MEEG333 FLUIDS LABORATORY

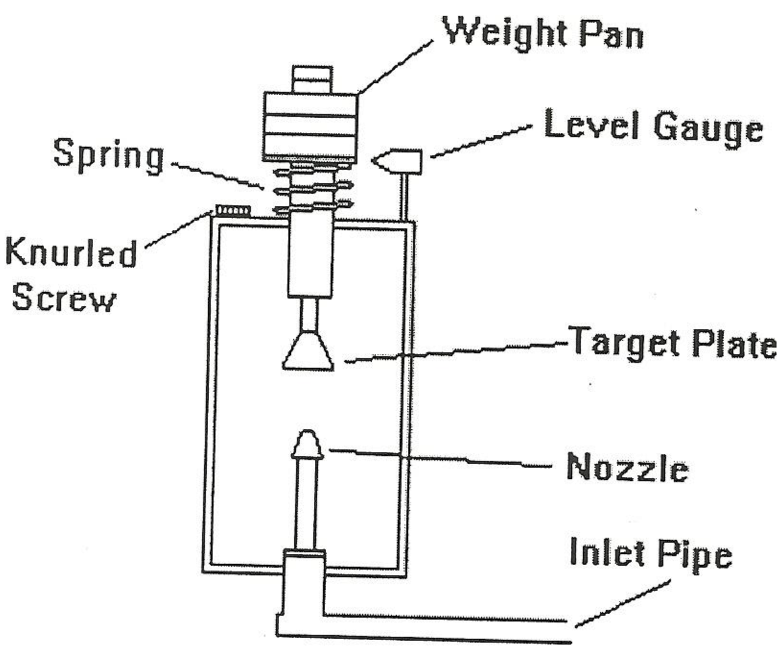
X3. Impact force of a jet (Conservation of linear momentum)

Objectives

This experiment demonstrates the principle of conservation of linear momentum by measuring directly the force generated on a circular flat target by an impinging water jet, and comparing it with the theoretical value. The Design Objective is to estimate the forces of a wave surge and of hurricane winds on a representative building wall structure.

Apparatus

As shown below, the water supply from the hydraulic bench is led to a vertical pipe, terminating in a tapered nozzle. This produces a water jet which impinges on a small flat plate target. The nozzle and plate are contained in a transparent cylinder. An outlet at the base of the cylinder directs the flow to a catch tank for measuring the flow rate.



The vertical force on the target plate is measured by weights on the weight pan. For a given weight the flow is adjusted so that the mark on the weight pan corresponds to the level gauge pointer. This insures that the compression in the spring is always constant and does not affect the measurements.

This apparatus is measuring the hydrodynamic force directly, rather than with a lever system as in Lab X1. This will potentially simplify your analysis and decrease experimental uncertainty.

The nozzle exit diameter is **8 mm**. You will need to estimate the vertical distance between the nozzle exit and the target plate, and measure the temperature of the water.

Theory

A control volume analysis from textbook Chapter 3, shows that the force F_p exerted by the flat horizontal plate on the jet causes a change in momentum of the jet given by

$$F_p = \dot{m}*V_p = \rho A V^2 \qquad (1)$$

Where m is the mass flux ($=\rho A V_p$), A = cross section area of the jet at impact, and V_p is the velocity of the jet at impact. Obviously an equal and opposite force F_j is exerted upward by the jet on the plate. (This is a simplified version of text book example 3.7).

Consider that the velocity of the jet at the plate may be somewhat smaller than the nozzle exit velocity V_o due to the deceleration caused by gravity. The nominal nozzle exit velocity is flow Q/A_n where A_n is the nozzle diameter Look carefully at the stream of water as it rises. Can you tell if its cross section is changing before hitting the plate? If this were a garden hose, yes. Here?

Procedure

1. Begin with no flow and no weights. Be sure that the mark on the pan edge matches the level gauge pointer. Adjust the level gauge height as needed until they match.

2. Do the following for a series of weights, beginning with 100 grams, and adding weight in 100 gram increments to about 1 kg, or until the maximum water force is unable to lift the pan.

3. For each weight, adjust the water flow until the pan is raised even with the level gauge again. Now measure the volume flow rate using the volumetric tank and gauge. This is done by closing the ball valve and measuring with a stop watch the time taken to accumulate a known volume of fluid in the tank, as measured from the sight glass next to the pump flow switch.

4. Open the ball valve and empty the catch tank. Add weights and repeat.

Data Analysis and Discussion

1. Plot the Force as measured by the weights (remember, w=mg) versus the calculated Force from the change in momentum of the fluid on impact. Fit a least-squares line to the data. Make a Measured vs Calculated graph with a 45^o line. If measured versus calculated were perfect, all points would fall on this line.
2. If the slope of the least-squares line is different from what you expect, speculate on the possible causes, including
    - Decrease in velocity between nozzle exit and plate because of gravity. Is this negligible effect (estimate)
    - Difference between the nominal nozzle exit area and a vena contracta area.
    - Change in cross section of the jet stream between nozzle exit and impact from frictional effects. Other effects related to the apparatus or experimental method.

Uncertainty Analysis

Perform a propagation of error analysis as explained in Lab Discussion for F_p (equation 1). Include the full expression ρ A V_p for the mass flow rate. For your uncertainty estimates, consider the items listed above.

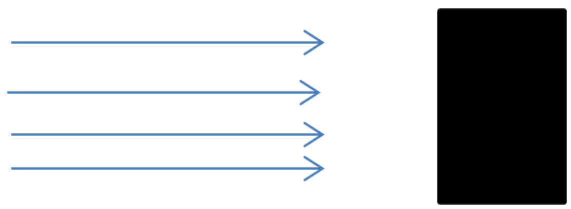
Design Objective.

Hurricane damage reports in recent years from Houston, the Florida Keys, North Carolina, and the Caribbean islands showed damage to building structures from both water (waves, storm surges) and wind.

Calculation of these forces for building design a challenge for our Civil Engineering friends. However, we share fluid dynamics technology with them and can get an order of magnitude estimate and appreciation for hurricane forces and the damage they can cause.

Assume a simple wall structure, exposed to wind and to water. For simplification, assume that the wind or water striking the wall has a uniform velocity profile. Wall is 3m tall, 10m long, and varies in thickness (use t=.25, .5, .75, and 1 m)

dens=	1030	kg/m3	seawater
g=	980	m/s^2	Vavg



Thickness t

3	m hig
10	m lon

1. For a range of surge water velocities from 1 m/s to 10 m/s, calculate the force on the wall.
2. Design your spreadsheet so that by simply changing the fluid density from seawater to air, and making Vavg something like reported for Jose or Maria (140 – 160 mph), recalculate the forces.
3. Obviously the damage depends on how the wall foundation and on how it was attached to the rest of the building. But leave that to the Civils. Assume that the wall was made of concrete block (density= 800 kg/m3) and varies in thickness – (1 block thick= 0.25 m) approx. For a simple estimate of failure, calculate the "tipping point", that is, when the moment of the fluid forces around the lower inside corner equals the moment of the wall mass around the same point (Tipping point does not depend on fluid force, just on wall dimensions) . Do for both seawater and wind. Repeat by assuming wall was poured reinforced concrete (Density = 2000 kg/m3).

4. Summarize your findings in a table or graph, and provide in a letter to an architectural firm. For example, plot Force on y-axis and fluid velocity on the x-axis. The tipping force is a straight horizontal line, depending only on thickness. The fluid force is a parabola (velocity squared). Their intersection indicates (within the assumptions made) where the wall might fail. Best if you do two graphs, one for water and one for air, since the scale ranges are quite different.

Letter format:

Letterhead

StormyCoast Architects, Inc.
Sea Island, GA

You requested us to…

Our calculations are shown on the attached..

These are worst case estimates, with no allowance for structural reinforcements or foundations. We suggest that you also consult with a civil engineering firm for additional information before completing your design.

Sincerely,
etc