Sydney

School of Mechanical and Manufacturing Engineering

AERO3630 - Aerodynamics

Term 1 - 2020

Lab Report:
Compressible Flow Through a Nozzle

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Abstract

In this laboratory, the performance of pressure in different specific location with different air speeds are investigated. Eventually 3 relational diagrams have been drawn, and which corresponded to the initial expected or calculated results.

Contents

Chapter 1

Introduction

The compressible flow through a nozzle experiment gives students deeper understanding about how air will perform in a high speed situation, and this experiment also solidates students' perceptive about real world applications, for example, the after burner applied by the fighter jet are the advanced version of the converging-diverging nozzle that has been discussed in this experiment.

Chapter 2

Theory

- Ideal Gas Law

$$PV = mRT \tag{2.1}$$
$$P = \rho RT \tag{2.2}$$
$$\rho = \frac{P}{RT} \tag{2.3}$$

Where P is pressure, $R = 287(J.K^{-1}kg^{-1})$ is gas constant for air, T is temperature in Kelvin.

- Dynamic Pressure

$$P_{Dynamic} = P_{Total} - P_{Static} \tag{2.4}$$

- Mach Number and Pressure Ratio

$$\frac{P_0}{P_6} = (1 + \frac{\gamma - 1}{2}M^2)^{\frac{\gamma}{\gamma-1}} \tag{2.5}$$
$$\frac{P_0}{P_6}^{\frac{\gamma-1}{\gamma}} = (1 + \frac{\gamma - 1}{2}M^2) \tag{2.6}$$
$$\frac{\gamma - 1}{2}M^2 = \frac{P_0}{P_6}^{\frac{\gamma-1}{\gamma}} - 1 \tag{2.7}$$
$$M^2 = \frac{2}{\gamma - 1}\frac{P_0}{P_6}^{\frac{\gamma-1}{\gamma}} - 1 \tag{2.8}$$
$$M = \sqrt{\frac{2}{\gamma - 1}\frac{P_0}{P_6}^{\frac{\gamma-1}{\gamma}} - 1} \tag{2.9}$$

Chapter 3

Results

Detailed calculations, data sets and figures have been attached in appendix A.1.

Chapter 4

Discussion

Based on mass and momentum conservation equations, the relationship between area and velocity can be derived as, $\frac{dA}{A} = (M^2 - 1)\frac{du}{u}$. This relationship is depends on the Mach number, in this case, Mach number is general greater than 0.3 but lower than 1 at exit position as indicated in table A.5, hence the converging-diverging nozzle is in the subsonic condition, and also area and velocity are inversely proportional to each other as M is smaller than 1. Due to Bernoulli's principle, velocity is inversely proportional to pressure. Hence, smaller area will results higher velocity, and lower pressure, in particular, maximum velocity and minimum pressure will occur at P_1 (throat), as where has the minimum area. The data in the table A.4 harmonise with this relationship, as the area increase, the pressure also increase for the same rotational fan speed. This relationship is also true for the situation of fixed location but different rotational fan speed, as pressure is dropped correspondingly as fan speed or velocity increased.

If the fan speed significantly increases to 40000 RPM, the inlet velocity can be calculated as 71.2m/s by $v = r\omega$, the estimation is that the supersonic situation will be occurred near the exit for Mach number is greater than 1. which gives the proportional relationship between area and velocity. This means the pressure will decrease as x progress. Ultimately, pressure versus x position diagram will be illustrated by the inverse proportional curve.

There might have some errors exist in the experiment, which can be improved in order to obtained better or more accurate results. For example, systematic error can be occurred as the reading on the control box is floating on random numbers, the recorded data might not be accurate enough, which can leads to the generation of errors. Also, the human error can be aroused as operator might not connected the pressure tap perfectly and closely with the converging and diverging nozzle, results in pressure leak, and hence the inaccurate results. These errors can be improved by recording several floating data at a time, and record the mean or median values into the result. What's more, do the pre -experimental check regarding accuracy and reliability of the machine, and check the connections frequently during the experiment.

Chapter 5

Conclusion

In conclusion, the experimental calculations have been successfully transformed into the formation of relationships, and which became clear and apparent figures for easier understanding, the experimental relationships also have been successfully proposed through figures by Matlab, eventually detailed discussions have been created based on the existence of errors during the experiment. Overall,this can be considered as an accurate and successful reports.

References

[1] UNSW. (). Compressible flow experiment data. Visited on 23/04/2020, [Online]. Available: https://moodle.telt.unsw.edu.au/mod/folder/view.php?id=2855505.

Appendix A

Appendices

A.1 Detailed Results for Compressible Flow Through a Nozzle Experiment

A.1.1 Calculations for Compressible Flow Through a Nozzle Experiment

Given:

$$T = 22°C = 295.15K \tag{A.1}$$

$$P_{atm} = 103200Pa \tag{A.2}$$

For calculating ρ_{atm}:

$$PV = mRT \tag{A.3}$$

$$P = \rho RT \tag{A.4}$$

$$\rho = \frac{P}{RT} \tag{A.5}$$

$$\rho = \frac{103200}{287 \times 295.15} \tag{A.6}$$

$$\rho = 1.218kg/m^3 \tag{A.7}$$

Static Pressure is recorded by reading the value from the control box, hence P_n is asking dynamic pressure, For example, location 1 at 10000RPM:

$$P_{atm} - P_{1,dynamic} = P_{1,static} \tag{A.8}$$

$$P_{atm} - P_{1,static} = P_{1,dynamic} \tag{A.9}$$

$$P_1 = 1.032 - 0.24 \tag{A.10}$$

$$P_1 = 0.792bar \tag{A.11}$$

For calculating the critical pressure in a nozzle flow for air, given $\gamma = 1.4$:

$$P_{cr} = P_{atm}(\frac{2}{\gamma+1})^{\frac{\gamma}{\gamma-1}} \quad \text{(A.12)}$$

$$P_{cr} = 103200(\frac{2}{1.4+1})^{\frac{1.4}{1.4-1}} \quad \text{(A.13)}$$

$$P_{cr} = 54518.68Pa \quad \text{(A.14)}$$

For calculating the mach number at position 6:

$$M = \sqrt{\frac{2}{\gamma-1}\frac{P_0}{P_6}^{\frac{\gamma-1}{\gamma}} - 1} \quad \text{(A.15)}$$

$$M = \sqrt{\frac{2}{1.4-1}\frac{1.032}{0.995}^{\frac{1.4-1}{1.4}} - 1} \quad \text{(A.16)}$$

$$M = 0.229 \quad \text{(A.17)}$$

A.1.2 Data sets for Compressible Flow Through a Nozzle Experiment

Table A.1: Atmospheric Data for Compressible Flow Experiment

T	22	$°C$	T	295.15	K
P_{atm}	103200	Pa	ρ_{atm}	1.218	$kg.m^{-3}$

Table A.2: Experimental Data for Compressible Flow Experiment

$n(RPM)$	$U(m/s)$	$P_{atm}-P_1(bar)$	$P_{atm}-P_2(bar)$	$P_{atm}-P_3(bar)$	$P_{atm}-P_4(bar)$	$P_{atm}-P_5(bar)$	$P_{atm}-P_6(bar)$
10000	21.4	0.24	0.12	0.07	0.052	0.042	0.037
15000	25	0.433	0.231	0.144	0.109	0.093	0.087
20000	25.3	0.465	0.339	0.225	0.178	0.158	0.153
23000	25.3	0.468	0.441	0.283	0.228	0.206	0.202
Max:24350	25.3	0.469	0.478	0.309	0.249	0.259	0.222

Table A.3: General Information about Converging-Diverging Nozzle

Corresponded Position	$P_0(atm)$	$P_1(Throat)$	$P2$	$P3$	$P4$	$P5$	$P_6(Exit)$
Axial Position(mm)	0	33	54	78	114	168	200
Diameter(mm)	34	12	14.2	17.6	22.6	30.2	34
Area(mm^2)	907.9202769	113.0973355	158.3676857	243.2849351	401.1499659	716.3145409	907.9202769

Table A.4: Modified Experimental Data for Compressible Flow Experiment

$n(RPM)$	$U(m/s)$	$P_1(bar)$	$P_2(bar)$	$P_3(bar)$	$P_4(bar)$	$P_5(bar)$	$P_6(bar)$
10000	21.4	0.792	0.912	0.962	0.98	0.99	0.995
15000	25	0.599	0.801	0.888	0.923	0.939	0.945
20000	25.3	0.567	0.693	0.807	0.854	0.874	0.879
23000	25.3	0.564	0.591	0.749	0.804	0.826	0.83
Max:24350	25.3	0.563	0.554	0.723	0.783	0.773	0.81

Table A.5: Mach Number at Position 6 (Exit) for Different Rotational Fan Speed

n(RPM)	Mach Number at Position 6 (Exit)
10000	0.228980071
15000	0.356944158
20000	0.484332434
23000	0.566631062
Max:24350	0.598567244

A.1.3 Figures for Compressible Flow Through a Nozzle Experiment

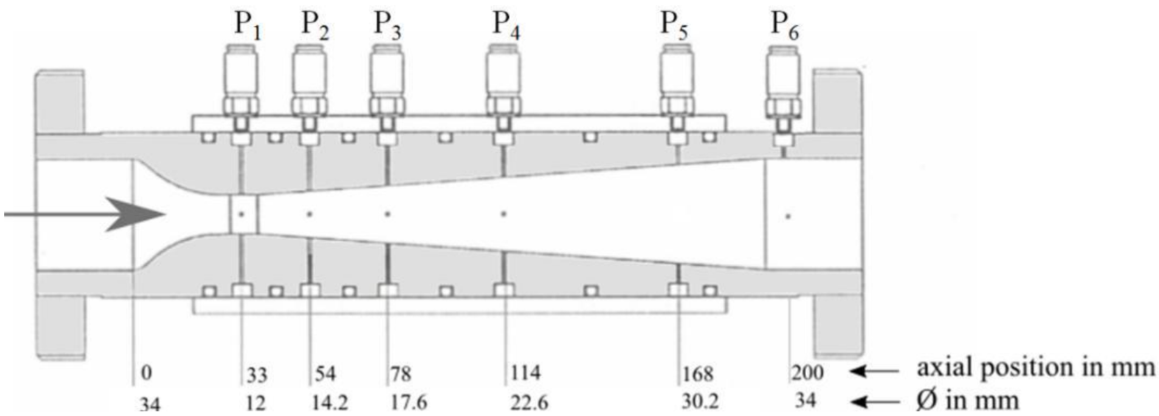

Figure A.1: Schematic of Converging-Diverging Nozzle, Credit from [1]

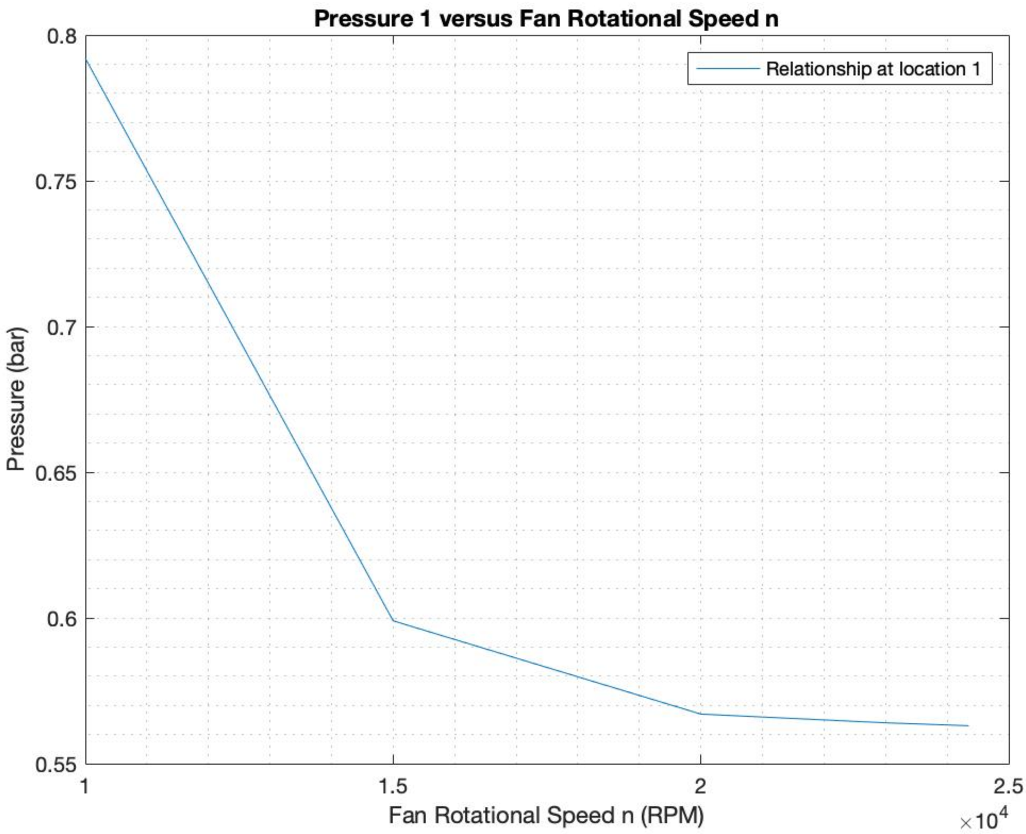

Figure A.2: Pressure at Position 1 versus Rotational Fan Speed n

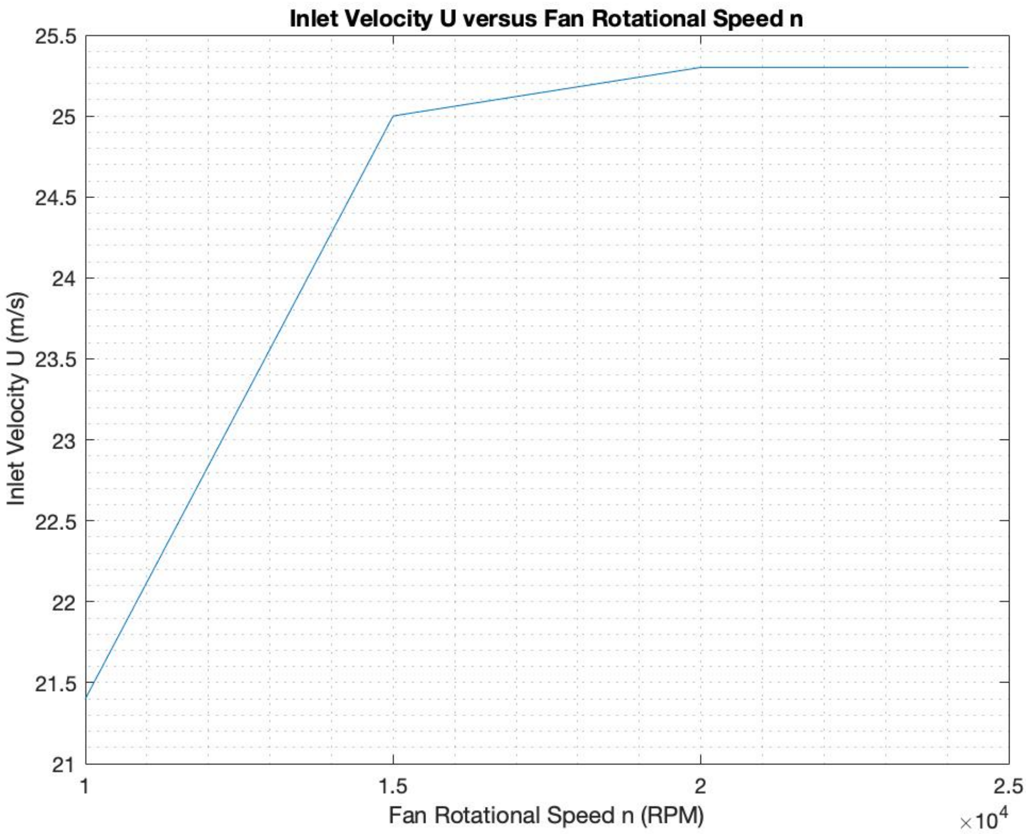

Figure A.3: Inlet Speed U versus Rotational Fan Speed n

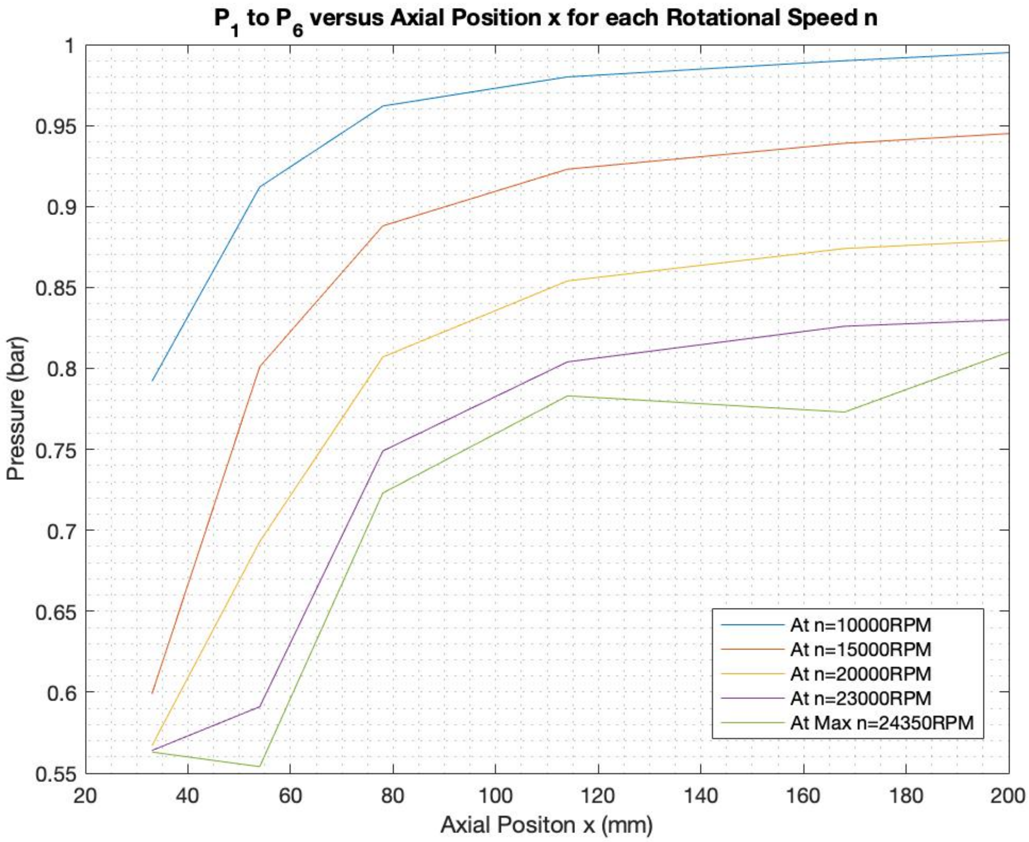

Figure A.4: Pressure versus Axial Position x at Varies Locations for Different n