# Indian Institute of Technology Gandhinagar

# ME - 351 Report

# Lab Experiment - 2

## Measurement of force due to jet impingement

29 August 2022


Abhiraj R.Mohan - 20110004

Ashutosh Choudary - 20110028

Chhavi Gautham - 20110046

Gautham Biju - 20110069

Hrishikesh C.P - 20110078

Ishika Saraiya - 22120024

Rahul R.Pai - 20110155

# Contents

# Objective:

Study of hydraulic force.

# Aim:

To study the effect of force on following type of vanes:

1. Hemispherical Vane
2. Flat Plate Vane

# Task 2.1: The Essential background:

**Why are liquid jets important? Briefly discuss any 3 applications of liquid jets.**

Liquid jets are a very common phenomenon that we see in our everyday life. A liquid jet projected/issued from a nozzle has a velocity and hence it possesses a kinetic energy. Moreover when the liquid jet strikes any surface, it exerts a force which is consistent with the principle of conservation of linear momentum. Liquid jets can also travel long distances without dissipating. These properties of liquid jets make it very useful and important.

Applications of liquid jets:

- In the field of medicine, you can find liquid jets for example in injection procedures or inhalers.
- In agriculture, they play a role in irrigation and in the application of crop protection products.
- Industry uses liquid jets for waterjet cutting, for coating materials or in cooling towers. Atomized liquid jets are essential for the efficiency of internal combustion engines.

- Liquid jets also used in pressure washing, waterjet machining and fire extinguishing jets

**2. Read up on the Reynolds transport theorem (RTT). How is momentum conservation expressed in this theorem?**

General form of RTT is given by.

$$\frac{d}{dt}(B_{sys}) = \frac{d}{dt}\left(\int_{CV} \beta \rho \, dV\right) + \int_{C.S} \beta \rho (V \cdot n) \, dA$$

For linear momentum eq. substitute.

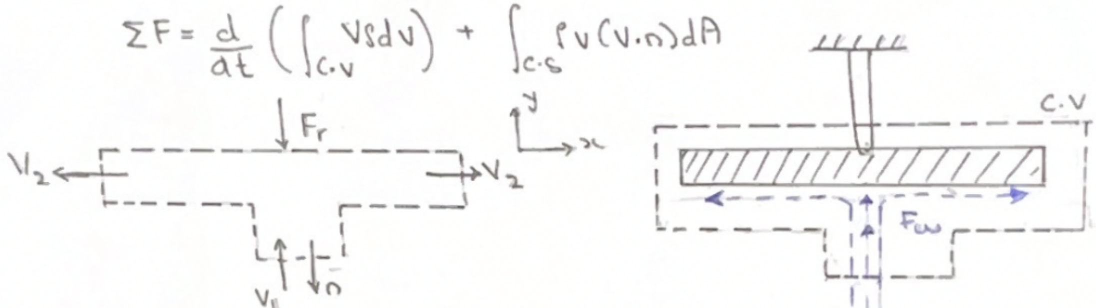
$$B_{sys} = mV \qquad \beta = \frac{dB}{dm} = V$$

$$\rightarrow \frac{d}{dt}(mV)_{sys} = \Sigma F = \frac{d}{dt}\left(\int_{CV} V \rho \, dV\right) + \int_{CS} V \rho (V_r \cdot n) \, dA$$

**3. Can you compute the force exerted by a liquid jet impinging on a flat surface, using the RTT?**

From RTT

$$\Sigma F = \frac{d}{dt}\left(\int_{C.V} V \rho \, dv\right) + \int_{C.S} \rho v (v \cdot n) \, dA$$




Assuming ① flat plate has negligible weight

② velocity near vane = velocity at the exit of nozzle.

At steady state: $\frac{d}{dt}\int_{CV} (\rho v) \, dv = 0$

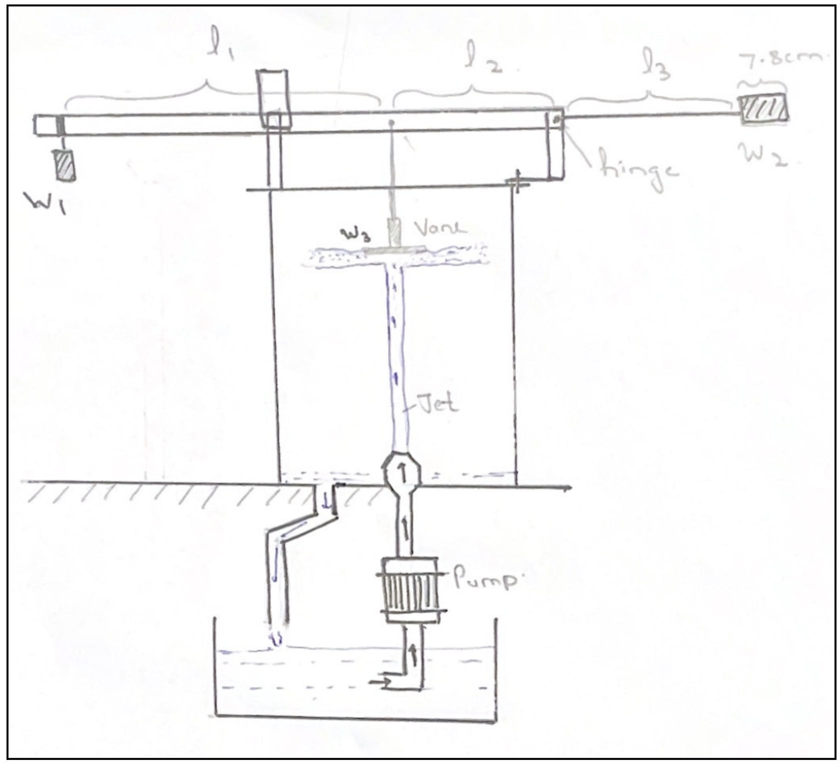
$$\Rightarrow \quad -F_r = \int_{CS} \rho V_1 (V_1 \cdot n) \, dA$$

$$= -\rho V_1 (V_1) A$$

$$F_r = \rho A V_1^2 \quad \ldots\ldots \quad (1)$$

# Task 2.2 :Experimental analysis

## Experimental setup




## Experimental procedure

<u>Measuring the force due to liquid jet</u>:

The valve is opened such that the liquid jet from the nozzle strikes the vane at a constant force. The distance of the primary weight is adjusted such that the moment created due to the liquid jet is balanced.

<u>Measuring the Flow rate</u>

Water from the nozzle after striking the vane flows into the secondary tank. The outlet of this secondary tank is closed and the water level and the time required for the same is calculated.

# Calculations :

**Moment Equation**

$$F_1 \cdot (l_1 + l_2) + F_3 \cdot (l_2) - F_2 \cdot (l_3) - F_w \cdot (l_2) + M = 0$$

$$\Rightarrow F_w = \frac{F_1 \cdot (l_1 + l_2) + F_3 \cdot (l_2) - F_2 \cdot (l_3) + M}{l_2}$$

Where; F1 = $W_1$ * g

F2 = $W_2$ * g

F3 = $W_3$ * g

$W_1$ = Primary Balancing Weight.

$W_2$ = Secondary Balancing Weight.

$W_3$ = Weight of the Steel rod + Weight of the vane.

$l_1$ = Length between Primary Balancing Weight and the Vane.

$l_2$ = Length between Vane and Hinge.

$l_3$ = Length between Secondary Balancing Weight and the Hinge.

$F_w$ = force exerted on the vane by the liquid jet.

M=Moment due to the weight of the steel scale about the hinge

Error calculation:

$$\Delta F_w = F_w \cdot \left[ \frac{\Delta F_1 \cdot (l_1 + l_2) + F_1 \cdot (\Delta l_1 + \Delta l_2) + \Delta F_3 \cdot (l_2) + F_3 \cdot (\Delta l_2) + \Delta F_2 \cdot (l_3) + F_2 \cdot (\Delta l_3) + \Delta M}{F_1 \cdot (l_1 + l_2) + F_3 \cdot (l_2) - F_2 \cdot (l_3) + M} \right] + F_w \cdot \frac{\Delta l_2}{l_2}$$

Here $\Delta l$ = 0.1 cm [ Least count error ]

**Rate of Water flow**

Q = [ ( $R_2$ - $R_1$ ) * A ] / t

Where ;

R2 = Final level of water tank

R1 = Initial level of water tank

t = Time taken for water level to fall

A  =  area of cross section of tank

Error calculation:

$$\frac{\Delta Q}{Q} = \frac{\Delta(R2 - R1)}{R2 - R1} + \frac{\Delta t}{t}$$

Here, $\Delta t$ = 1s [ Error due to human reaction ]

$\Delta l$ = 0.1 cm [ Least count error ]

**Velocity of water jet**

V = Q / $A_n$

Where ;

Q  = Rate of Water flow

$A_n$ = Area of cross section of nozzle

**Theoretical force due to water jet on a Flat plane vane**

$F_t$ = ρ* $A_n$* $V^2$ [ From equation ( 1 ) in Task 2.1.3 ]

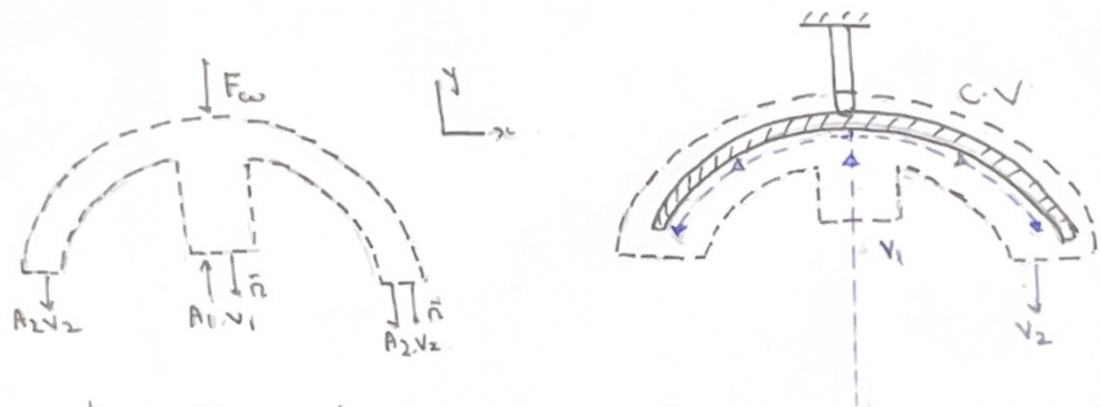
= ρ* $A_n$*$[Q / A_n]^2$

Error calculation :

$$\Delta F = F \cdot \left[\frac{2\Delta Q}{Q} + \frac{2\Delta r}{r}\right]$$

Where r is radius of nozzle

**Theoretical force due to water jet on a Hemispherical vane**




Assumptions: ① vane has negligible weight.
② velocity near vane = velocity at the exit of nozzle.
③ $A_2 \simeq A_1 \quad \therefore V_1 \simeq V_2$.

From RTT;

$$-F_\omega = \int_{cs} \rho v(v \cdot n)\,dA$$

$$= \rho V_1(-V_1)A_1 + (\rho - V_2(V_2)A_2) \times 2.$$

$$F_\omega = \rho V_1^2 A_1 + \rho A_1 V_2^2.$$

$$= 2\rho A_1 V_1^2$$ //

Error calculation :

$$\Delta F = F \cdot \left[\frac{2\Delta Q}{Q} + \frac{2\Delta r}{r}\right]$$

Where r is radius of nozzle

**Required Data**

Weight of the Steel rod + Weight of the Flat Plate vane + Weight of Aluminium Disc

( $W_3$ ) = 345.5 g

Weight of the Steel rod + Weight of the Hemispherical vane + Weight of Aluminium Disc ( $W_3$ ) = 468.3 g

Secondary Balancing Weight ( $W_2$ ) = 961.1 g

Length between Vane and Hinge ( $l_2$ ) = 21 cm

Density of water at ambient conditions,ρ = 1000 Kg/m3

Area of cross section of nozzle, $A_n$ = 2.82 x 10-5 m2

Area of cross section of tank = 0.0885 $m^2$ [ Dimensions of water tank = 295 mm * 300 mm ]

Moment due to steel scale (M) = 1.477 N.m

# Results:

## **Flat vane**:

Flow rate:

| Sl No | R1(cm) | R2(cm) | Time(s) | Area(cmxcm) | Volume(cc) | Q(cc/s) | Q error ( cc/s) | Q Avg(cc/s) |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | | |
| | 7.6 | 12.7 | 11.95 | 88500 | 4495.8 | 376.2 | 46.3 | |
| | 15.0 | 20.0 | 12.08 | 88500 | 4425.0 | 366.3 | 45.0 | 369.0 |
| 1 | 20.0 | 25.0 | 12.15 | 88500 | 4425.0 | 364.3 | 44.6 | |
| | 15.0 | 20.0 | 11.98 | 88500 | 4425.0 | 369.4 | 45.6 | |
| | 20.0 | 24.0 | 9.55 | 88500 | 3540.0 | 370.9 | 57.4 | 371.2 |
| 2 | 15.0 | 19.0 | 9.48 | 88500 | 3540.0 | 373.4 | 58.1 | |
| | 20.0 | 25.0 | 19.44 | 88500 | 4425.0 | 227.7 | 20.8 | |
| | 10.0 | 20.0 | 38.22 | 88500 | 8850.0 | 231.6 | 10.7 | 230.5 |
| 3 | 10.1 | 15.1 | 19.06 | 88500 | 4425.0 | 232.2 | 21.5 | |

Experimental Value of Force:

| Sl no | L1(cm) | L3(cm) | W1(g) | Force(mN) | Error( ±mN) |
|---|---|---|---|---|---|
| | 24.8 | 28.6 | 357.8 | 5242.2 | 28.3 |
| | 24.9 | 28.6 | 357.8 | 5258.9 | 28.4 |
| 1 | 24.8 | 28.6 | 357.8 | 5242.2 | 28.3 |
| | 33.2 | 20.7 | 158.9 | 5157.2 | 36.8 |
| | 33.1 | 20.7 | 158.9 | 5149.8 | 36.8 |
| 2 | 33.4 | 20.7 | 158.9 | 5172.0 | 36.9 |
| | 23.2 | 29.9 | 257.1 | 2314.9 | 16.7 |
| | 23.3 | 29.9 | 257.1 | 2326.9 | 16.7 |
| 3 | 23.4 | 29.9 | 257.1 | 2338.9 | 16.7 |

Theoretical Value of Force:

| Sl no | Q | Force(mN) | error ( ± mN) |
|---|---|---|---|
| | 376.2 | 5008.5 | 1232.6 |
| | 366.3 | 4748.1 | 1166.0 |
| 1 | 364.3 | 4697.4 | 1149.3 |
| | 369.4 | 4827.7 | 1192.2 |
| | 370.9 | 4867.2 | 1506.6 |
| 2 | 373.4 | 4934.2 | 1534.4 |
| | 227.7 | 1834.4 | 335.5 |
| | 231.6 | 1897.3 | 175.2 |
| 3 | 232.2 | 1908.3 | 352.9 |

# Hemispherical Vane

Flow rate:

| Sl No | R1(cm) | R2(cm) | Time(s) | Area(cmxcm) | Volume(cc) | Q(cc/s) | Q error | Q Avg(cc/s) |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | | |
| 1 | 15 | 20 | 16.92 | 88500 | 4425 | 261.6 | 25.9 | 256.3 |
| | 10 | 15 | 17.42 | 88500 | 4425 | 254.1 | 24.8 | |
| | 15 | 20 | 17.47 | 88500 | 4425 | 253.3 | 24.6 | |
| 2 | 20 | 25 | 15.52 | 88500 | 4425 | 285.2 | 29.8 | 287.5 |
| | 12 | 17 | 15.01 | 88500 | 4425 | 294.9 | 31.4 | |
| | 20 | 25 | 15.68 | 88500 | 4425 | 282.3 | 29.3 | |
| 3 | 15 | 20 | 16.51 | 88500 | 4425 | 268.0 | 27.0 | 269.5 |
| | 10 | 15 | 16.23 | 88500 | 4425 | 272.6 | 27.7 | |
| | 20 | 25 | 16.52 | 88500 | 4425 | 267.9 | 26.9 | |

Experimental Value of Force:

| Sl no | L1(cm) | W1(g) | Force (mN) | error( ±mN) |
|---|---|---|---|---|
| 1 | 25.3 | 257.1 | 3770.3 | 21.9 |
| | 25.4 | 257.1 | 3782.3 | 22.0 |
| | 25.2 | 257.1 | 3758.3 | 21.9 |
| 2 | 33.3 | 257.1 | 4730.1 | 25.2 |
| | 33.1 | 257.1 | 4706.1 | 25.1 |
| | 33.0 | 257.1 | 4694.1 | 25.1 |
| 3 | 28.2 | 257.1 | 4118.2 | 23.1 |
| | 28.4 | 257.1 | 4142.2 | 23.2 |
| | 28.5 | 257.1 | 4154.2 | 23.2 |

Theoretical Value of Force:

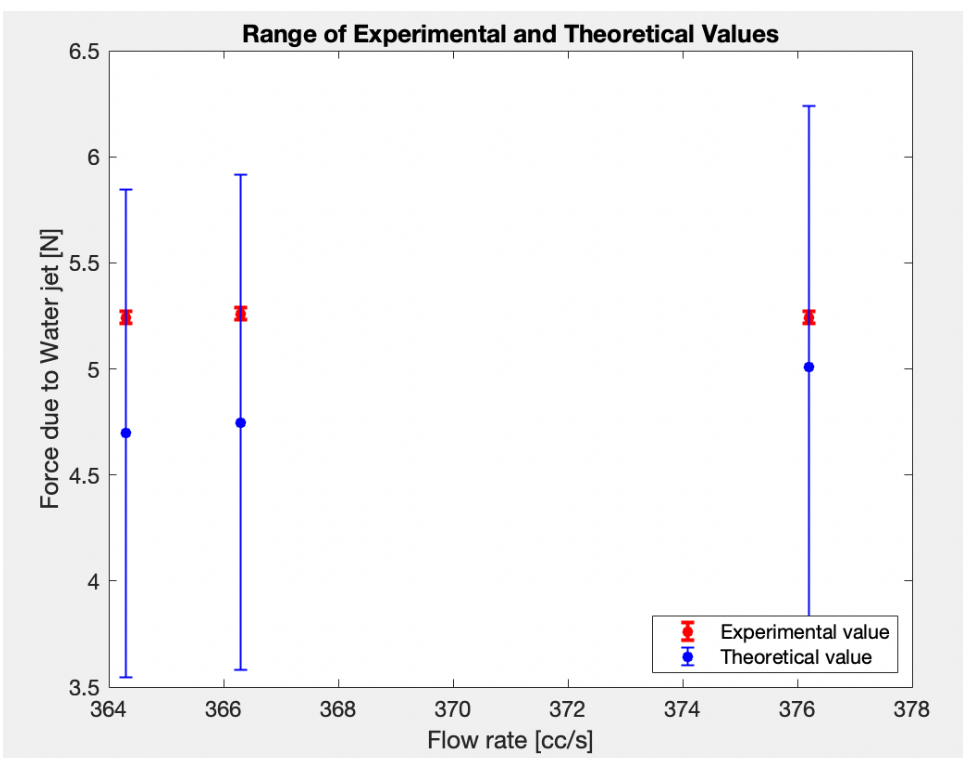
| Sl no | Theoretical(mN) | Error( ±mN) |
|---|---|---|
| 1 | 4843.3 | 960.1 |
| | 4569.2 | 890.3 |
| | 4540.4 | 883.0 |
| 2 | 5756.8 | 1202.6 |
| | 6154.8 | 1312.7 |
| | 5639.9 | 1170.8 |
| 3 | 5083.8 | 1022.6 |
| | 5260.7 | 1069.1 |
| | 5080.7 | 1021.7 |

# Comparison between Practical and Theoretical Values

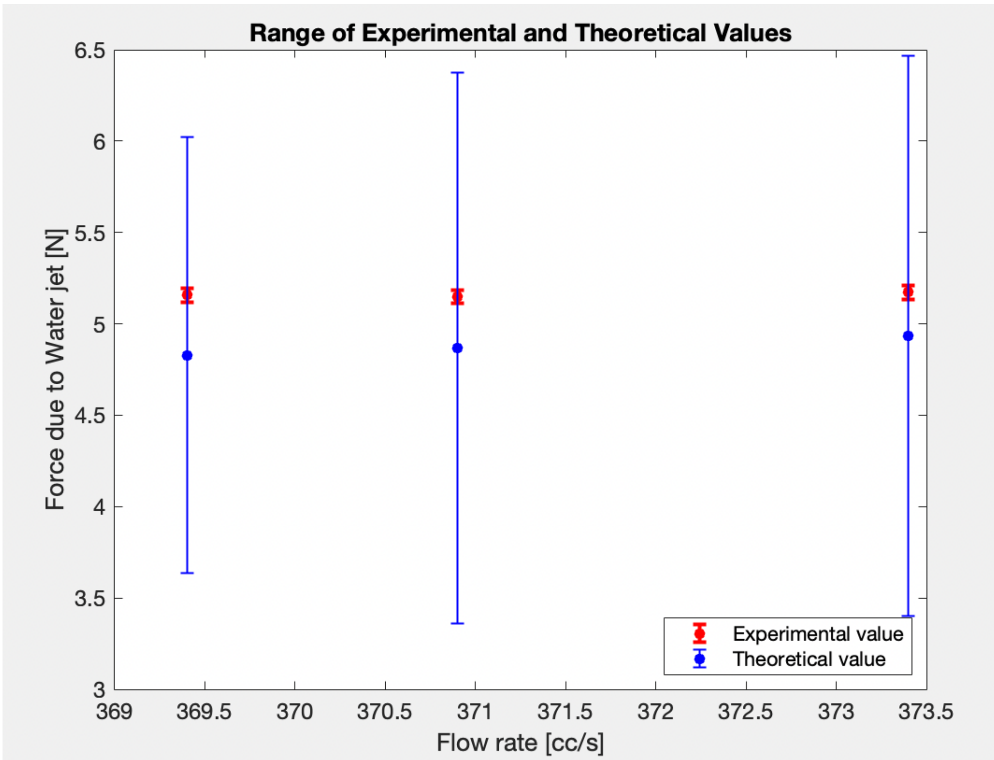
## Flat vane

| Sl no | Practical(mN) | error( ±mN) | Theoretical(mN) | error ( ± mN) | % deviation |
|---|---|---|---|---|---|
| 1 | 5242.2 | 28.3 | 5008.5 | 1232.6 | 4.7 |
| | 5258.9 | 28.4 | 4748.1 | 1166.0 | 10.8 |
| | 5242.2 | 28.3 | 4697.4 | 1149.3 | 11.6 |
| 2 | 5157.2 | 36.8 | 4827.7 | 1192.2 | 6.8 |
| | 5149.8 | 36.8 | 4867.2 | 1506.6 | 5.8 |
| | 5172.0 | 36.9 | 4934.2 | 1534.4 | 4.8 |
| 3 | 2314.9 | 16.7 | 1834.4 | 335.5 | 26.2 |
| | 2326.9 | 16.7 | 1897.3 | 175.2 | 22.6 |
| | 2338.9 | 16.7 | 1908.3 | 352.9 | 22.6 |

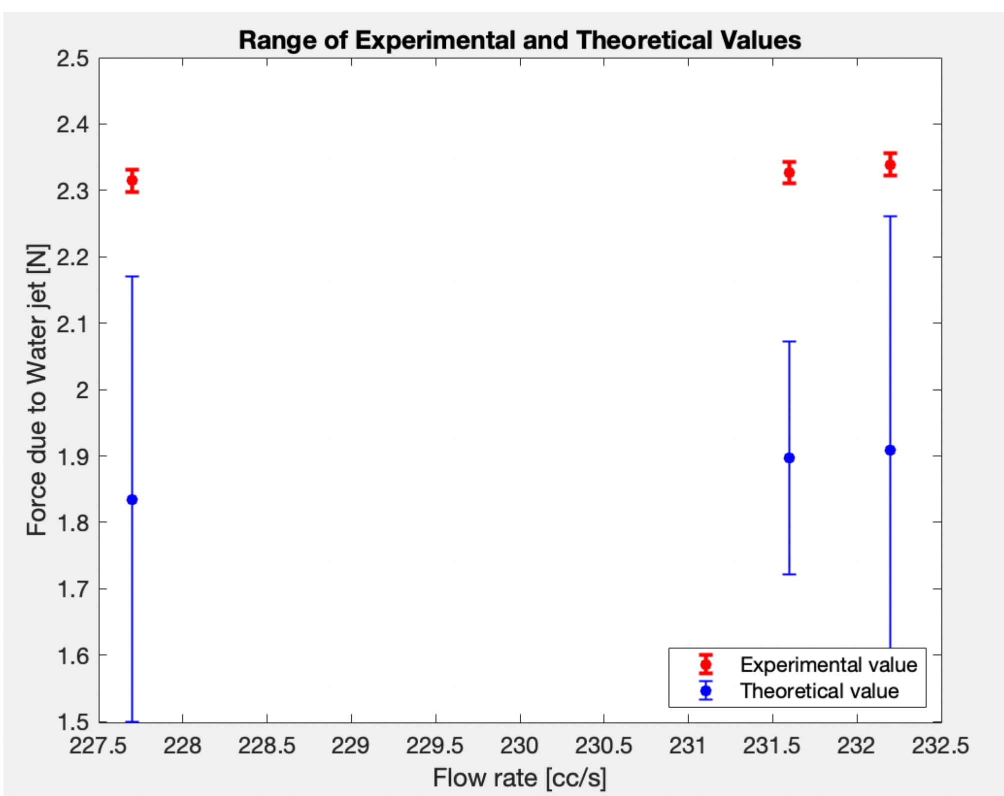
Flow rate 1



Flow Rate 2



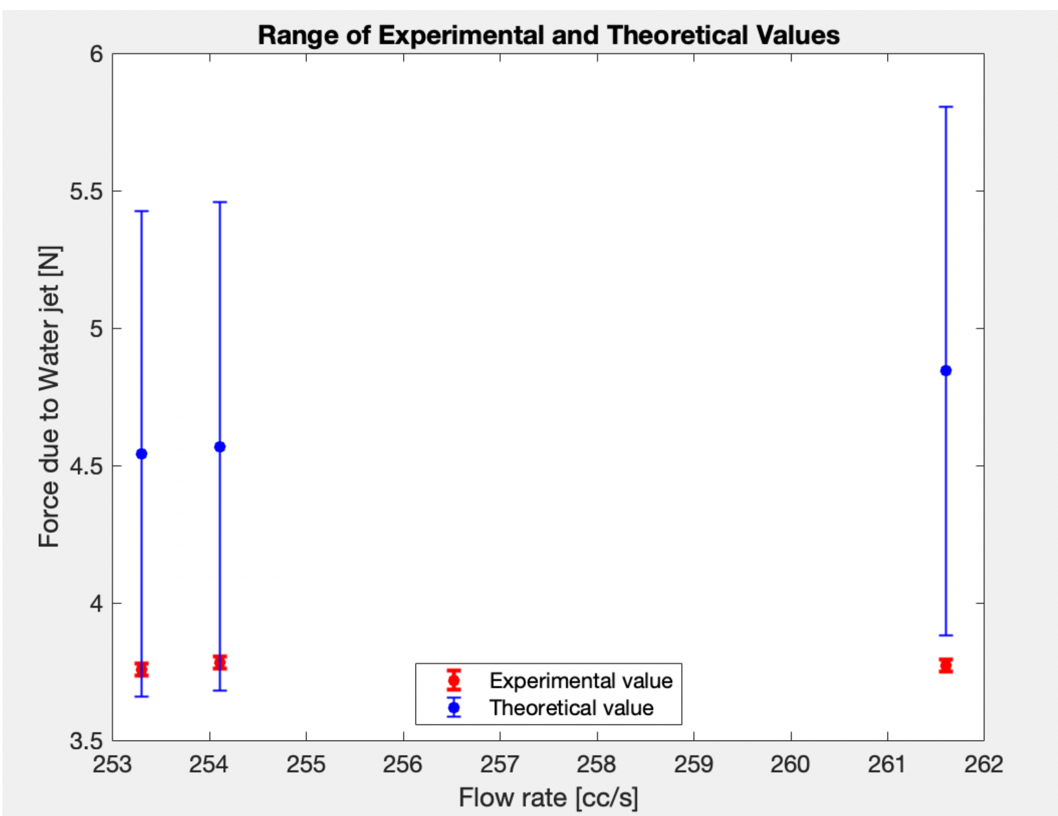

Flow Rate 3



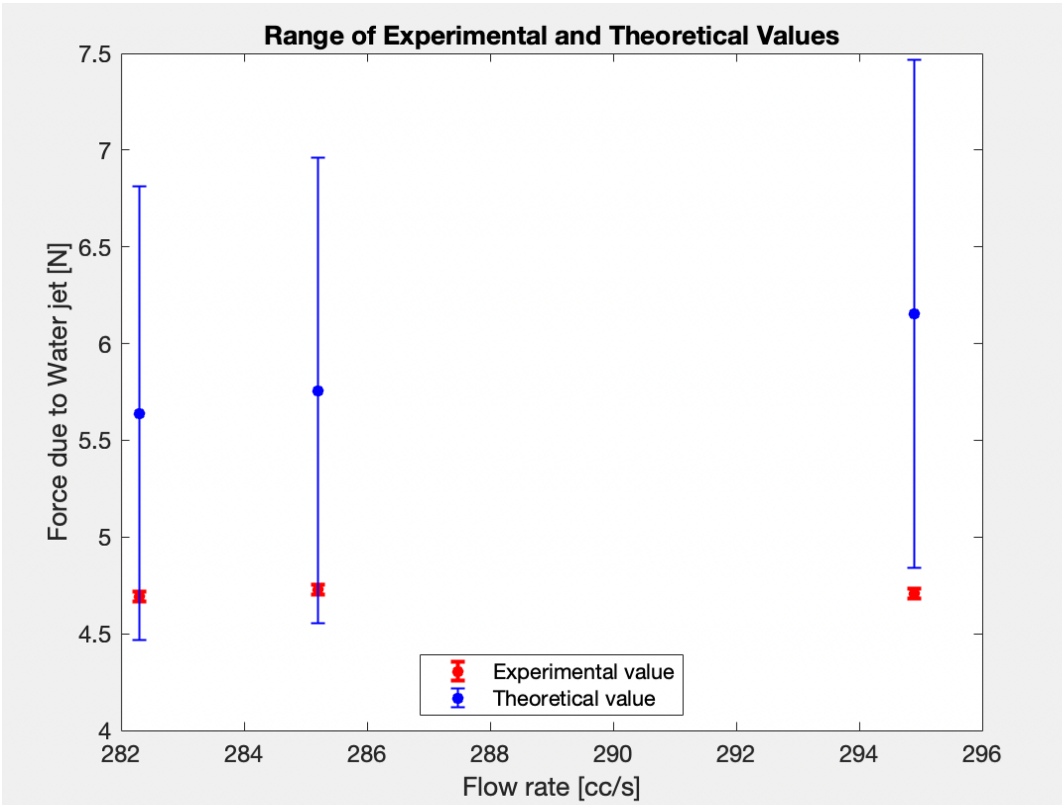
Hemispherical vane

| Sl no | Practical(mN) | error( ±mN) | Theoretical(mN) | error ( ± mN) | % deviation |
|---|---|---|---|---|---|
| 1 | 3770.3 | 21.9 | 4843.3 | 960.1 | -22.2 |
| | 3782.3 | 22.0 | 4569.2 | 890.3 | -17.2 |
| | 3758.3 | 21.9 | 4540.4 | 883.0 | -17.2 |
| 2 | 4730.1 | 25.2 | 5756.8 | 1202.6 | -17.8 |
| | 4706.1 | 25.1 | 6154.8 | 1312.7 | -23.5 |
| | 4694.1 | 25.1 | 5639.9 | 1170.8 | -16.8 |
| 3 | 4118.2 | 23.1 | 5083.8 | 1022.6 | -19.0 |
| | 4142.2 | 23.2 | 5260.7 | 1069.1 | -21.3 |
| | 4154.2 | 23.2 | 5080.7 | 1021.7 | -18.2 |

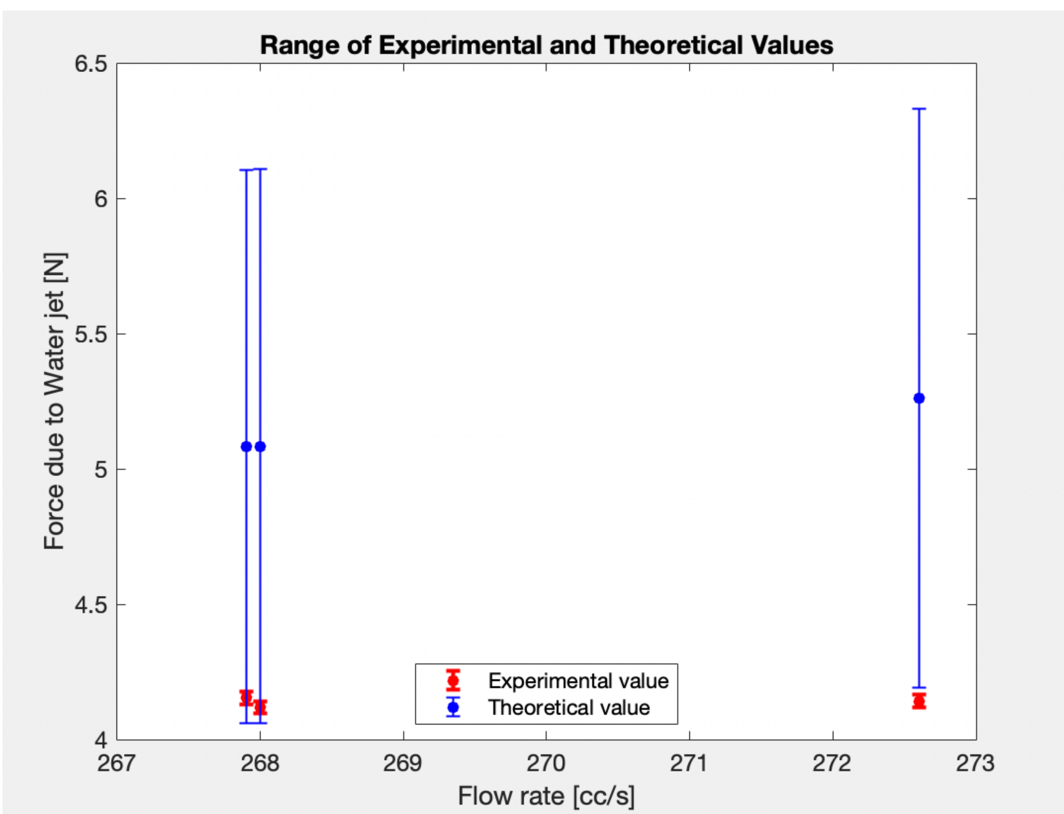
Flow rate 1



Flow rate 2




Flow rate 3



## Observations and conclusions

There are errors in the readings, as visible from the difference between the theoretical and practical values. We can also observe that the deviation in Theoretical and Experimental values is more in case of flow rates of lower value.

The reasons for this deviations can include:

- Friction at different points in the experimental setup are not considered.It was observed that the power of the pump was fluctuating, this would have affected the value of flow rate and hence the theoretical value.
- The velocity of the water jet at the exit of the nozzle and near the vane may not be equal due to gravitational force. This would be particularly visible when Q gets smaller.
- The least count of the apparatus provided could also affect the accuracy of the result.
- The area of the cross section of the water jet will also not remain constant throughout. This area will vary more for lower values of water jet
- For calculating the flow rate the change in length over a small time interval was taken, this increases the error.