THE UNIVERSITY OF ZAMBIA

SCHOOL OF ENGINEERING

DEPARTMENT OF CIVIL AND ENVIRONMENTAL ENGINEERING

CE369- FLUID MECHANICS I

LAB 3. IMPACT OF FLUID TEST

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1.0 OBJECTIVE:

To compare the momentum in a fluid with the force generated when it strikes a fixed surface.

2.0 THEORY:

A FLUID JET is a stream of fluid liquid passing through a nozzle with a high velocity. This stream of fluid on impact moves over the surface until boundaries are reached and the fluid then leaves the surface tangentially. The impact of the fluid on the plate or vane exerts a force on the respective surface due to change in momentum. This change in momentum is due to the change in the velocity before impact to a new velocity of deflected fluid. The Impulse-Momentum principle shows that the rate of change of momentum is equal to the impact force according to Newton's 2nd law of motion of motion

$$F = ma = \frac{mv_f - mv_i}{t} \dots eqn. 1$$

Where $m = mass;\ v_f = final\ velocity;\ v_i = initial\ velocity; t = time; a = acceleration$

Theory shows that;

$$F_x = \rho Q(v_1 \cos\theta_1 \ \ - v_2 \cos\theta_2 \ \ )$$

Where $\rho = density\ of\ fluid; Q = flow\ rate;\ F_x = force\ in\ x - component;\ \theta = angle\ of\ inclination\ from\ horizontal$

- *Assumptions for theory:*
- 2 points are considered here in a fluid stream of steady flow.
- Fluid is uniform and normal to the inlet and the outlet.
- There is conservation of mass.

Taking the direction of v_i as x direction and the angle between v_1 and v_2 to be β, the equation becomes

$$F_x = \rho Q v(1 - \cos\beta)$$

For a Flat plate, $\beta = 90^0$ hence the formula becomes

$$F_x = \rho Q v$$

For a hemispherical plate, $\beta = 180^0$, the equation becomes

$$F_x = 2\rho Q v$$

3.0 DESCRIPTION OF APPARATUS:

The apparatus used is as shown below:

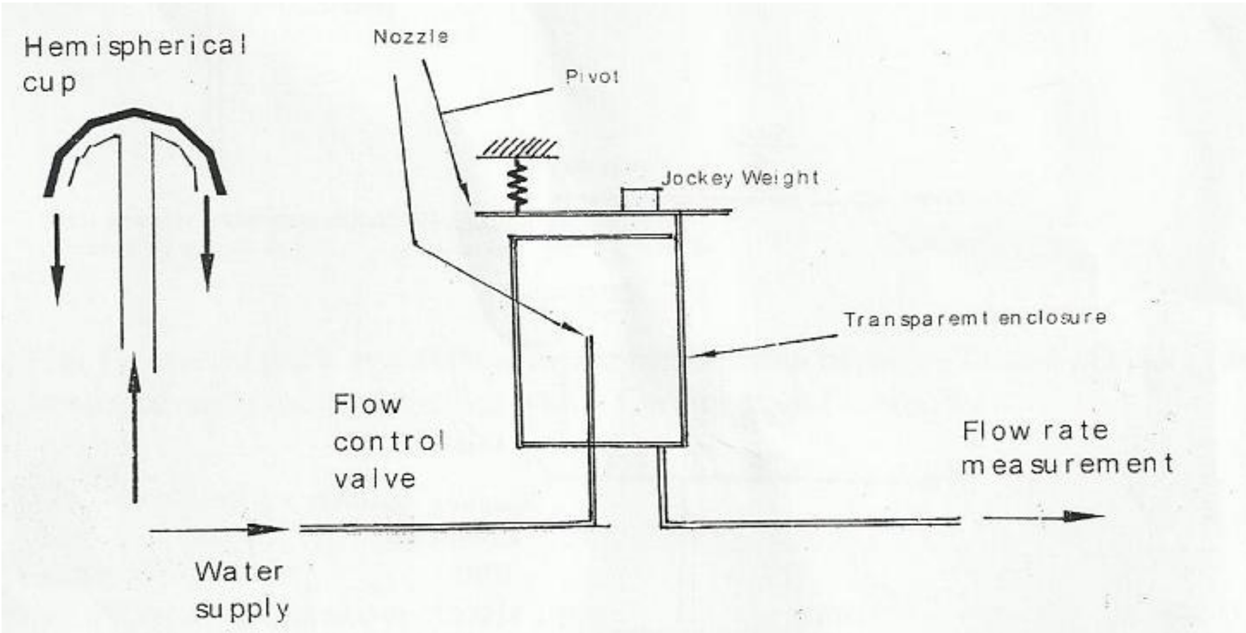


fig.1. ***Apparatus***

The water supply is connected to a vertical pipe with a tapered nozzle as the outlet.

The surfaces used were a flat plate 90° and a hemispherical plate 180°.

For a transparent observation, both the nozzle and the test plate are contained in a transparent cylinder.

A drain tube, in the base of the cylindrical vessel was used to direct the water to the weight bucket where the low can be measured.

4.0 PROCEDURE:

The apparatus was set up as illustrated in the figure captioned under **description of apparatus.**

The hemispherical plate and the flat plate were used in the experiment, one plate at a time. Firstly a flat plate was initially installed before starting the actual experiment. The apparatus was then leveled when there was no flow; this was done ensuring that the beam was horizontal.

Using he control valve, the water supply was opened to the maximum. The jockey weight was then moved until the horizontal balanced position was attained again. The time it took to fill 6kg of water was recorded. This procedure was repeated for varied pressures.

The exact same procedure was done for a hemispherical plate.

4.1 PROCEDURE: *Determining* F_x

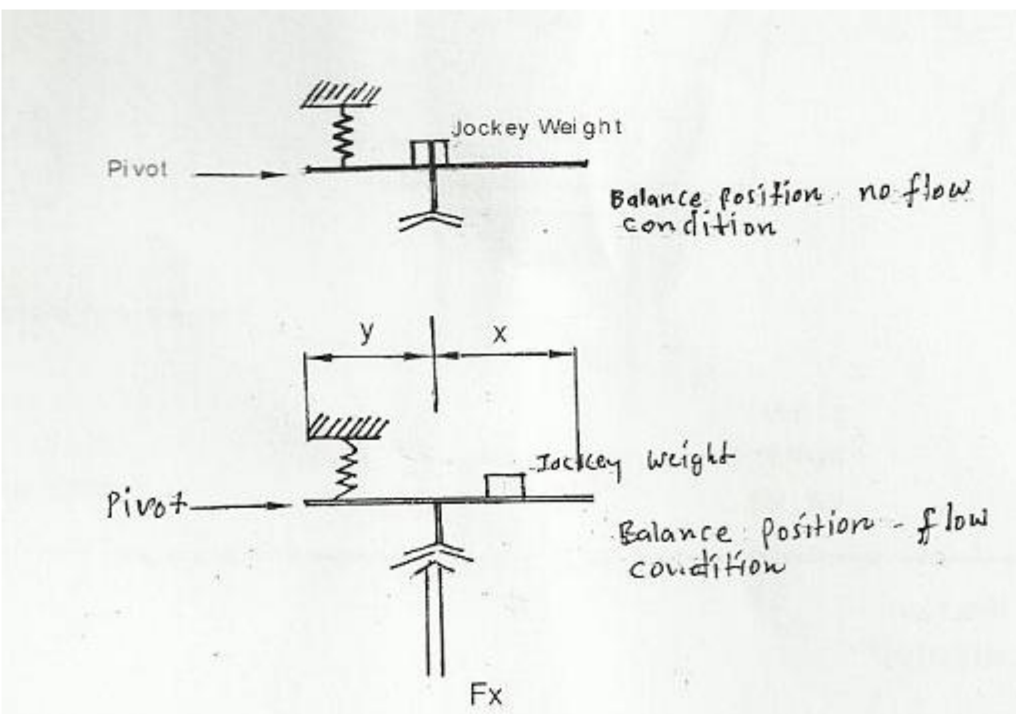


fig.2. ***Measuring*** $\boldsymbol{F_x}$

$$\Delta \boldsymbol{m} = F_x . y \quad \textit{Additional moment due to mass m}$$

This was balanced by an additional moment due to mass m of the jockey.

$$\Delta \boldsymbol{m} = mg(x + y)$$

Thus equating the two, we have

$$F_x . y = mg . x$$

Hence,

$$F_x = \frac{mg . x}{y}$$

4.2 PROCEDURE: *Calculating flow rate Q*

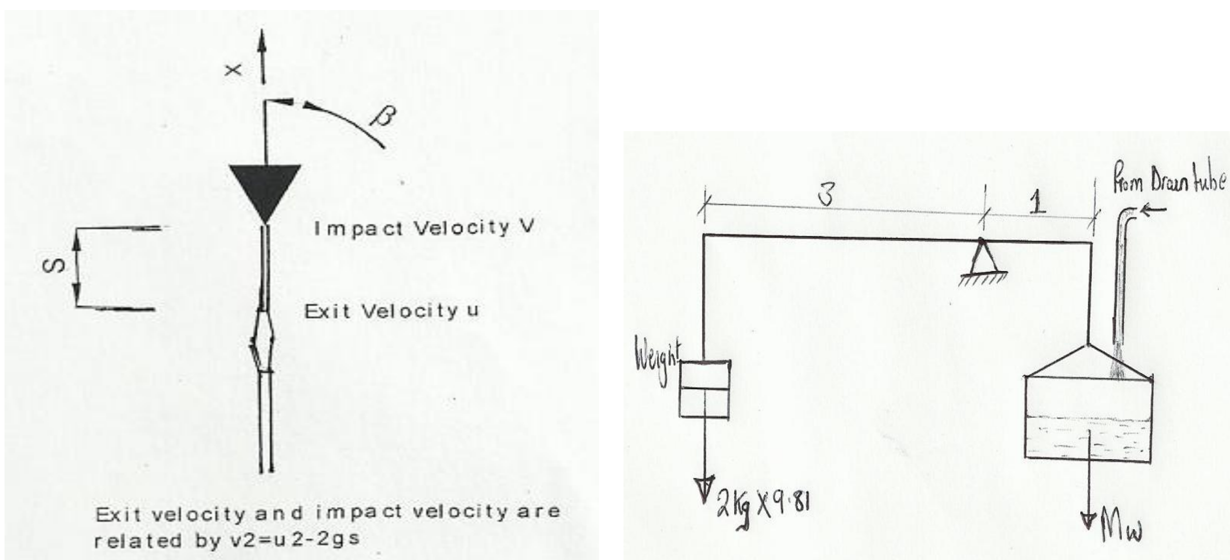


fig.3 ***Calculating the flow rate Q***

Mass used was a 2kg, with a ratio of 3:1 the actual mass of the water collected was $3\times\ 2kg = 6kg$

From the mass of the water, the volume is calculated as follows

$$volume_{water} = \frac{mass}{density}$$

$$Q = \frac{volume}{time} \dots flow\ rate$$

$$u = \frac{Q}{area_{nozzle}} \dots calculation\ of\ nozzle\ velocity$$

$$v^2 - u^2 = 2gs \dots velocity\ at\ impact$$

Where $v = velocity\ at\ impact; u = exit\ velocity(nozzle\ velocity)$

5.0 RESULTS:

The table below shows the results obtained from the experiment. Mass of weight used to measure mass of water was 2kg. Thus, mass of water was 6kg from ratio 3:1 of the ratio of the weight in apparatus used to actual mass of water collected.

Table 1: results for flat plate ($\beta = 90^0$)

Mass of water (kg)	Time (s)	Q (m^3/s)	$u(m/s)$	$v(m/s)$	Position of jockey x	$F_x(N)$	$\rho Q v$
6.0	19	0.000316	4.02	3.93	37	1.45	1.24
6.0	10.5	0.000571	7.27	7.22	154	6.04	4.12
6.0	14.7	0.000408	5.19	5.12	74	2.90	2.09
6.0	35.5	0.000169	2.15	1.98	11	0.43	0.33
6.0	20.36	0.000295	3.76	3.67	42	1.65	1.08
6.0	14.28	0.000420	5.35	5.29	91	3.57	2.22

Table 2: results for hemispherical plate ($\beta = 180^0$)

Mass of water (kg)	Time (s)	Q (m^3/s)	$u(m/s)$	$v(m/s)$	Position of jockey x	$F_x(N)$	$\rho Q v$
6.0	12.33	0.000487	6.20	6.14	179	7.02	2.99
6.0	14.73	0.000407	5.18	5.11	116	4.55	2.08
6.0	23.6	0.000254	3.23	3.12	50.5	1.98	0.79
6.0	18.83	0.000319	4.06	3.97	77.0	3.02	1.27
6.0	21.71	0.000276	3.51	3.41	57	2.24	0.94
6.0	44.59	0.000135	1.72	1.50	14.5	0.57	0.20

Where:

a. *Nozzle dia. = 10mm*

b. *Vane above nozzle. (Height of impact above the nozzle tip) = 35mm=s*

c. *Distance from pivot to centre line = 150mm=y*

d. *Jockey weight = 600g=0.6kg*

6.0 DATA ANALYSIS:

a) The relationship $F_x = \rho Q v\,(1 - \cos\beta)$ is derived as follows:

Assumptions:

1. *The fluid is uniform and normal to the inlet and the outlet*
2. *conservation of mass*

$$thus, \quad F_x = \rho Q(v_1 \cos\theta_1 - v_2 \cos\theta_2)$$

Where: $\rho = density\ of\ fluid; Q = flow\ rate;$

$$F_x = force\ in\ x - direction;$$

$$\theta = angle\ of\ inclination\ from\ horizontal$$

Using CONTROL VOLUMES

$$\sum F = \frac{\partial}{\partial t}\int_{c\forall} \rho\bar{v}d\forall + \int_{cs} \rho\bar{v}(\bar{V}.\bar{N})dA$$

$$but\ for\ a\ steady\ state\ system\ and\ constant\ control\ volume\ all\ partials\ go\ to\ zero$$

Thus$\frac{\partial}{\partial t}\int_{c\forall} \rho\bar{v}d\forall = 0$,

$$\bar{V}.\bar{N} = v_{1.}cos180° = -v_1$$

$$\bar{V}.\bar{N} = v_2 cos0° = v_2$$

$$-F_x = \int_{cs1} \rho v_{1x}(-v_1)dA + \int_{cs2} \rho v_{2x}(v_2)dA$$

$$\boldsymbol{However}, \int_{cs} v_i dA = vA = QA$$

$$v_1 = v_2 = v \quad and \quad v_{1x} = v\ and\ v_{2x} = vcos\beta$$

Therefore;

$$-F_x = -\rho Q(v - vcos\beta)$$

$\boldsymbol{F_x = \rho Q v(1 - cos\beta)}$***.........equation derived.***

b) <u>Sample Calculation;</u>

s=35mm=0.035m; y=150mm=0.15m; dia.=10mm=0.01m

$v^2 = u^2 - 2gs$.............***equation relating exit velocity and impact velocity***

$$radius = \frac{dia.nozzle}{2} = \frac{10 \times 10^{-3}}{2} = \frac{0.01}{2} = 0.005m$$

$$area_{nozzle} = \boldsymbol{\pi 0.005^2 m^2}$$

Taking the first reading of table 1 as sample calculation, we have.

$$volume_w = \frac{6kg}{1000kg/m^3}$$

$$= \mathbf{0.006m^3}$$

Calculating the flow rate Q;

$$Q = \frac{volume}{time} = \frac{0.006}{19}$$

$$\boldsymbol{Q = 0.000316\mathrm{m^3}/s}$$

Calculating u:

$$u = \frac{Q}{area_{nozzle}} = \frac{0.000316}{\pi 0.005^2}$$

$$= \mathbf{4.02m/s}$$

To calculate v:

$$v = \sqrt{u^2 - 2gs}$$

$v = \sqrt{\mathbf{4.02}^2 - 2 \times 9.81 \times 0.035}$= **3.93**$\boldsymbol{m/s}$

To calculate Fx:

x=0.037m; y=0.15m

$$mg(x) = F_x(0.15)$$

$$0.6 \times 9.81(0.037) = F_x(0.15)$$

$$F_x = 39.24 \times (x) = 39.24 \times 0.037 = \mathbf{1.45N}$$

c) To calculate $\boldsymbol{\rho Q v}$***;***

$$\rho Q v = 1000 \times \frac{0.000316\mathrm{m^3}}{\mathrm{s}} \times \frac{3.93\mathrm{m}}{\mathrm{s}}$$

$$= \mathbf{1.24N}$$

FOR A FLAT PLATE $\beta = 90°$ $\boldsymbol{hence\ F_x = \rho Q v}$

FOR A HEMISPHERICAL PLATE $\beta = 180°$ $\boldsymbol{hence\ F_x = 2\rho Q v}$

here $\boldsymbol{\beta = 90}$ for sample calculation;

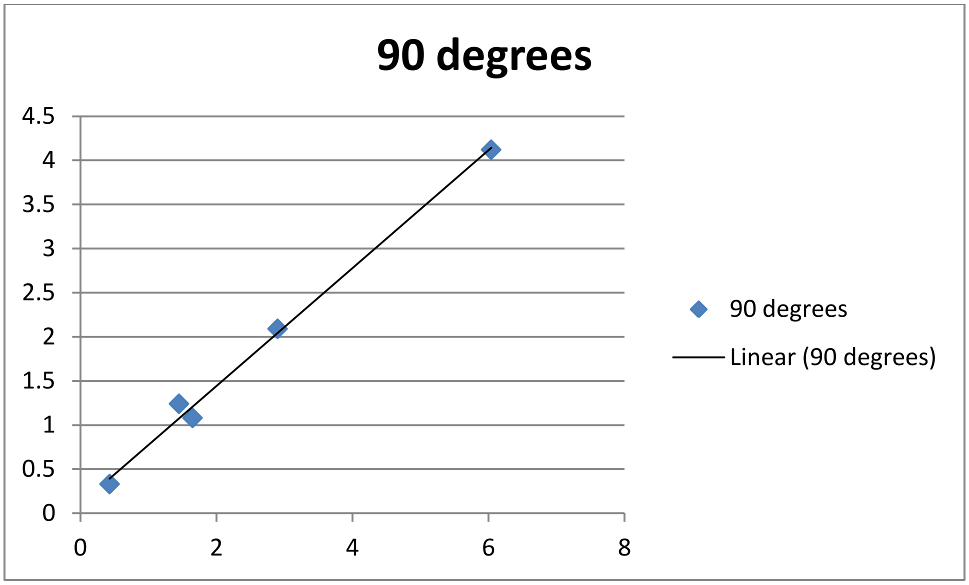
$$\boldsymbol{F_x = \rho Q v(1 - cos\beta)}$$

$$1.24(1 - cos90) = \rho Q v = \mathbf{1.24N}$$

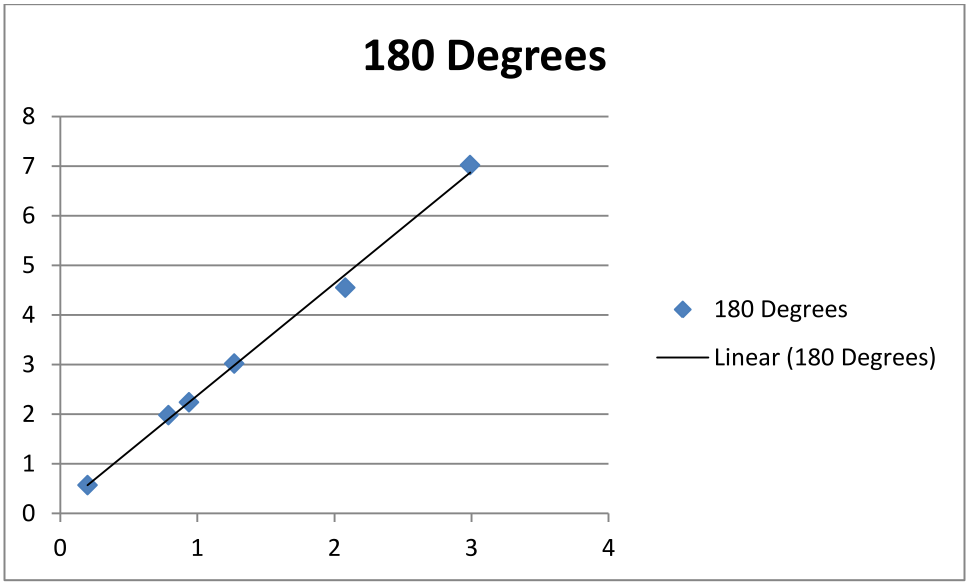
d) ABSOLUTE ERROR= $|1.24 - 1.45| = \mathbf{0.21}$

PERCENT ERROR=$\frac{0.21}{1.24} \times 100\% = \mathbf{17.1}\%$

e) graph of $\boldsymbol{F_x\ vs\ \rho Q v}$



f) graph of $\boldsymbol{F_x\ vs\ \rho Q v}$



g) Slope as calculated from graphs by linear regression;

From theory slope=1

$since\ Slope = \frac{\Delta F_x}{\Delta \rho Q v}$ Then the error for each plate is found as follows:

1. **FOR A FLAT PLATE $\boldsymbol{\beta = 90°}$ $\boldsymbol{F_x = \rho Q v}$,**
   $relative\ error = slope - 1$
   Slope from linear regression=1.54
   Therefore $relative\ error = slope - 1$

   $=1.54 - 1$

   $= \mathbf{0.54}$

2. **FOR A HEMISPHERICAL PLATE $\boldsymbol{\beta = 180°}$ $\boldsymbol{F_x = 2\rho Q v}$,**
   $relative\ error = \frac{slope}{2} - 1$
   Slope from linear regression=2.26
   Therefore $relative\ error = \frac{slope}{2} - 1$

   $=\frac{2.26}{2} - 1$

   $= \mathbf{0.13}$

7.0 DISCUSSION:

For the time t$\approx$ 14.7s the forces of the separate surfaces showed that there was a greater impact for this time (16.257N$>$ 10.37N) for the hemispherical plate.

The errors found were 0.54 and 0.13 for the plates $\boldsymbol{\beta = 90°\ and\ 180°}$ respectively. The graphical plot showed a linear correlation of values implying the linear relationship between$\boldsymbol{F_x\ and\ \rho Q v}$. The errors were due to inaccuracies that could have resulted by experimental errors such as when recording time and also due to rounding off.

Discussing the results, the impact force was observed to be directly proportional to the flow rate as seen from the slopes. Hence the greater the discharge, the greater the value of the impact force.

8.0 CONCLUSION:

The objectives of the laboratory experiment were achieved. The force generated by the momentum of a fluid when it strikes a fixed surface was determined. It was concluded that $mg(x) = F_x(0.15)$ was appreciably valid to find the value of F_x experimentally as its value was $\approx\ \boldsymbol{\rho Q v(1 - cos\beta)}\ from\ theory$.

9.0 REFERENCES:

1. Kothandaraman C.P & Rudramoorthy R. (1999), **Fluid Mechanics and Machinery** (2ND edition), New Age International Ltd., Publishers, New Delhi, India.
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3. White F.M (2011), **Fluid Mechanics** (SIE,7th edition),McGraw-Hill companies, Inc, New York, United States of America