MET 335W

Orifice Plate Coefficients

March 3, 2019

William McClenney

wmccl001@odu.edu

Experiment Title: Orifice Plate Coefficients

Purpose:

1. The purpose of this experiment is to compute the friction losses due to an orifice plate in a flow path of an axial turbofan and how it varies as a function of the Reynolds number.
2. The application of Bernoulli's equation to the orifice plates will be used to calculate the orifice plate coefficient.
3. The actual volumetric flow rate through a venturi tube will be measured against adjustments to the fan speed.
4. The calculations obtained will be used to plot a graph of the coefficient of the orifice (C_O) versus the Reynolds number (N_R, actual) for each size orifice, all on one graph.
5. The results obtained in the experiment and the curves developed will be discussed.

Theoretical Considerations:

Orifice plates introduce frictional losses to a system. In this lab, the losses due to friction, as depicted in the orifice coefficient, will be calculated and compared to the Reynolds number. Using Bernoulli's equation, flow measures with the orifice plates can be calculated. Measurement of the flow rate is accomplished with a venturi attached to the end of the apparatus.

Description of Apparatus:

1. 115 volt AC variable speed cradle-mounted fan motor
2. Output shaft (attached to the motor)
3. Turbofan (attached to the output shaft)
4. Control panel (containing main switches and the fan speed control knob)
5. 3 metal orifice plates (ranging incrementally from small, medium and large openings)
6. Discharge ducting (with flow straightener and venturi)
7. Orifice clamp (for orifice plate insertion)
8. Digital manometer (calibrated in inches of water)

Step-by-Step Procedure:

1. The main power switch and the fan control switch on the control panel were switched on to apply voltage to the test instrument.
2. The digital manometer display board switch was turned on to apply voltage to the digital readout displays.
3. The manometer was zeroed out so that all display indicate no readings (zero).
4. Among the 3 available metal orifice plates, the orifice plate with the smallest opening was first selected to be installed in the air flow tube (it was noted that the orifice plates had beveled edges on one side and flat edges on the opposite side).
5. The clamp on the air flow tube was released and the two sections of tube were separated slightly.
6. The orifice plate was seated firmly between the separated sections of air flow tube, assuring the flat edge of the orifice plate is positioned facing upstream (to avoid a nozzle effect) towards the motor.
7. The two sections of air flow tube were reconnected against the orifice plate, and the clamp was secured around the orifice plate and the flanges of the two sections.
8. The fan speed control knob was then dialed clockwise to 80% power in order to increase the revolutions per minute (rpm) of the output shaft for the fan motor.
9. The orifice head (H_O), as indicated on the digital readout in inches of water, was

recorded in the data table.

10. The venturi head (H_V), as indicated on the digital readout in inches of water, was recorded in the data table.
11. Once the orifice readings were recorded, the fan speed control knob was then dialed counterclockwise to reduce the power to 75% for the output shaft for the fan motor.
12. Again, the orifice head readings were taken from the digital manometer display and recorded on the data sheet.
13. The fan speed control knob was then dialed counterclockwise to reduce the power to 70% for the output shaft for the fan motor.
14. The orifice head readings were taken from the digital manometer display and recorded on the data sheet.
15. This process was repeated until the fan speed was reduced down to 40% and all orifice head readings had been recorded.
16. The fan speed knob was dialed completely down to 0% and the fan allowed to completely stop so that air pressure on the orifice plate was no longer present.
17. The clamp on the air flow tube was released and the two sections of tube were separated slightly.
18. The orifice plate in the air flow tube was removed.
19. The orifice plate with the medium sized opening was seated firmly between the separated sections of air flow tube, assuring the flat edge of the orifice plate is positioned facing upstream (to avoid a nozzle effect) towards the motor.
20. The two sections of air flow tube were reconnected against the orifice plate, and the clamp was secured around the orifice plate and the flanges of the two sections.
21. The fan speed control knob was then dialed clockwise to 80% power in order to increase the revolutions per minute (rpm) of the output shaft for the fan motor.
22. The orifice head (H_O), as indicated on the digital readout in inches of water, was recorded in the data table.
23. The venturi head (H_V), as indicated on the digital readout in inches of water, was recorded in the data table.
24. Once the orifice readings were recorded, the fan speed control knob was then dialed counterclockwise to reduce the power to 75% for the output shaft for the fan motor.
25. The entire process was repeated with the medium sized orifice plate until incrementally reaching 40% speed, and the readings were recorded in the data chart.
26. Again, the fan speed knob was dialed completely down to 0% and the fan allowed to completely stop so that air pressure on the orifice plate was no longer present.
27. The orifice plate was replaced with the third orifice plate with the largest opening.
28. The entire process was repeated with the medium sized orifice plate and the readings recorded in the data chart, completing the experiment.

Recorded Data Tables:

Table 1: Orifice Coefficient Lab Raw Data

Ambient Temperature:	75.0° F	Barometric Pressure:	29.95 inches Hg
Tube Diameter (D_T):	5.125 inches	Venturi Diameter (D_V):	2.562 inches

Orifice diameter	Motor Power **(%)**	Orifice reading (h_O) **(inches of water)**	Venturi reading (h_V) **(inches of water)**
1.03 inches	80	3.00	0.027
	75	2.76	0.023
	70	2.48	0.020
	65	2.17	0.018
	60	1.91	0.013
	55	1.65	0.013
	50	1.41	0.010
	45	1.21	0.008
	40	0.99	0.007

Orifice diameter	Motor Power **(%)**	Orifice reading (h_O) **(inches of water)**	Venturi reading (h_V) **(inches of water)**
2.055 inches	80	2.24	0.335
	75	2.04	0.313
	70	1.79	0.279
	65	1.59	0.249
	60	1.40	0.215
	55	1.20	0.182
	50	1.04	0.157
	45	0.864	0.132
	40	0.72	0.109

Orifice diameter	Motor Power **(%)**	Orifice reading (h_O) **(inches of water)**	Venturi reading (h_V) **(inches of water)**
4.1 inches	80	0.515	2.5
	75	0.463	2.23
	70	0.402	1.95
	65	0.352	1.72
	60	0.31	1.5
	55	0.261	1.292
	50	0.225	1.1
	45	0.192	0.932
	40	0.158	0.777

Sample Calculations:

$$Q_{max} = C_v A_{Throat} \frac{\sqrt{2ghv \frac{\gamma\ manometer}{\gamma\ air}}}{1- [A_{throat}/A_{duct}}$$

$$= (1)(0.0356\ ft^2) \frac{\sqrt{(2)(32.2\ ft/s)(0.00225\ ft) \frac{(62.4\ lb/ft^3)}{(0.0742\ lb/ft^3)}}}{1- [(0.0356\ ft^2)/(0.1431 ft^2)}$$

$$= (0.0356\ ft^2) \frac{\sqrt{[64.4\ ft/s][0.00225\ ft2][841]}}{0.938}$$

$$= 0.4058\ ft^3/s$$

$$V_{max} = \frac{Qmax}{A_{Duct}} = \frac{0.4058\ ft^3/s}{0.1431\ ft^2} = 2.836\ ft/s$$

$$N_{Rmax} = \frac{VmaxD_{tube}}{V_{kair}} = \frac{(2.836\ ft/s)(0.427\ ft)}{*0.000166\ ft^2/s} = 7295$$

*air kinematic viscosity, at 75 degrees F, atmospheric pressure of 760 mm Hg

$$C_v = 0.986 - \frac{471.5}{N_{Rmax}} = 0.986 - \frac{471.5}{7295} = 0.9214$$

$$Q_{duct} = C_v Q_{max} = (0.9214)(0.4058\ ft^3/s) = 0.3739\ ft^3/s$$

$$N_{RDuct} = C_v N_{Rmax} = (0.9214)(7295) = 6722$$

$$V_{duct} = C_v V_{max} = (0.9214)(2.836\ ft/s) = 2.613\ ft/s$$

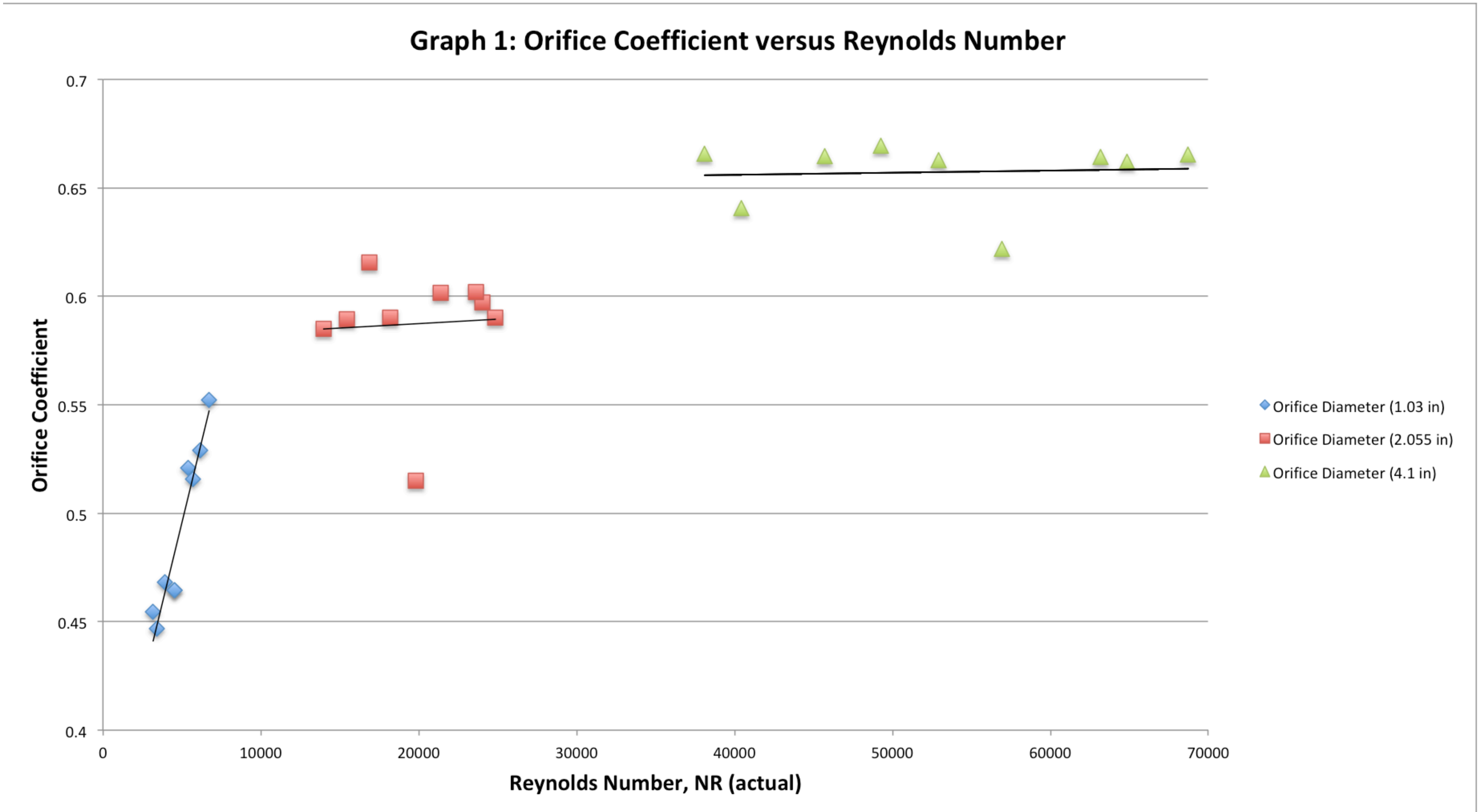
$$Co = \frac{Q_{actual}}{A_{orifice}} \sqrt{\frac{1- [A_{orifice}/A_{duct}}{2gh_v \frac{\gamma\ manometer}{\gamma\ air}}} = \frac{1.383\ ft^3/s}{0.023\ ft^2} \sqrt{\frac{1- [0.0231 ft^2/ 0.1431\ ft^2]}{[32.2\ ft/s^2][0.1867]\frac{[62.4\ lb/ft^3]}{0.0742 lb/ft^3}}}$$

$$= 0.5902$$

__Calculated Data Table:__

Table 2: Orifice Coefficient Lab Calculated Data

Orifice Diameter (in)	Power (%)	Orifice Reading (ft H_2O)	Venturi Reading (ft H_2O)	Maximum Flow Rate (ft^3/sec)	Maximum Velocity (ft/sec)	Maximum Reynolds Number	Venturi Coefficient	Duct Flow Rate (ft^3/sec)	Duct Reynolds Number	Duct Velocity (ft/sec)	Orifice Coefficient
1.03	80	0.2500	0.0023	0.406	2.836	7295	0.9214	0.3739	6722	2.613	0.5523
	75	0.2300	0.0019	0.375	2.621	6741	0.9161	0.3435	6175	2.401	0.5290
	70	0.2060	0.0017	0.349	2.439	6273	0.9108	0.3170	5713	2.221	0.5159
	65	0.1808	0.0015	0.331	2.313	5949	0.9067	0.3001	5394	2.097	0.5210
	60	0.1590	0.0011	0.281	1.964	5052	0.8927	0.2508	4509	1.753	0.4646
	55	0.1375	0.0011	0.281	1.964	5052	0.8927	0.2508	4509	1.753	0.4646
	50	0.1175	0.0008	0.247	1.726	4440	0.8798	0.2173	3906	1.519	0.4681
	45	0.1008	0.0007	0.220	1.537	3954	0.8668	0.1907	3427	1.332	0.4467
	40	0.0825	0.0006	0.206	1.439	3702	0.8586	0.1768	3178	1.235	0.4546
2.055	80	0.1867	0.0279	1.429	9.986	25687	0.9676	1.3830	24854	9.662	0.5902
	75	0.1700	0.0261	1.381	9.651	24825	0.9670	1.3350	24005	9.332	0.5970
	70	0.1490	0.0233	1.304	9.112	24438	0.9667	1.2606	23624	8.809	0.6021
	65	0.1325	0.0208	1.232	8.609	22145	0.9647	1.1880	21363	8.305	0.6017
	60	0.1167	0.0179	1.144	7.994	20563	0.9631	1.0170	19804	7.699	0.5151
	55	0.1000	0.0152	1.054	7.363	18940	0.9611	1.0120	18203	7.076	0.5900
	50	0.0867	0.0131	0.978	6.836	17584	0.9592	0.9383	16866	6.557	0.6155
	45	0.0720	0.0110	0.897	6.269	16125	0.9567	0.8582	15426	5.997	0.5896
	40	0.0600	0.0091	0.815	5.695	14649	0.9538	0.7772	13972	5.431	0.5849
4.1	80	0.0429	0.2083	3.904	27.282	70177	0.9793	3.8230	68724	26.717	0.6652
	75	0.0386	0.1858	3.687	25.762	66267	0.9789	3.6090	64868	25.218	0.6619
	70	0.0335	0.1625	3.448	25.095	64551	0.9787	3.3745	63176	24.560	0.6642
	65	0.0293	0.1433	3.238	22.628	58206	0.9779	3.1660	56919	22.128	0.6220
	60	0.0258	0.1250	3.024	21.132	54358	0.9773	2.9550	52906	20.652	0.6626
	55	0.0218	0.1077	2.807	19.616	50458	0.9767	2.7410	49282	19.158	0.6694
	50	0.0188	0.0917	2.590	18.099	46813	0.9759	2.5270	45684	17.662	0.6648
	45	0.0160	0.0777	2.309	16.136	41506	0.9746	2.2500	40451	15.726	0.6408
	40	0.0132	0.0648	2.177	15.213	39132	0.9740	2.1200	38114	14.817	0.6656



Graph 1: Orifice Coefficient versus Reynolds Number
Orifice Coefficient
0.7
0.65
0.6
0.55
0.5
0.45
0.4
0
10000
20000
30000
40000
50000
60000
70000
Reynolds Number, NR (actual)
Orifice Diameter (1.03 in)
Orifice Diameter (2.055 in)
Orifice Diameter (4.1 in)

Discussion of Results and Conclusions:

Per Bernoulli's equation, orifice plates are used to measure flow rate. Orifice loss coefficients for different size orifices can be established as a function of the Reynolds number. As flow rate changes, the Reynolds number changes.

Graph I, Orifice Coefficient versus the Reynolds number depicts three scenarios with three different size orifice coefficients: orifice diameter of 1.03 inches (Area of 0.00578 ft^2), orifice diameter of 2.055 inches (Area of 0.023 ft^2), and orifice diameter of 4.1 inches (Area of 0.0916 ft^2). The orifice coefficient is dependent on the orifice plate's hole diameter. Apparently the smaller the orifice hole, the greater the restriction, which leads to a smaller orifice coefficient. The range of the orifice coefficient is zero to one. If the orifice coefficient is 1.0, then there are no friction losses and the flow rate is maximum.

Based on the trend lines, results showed that the velocity, Reynolds number and Orifice Coefficient increase with increasing orifice diameter. The venturi caused resistance in the duct before the orifice. With increasing velocity of fluid, the fluid pressure will decrease to conserve the mechanical energy according to the law of conservation of energy.

Sources of error include the alignment of our orifice plates, which appeared to be somewhat of a challenge getting the clip set correctly and the manometer oscillation readings. Friction losses in the entrance and exits of our flow system and leaks are also noted.