MET 335

Module 10 – Forces on Vanes

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Purpose, Theory, and Procedure

1. **Experiment Title**
    a. Forces on Vanes
2. **Purpose**
    a. The purpose of this lab report is the understand how the "impact" force of a water jet is affected by using different shaped vanes and learn how to fit a curve to experimental data in order to determine an equation that models the experimental results. Students will calculate mass flow rates and forces of the jet for each vane and flow setting. Students will plot the force exerted by the jet on the vane versus the mass flow rate on a log-log plot and determine the slope and y-intercept. Then students will compare the calculated results with the predicted values from the curve fitted equation. Then wrapping up the lab report, students will thoroughly discuss results and sources of error.
3. **Theoretical Considerations**
    a. Relation to the flow rate
        i. $\dot{m} = AV_J$
    b. Determining the jet force by examining the forces and their locations relative to the fixed hinge.
        i. $F_J, proposed = K\,\dot{m}^c$
    c. Summing the moments about the hinge with no flow, and placing the weight at the same location as the jet force (D=0), and leveling the spring adjustment
        i. $\sum M = 0 \rightarrow x(F_S) = 150mm(W)$
    d. Summing the moments about the hinge with flow and after sliding the movable weight a distance D in order to level the arm
        i. $\sum M = 0 \rightarrow x(F_S) + 150mm(F_J) = (150mm + D)(W)$
    e. Combining both moment equations
        i. $150mm(W) + 150mm(F_J) = (150mm + D)(W)$
    f. Solving for jet force
        i. $F_J = \dfrac{(D)(W)}{150mm}$
    g. Since proposed equation of $F_J, proposed = K\,\dot{m}^c$, we can take the log of both sides and rearrange to get:
        i. $\log F_J, proposed = c \log \dot{m} + \log K\,\dot{m}$
    h. This suggests a straight-line relationship of $y = mx + b$
    i. Jet force (ordinate) (y)
    j. Mass flow rate (abscissa) (x)

k. Y-intercept = K
l. Y-intercept on log-log graph occurs at x=1
m. Slope
    i. $$\frac{\log(y_2)-\log(y_1)}{\log(x_2)-\log(x_1)}$$

4. Drawing or Sketch

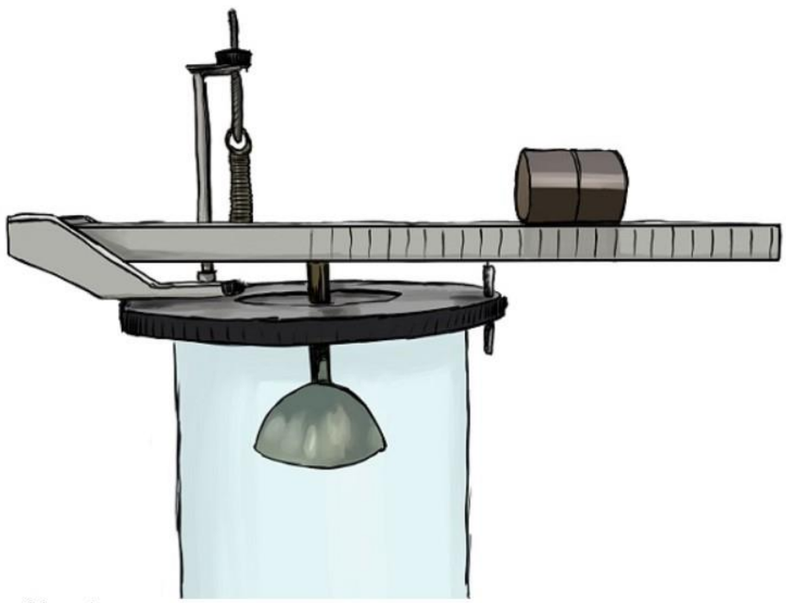


Figure 1 Apparatus

a.

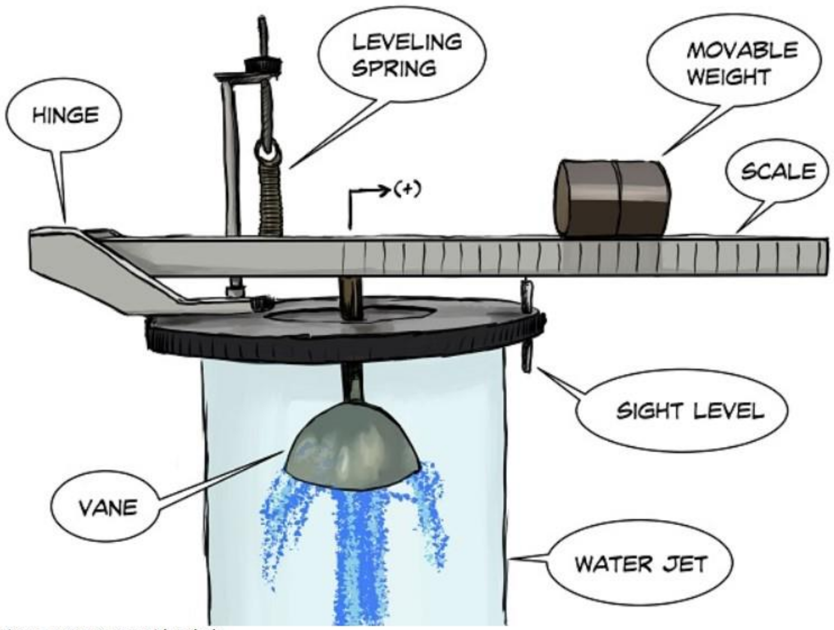


Figure 2 Apparatus with Labels

b.

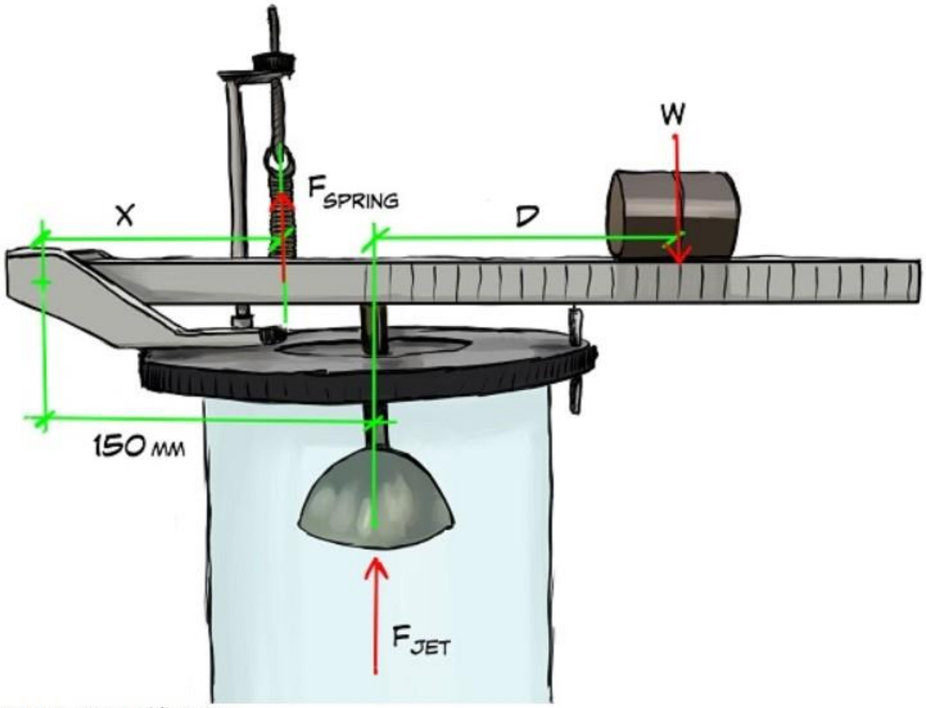
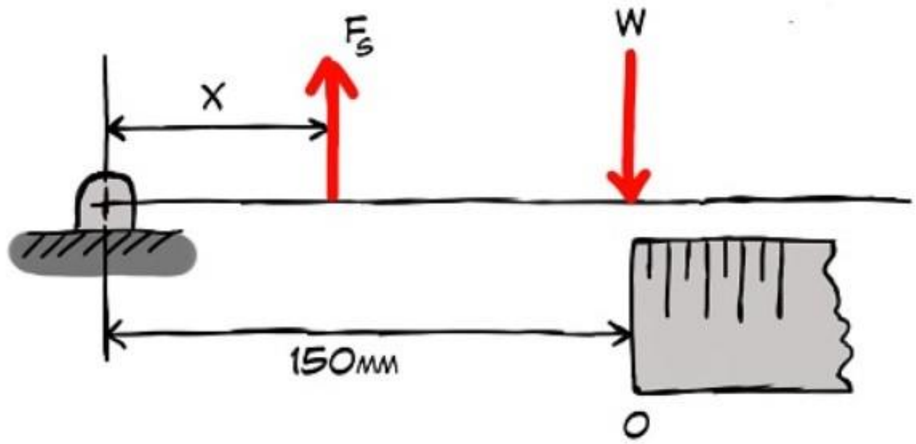
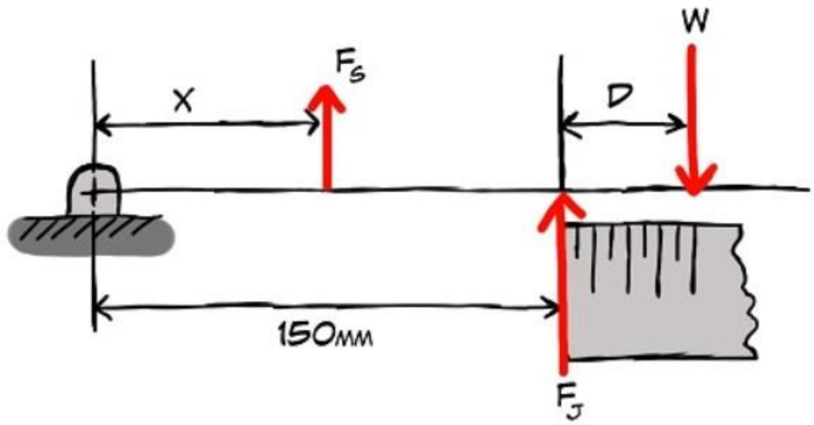


Figure 3 Apparatus with Forces

c.



d. Figure 4 Calculation of Moment Arm with No Flow



e. *Figure 5 Calculation of Moment Arm with Flow*

5. **Verbal Description**
    a. The apparatus above in the images consists of a vertical nozzle enclosed inside a circular transparent cylinder. A centrifugal pump supplies water to the nozzle, and the water discharged is returned to a weighing tank, then to a sump, then to a pump, thus forming a closed circuit. The valve before the nozzle controls the flow of the water. The mass flow rate is measured by timing how long it takes to collect a certain amount of water in the weighing tank. On top of the cylinder, a precision weight beam is mounted that is pivoted at one end on hardened steel knife-edges. The water that is controlled by the valve has a smooth stream that is directed against various shaped vanes, a flat plate, and a hemisphere. These vanes are alternatively fitted to the weight beam, which carries a sliding weight. The beam is first balanced level by the spring with the weight at point 0 on the scale and the vane installed. When a flow is initiated, the weight must be moved down the scale to counterbalance the force of the water stream.
6. **Step-by-Step Procedure**
    a. Entered lab room.
    b. Identified the five components used for this lab:
        i. Upstream Valve
        ii. Scales and Vane Apparatus
        iii. Tank
        iv. Bucket
        v. Plunger (Pipe)
    c. Identified the seven components of the Scales and Vane apparatus:
        i. Hinge
        ii. Leveling Spring
        iii. Movable Weight
        iv. Scale/Beam
        v. Sight Level

    vi. Vane
    vii. Water Jet

d. Collected data for the Flat Vane.
e. Inserted Flat Vane by dragging it to the Apparatus.
f. Installed Flat Vane.
g. Looked at left-side panel of Tank.
h. Selected on/off Pump Panel
i. Turned the pump on by selecting black button.
j. Opened valve to adjust water flow.
k. Turned valve all the way to the left until the valve was fully open.
l. Selected the movable weight to balance the scale/beam.
m. Recorded the position of the weight (Flat Vane 1) on the scale/beam in millimeters.
    i. 185mm
n. Filled the tank with water by inserting the plunger into the tank drain.
o. Waited for tank to fill with 15 liters of water.
p. Selected stopwatch to begin timer.
q. Recorded the flow time (in seconds).
    i. 9.97 seconds
r. Removed the plunger from the fill tank to drain the water.
s. Turned Upstream Valve slightly to the right to reduce water flow.
t. Selected the movable weight to balance the scale/beam.
u. Recorded the position of the weight (Flat Vane 2) on the scale/beam in millimeters.
    i. 170mm
v. Filled the tank with water by inserting the plunger into the tank drain.
w. Waited for tank to fill with 15 liters of water.
x. Selected stopwatch to begin timer.
y. Recorded the flow time (in seconds).
    i. 10.89 seconds
z. Removed the plunger from the fill tank to drain the water.
aa. Turned Upstream Valve slightly to the right to reduce water flow.
bb. Selected the movable weight to balance the scale/beam.
cc. Recorded the position of the weight (Flat Vane 3) on the scale/beam in millimeters.
    i. 155mm
dd. Filled the tank with water by inserting the plunger into the tank drain.
ee. Waited for tank to fill with 15 liters of water.
ff. Selected stopwatch to begin timer.
gg. Recorded the flow time (in seconds).
    i. 12.11 seconds

hh. Removed the plunger from the fill tank to drain the water.
ii. Turned Upstream Valve slightly to the right to reduce water flow.
jj. Selected the movable weight to balance the scale/beam.
kk. Recorded the position of the weight (Flat Vane 4) on the scale/beam in millimeters.
    i. 140mm
ll. Filled the tank with water by inserting the plunger into the tank drain.
mm. Waited for tank to fill with 15 liters of water.
nn. Selected stopwatch to begin timer.
oo. Recorded the flow time (in seconds).
    i. 12.76 seconds
pp. Removed the plunger from the fill tank to drain the water.
qq. Turned Upstream Valve slightly to the right to reduce water flow.
rr. Selected the movable weight to balance the scale/beam.
ss. Recorded the position of the weight (Flat Vane 5) on the scale/beam in millimeters.
    i. 125mm
tt. Filled the tank with water by inserting the plunger into the tank drain.
uu. Waited for tank to fill with 15 liters of water.
vv. Selected stopwatch to begin timer.
ww. Recorded the flow time (in seconds).
    i. 13.88 seconds
xx. Removed the plunger from the fill tank to drain the water.
yy. Turned Upstream Valve slightly to the right to reduce water flow.
zz. Selected the movable weight to balance the scale/beam.
aaa. Recorded the position of the weight (Flat Vane 6) on the scale/beam in millimeters.
    i. 110mm
bbb. Filled the tank with water by inserting the plunger into the tank drain.
ccc. Waited for tank to fill with 15 liters of water.
ddd. Selected stopwatch to begin timer.
eee. Recorded the flow time (in seconds).
    i. 15.32 seconds
fff. Removed the plunger from the fill tank to drain the water.
ggg. Turned Upstream Valve slightly to the right to reduce water flow.
hhh. Selected the movable weight to balance the scale/beam.
iii. Recorded the position of the weight (Flat Vane 7) on the scale/beam in millimeters.
    i. 95mm
jjj. Filled the tank with water by inserting the plunger into the tank drain.
kkk. Waited for tank to fill with 15 liters of water.

lll. Selected stopwatch to begin timer.
mmm. Recorded the flow time (in seconds).
    i. 16.92 seconds
nnn. Removed the plunger from the fill tank to drain the water.
ooo. Turned Upstream Valve slightly to the right to reduce water flow.
ppp. Selected the movable weight to balance the scale/beam.
qqq. Recorded the position of the weight (Flat Vane 8) on the scale/beam in millimeters.
    i. 80mm
rrr. Filled the tank with water by inserting the plunger into the tank drain.
sss. Waited for tank to fill with 15 liters of water.
ttt. Selected stopwatch to begin timer.
uuu. Recorded the flow time (in seconds).
    i. 18.63 seconds
vvv. Removed the plunger from the fill tank to drain the water.
www. Turned Upstream Valve slightly to the right to reduce water flow.
xxx. Selected the movable weight to balance the scale/beam.
yyy. Recorded the position of the weight (Flat Vane 9) on the scale/beam in millimeters.
    i. 65mm
zzz. Filled the tank with water by inserting the plunger into the tank drain.
aaaa. Waited for tank to fill with 15 liters of water.
bbbb. Selected stopwatch to begin timer.
cccc. Recorded the flow time (in seconds).
    i. 21.01 seconds
dddd. Removed the plunger from the fill tank to drain the water.
eeee. Turned Upstream Valve slightly to the right to reduce water flow.
ffff. Selected the movable weight to balance the scale/beam.
gggg. Recorded the position of the weight (Flat Vane 10) on the scale/beam in millimeters.
    i. 50mm
hhhh. Filled the tank with water by inserting the plunger into the tank drain.
iiii. Waited for tank to fill with 15 liters of water.
jjjj. Selected stopwatch to begin timer.
kkkk. Recorded the flow time (in seconds).
    i. 26.05 seconds
llll. Removed the plunger from the fill tank to drain the water.
mmmm. Turned upstream valve all the way to the right until water turned off.
nnnn. Removed flat vane.
oooo. Concluded data collection for flat vane.

pppp. Collected data for hemispherical vane.
qqqq. Inserted hemispherical vane into apparatus.
rrrr. Installed hemispherical vane.
ssss. Turned upstream valve all the way to the left, until water flow was at maximum flow settings.
tttt. Selected the movable weight to balance the scale/beam.
uuuu. Recorded the position of the weight (Hemispherical Vane 1) on the scale/beam in millimeters.
    i. 200mm
vvvv. Filled the tank with water by inserting the plunger into the tank drain.
wwww. Waited for tank to fill with 15 liters of water.
xxxx. Selected stopwatch to begin timer.
yyyy. Recorded the flow time (in seconds).
    i. 15.48 seconds
zzzz. Removed the plunger from the fill tank to drain the water.
aaaaa. Turned Upstream Valve slightly to the right to reduce water flow.
bbbbb. Selected the movable weight to balance the scale/beam.
ccccc. Recorded the position of the weight (Hemispherical Vane 2) on the scale/beam in millimeters.
    i. 180mm
ddddd. Filled the tank with water by inserting the plunger into the tank drain.
eeeee. Waited for tank to fill with 15 liters of water.
fffff. Selected stopwatch to begin timer.
ggggg. Recorded the flow time (in seconds).
    i. 16.13 seconds
hhhhh. Removed the plunger from the fill tank to drain the water.
iiiii. Turned Upstream Valve slightly to the right to reduce water flow.
jjjjj. Selected the movable weight to balance the scale/beam.
kkkkk. Recorded the position of the weight (Hemispherical Vane 3) on the scale/beam in millimeters.
    i. 160mm
lllll. Filled the tank with water by inserting the plunger into the tank drain.
mmmmm. Waited for tank to fill with 15 liters of water.
nnnnn. Selected stopwatch to begin timer.
ooooo. Recorded the flow time (in seconds).
    i. 17.05 seconds
ppppp. Removed the plunger from the fill tank to drain the water.
qqqqq. Turned Upstream Valve slightly to the right to reduce water flow.
rrrrr. Selected the movable weight to balance the scale/beam.
sssss. Recorded the position of the weight (Hemispherical Vane 4) on the scale/beam in millimeters.

i. 140mm

ttttt. Filled the tank with water by inserting the plunger into the tank drain.

uuuuu. Waited for tank to fill with 15 liters of water.

vvvvv. Selected stopwatch to begin timer.

wwwww. Recorded the flow time (in seconds).

i. 18.47 seconds

xxxxx. Removed the plunger from the fill tank to drain the water.

yyyyy. Turned Upstream Valve slightly to the right to reduce water flow.

zzzzz. Selected the movable weight to balance the scale/beam.

aaaaaa. Recorded the position of the weight (Hemispherical Vane 5) on the scale/beam in millimeters.

i. 120mm

bbbbbb. Filled the tank with water by inserting the plunger into the tank drain.

cccccc. Waited for tank to fill with 15 liters of water.

dddddd. Selected stopwatch to begin timer.

eeeeee. Recorded the flow time (in seconds).

i. 21.03 seconds

ffffff. Removed the plunger from the fill tank to drain the water.

gggggg. Turned Upstream Valve slightly to the right to reduce water flow.

hhhhhh. Selected the movable weight to balance the scale/beam.

iiiiii. Recorded the position of the weight (Hemispherical Vane 6) on the scale/beam in millimeters.

i. 100mm

jjjjjj. Filled the tank with water by inserting the plunger into the tank drain.

kkkkkk. Waited for tank to fill with 15 liters of water.

llllll. Selected stopwatch to begin timer.

mmmmmm. Recorded the flow time (in seconds).

i. 23.62 seconds

nnnnnn. Removed the plunger from the fill tank to drain the water.

oooooo. Turned Upstream Valve slightly to the right to reduce water flow.

pppppp. Selected the movable weight to balance the scale/beam.

qqqqqq. Recorded the position of the weight (Hemispherical Vane 7) on the scale/beam in millimeters.

i. 80mm

rrrrrr. Filled the tank with water by inserting the plunger into the tank drain.

ssssss. Waited for tank to fill with 15 liters of water.

tttttt. Selected stopwatch to begin timer.

uuuuuu. Recorded the flow time (in seconds).

i. 25.86 seconds

vvvvvv. Removed the plunger from the fill tank to drain the water.

wwwwww. Turned Upstream Valve slightly to the right to reduce water flow.
xxxxxx. Selected the movable weight to balance the scale/beam.
yyyyyy. Recorded the position of the weight (Hemispherical Vane 8) on the scale/beam in millimeters.
    i. 60mm
zzzzzz. Filled the tank with water by inserting the plunger into the tank drain.
aaaaaaa. Waited for tank to fill with 15 liters of water.
bbbbbbb. Selected stopwatch to begin timer.
ccccccc. Recorded the flow time (in seconds).
    i. 30.83 seconds
ddddddd. Removed the plunger from the fill tank to drain the water.
eeeeeee. Turned Upstream Valve slightly to the right to reduce water flow.
fffffff. Selected the movable weight to balance the scale/beam.
ggggggg. Recorded the position of the weight (Hemispherical Vane 9) on the scale/beam in millimeters.
    i. 40mm
hhhhhhh. Filled the tank with water by inserting the plunger into the tank drain.
iiiiiii. Waited for tank to fill with 15 liters of water.
jjjjjjj. Selected stopwatch to begin timer.
kkkkkkk. Recorded the flow time (in seconds).
    i. 38.53 seconds
lllllll. Removed the plunger from the fill tank to drain the water.
mmmmmmm. Turned Upstream Valve slightly to the right to reduce water flow.
nnnnnnn. Selected the movable weight to balance the scale/beam.
ooooooo. Recorded the position of the weight (Hemispherical Vane 10) on the scale/beam in millimeters.
    i. 20mm
ppppppp. Filled the tank with water by inserting the plunger into the tank drain.
qqqqqqq. Waited for tank to fill with 15 liters of water.
rrrrrrr. Selected stopwatch to begin timer.
sssssss. Recorded the flow time (in seconds).
    i. 61.94 seconds
ttttttt. Removed the plunger from the fill tank to drain the water.
uuuuuuu. Removed hemispherical vane from apparatus.
vvvvvvv. Concluded data collection for hemispherical vane.
wwwwwww. Concluded lab.

Recorded Data Table(s)

Sliding weight, W:	5.89	N
Mass H_2O measured:	15	L = kg

Flat Plate Vane Data:

Flow time (sec)	**Position, D (mm)**
9.97	185
10.89	170
12.11	155
12.76	140
13.88	125
15.32	110
16.92	95
18.63	80
21.01	65
26.05	50

Hemisphere Vane Data:

Flow time (sec)	**Position, D (mm)**
15.48	200
16.13	180
17.05	160
18.47	140
21.03	120
23.62	100
25.86	80
30.83	60
38.53	40
61.94	20

Sample Calculations

$$\dot{m} = \left(\frac{\pi\left(\frac{150}{1000}\right)^2}{4}\right)\left(\frac{\frac{185}{1000}}{9.97}\right) = 0.000327906\frac{m^3}{s} = \boxed{5.20gpm}$$

$$F_J = \frac{(5.89N)(185mm)}{150mm} = \boxed{7.26N}$$

$$K_{flat} = 1.1377(1) + 1.7762 = \boxed{2.9139}$$

$$K_{hemispherical} = 1.9185(1) + 1.2358 = \boxed{3.1543}$$

$$c = \frac{\log(6.68) - \log(4.37)}{\log(3.14) - \log(1.20)} = \boxed{0.58}$$

$$F_J, proposed = (2.9139)(5.20^{0.58}) = \boxed{7.63N}$$

Calculated Data Table(s)

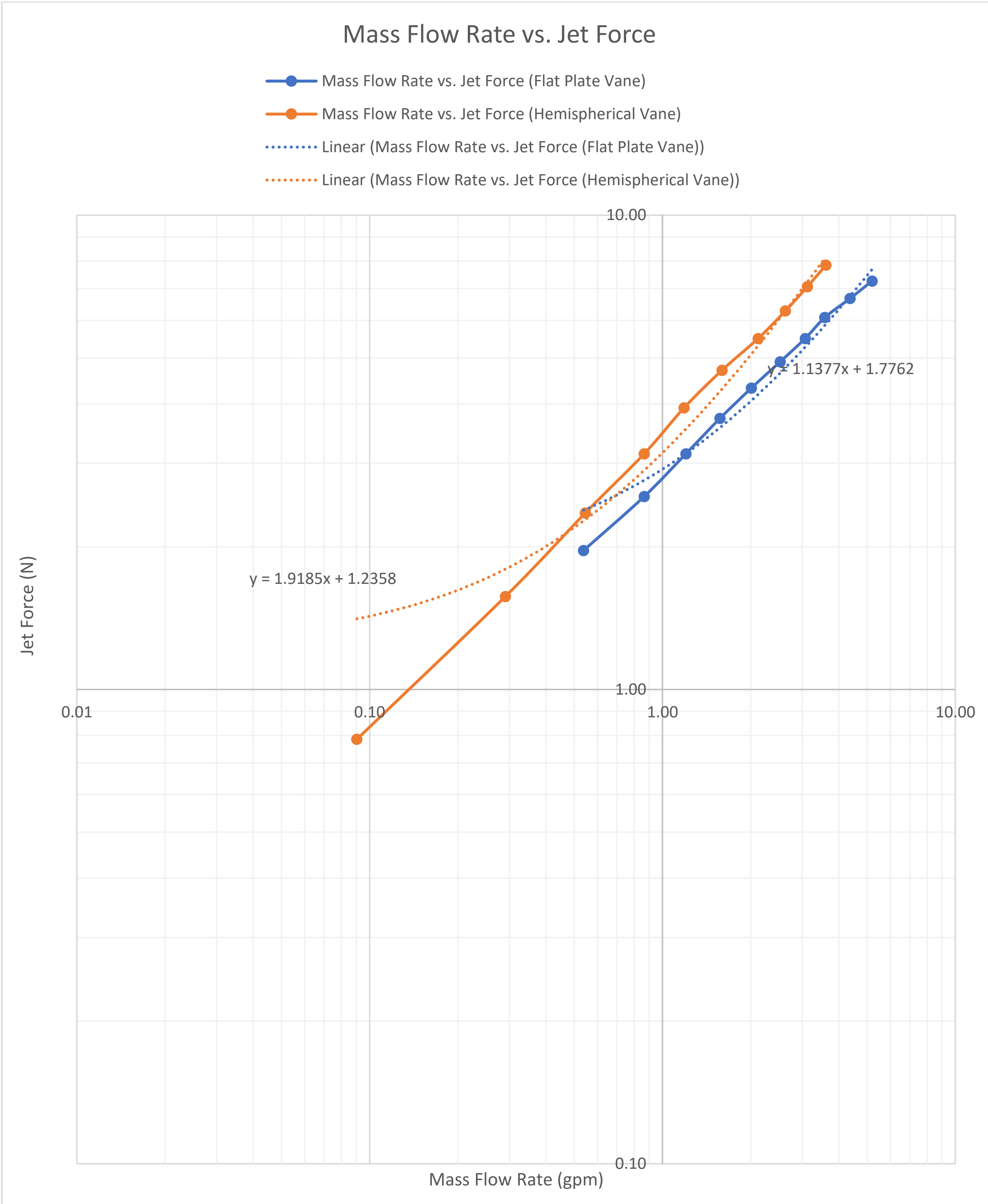
Flat Plate Vane Data:		
Mass flow rate (m^3/s)	**Mass flow rate (gpm)**	**Jet Force (N)**
0.000327906	5.20	7.26
0.000275863	4.37	6.68
0.000226183	3.59	6.09
0.000193887	3.07	5.50
0.000159145	2.52	4.91
0.000126884	2.01	4.32
9.92192E-05	1.57	3.73
7.58839E-05	1.20	3.14
5.46713E-05	0.87	2.55
3.39183E-05	0.54	1.96

Flat Plate Vane Data:		
K (y-intercept at x=1)	**c**	**Jet Force, Proposed (N)**
2.9139	0.58	7.63
		6.90
		6.14
		5.61
		5.00
		4.38
		3.80
		3.25
		2.68
		2.03

Hemispherical Vane Data:		
Mass flow rate (m^3/s)	Mass flow rate (gpm)	Jet Force (N)
0.000228313	3.62	7.85
0.000197202	3.13	7.07
0.000165832	2.63	6.28
0.000133947	2.12	5.50
0.000100836	1.60	4.71
7.48157E-05	1.19	3.93
5.46681E-05	0.87	3.14
3.43914E-05	0.55	2.36
1.83457E-05	0.29	1.57
5.70599E-06	0.09	0.79

Hemispherical Vane Data:		
K (y-intercept at x=1)	c	Jet Force, Proposed (N)
3.1543	0.63	7.08
		6.46
		5.79
		5.07
		4.24
		3.51
		2.88
		2.15
		1.45
		0.70

Graph(s)


Mass Flow Rate vs. Jet Force
Mass Flow Rate vs. Jet Force (Flat Plate Vane)
Mass Flow Rate vs. Jet Force (Hemispherical Vane)
Linear (Mass Flow Rate vs. Jet Force (Flat Plate Vane))
Linear (Mass Flow Rate vs. Jet Force (Hemispherical Vane))
10.00
y = 1.1377x + 1.7762
y = 1.9185x + 1.2358
Jet Force (N)
1.00
0.01
0.10
1.00
10.00
0.10
Mass Flow Rate (gpm)

Discussion of Results and Conclusions

The results above show that F_J and F_J proposed have similarities since they are within a 1%-5% error range from each other. This was for the flat plate data, for the hemispherical data, that range jumps to 8-11%. These values aren't great for a lab report, but they are the values that show themselves from the graphical data and calculations.

The values of K are higher for the hemispherical plate versus the flat plate (3.15 vs 2.91) and the same thing stands true for the values of c (0.63 vs 0.58). I would assume that this is because of the more surface are the water jet collides with (since it's a cone shape) versus the flat plate where there's one "point" where the water jet is hitting.

The log-log axes above show that the flat plate and the hemispherical plate values follow the same trend, however, the hemispherical has slightly higher values for the jet forces. We see this stand true with how close the c value is for both plates.

Sources of error that could play a factor into values is rounding. While it may not seem very important, all digits (in calculations) play a factor into the final value. i.e., a student using a mass flow rate of 5.20gpm could get a different answer than a student using a mass flow rate of 5.197415gpm. Another source of error that could play a factor is not correctly converting units. Changing mm to m for area calculations or changing m^3/s to gallons per minute would play a significant role in the final calculations that are used for the graph shown above. Finally, simple errors in the formulas in Excel can cause havoc. Some of these errors include not including a parenthesis in a particular spot or not including the $ symbol in front of a cell.