AENG 411: Aerospace Laboratory

Performance Characteristics of a Single Stage Axial Flow Air Compressor

by

Group No. 2

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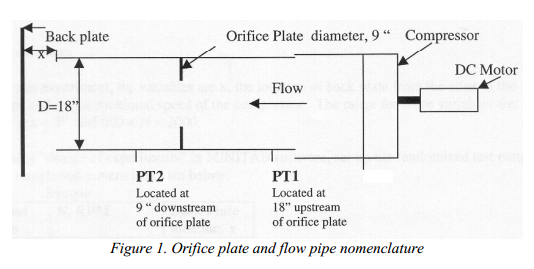
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# **Introduction**

Park's axial compressor consists of a set of stater blades and a set of compressor blades. The stater blades straighten and smooth out the flow before it enters the compressor. The compressor blades then compress the air.



The location of the back plate affects several properties of the flow leaving the compressor. The relationship of these properties is given by:

f (P, ω, D, Q, Δp, ρ, μ) = 0 (1)

Several dimensionless variables can be derived from this functional form using the Buckingham Pi Theorem. The first of these is the power coefficient. It relates the power of motor to it's rotational velocity, the density of the air, and the diameter of the pipe. It is given by:

Cw = P/ρω3D5 (2)

The second dimensionless number is the pressure coefficient. It relates the change in pressure between the two pressure taps to the density of the air, rotational velocity of the compressor, and the diameter of the pipe. It is given by:

CP = ∆p/ρω2D2 (3)

The flow coefficient is the next dimensionless number. It relates the volume flow rate to the compressor's rotational velocity and the pipes diameter. It is given by:

CQ = Q/ωD3 (4)

The final dimensionless number is the Reynolds number, which relates the inertial forces to the viscous forces and its given by:

Re = ρVD/μ (5)

V is the average velocity, given by:

V = Q/A (6)

To find the pressure difference between the two pressure taps all that is required is the distance between the pressure taps and the density of water. The formula is given by:

∆p = ρH2Og∆h (7)

The volume flow rate is dependent on the coefficient of drag of the pipe, its area, the pressure difference, the air density, and the diameter change from the orifice to the pipe. The drag coefficient is calculated using the location of the pressure taps, the Reynolds number, and the diameter ratio. The formulas are given by:

(8)

(9)

# Design of Test

#### 2.1. Objective

The objective of this experiment will was to analyze the performance of a single-stage axial compressor.

#### 2.2. Test Apparatus and Function

The measurement tools and apparatus that were necessary to run this experiment are listed below:

* Single-stage axial flow compressor
* orifice meter
* ruler and
* dynamo-meter

# Procedure

1. The measurements on the Lab View control panel were tared.
2. A ruler was used to measure the back plate distance
3. The compressor was set to roughly 600 RPM. At this point, dynometer force, HP, PT1, and PT2 were recorded.
4. Step three was repeated for RPM values of 1200 and 1800.
5. The compressor was then turned off and reset.
6. Steps 1-5 were then repeated for two other back plate distances.

# Results

For this experiment, pressure measurements at two separate points (P1 and P2), compressor shaft RPM measurements (N), and force measurements (Scale Reading) were collected for three separate back plate configurations. The static pressure and temperature of the room were also recorded, for use in finding the density of the air in Oliver Hall. Each pressure measurement (besides the static pressure of Oliver Hall) was recorded in inches of water, with the former being a measurement of the pressure difference between the atmosphere and the larger of the two tube diameters within the compressor, and the latter being a measurement of the pressure difference between the smaller of the two tube diameters within the compressor and the first pressure reading.

With these values collected, the shaft horse power of the compressor was calculated through the use of Equation (1) below:

(10)

This value, whose units were in horse power, was then converted to W through the use of Equation (11) below:

(11)

Once this was completed, the pressure values, which were recorded in inches of water, were converted to Pascals through the use of Equation (7) in Section (1), where is the density of water (1000 kg/m3), h is the height of the water in meters, and g is the acceleration of gravity (9.81 m/s2).

With all of these values calculated, the flow rate through the compressor was then found. This was accomplished by assuming a different Reynold’s Number for each RPM increment in each trial. Based on this Reynold’s Number, a coefficient of drag was calculated for each trial based on Equation (9) in Section (1), where β is given as 0.5 and L2, the location of PT2, is 0.5. The results of this work are listed in Table (1) on the following page.

This value was then used to calculate the volume flow rate through the compressor, as described in Equation (8) in Section (1), where A2 is the smallest area within the compressor, which was found to be 0.041 m2.

The Power Output of the compressor (Po) was then found by multiplying Q by P2. With all of these values calculated, the coefficients associated with the flow through the compressor were then found through the use of Equations (2-5) in Section (1), where µ is the kinematic viscosity of air, for which a value of 1.983 x 10-5 kg/ms was used. Once the Re of each trial was found, the initial Re used to calculated CD was changed until the two Re’s were reasonably close for each case (Within 1000 of each other). The final efficiency for each trial (η) was then found by dividing the output power by the input power.

Tables 4-1 through 4-3 list all of the data collected, used, and collected over the course of the experiment.

**Table 4-1. Shaft RPM, Force, Power, and Compressor Pressures**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Test No** | **N (RPM)** | **Back Plate Location (in)** | **Scale Reading** | **HP** | **PT1 (m)** | **PT2 (m)** |
| 1 | 631 | 3 | 0.5 | 0.078875 | 0.0089 | 0.0000 |
| 2 | 1204 | 3 | 1.75 | 0.52675 | 0.0356 | 0.0000 |
| 3 | 1823 | 3 | 3.9 | 1.777425 | 0.0978 | 0.0000 |
| 4 | 625 | 2 | 0.5 | 0.078125 | 0.0089 | 0.0025 |
| 5 | 1227 | 2 | 1.6 | 0.4908 | 0.0394 | 0.0127 |
| 6 | 1809 | 2 | 3.6 | 1.6281 | 0.0991 | 0.0330 |
| 7 | 625 | 1 | 0.1 | 0.015625 | 0.0089 | 0.0051 |
| 8 | 1286 | 1 | 1.3 | 0.41795 | 0.0432 | 0.0203 |
| 9 | 1812 | 1 | 2.5 | 1.1325 | 0.0914 | 0.0419 |

**Table 4-2. Room Pressure and Temperature, Density, Kinematic Viscosity, and Airflow Parameters**

|  |  |
| --- | --- |
| **Parameter** | **Value** |
| **Temp (K)** | 294.1 |
| **Static Pressure (Pa)** | 100250 |
| **Air Density (kg/m^3)** | 1.1877 |
| **Water Density (kg/m^3)** | 1000 |
| **μ (kg/m s)** | 0.00001983 |
| **A2 (m^2)** | 0.041 |
| **β** | 0.5 |
| **Re (N~600)** | 210000 |
| **Re2 (N~1200)** | 430000 |
| **Re3 (N~1800)** | 690000 |
| **Cd (N~600)** | 0.630 |
| **Cd2 (N~1200)** | 0.618 |
| **Cd3 (N~1800)** | 0.613 |

**Table 4-3. Airflow Coefficients for Each Back Plate Configuration**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Test No** | **Cw** | **Cp** | **Cq** | **Re** | **η** |
| 1 | 0.000375 | 0.0805 | 0.051 | 216041 | 0 |
| 2 | 0.000361 | 0.0884 | 0.053 | 423520 | 0 |
| 3 | 0.000351 | 0.1060 | 0.057 | 697223 | 0 |
| 4 | 0.000383 | 0.0820 | 0.052 | 216041 | 0.139 |
| 5 | 0.000318 | 0.0942 | 0.054 | 445632 | 0.227 |
| 6 | 0.000329 | 0.1091 | 0.058 | 701736 | 0.281 |
| 7 | 0.000077 | 0.0820 | 0.052 | 216041 | 1.385 |
| 8 | 0.000235 | 0.0941 | 0.054 | 466697 | 0.447 |
| 9 | 0.000228 | 0.1004 | 0.056 | 674206 | 0.492 |

# Discussion of Results

Based on the data listed in Tables 4-1 through 4-3, several different parameters were plotted with respect to Re for each back plate configuration. The first parameter that was plotted was that of the compressor efficiency, as shown in Figure 5-1 on the following page.

**Figure 5-1. Compression Efficiency vs. Re for Each Back Plate Configuration**

As can be seen in the above figure, as Re increases, so does the efficiency of the compressor. This is likely due to the reduced effect of viscosity at higher Re’s, meaning that the flow through the compressor is behaving more isentropic ally, and thus, more efficiently.

However, some discrepancies can be observed, mainly, for the lowest Re value on the X = 2 Inches plot, the efficiency actually exceeds 100%. This result most certainly arose from the mis-recording of the scale force associated with said trial (0.1 lbs for Trial 7, in comparison to 0.5 lbs for Trials 1 and 4). If this experiment were run again and a more accurate force measurement were made, the trend for the 2 inch case would have likely followed that of the 1 inch case.

A final flow characteristic to make note of from this figure is the behavior of the compressor when the back plate was located at 3 inches. In this configuration, the efficiency was zero in each trial. This indicates that absolutely no compression was occurring and that the compressor was essentially acting as an airflow accelerator.

The next parameter that was plotted was that of the power coefficient, as shown in Figure 5-2 on the following page.

**Figure 5-2. Power Coefficient vs. Re for Each Back Plate Configuration**

As can be observed from the figure, the power coefficient for each case tended to decrease slightly as Re increased, with the disclaimer that the first point in the 1 inch case be ignored due to the points raised in the previous paragraphs of this analysis. With this point being ignored, a decrease in the power coefficient over the Re range falls in line with the principal that for increased Re, viscosity effects decrease, meaning that the compressor has to do less work to accelerate the same amount of fluid, thus leading to the observed decrease in the power coefficient.

Figure 5-3 below plots the change in the coefficient of pressure with Re. As expected, for an increase in flow velocity (Re), an increase in CP was observed. This is due to the fact that for increased flow speeds, the air in the compressor has less time to react to the presence of the back plate at the end of the compressor. Thus, more particle collision occur between air molecules, increasing the dynamic pressure at a given point, which in turn increased the overall CP of the compressor itself.

**Figure 5-3. Pressure Coefficient vs. Re for Each Back Plate Configuration**

The final parameter that was plotted against Re was that of the flow coefficient. As discussed in the previous paragraph, any parameter associated with interaction between air molecules is expected to increase with airspeed. This prediction was verified by the results observed, as can be seen from Figure 5-4 below on the following page.

**Figure 5-4. Flow Coefficient vs. Reynold’s Number for Each Back Plate Configuration**

Finally, the accuracy of each of these results was calculated through an uncertainty analysis of all of the measurements made over the course of the experiment. Table 5-1 below lists the uncertainty values associated with the five measurements made within the lab, those of: pressure, diameter, temperature, force, and RPM.

**Table 5-1. Measurement Uncertainties**

|  |  |
| --- | --- |
| **Uncertainty** | **Value** |
| N (±RPM) | 0.5 |
| Scale Reading (±lb) | 0.05 |
| Pressure (±in) | 0.05 |
| Temperature (±F) | 0.5 |
| Diameter (±in) | 0.05 |

Based on these uncertainties, the uncertainty of each measurement made was found by dividing the uncertainty by the value associated with it. For example, for a recorded RPM of 631, the uncertainty of the measurement would be given by:

Thus, that particular measurement was certain within 3 decimal places of the result that was obtained. If a calculation involved the product or division of these uncertainty values, the total uncertainty of the calculation was found by multiplying the recorded value by the sum of the uncertainties of the values used in the calculation. For example, the uncertainty of calculating CW, which involves the use of pressure, density, N3, and D5 would be found by the following method:

This type of calculation was done for each value that was found in Table 4-3. The results of this are shown in Table 5-2 below:

**Table 5-2. Uncertainty of Each Measurement made for Each Trial**

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **N (± RPM)** | **Scale (± lbf)** | **HP (±hp)** | **Q (±m^3/s)** | **PT1 (± in h20)** | **Cw (±)** | **Cp (±)** | **Cq (±)** | **η (±)** | **Re (±)** |
| 0.00079 | 0.1000 | 0.0080 | 0.00048 | 0.0175 | 0.0000692 | 0.0034 | 0.00092 | 0 | 2503 |
| 0.00042 | 0.0286 | 0.0153 | 0.00187 | 0.07 | 0.0001066 | 0.0129 | 0.00100 | 0 | 5496 |
| 0.00027 | 0.0128 | 0.0233 | 0.00509 | 0.1925 | 0.0001923 | 0.0415 | 0.00126 | 0 | 11299 |
| 0.00080 | 0.1000 | 0.0079 | 0.00048 | 0.0175 | 0.0000705 | 0.0035 | 0.00093 | 0.000022 | 2503 |
| 0.00041 | 0.0313 | 0.0155 | 0.00207 | 0.0775 | 0.0000987 | 0.0152 | 0.00104 | 0.000071 | 5872 |
| 0.00028 | 0.0139 | 0.0231 | 0.00516 | 0.195 | 0.0001818 | 0.0432 | 0.00128 | 0.000129 | 11419 |
| 0.00080 | 0.5000 | 0.0078 | 0.00048 | 0.0175 | 0.0000141 | 0.0035 | 0.00093 | 0.000217 | 2503 |
| 0.00039 | 0.0385 | 0.0162 | 0.00227 | 0.085 | 0.0000767 | 0.0166 | 0.00105 | 0.000145 | 6243 |
| 0.00028 | 0.0200 | 0.0230 | 0.00476 | 0.18 | 0.0001190 | 0.0367 | 0.00121 | 0.000226 | 10703 |

From these results, an average uncertainty was found for each calculation, the results of which are shown in Table 5-3 below:

**Table 5-3. Average Uncertainty of Each Flow Parameter**

|  |  |
| --- | --- |
| **Parameter** | **Value** |
| Cw (±) | 0.0001032 |
| Cp (±) | 0.0196 |
| Cq (±) | 0.00107 |
| η (±) | 0.000090 |
| Re (±) | 6505 |

From this analysis, it can be seen that most of the calculations have a fair amount of certainty associated with them. In the case of the efficiency and power coefficient parameters, certainty can be assumed out to four and three decimal places respectively, while for the flow coefficient the same can be assumed out to two decimal places. For the coefficient of pressure, however, certainty is less assured, with the results only being accurate out to one decimal place. This is expected, however, since a fair amount of error is associated with recording values off of the labview pressure readers used during the lab. This particular error could be mitigated by taking multiple pressure readings at each RPM level and then taking the average of the result, using it in the same calculations used throughout this report.

This idea of taking multiple measurements at each point would likely improve the results attained from this lab considerably, since this method would likely cut down on the chances of a result such as the force value from Trial 7 being obtained. Other ways of improving the accuracy of the lab could arise from using physical pressure gauges, as opposed to digital ones. Large monometer tubes, though cumbersome, can achieve high accuracy if they are tilted at an angle and measurements are made directly from them. Such a measurement system, with more refined data increments, would likely lead to an observation of a pressure change in the first three trials, as would be expected, whereas during this lab, no such compression was observed.

With those improvements in mind, the data collected over the course of the lab was generally accurate, and the results obtained modeled what was to be expected of the behavior of air passing through a compressor at various speeds and exit areas, meaning that the lab can be considered a success.

# Conclusion

In this experiment measurements were taken to determine the performance of an axial compressor. Labview software was used to obtain readings for three different rotational speeds of the compressor (800, 1200, and 1600 rpms) at back plate locations of one, two, and three inches. The dynamometer readings that were obtained were used to determine power, pressure, and flow coefficients. In addition, Reynolds numbers were obtained. Plots were made of Reynolds number vs each of the coefficients. Increases in Reynolds numbers saw increases in the pressure coefficients and in the flow coefficients at each of the three distances. For the two and three inch back plate locations, the power coefficient tended to decrease slightly with increase in Reynolds number. (The back plate distance of one inch was felt to have spurious results due to inaccuracies in measurements, when the power coefficient was measured.)

Error analysis was done using percent uncertainty for five variables in the lab – rpm, scale reading, temperature, pressure, and diameter. These were then incorporated into the error analysis to obtain a +/- reading for each of the coefficients. The uncertainty of each of the coefficients ranged from a factor of 10 ^-2 to 10 ^-4. The Reynolds number had an uncertainty value of +/- 6505. However, this should be kept in context that Reynolds numbers are of the 10^5 range.

The objective of the experiment was meant in that it showed the performance characteristics of the single stage axial flow air compressor were quite good with the efficiency of the axial compressor having an uncertainty value of +/- 0 .000090.