CE 3105 - Mechanics of Fluids Laboratory

Experiment 6: Impact of a Jet

bit.ly/CE3105Jets

1 Objectives

- To demonstrate that the force on a vane is proportional to the rate of delivery of momentum
- To show that you can predict the force on a vane from a combination of its surface shape and the properties of the jet directed at it

2 Theory

Magnitude and direction of fluid stream change after it hits a vane. Newton's second law can be used to derive impulse momentum principle. For the horizontal vane below (Figure 1):

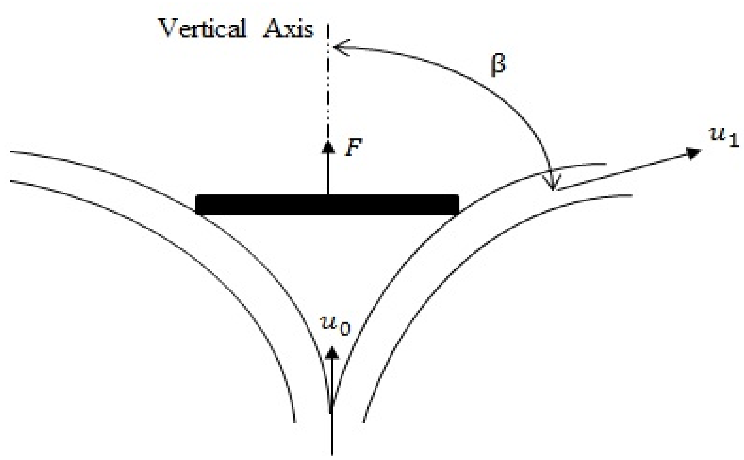

Figure 1: Fluid Jet Striking a Flat Plate

A vertical jet of fluid is coming out of the nozzle with a velocity u, hitting the vane with velocity u_o and deflects at an angle β with the vertical axis with a velocity u_1. If the rate of flow is $\dot{m}$ along the vertical axis, the rate of momentum entering the system is $\dot{m}u_0$. The momentum leaving at the same direction is $\dot{m}u_1 cos\beta$. The force on the vane along the vertical axis on the vane is the rate of change of momentum:

$$F = \dot{m}(u_0 - u_1 cos\beta) \quad (1)$$

$$u_0^2 = u^2 - 2gs$$

where s is the distance from the nozzle to the vane and u is the velocity of water exiting the nozzle. If the jets have constant velocity, the theoretical force becomes

$$F \approx \dot{m}u_0(1 - cos\beta) \tag{2}$$

Depending on the type of vane, theoretical force can be calculated using the above equation. The values are shown in the following table:

Vane Type	**F**
Flat Plate ($\beta = 90^O$)	$\dot{m}u_0$
Hemisphere ($\beta = 180^O$)	$2\dot{m}u_0$

In the table above, jet momentum is

$$J = \dot{m}u_0$$

$$J = \rho Q u_0 \tag{3}$$

The force on the vane can be calculated using the moments. For the pivoted weight beam below, the force F is acting upward at a distance a from the pivot end. Mass of the weight beam can be cancelled out using the balance spring. The downward force acting is the mass of the jockey M.

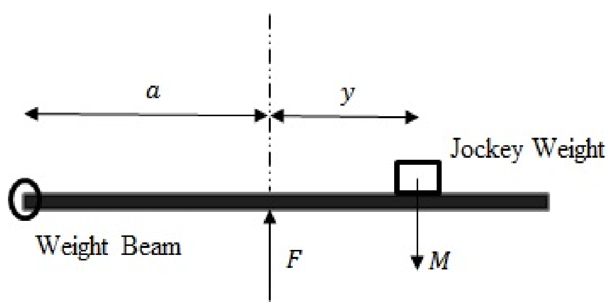

Figure 2: Force on the Vane

For the system in the above figure:

$$Fa = Mg(y + a)$$

$$F = \frac{Mg(y + a)}{a} \tag{4}$$

F can be determined by knowing the values of M and a, and putting the value of gravity g. The arrangement of the systems are shown in the Figure 3 (flat plate) and Figure 4 (hemispherical cup).

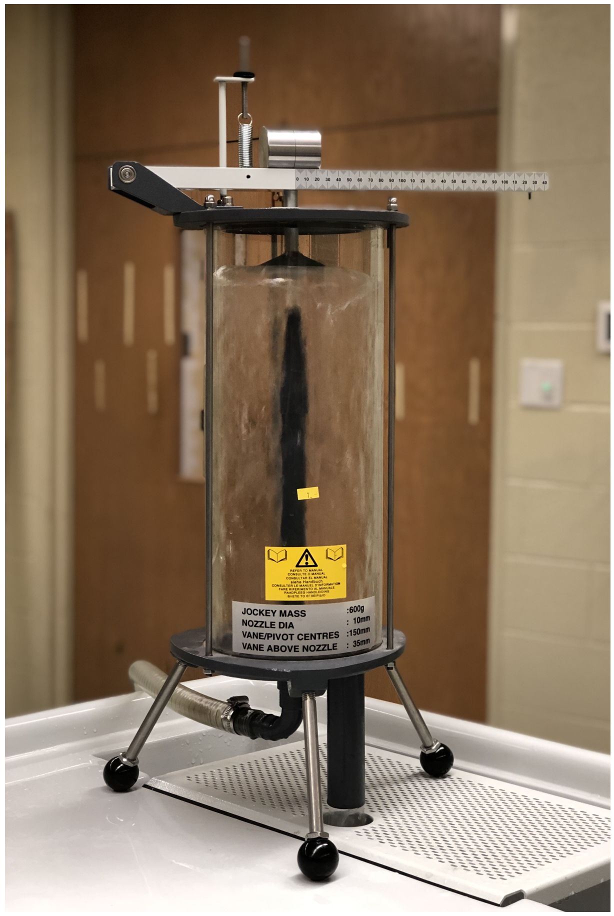

Figure 3: Arrangement of the System: Flat Plate

Figure 4: Arrangement of the System: Hemispherical Cup

3 Variables/Units

Variables	Description (Units)
Q	Flow Rate (ft^3/s)
$\dot{m}$	Mass Flow Rate(lb/s)
ρ	Density of Water (lb/ft^3)
A	Nozzle Area (0.000845 ft^2)
u	Velocity at Nozzle Exit (ft/s)
u_0	Velocity Deflected from Vane (ft/s)
s	Vertical Distance (0.115ft)
F	Force on Vane ($lb.ft/s^2$)
M	Mass of Jockey Weight (1.32 lb)
g	Gravity (ft/s^2)
y	Horizontal Distance (ft)
a	Point of Application of F from Pivot (0.50 ft)

4 Procedure

1. Install the Flat Plate Vane
2. Ensure the weight beam is balanced at the zero position
3. Start the hydraulic bench and set to maximum flow
4. Move the jockey weight until the beam balances again
   (a) Record distance, y, from the zero position
   (b) Record the flow rate using the hydraulic bench
5. Reduce the hydraulic bench flow rate in relatively equal increments for 4 additional readings
   (a) Record distance, y, from the zero position for each trial
   (b) Record the flow rate using the hydraulic bench for each trial
6. Repeat steps 2-5 for the Hemispherical Cup Vane

5 Calculations

1. Convert flow rate to mass flow rate, $\dot{m}$
2. Calculate the flow velocity, u
3. Calculate u_0
4. Calculate rate of delivery of momentum, $\dot{m}u_0$
5. Calculate force, F
6. Create a plot of force, F (y-axis) vs. rate of delivery of momentum, $\dot{m}u_0$ (x-axis)
    (a) Create a trendline for the data points
    (b) The slope of the trendline indicates the coefficient for theoretical force
7. Do calculations 1-6 for both the Flat Plate Vane and the Hemispherical Cup Vane

6 Interpretation Questions (for Report)

1. What percentage of velocity compared to that exiting the nozzle is lost as the jet deflects from the Flat Plate Vane?

2. What percentage of velocity compared to that exiting the nozzle is lost as the jet deflects from the Hemispherical Cup Vane?

3. Compare the coefficient of theoretical force found using the plot in Calculations 6b with the given, typical values for the coefficient of theoretical force on a Flat Plate Vane

    (a) Compare your values for each trial using difference or some other mathematical comparison.

4. Compare the coefficient of theoretical force found using the plot in Calculations 6b with the given, typical values for the coefficient of theoretical force on a Hemispherical Cup Vane

    (a) Compare your values for each trial using percentage difference or some other mathematical comparison

5. If an Angled Plate Vane, with an angle of 30^0, was examined using Impact Jets, would you expect the coefficient of theoretical force to be higher or lower than the coefficients of theoretical force for Flat Plate and Hemispherical Cup Vanes?

    (a) Justify your answer using data found in this experiment

6. Which source of error do you think is most significant in your experiment, and why?

7. Give an example of a real-life application of the principles and theories explored in this lab

CE3105 Mechanics of Fluids Laboratory
Department of Civil Engineering
Texas Tech University

Experiment: Impact of a Jet- Data Sheet
Date of Experiment: .... ,Name:....................
Experimental Data:
Temperature of water, T= celsius
Water density, $\rho =$ (lb/ft^3)
Gravity, g= 32.2 (ft/s^2)

Flat Plate Vane			
Trial	Distance, y (mm)	Volume, V (L)	Time, t (s)
1			
2			
3			
4			
5			

Hemispherical Cup Vane			
Trial	Distance, y (mm)	Volume, V (L)	Time, t (s)
1			
2			
3			
4			
5			

Instructor's Signature

For Calculation:

Flat Plate Vane:						
Flow Rate Q (ft^3/s)	Mass Flow Rate $\dot{m}$ (ft/s)	Distance y (ft)	Velocity u (ft/s)	Velocity u_0 (ft/s)	Rate of delivery of momentum $\dot{m}u_0$ $(lb.ft/s^2)$	Force F $(lb.ft/s^2)$

Hemispherical Cup Vane:						
Flow Rate Q (ft^3/s)	Mass Flow Rate $\dot{m}$ (ft/s)	Distance y (ft)	Velocity u (ft/s)	Velocity u_0 (ft/s)	Rate of delivery of momentum $\dot{m}u_0$ $(lb.ft/s^2)$	Force F $(lb.ft/s^2)$