Indian Institute Of Technology Kanpur

AE 351A

Experiments in Aerospace Engineering 2020-21

Semester II

Experiment 4

Calibration of Supersonic Wind Tunnel

Submitted By:

Ankit Lakhiwal

180102

(ankitl@iitk.ac.in)

Department of Aerospace Engineering

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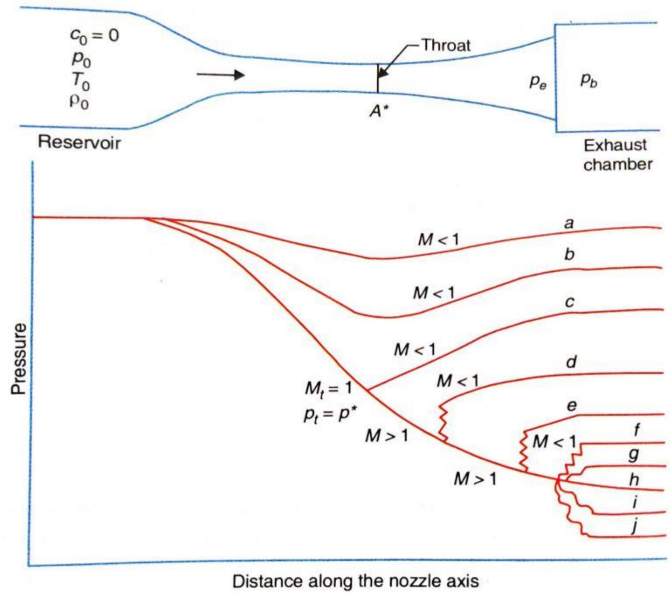
1. **Objective**

To compare and study the actual and isentropic Mach number distribution along the length of the contour provided.

2. **Formulae and Theory**



Equation 1

$$\frac{P_o}{P} = \left[1 + \frac{\gamma-1}{2} M^2\right]^{\frac{\gamma}{\gamma-1}}$$

Equation 2

$$A/A^* = \frac{1}{M}\left[\frac{2}{\gamma+1}\left(1 + \frac{\gamma-1}{2} M^2\right)\right]^{\frac{\gamma+1}{2(\gamma-1)}}$$

3. **Equipments'**

a) **Wind-Tunnel Setup**

This is an open-circuit blow-down type supersonic wind tunnel with no diffuser. The integral parts of the wind tunnel are shown in the figure below.

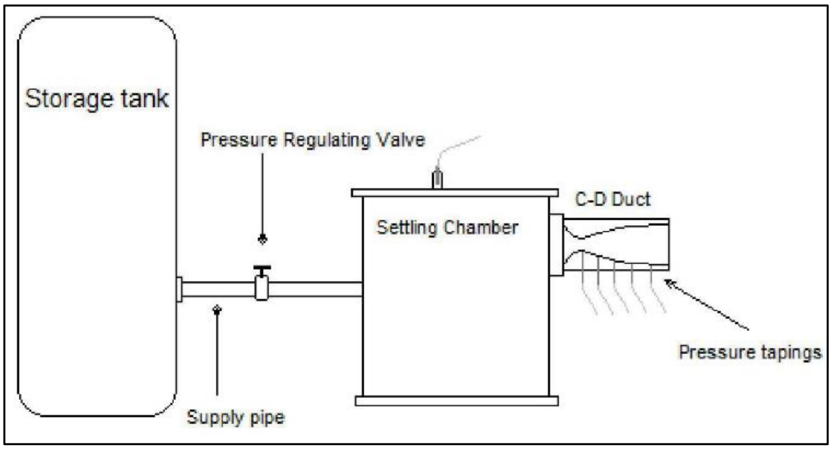


Figure 1 Wind Tunnel Setup

b) Storage Tank

It is a high-pressure tank used to store large volume of high-pressure air. It supplies high-pressure air continuously to run the wind tunnel. Usually the tank is kept at a safe distance outside the lab. In our facility, the storage tank can be pressurized up to a safe limit of 200 psi.

c) Supply pipe

It supplies air from storage tank to the settling chamber. It should be able to provide the required mass flow rate with minimum pressure loss.

d) Pressure Regulating Valve

This valve regulates the pressure required to operate the wind tunnel. Schematic diagram of a simple pressure regulating valve is show below.

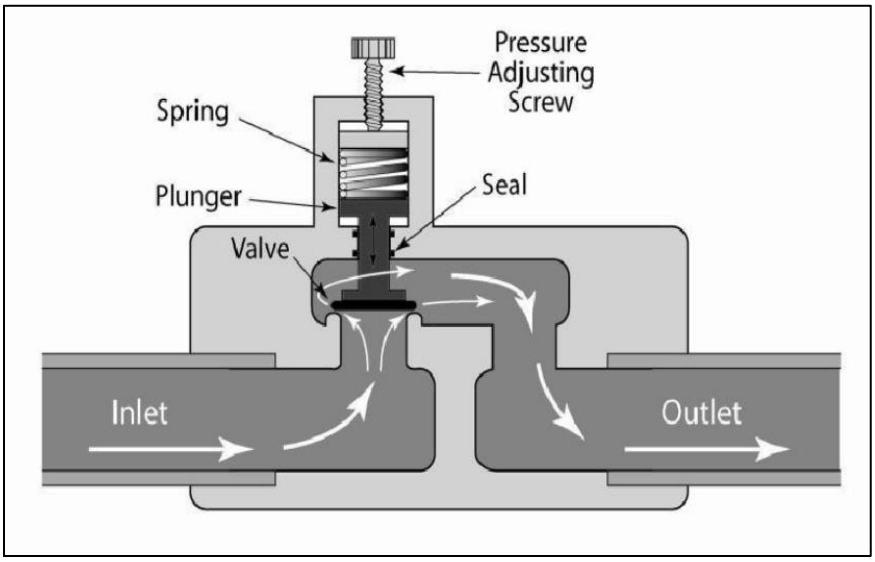


Figure 2 Pressure Regulating Valve

e) Settling Chamber

It settles down the pressure oscillations and perturbations from the upstream and provides steady downstream conditions for the operation of wind tunnel. In our facility, the chamber pressure is maintained within the safe pressure limit of 60 psi.

f) Convergent-Divergent Duct (C-D Duct)

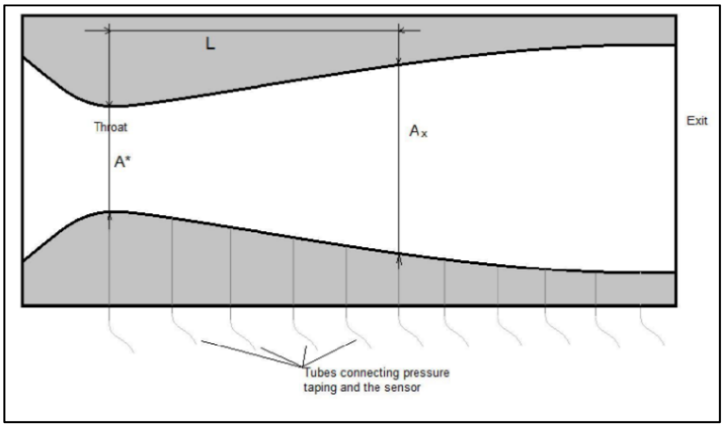


Figure 3 C-D Duct

Figure 4 C-D duct with Pressure Ports

g) Pressure Ports

There is a port at the settling chamber to measure the settling chamber pressure P sc which can be approximated to P 0 (total pressure) of the flow. As discussed in the C-D Duct, there are pressure tapings along the tunnel contour from throat to the exit. They give static pressures along the contour.

h) Pressure Sensor

The pressure sensor used in our experiment (Pressure scanner 9016) can measure up to 100 psi from 16 ports simultaneously at the rate of 1000 samples per second. It uses 16 silicon piezo-resistive pressure sensors to sense the pressure data. The data is transferred to the computer via ethernet cable. The data is then analyzed and stored using LabVIEW program.

4. **Precautions**

a) Do not exceed the pressure limits of the settling chamber.

b) Make sure that there are no loose parts and there are no objects placed inside the duct.

c) Make sure that the pressure ports are not blocked by dust or any other material.

5. **Procedure and Measurements**

a) Familiarize with the major components of the wind tunnel setup.

b) Familiarize with the principles of how the data is acquired and reduced to required values. Slowly open the pressure regulating valve till the flow is completely supersonic inside the wind tunnel.

c) Using LabView program take pressure (guage) measurements of the settling chamber and along the contour of the tunnel.

d) Convert the obtained pressure values to absolute pressure.

e) Using 2nd formula, find the actual Mach numbers (M_{ac}) at the location of the pressure ports with $P_0 \approx P_{sc}$ and P_x values.

f) Measure the location of the pressure ports from throat and also find the cross section at the same location for the tunnel contour used. From the area ratios at different locations of the contour $(A/A^*)_x$ find the isentropic Mach number M_{isen} for that area ratio from the 1st formula.

g) Wind tunnel dimension and Pressure port position

Cross section height at port (Ax) in cm	Pressure port distance from throat (L) in cm
26.78	0
29.01	1
67.21	3.2
79.05	5.3
85.46	9.8
87.09	14.2
88.27	16.5
88.51	17.1
88.79	18.1
89.01	18.7
89.47	19.3
89.87	19.9
89.98	20.5
90.25	21.1

90.45	22.1

Table 1 Wind Tunnel data

Wind tunnel test section top and bottom width = 25cm

Atmospheric pressure = 29.9192 Inches of Hg

	Po(in-Hg)	**64.29847458**		Po	**84.502111**
x(cm)	P	Po/P		P	Po/P
0	4.152350282	15.48483875		11.39683333	7.414525477
1	-15.1939322	-4.231852144		-11.92861111	-7.083985749
3.2	-17.63824294	-3.645401348		-14.75572222	-5.726735014
5.3	-14.25226554	-4.5114564		-15.14166667	-5.580766832
9.8	-4.845638418	-13.2693505		-6.133888889	-13.77627027
14.2	-8.25099435	-7.792815247		-7.920555556	-10.66871011
16.5	-6.249	-10.28940224		-18.95955556	-4.456966877
17.1	-1.764887006	-36.432063		-4.916444444	-17.1876469
18.1	-3.629700565	-17.71453965		-5.877611111	-14.37694831
18.7	-3.744067797	-17.17342689		-6.673333333	-12.66265401
19.3	-0.370141243	-173.7133481		-5.2865	-15.98450981
19.9	-0.93819774	-68.53403267		-4.758111111	-17.75959181
20.5	-1.095355932	-58.70098722		-4.936555556	-17.11762587
21.1	-1.045683616	-61.48941573		-4.125944444	-20.48067109
22.1	-0.354389831	-181.4343106		-4.326	-19.53354395

Table 2 Pressure ports Data at different Pressure condition

6. **Calculation**

Calculation for 64 Inches of Hg data at pressure port distance 5.3cm

P0(aquired) = 64.29847458 in-Hg

P0 = Patm + P0(aquired)

= 29.9192 + 64.29847458 = 94.21967458 in-Hg

P1 = Patm + P1(aquired)

= 29.9192 + (-14.25226554) = 12.28295706 in-Hg

using equation 1

M actual = 1.829691965

and by using equation 2

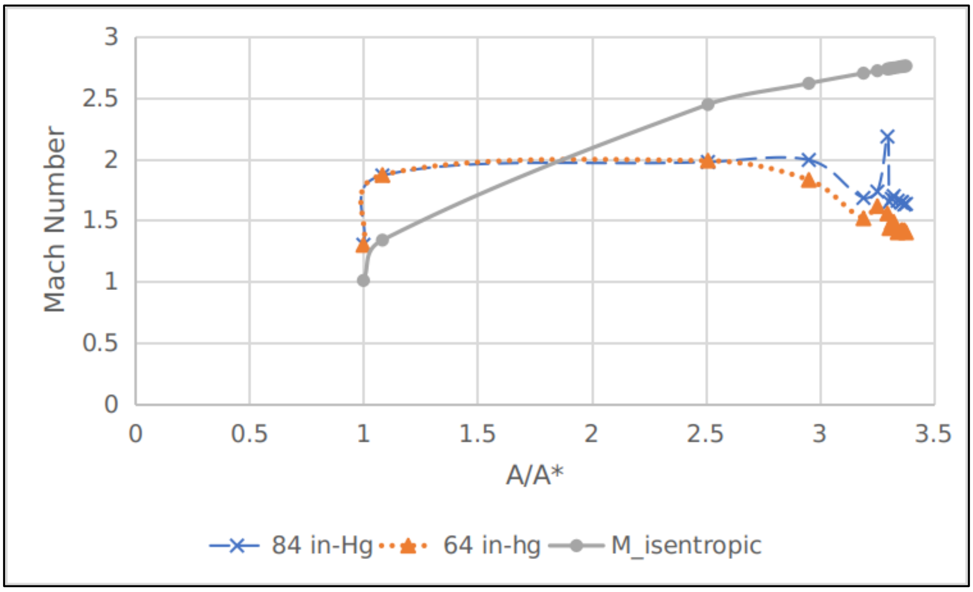
M isentrop = 2.62

Calculation for 84 inches of Hg data is same as above.

7. Results

A/A*	M (64 in-Hg)	M (84 in-Hg)	M isentropic
1	1.298523169	1.299624976	1.008
1.083271098	1.87000397	1.866119341	1.338
2.509708738	1.987243025	1.976603402	2.447
2.951829724	1.829691965	1.993189656	2.62
3.191187453	1.51603028	1.682869717	2.703
3.252053771	1.615281817	1.734571146	2.723
3.296116505	1.555453425	2.184625737	2.737
3.305078417	1.435503609	1.64959078	2.74
3.315533981	1.483331546	1.675740864	2.743
3.323749066	1.4863534	1.698101924	2.746
3.340926064	1.401359029	1.659551754	2.751
3.355862584	1.415109106	1.645368465	2.756
3.359970127	1.418950505	1.650128771	2.757
3.370052278	1.417734592	1.628739402	2.76
3.377520538	1.400980712	1.633962858	2.762

Table 3 Mach no. and Area Ratio Data



Graph 1 M vs A/A*

8. **Error Analysis and Discussion**

a) **Source of Error**

i. Error during measuring the dimension of wind tunnel

ii. Pressure port malfunctioning

iii. Error during aquiring data from pressure ports

b) **Conclusion**

i. Due to Oblique shock, Mach No. decreases at Area ratio 3.19(Port 5) from the duct throat.

ii. Total stagnation pressure increases can lead to hIgher exit velocity

9. **References**

a) Alan Pope, “Wind Tunnel Calibration Techniques” NATO Advisory Group for Aeronautical Research and Development, April 1961.

b) J. D. Anderson, “Modern Compressible Flow: With Historical Perspective (Second Edition)” Mc-Graw Hill International Publications, 1990.