ME 312 LAB #2

Conservation of Linear Momentum
(Water Jet Propulsion)

Purpose: This experiment investigates the principle of conservation of linear momentum. A water jet apparatus is employed in the experiment.

Background: The principle of conservation of linear momentum has many practical applications. It describes the behavior of most fluid-mechanical devices (turbines, paddle wheels, compressors, etc.). Our objective is to explore a relatively simple application, the lifting of a weight with a jet of water, and to obtain a feel for the predictive power of theoretical equations.

Report: A formal report is not required for this lab. Turn in a copy of the attached laboratory summary sheet with all additional information specified on the summary sheet.

Experimental Procedure: Predict the flow rate required to lift three specified weights for each of three targets. Perform the experiment to evaluate your predictions.

Experimental Steps:
1. Using a thermometer, measure the temperature of the water in the reservoir. Using this temperature and tables for water, determine the fluid density.
2. Mount the flat object on the rod attached to the weight pan.
3. Align the indicator next to weight pan so that the silver line on the weight pan lines up with the indicator point.
4. Place 200 grams on the weight pan.
5. Start the pump and adjust the flow rate with this value until the weight pan returns to the position of the indicator point.
6. Plug the drain and fill the reservoir until volume indicator indicates 0 liters.
7. Using a stop watch measure the time it takes for the volume indicator to reach 20.
8. Repeat steps five through seven for 400 and 600 grams.
9. Remove the flat object from the rod and attach the object that turns the flow 120°, then repeat steps five through eight.
10. Remove the second object from the rod and attach the hemispherical object then repeat steps five through eight.

Analysis: The conservation of linear momentum can be expressed in vector form as:

$$\sum F = \frac{\partial}{\partial t} \int_{c,s} \rho \vec{v} d\vec{V} + \int_{c,s} \rho \vec{v} (\vec{v} \cdot \hat{n}) dA$$

Recall that this is a vector equation and thus represents three equations.

For this laboratory we will apply only the z component of this equation as we experimentally investigate the force exerted on an object by a water jet. A water jet of diameter 8 mm is directed vertically upward such that a jet impinges upon a target as shown in Fig. 1. Our objective is to determine the force exerted on three objects and to compare the measured force
with the force predicted by the conservation of momentum principle.

Assuming that the jet velocity is 1-D (i.e. it does not vary with radial location) and the flow is steady we can write the conservation of momentum in the z direction for the control volume shown in Fig. 2:

\[ \sum F_z = \int \rho v_z \left( \vec{v} \cdot \hat{n} \right) dA \]  

(2)

Assuming small changes in elevation and applying Bernoulli’s Eq. along a streamline the magnitude of the velocity can assumed to be constant at all points and equal to the volume flow rate divided by the area of the pipe/jet (8 mm).

Figure 1 Equipment schematic.
Figure 2  Suggested control volume.
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Laboratory Summary

1. Starting from Eq. 2, derive an expression for the volume flow rate in terms of the mass placed on the weight plate, fluid density, area of jet, g, and angle $\theta$, that is valid for any of the three objects employed.

2. Using your relation from number 1 above compute the expected flow rate using the conservation of linear momentum principle. Record these values in the ‘predicted’ columns below.

<table>
<thead>
<tr>
<th>Mass</th>
<th>Predicted flow rate</th>
<th>Measured flow rate</th>
<th>Predicted flow rate</th>
<th>Measured flow rate</th>
<th>Predicted flow rate</th>
<th>Measured flow rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>200 g</td>
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<td></td>
<td></td>
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<td></td>
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<tr>
<td>400 g</td>
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<td>600 g</td>
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</tbody>
</table>

3. Perform the experiment for each object and mass. Measure the volume flow rate for a volume change of at least 20 L. Record your data above.

4. Plot the flow rate required for each case as measured in the laboratory and the flow rate predicted from the conservation of momentum vs. the mass.

5. Nondimensionalize your data and plot the non-dimensionalized weight vs. Reynolds number for the theoretical and measured cases.

6. On a separate page; summarize your observations from the data, give a comparison between theory and experiment and discuss what leads to the deviations. Also describe the results and significance of normalization, and discuss the error analysis.

Note: Make all plots and tables presentation quality