Experiment 4
Calibration of Supersonic Wind Tunnel

List of Symbols:

L (L1, L2…)	Distance from throat (for locations 1, 2, …)
A_X	Cross sectional area at location X (e.g. 1, 2, …)
A*	Cross sectional area at throat
M	Mach number
M_{ac}	Actual Mach number
M_{isen}	Isentropic Mach number
P_0	Total pressure
P_{sc}	Settling chamber pressure
P_X	Pressure at location X
γ	Specific heat ratio of air

Formulas:

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

2.)
$$\frac{P_0}{P} = \left[1+\frac{\gamma-1}{2}M^2\right]^{\frac{\gamma}{\gamma-1}}$$

Objective:

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

Apparatus:

1) 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.

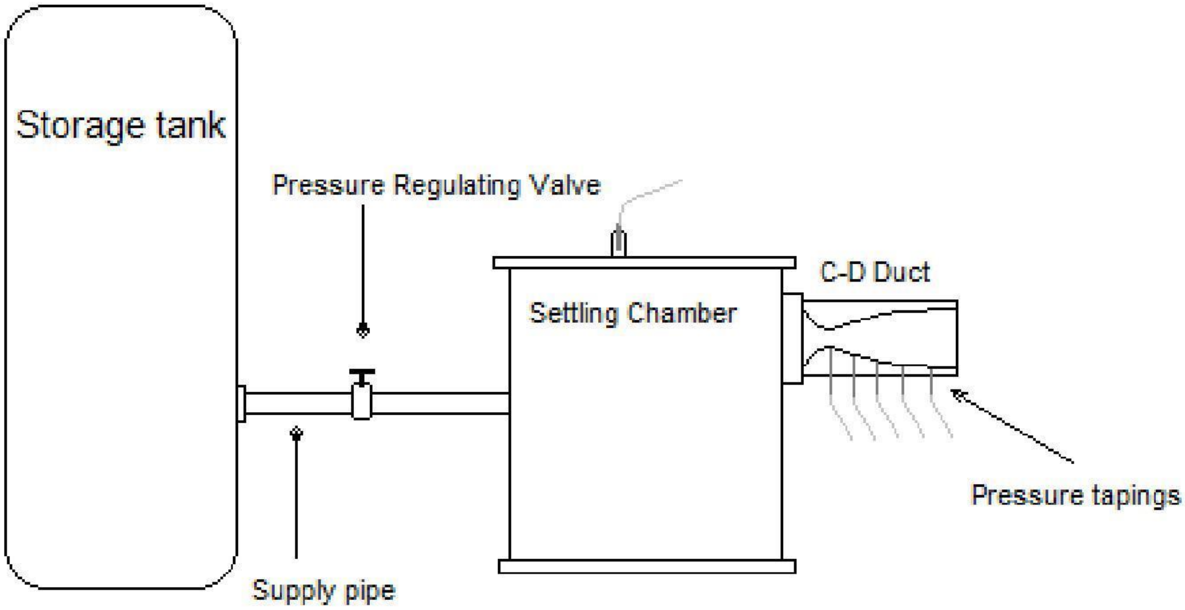


Figure 1: Wind tunnel Setup

a) 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.

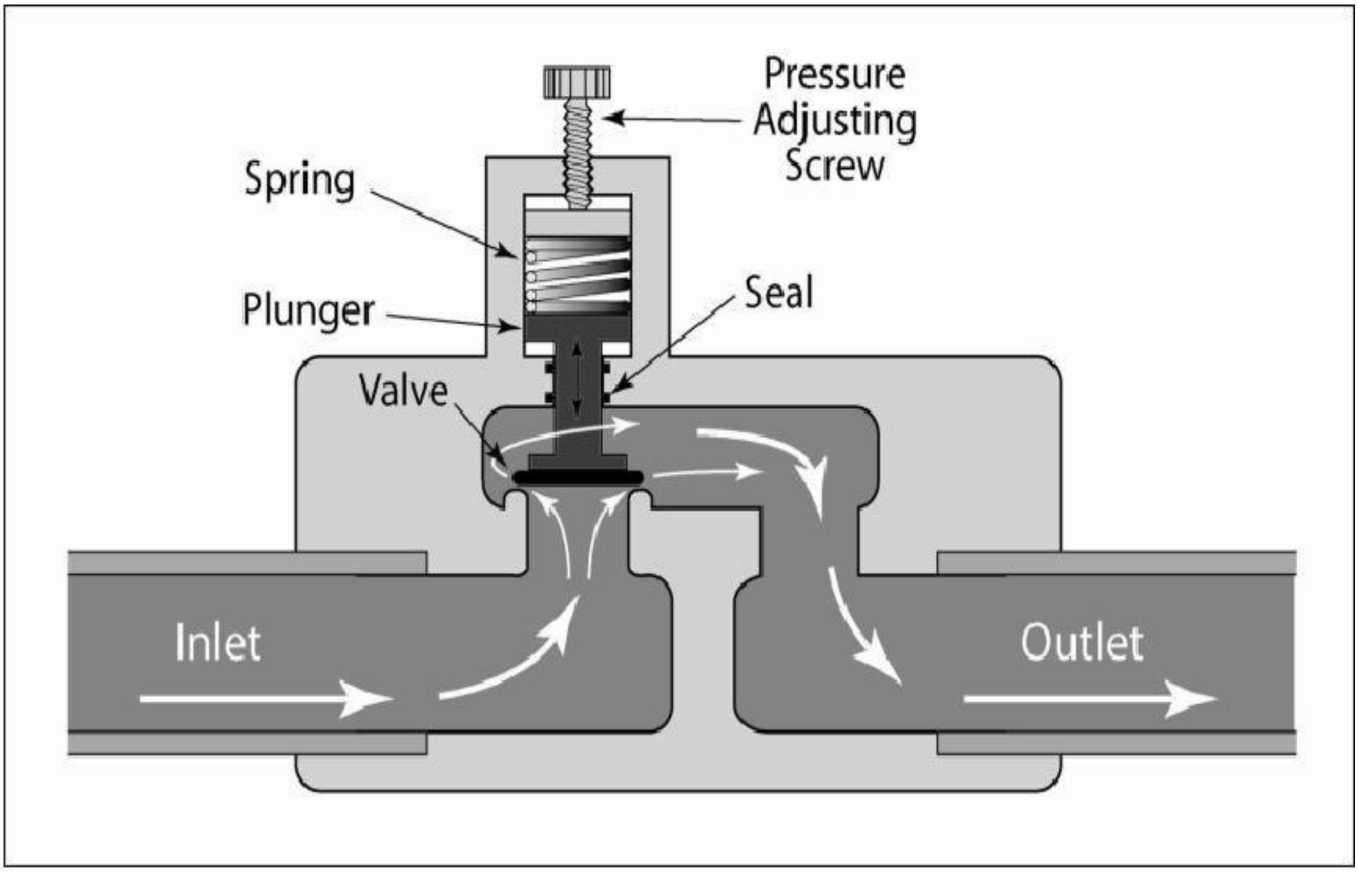
b) Supply pipe:

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.

c) 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



d) 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.

e) Convergent-Divergent Duct (C-D Duct):

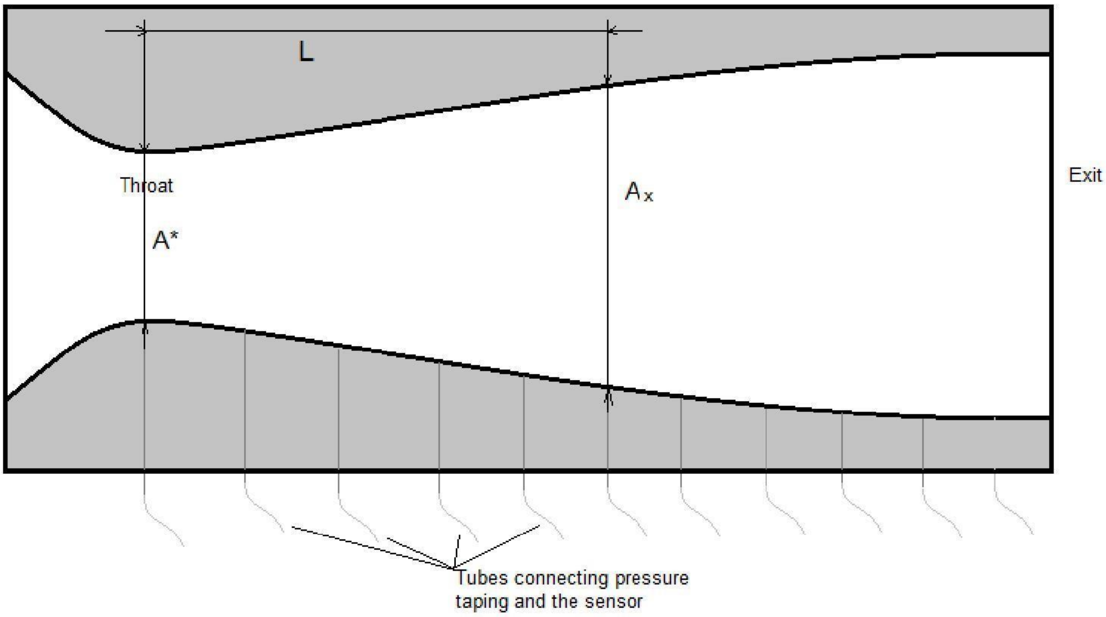


Figure 3: Convergent-Divergent Duct.

It is a varying area duct of rectangular cross section made of plexiglas sheets. The side walls of the duct are 25 mm apart. The top and bottom walls are contoured for varying area ratios (*A/A**) which expand the flow to the required test section Mach number. Since the Mach number is a function of area ratio in the duct, to obtain different test section Mach numbers different contours could be used.

There are tiny holes drilled at particular locations along the contour to measure the local static pressure. The static pressure (P_X) thus obtained along with the settling chamber pressure (P_{SC}) gives the local Mach number (using 2^{nd} formula). This is the actual Mach number M_{ac} at that location.

The test piece or the model can be kept just before the duct exit where the area remains almost constant. Since there is no diffuser after the test section the achievable Mach numbers are less than that could be achieved with diffuser.

f) 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.

2) 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.

Precautions:

Do not exceed the pressure limits of the settling chamber.

Make sure that there are no loose parts and there are no objects placed inside the duct.
Make sure that the pressure ports are not blocked by dust or any other material.

Procedure:

Familiarize with the major components of the wind tunnel setup.

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.

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

Convert the obtained pressure values to absolute pressure.
Using 2^{nd} 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.

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.

Results and Discussion:

i) Plot and Discuss M_{ac} vs. A/A^* for locations along the contour.
ii) Compare and discuss Isentropic Mach number (M_{isen}) distribution and actual Mach number (M_{ac}) distribution along the length of the duct.
iii) Discuss what you have understood from this experiment.

References:

i) Alan Pope, "*Wind Tunnel Calibration Techniques*" NATO Advisory Group for Aeronautical Research and Development, April 1961.
ii) J. D. Anderson, "*Modern Compressible Flow: With Historical Perspective (Second Edition)*" Mc-Graw Hill International Publications, 1990.

With reference to Figure 3.

S.no.	Cross section height at port (A_x) in cm	Pressure port distance from throat (L) in cm
1	26.78	0
2	29.01	1
3	67.21	3.2
4	79.05	5.3
5	85.46	9.8
6	87.09	14.2
7	88.27	16.5
8	88.51	17.1
9	88.79	18.1
10	89.01	18.7
11	89.47	19.3
12	89.87	19.9
13	89.98	20.5
14	90.25	21.1
15	90.45	22.1