MET 335W

Forces on Vanes

April 10, 2019

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Experiment Title: Forces on Vanes

Purpose:
This lab will have the student consider two differently shaped vanes, the flat plate and the hemispherical. Determination of the impact force of water will be plotted to reveal equations that model the behavior for each of the specific vanes.

Theoretical Considerations:
The force of a stream or jet of water on a our vane surfaces increases as the velocity of the jet force increases. The relationship to the mass flow rate ($\dot{m} = AVj$) is utilized in this lab rather than the velocity. Jet force depends on both.

Description of Apparatus:

1. Water collection tank (with tank fill gauge)
2. Bucket
3. Scales and vane apparatus:
    a. Hinge
    b. Leveling spring
    c. Movable slide weight
    d. Scale/beam
    e. Sight level
    f. Vane
    g. Water jet
4. Upstream gate valve
5. Plunger (pipe)
6. Nozzle/vane tank
7. Flat plate vane
8. Hemispherical vane

Step-by-Step Procedure:

1. The flat vane was installed into the top of the apparatus.
2. On the left-side panel of the water collection tank, the black "power on" button controlling the pump motor was pressed to turn the pump on.
3. The red gate valve controlling upstream water flow was rotated counterclockwise all the way to fully open and allow the maximum flow of water to the nozzle.
4. The water was observed pushing against the jet and causing the scale/beam arm above the tank to rise.
5. The slide weight was carefully slid over to the right until the top groove on the sight level hanging from the arm was lined up with the top of the nozzle/vane tank, indicating the arm was level.

6. The position of the slide weight was read on the scale/beam and recorded on the data sheet in millimeters (mm).
7. The plunger (pipe) for the water collection tank was inserted into the drain in order to stop the water from draining out, and a stopwatch was started immediately to record how long it takes to fill the tank with 15 liters of water.
8. The water level rise was observed on the tank fill gauge on the side of the collection tank, and the stopwatch was stopped when the water level reached 15 liters.
9. The flow time (in seconds) on the stopwatch was recorded on the data sheet.
10. The plunger was removed from the tank to allow water to drain completely out.
11. The red gate valve controlling upstream water flow was rotated slightly clockwise to reduce the flow of water by a small amount.
12. Again, the slide weight was carefully slid over to the right until the top groove on the sight level was lined up with the top of the nozzle/vane tank, indicating the arm was level.
13. The position of the slide weight was read on the scale/beam and recorded on the data sheet in millimeters (mm).
14. Again, the plunger (pipe) for the water collection tank was inserted into the drain, and a stopwatch was started immediately.
15. Once reaching the 15 liter mark indicated on the tank fill gauge, the stopwatch was stopped and the time was recorded on the data sheet.
16. The plunger was removed from the tank to allow water to drain completely out.
17. The red gate valve controlling the upstream water flow was again rotated slightly clockwise to reduce the flow of water by a small amount.
18. The slide weight was again carefully slid over to the right until the top groove on the sight level was lined up with the top of the nozzle/vane tank, indicating the arm was level.
19. The position of the slide weight was read on the scale/beam and recorded on the data sheet in millimeters (mm).
20. The plunger (pipe) for the water collection tank was again inserted into the drain, and a stopwatch was started immediately.
21. Once reaching the 15 liter mark indicated on the tank fill gauge, the stopwatch was stopped and the time was recorded on the data sheet.
22. The plunger was removed from the tank to allow water to drain completely out.
23. The entire process was repeated until a total of 10 incremental readings were recorded on the data chart using the flat plate vane.
24. Once completing the 10^{th} reading, the red upstream valve was turned clockwise all the way until the water flow was completely turned off.
25. The flat plate vane was then removed from the apparatus, and the hemispherical vane was inserted in its place.
26. The entire process was repeated using the hemispherical vane, until a total of 10 incremental readings were recorded on the data chart.
27. This concluded the Forces on Vanes experiment.

Recorded Data Table:

Sliding Weight: 5.89 N
Mass Measured H_2O: 15L = 15 kg
Beam Weight Position: 150 mm

Table 1. Raw Data Forces on Vanes: Flat Plate Vane

Flow Time (seconds)	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

Table 2. Raw Data Forces: Hemisphere Vane

Flow Time (seconds)	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:

1. mass flow rate = m = mass H_2O/time = 15 kg/ 9.97 seconds = 1.5 kg/s

2. For of the jet, F_j = [D(mm)] [sliding weight = 5.98 N]/ beam weight position = 150 mm]
   = (185 mm) (5.98 N)/ (150 mm)
   = 7.26 N
3. Calculation of the slope of the Flat Plate Vane:

$$c, \text{ slope} = \frac{\text{Log}(Fj_2) - \text{Log}(Fj_1)}{\text{Log}\,\dot{m}_2 - \text{Log}\,\dot{m}_1} = \frac{\text{Log}(7.26) - \text{Log}(6.68)}{\text{Log}(1.50) - \text{Log}(1.38)}$$

= 0.036166/0.036211

= 0.9987

Calculation of the y-intercept, K for Flat Plate Vane

b = F_j -slope ($\dot{m}$) = 7.26 - (0.9987) (1.50)
= 5.762

4. Calculation of the slope of the Hemispheric Vane:

$$c, \text{ slope} = \frac{\text{Log}(Fj_2) - \text{Log}(Fj_1)}{\text{Log}\,\dot{m}_2 - \text{Log}\,\dot{m}_1} = \frac{\text{Log}(7.85) - \text{Log}(4.71)}{\text{Log}(0.969) - \text{Log}(0.713)}$$

= 0.22185/0.133234

= 1.665

Calculation of the y-intercept, K for Hemispheric Vane

b = F_j -slope ($\dot{m}$) = 7.85 - (1.665) (0.969)
= 6.236

5. Testing K and c values in $F_j = K(\dot{m})^c$ for Flat Plat Vane

$F_j = (5.762)\,(1.1)^{0.9987} = 6.337$ N [using calculated intercept]

$F_j = (4.9)\,(1.1)^{0.9987} = 5.38$ N [using intercept direct from graph]

6. Testing K and c values in $F_j = K(\dot{m})^c$ for Hemispheric Vane

$F_j = (6.236)\,(0.90)^{1.665} = 5.233$N [using calculated intercept]

$F_j = (7.2)\,(0.90)^{1.665} = 6.04$ N [using intercept direct from graph]

Calculated Data Table:

Sliding Weight: 5.89 N
Mass Measured H2O: 15L = 15 kg
Beam Weight Position: 150 mm

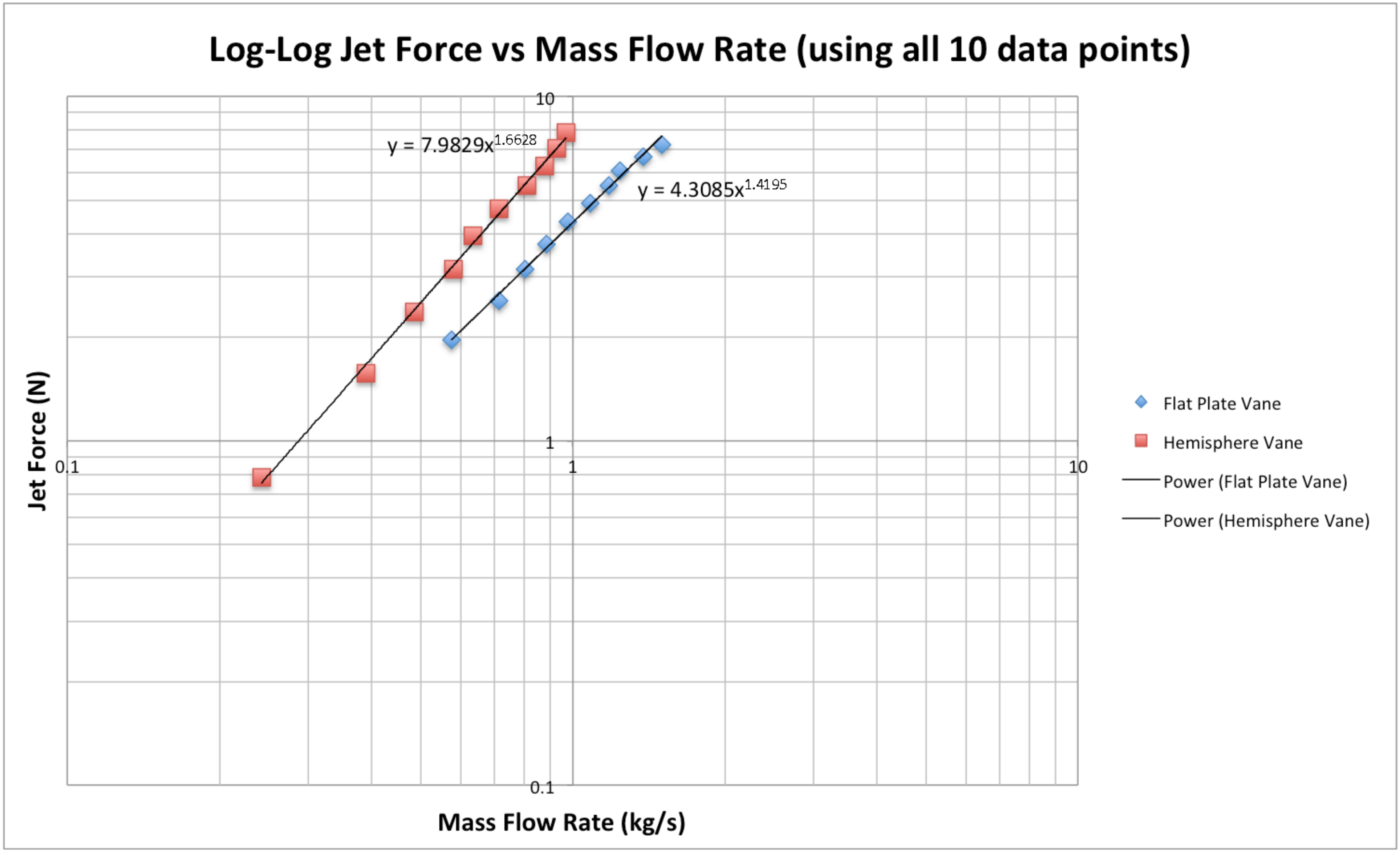
Table 3. Calculated Data Forces on Vanes: Flat Plate Vane

Flow Time (seconds)	Position, D (mm)	Mass Flow Rate (kg/s)	Jet Force (N)
9.97	185	1.50	7.26
10.89	170	1.38	6.68
12.11	155	1.24	6.09
12.76	140	1.18	5.50
13.88	125	1.08	4.91
15.32	110	0.979	4.32
16.92	95	0.886	3.73
18.63	80	0.805	3.14
21.01	65	0.714	2.55
26.05	50	0.576	1.96

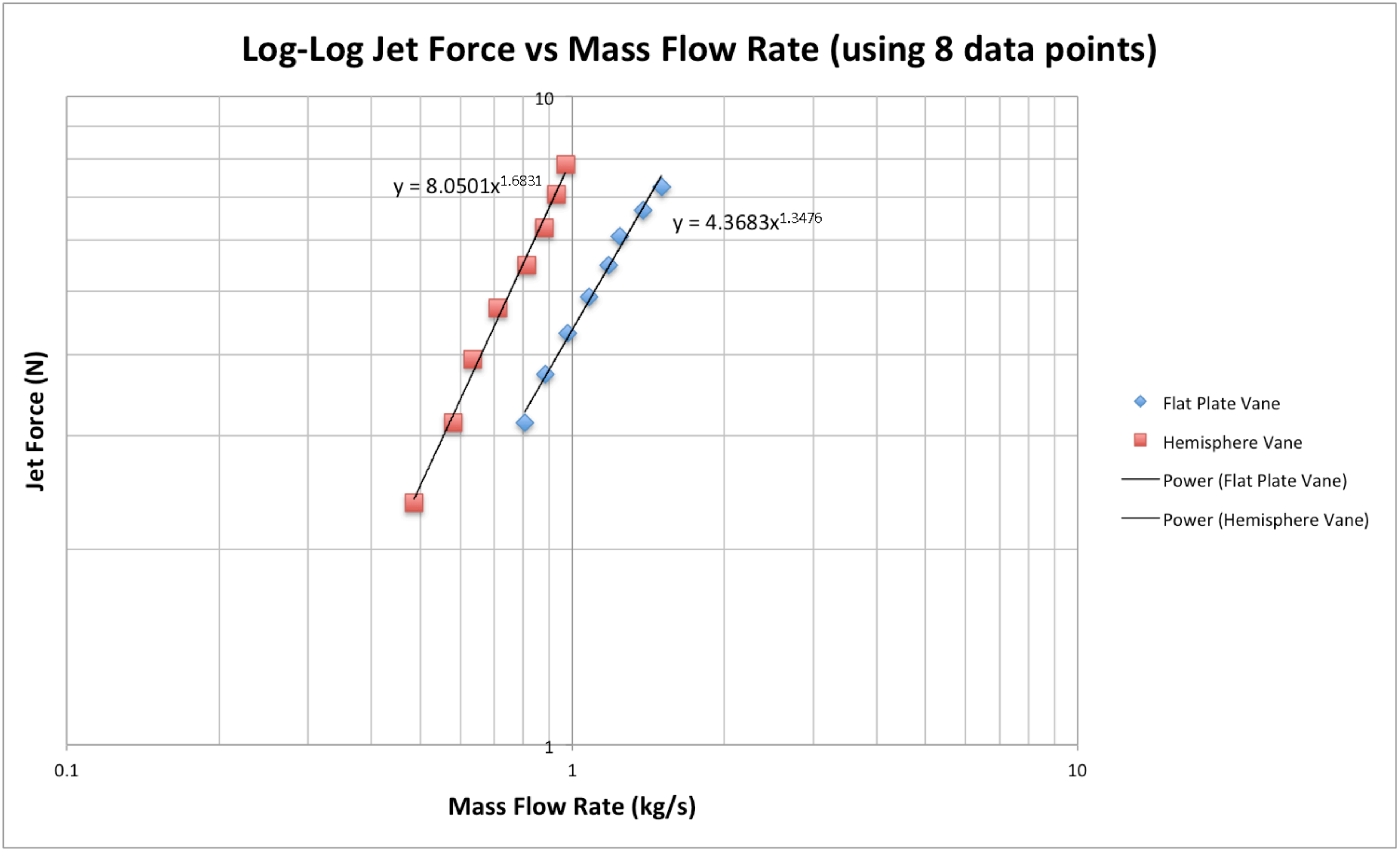
Table 4. Calculated Data Forces: Hemisphere Vane

Flow Time (seconds)	Position, D (mm)	Mass Flow Rate (kg/s)	Jet Force (N)
15.48	200	0.969	7.85
16.13	180	0.930	7.07
17.05	160	0.880	6.28
18.47	140	0.812	5.50
21.03	120	0.713	4.71
23.62	100	0.635	3.93
25.86	80	0.580	3.14
30.83	60	0.486	2.36
38.53	40	0.389	1.57
61.94	20	0.242	0.785

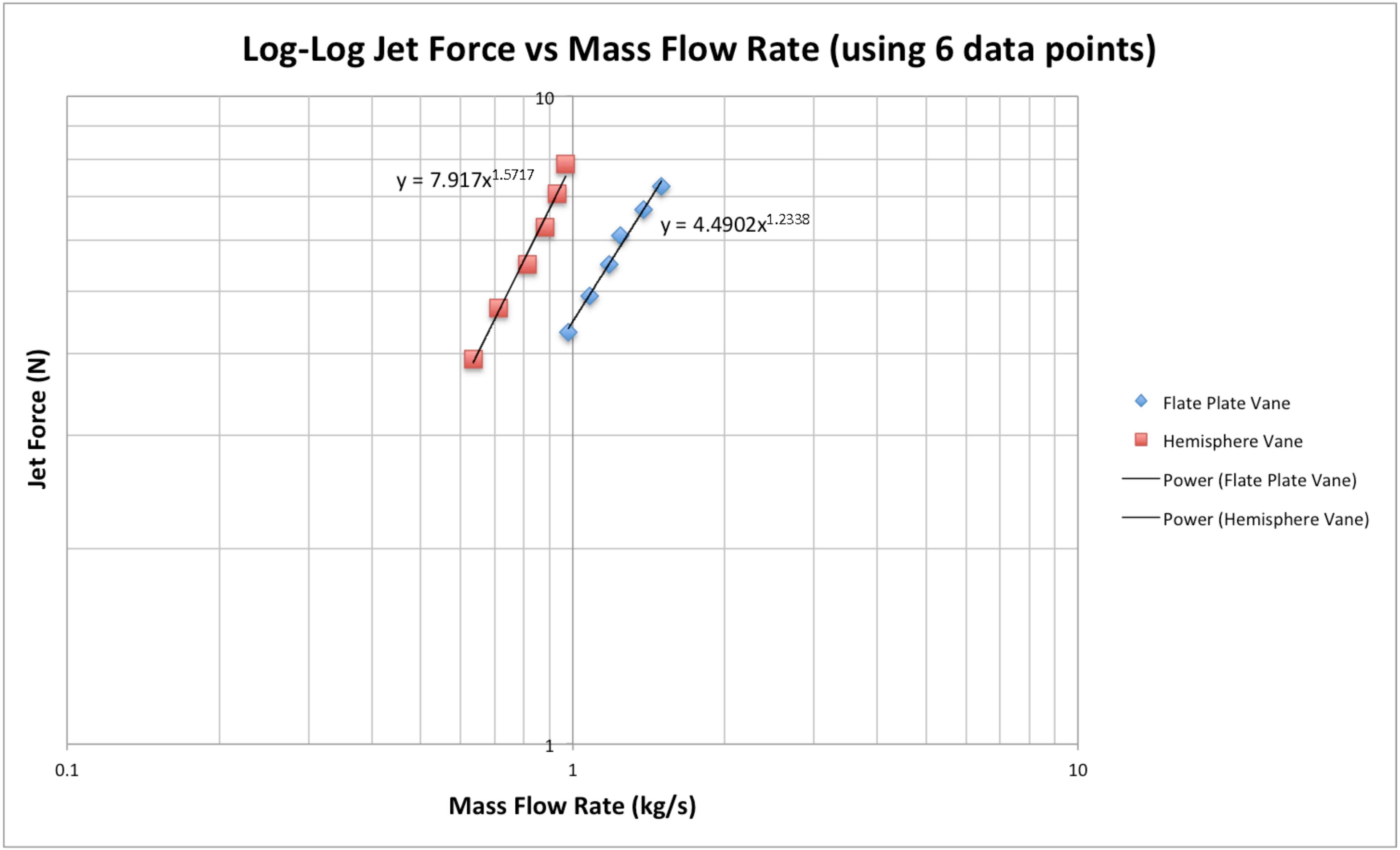
Graph 1: Log-Log Jet Force vs Mass Flow Rate (using all 10 points)



Graph 2: Log-Log Jet Force vs Mass Flow Rate (using 8 points)



Graph 3: Log-Log Jet Force vs Mass Flow Rate (using 6 points)



Discussion of Results and Conclusions:

In this Force on Vanes Lab, we determine an equation for both a flat and hemispherical vane, that models the behavior for each vane. As the velocity of a jet of water increases, so does its force on a surface. Using the log-log plot of mass flow rate and the jet impact force resulted in two straight lines for our Graph 3. Graph 3 utilized (by direction) the upper six values of our data for both the flat plate and hemisphere vane.

Initially, in Graph 1, all ten data points were plotted for each vane. The lower four values tended to skew our trend line. This is due to the error being introduced per our nozzle location being 10 mm below the vane. However, it was necessary for the nozzle to be located there to allow for water to escape to the weighing tank.

Graph 2 used 8 data points and Graph 3 used 6 data points; the best straight lines were achieved with the upper six values.

It was proposed that the force of the jet, F_j, could be expressed as model equation

$$F_j = K\dot{m}^c$$

Our model equation has the form of a power function, and if plotted on regular graph paper would be a curved line. The relationship for our x and y is not linear. By using a logarithmic graph, we are able to plot our power function as a straight line.

From our log-log plot,

$$\log F_j = c\,(\log \dot{m}) + \log K$$

From the straight-line relationship, $y = mx + b$, the slope of the best fit line is c and the y-intercept will be K (where $\dot{m} = 1$ for $\log \dot{m}$ = zero).

Upon examination of Graph 3, K, the y-intercept looks to be about 4.9 for the flat plane vane and 7.2 for the hemisphere vane. Our calculated K was 5.762 for the flat plate vane and 6.236 for the hemisphere vane. In other words, we calculated a bit higher for the flat vane and a bit lower for the hemisphere vane. This throws our jet force off a bit, too.

Our model equation is still believed to be sound. We should consider differences in our vanes and some error source (other than that mentioned above). Our vanes have two different geometries, one being flat, and one being curved. It can be seen from our data that the mass flow rate was less for our hemisphere vane. This makes sense, since the flat plate vane is so much more spread out. Flat plate vanes deflect water at 90 degrees, while hemisphere deflect at 180 degrees.

Error due to friction on the vanes and also due to timing and filling should be considered.

The hemisphere line did not actually achieve a mass flow rate of one in our experimental data. Theoretically, a y-intercept of K for F_j was seen on the graph and calculated.