4.6 m/s
- d) 3.5 m/s

Q20

$$\Sigma F_x = (\dot{m}u)_{out} - (\dot{m}u)_{in}$$

$$\Sigma F_x = \dot{m}_2 u_2 - \dot{m}_1 u_1$$

$$\Sigma F_x = F_x = (\rho_2 V_{n2} A_2) u_2 - (\rho_1 V_{n1} A_1) u_1$$

Incompressible fluid :

$$\rho_2 = \rho_1 = \rho$$

Equal areas :

$$A_1 = A_2 = A$$

Continuity :

$$\dot{m}_1 = \dot{m}_2$$

$$\rho V_{n1} A = \rho V_{n2} A$$

$$V_{n1} = V_{n2} = V$$

∴

$$F_x = \rho V A (u_2 - u_1)$$

where

$$u_2 = V \cos \theta$$

$$u_1 = V$$

∴

$$F_x = \rho V^2 A (\cos \theta - 1) \quad (\text{Eq. 1})$$

with $\rho = 1000$, $V = 3$, $A = 0.006$, $\theta = 40^\circ$

$$F_x = -12.6 \text{ N}$$

Q21

$$\text{From (Eq. 1), } V = \sqrt{\frac{-30}{\rho A (\cos \theta - 1)}} = 4.6 \text{ m/s}$$