Impact of Water Jet

University of Jordan

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Objective:

1. To determine the force produced by a water jet when it strikes a flat vane and a hemispherical cup.
2. To compare the results measured with theoretical values calculated from the momentum flux in jet.

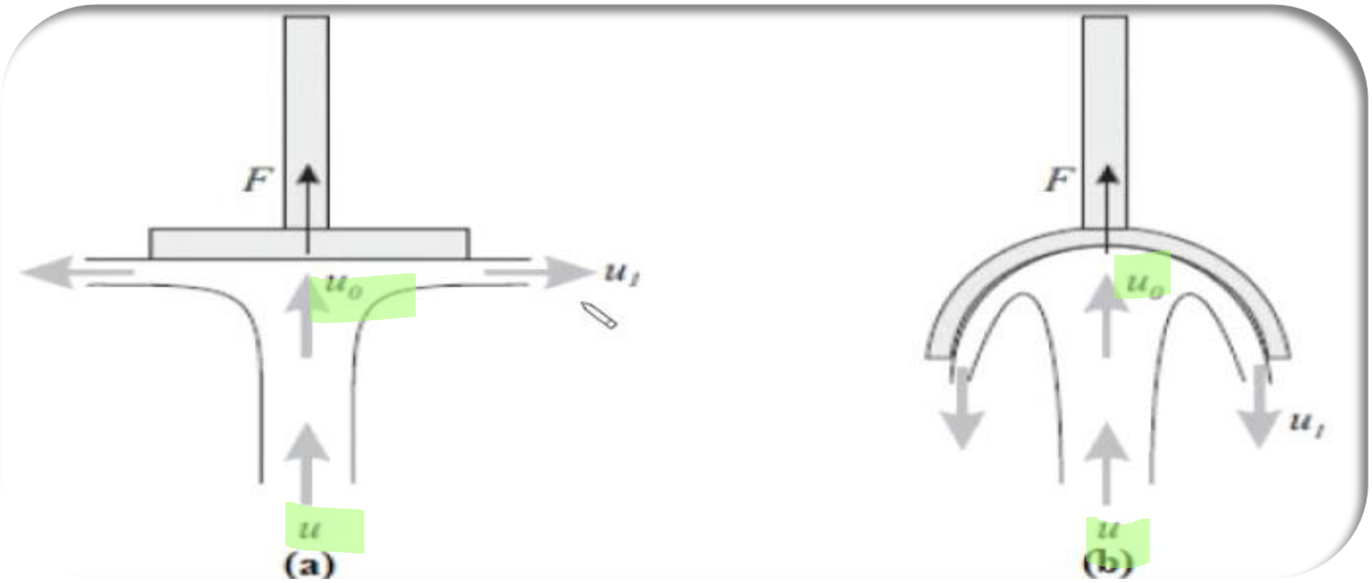
Apparatus:

1. A hydraulic bench.
2. Stopwatch.
3. Water jet apparatus.

Introduction:

- When fluid is in motion, whether in natural occurrences or engineered systems, it can exert forces on surrounding objects. Analyzing fluid motion typically involves selecting a finite region of the fluid, known as a control volume, and assessing the overall effects of the flow, such as its force or torque on objects, by calculating the net mass rate entering and leaving the control volume. Similar to solid mechanics, these forces can be determined using Newton's second law or the momentum equation. Specifically, the force exerted by a fluid jet on a flat or curved surface can be resolved by applying the momentum equation. Understanding and studying these forces are fundamental aspects of fluid mechanics and hydraulic machinery.

- In this experiment, water is supplied to the jet apparatus through a closed-loop system driven by a pump. The flow rate is measured using a weighing tank and a stopwatch. The water emerges vertically upward into the air via a nozzle. Two objects are utilized: a flat plate and a hemispherical cup. Each object can be positioned on a horizontal lever above the water jet to receive its impact. By attaching weights at various positions on the lever, the force acting on the object can be determined.



Technical Data:

Mass of jockey weight	m=0.610kg
Distance from center-line of vane to weigh-beam pivot	0.1525m
Diameter of nozzle,	d=0.01m
Height of vane above nozzle outlet	s=0.04m
Diameter of hemispherical cup	0.06m

Data Collected:

▪ Table 1: Results for flat plate

M (kg)	t (s)	Δx (mm)	ṁ (kg\s)	u (m\s)	u_o (m\s)	ṁ u_o (N)	F Theo.(N)	F Exp (N)	Error
7.5	15.85	70	0.473	6.025	5.960	2.820	2.820	2.747	2.56%
7.5	16.00	66	0.469	5.969	5.903	2.767	2.767	2.590	6.41%
7.5	16.35	62	0.459	5.840	5.773	2.648	2.648	2.433	8.12%
7.5	18.68	46	0.402	5.112	5.035	2.022	2.022	1.805	10.71%
7.5	21.95	30	0.342	4.351	4.260	1.456	1.456	1.177	19.12%
7.5	48.67	2	0.154	1.962	1.751	0.270	0.270	0.079	70.90%

Sample of calculations:

Take the first trial for flat plate as sample of calculations:

m=7.5 kg t=14 $\Delta x = 75\ mm$

Mass flow rate: $\dot{m} = \frac{m}{t} = \frac{7.5}{15.85}$ =0.473 kg/s

Velocity at the exit of the nozzle: u $=\frac{\dot{m}}{\rho A} = \frac{\dot{m}}{\rho \frac{\pi}{4} d^2} = \frac{0.536}{1000 * \frac{\pi}{4} * 0.01^2}$ =6.025 m/s

Velocity at the upstream of the vane:

$u_o = \sqrt{u^2 - 2gs} = \sqrt{6.025^2 - 2 * 9.81 * 0.04}$ = 5.960 m/s

Theoretical force: $F_{theo} = \dot{m} u_o$ = 0.473*5.960 = 2.820 N

Experimental force: F_{exp}= 4gΔx =4*9.81*0.070= 2.747 N

Error (%) = $\left|\frac{F_{exp} - F_{theo}}{F_{theo}}\right|$*100% = $\left|\frac{2.747 - 2.820}{2.820}\right|$*100%=2.56%

- **Table 1: Results for hemispherical cup**

M (kg)	t (s)	Δx (mm)	ṁ (kg\s)	u (m\s)	u_o (m\s)	ṁ u_o (N)	F Theo.(N)	F Exp (N)	Error
7.5	13.40	135	0.560	7.126	7.071	3.958	3.958	5.297	33.85%
7.5	15.88	132	0.472	6.013	5.948	2.809	2.809	5.180	84.39%
7.5	16.62	130	0.451	5.746	5.677	2.562	2.562	5.101	99.13%
7.5	16.70	117	0.449	5.718	5.649	2.537	2.537	4.591	80.96%
7.5	20.08	90	0.374	4.756	4.672	1.745	1.745	3.532	102.37%
7.5	24.65	55	0.304	3.874	3.771	1.147	1.147	2.158	88.09%

Sample of calculations:

Take the first trial for flat plate as sample of calculations:

m=7.5 kg t=14 $\Delta x = 75\ mm$

Mass flow rate: $\dot{m} = \frac{m}{t} = \frac{7.5}{13.40}$ =0.560 kg/s

Velocity at the exit of the nozzle: u =$\frac{\dot{m}}{\rho A} = \frac{\dot{m}}{\rho \frac{\pi}{4} d^2} = \frac{0.560}{1000 * \frac{\pi}{4} * 0.01^2}$ =7.126 m/s

Velocity at the upstream of the vane:

$u_o = \sqrt{u^2 - 2gs} = \sqrt{7.126^2 - 2 * 9.81 * 0.04}$ = 7.071 m/s

Theoretical force: $F_{theo} = \dot{m} u_o$ = 0.560*7.071 = 3.958 N

Experimental force: F_{exp}= 4gΔx =4*9.81*0.135= 5.297 N

Error (%) = $\left|\frac{F_{exp} - F_{theo}}{F_{theo}}\right|$*100% = $\left|\frac{5.297 - 3.958}{3.958}\right|$*100%=33.85%

Results:

The following figures represent the plots of the relationship between $(\dot{m}u_o)$and force (F) for the flat plate and the hemispherical cup.

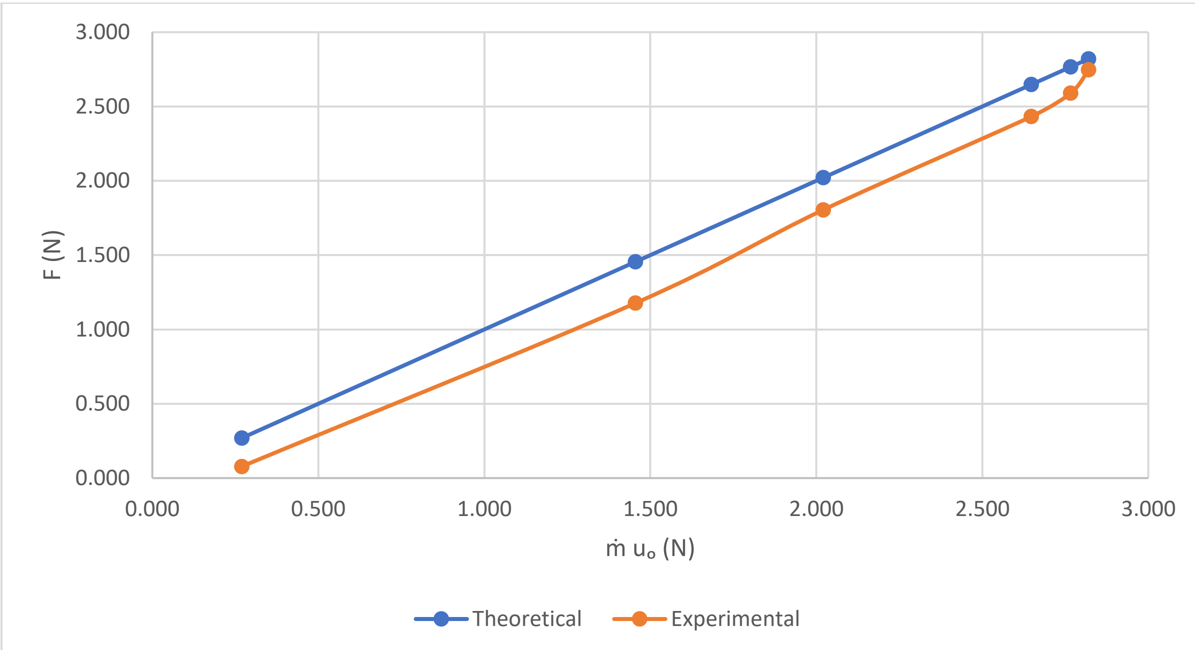


Figure1. Plot of the relationship between $(\dot{m}u_o)$and force (F) for flat plate

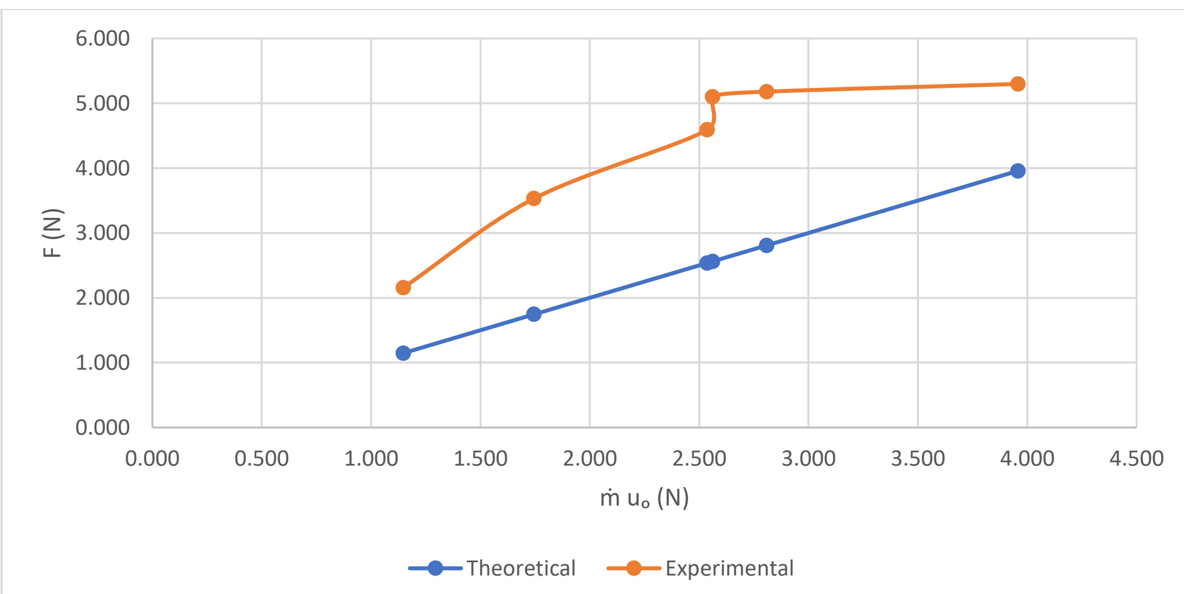


Figure2. Plot of the relationship between $(\dot{m}u_o)$and force (F) for the hemispherical cup

we note here in **Figure2** that we have clear error in measure the $\Delta \boldsymbol{X}$ in hemispherical cup experiment.

Discussion & Conclusions

A water jet is created by a high-speed stream of fluid leaving a nozzle. Several conclusions can be drawn after performing this experiment. First of all, as seen from figures 5 & 6 the lines of the experimental data do not pass through the origin. The main reason behind that is due to errors in measuring the time for calculating the mass flow rate and due to human errors in adjusting the beam to its datum position. Furthermore, we can notice that the force on the hemispherical cap somewhat twice that on the flat plate. The difference between the force exerted on the flat plate and the hemispherical cup is due to the difference between the two geometries. Referring to equation (1):

F= $\dot{m}\ (uo - u1 \cos \beta)$

For flat plate: β = 90 . So cosβ = 0 and equation (1) reduces to F = $\dot{m}uo$

For hemispherical cup, β =180 . So cos β = -1, $u1$ = $-\ uo$, and equation (1) reduces to

F = 2$\dot{m}uo$

In addition, there is a slight difference between the obtained values and theoretical values due to experimental error and human errors in recording the data. On average we achieved an accuracy of 82% for flat plate and 90% for hemispherical cup.