AE 351

EXPERIMENTS IN AEROSPACE ENGINEERING II

Propulsion Laboratory

List of experiments

1. Study and calibration of Pressure Sensor and Flow meters
2. Experimental investigations in LPG-Air premixed flames
3. High Speed Flow Visualization using Shadowgraph and Schlieren Technique
4. Calibration of Supersonic Wind Tunnel

Experiment 1

Study and calibration of Pressure sensor and Flow meter

List of symbols

P_1 Upstream Pressure (just before Flow meter)
P_2 Downstream Pressure (After Flow meter)
C_d Coefficient of Discharge
P_{atm} Atmospheric Pressure (N/m^2)
P_0 Total Pressure in flow (N/m^2)
P_{static} Static Pressure in flow (N/m^2)
$\dot{m}$ Mass Flow rate (Kg/s)

1. Objective

To study different types pressure sensor and flow meter, and to

1. Calibrate the Differential Pressure sensor.
2. Characterize the different flow meters (Orifice, Nozzle, and Venturi).

2. Apparatus

1. **Experimental Setup:** The open-circuit low speed wind tunnel consists of a centrifugal blower driven by an electric motor. The blower draws in air from the atmosphere and discharges through the pipe. The butterfly valve located downstream of the blower is used to control the mass flow rate. The flow meters are fixed downstream of the valve in the order as shown in the figure. The velocity profile is determined at the exit, which is used for calculating the mass flow rate.

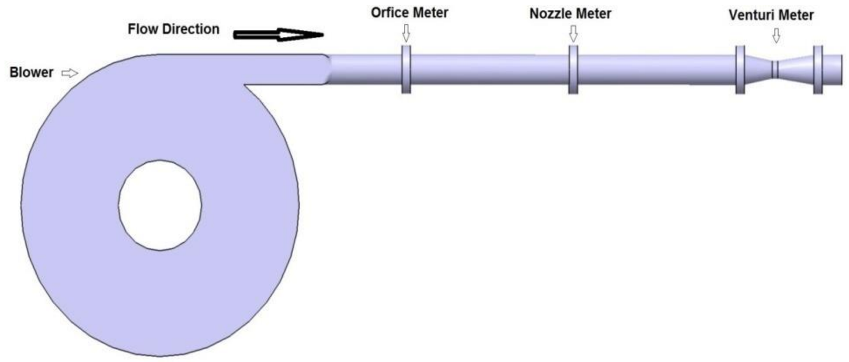
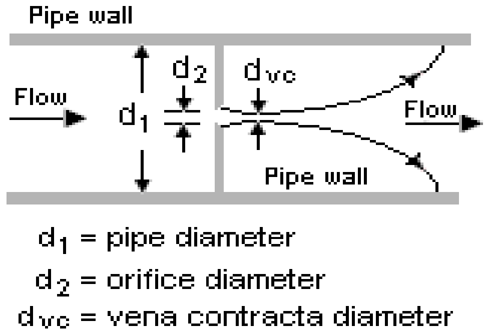


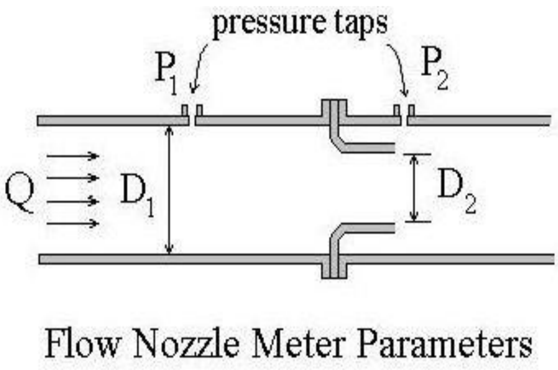
FIG 1: Schematic of Experimental setup

2. **Differential Pressure sensor:** An electronic differential pressure sensor is used to determine the pressure drop across flow-meters. An electronic differential pressure sends an electronic signal (DC voltage) based on the pressure difference between the two ports connected to it. For the present experiment one sensor of 0 to 7.25 psi range, three sensors of 0 to 14.5 psi range is used.

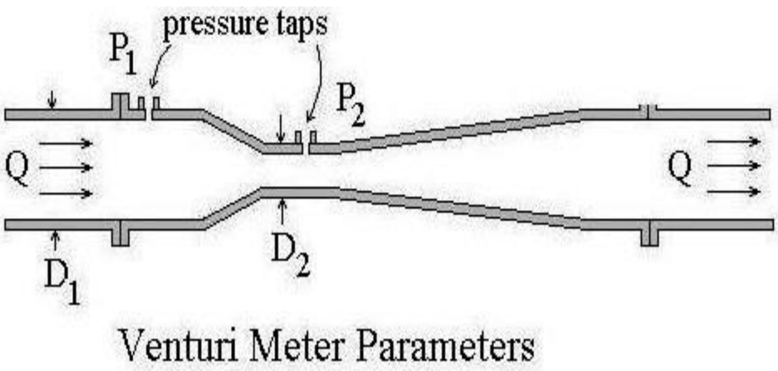
3. Flow meter and Pitot Probe



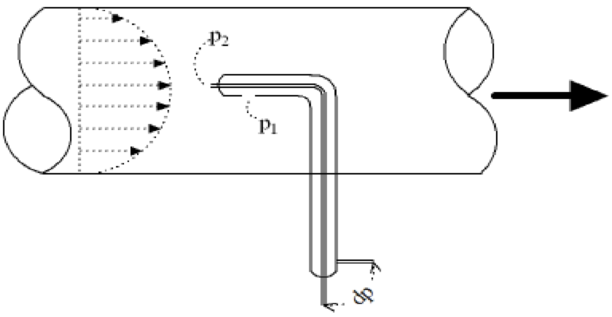
Orifice Meter



Nozzle meter



Venturi Meter



Pitot Probe

4. Precautions

1. The pressure applied to the sensor should be within the range specified on the sensor.
2. Ensure sufficient time for the pressure to stabilize after repositioning the probe at each point.
3. Make sure that, there are no blockages in the pipes.
4. Align the pitot probe parallel to the flow.
5. Do not block the flow at the exit, during data acquisition.

5. Procedure

1. Familiarize with the basic principles of Data Acquisition.
2. Note down the ambient temperature and pressure.
3. Calibration of Pressure sensor:

a) Connect the high pressure port of pressure sensor to the calibrator via T-joint and leave the other port of the pressure sensor open to the atmosphere.

b) Obtain the output voltage from the sensor at different pressures applied using the hand pump.

c) Using the acquired data, find the best fit curve (One degree in single variable), which defines the calibration equation for the sensor.

4. Calibration of Flow meter:

a) Connect the pressure taps of flow meters to the pressure sensors using rubber tubes.

b) Switch on the tunnel and set the mass flow rate using the butterfly valve.

c) After steady state is reached, obtain the pressure data from the sensors.

d) Traverse the pitot probe vertically, to determine the velocity profile across the cross-section of the pipe. Use this profile to determine the mass flow rate of air in the pipe.

e) Repeat the above two steps for different flow rates.

6. Performance Parameters

1. Coefficient of Discharge $C_d = \frac{\dot{m}}{\dot{m}_{the}}$

2. Theoretical Mass flow rate $\dot{m}_{the} = \sqrt{\frac{2\rho\Delta P}{\frac{1}{A^2{}_2} - \frac{1}{A^2{}_1}}}$

3. Flow Velocity $V = \sqrt{\frac{2(P_0 - P_{static})}{\rho}}$

7. Error Analysis

Error in Measurement: The error in measurement can be classified as

a) Systematic Error: These arise use to faulty or improperly calibration of instruments or some other known reasons. This can be eliminated by proper calibration of instruments or rectifying the fault. This defines the accuracy of the measurement made. Less the bias, more is the accuracy. These are biased in nature.

b) Random Error: These occur due to the natural disturbances that occur during the measurement process. These cannot be eliminated. This defines the precision of the measurement made. These are statistical in nature.

The systematic error can be eliminated after rectifying the problem.
The random error can be eliminated by statistical analysis

Statistical analysis of the data

1. Sample Mean $\overline{X} = \frac{\sum_{i=1}^{N} X_i}{N}$

2. Sample Variance $\sigma^2 = \frac{\sum_{i=1}^{N}(X_i - \bar{X})^2}{N}$

3. Sample Standard Deviation is σ

4. For the normal distribution the confidence of the estimate is defined using the standard deviation using the below table.

Confidence level	0	0.95	0.99	0.999
Interval	0	$\pm 1.96\sigma$	$\pm 2.58\sigma$	$\pm 3.29\sigma$

8. Results and Discussions

1. Explain difference between Absolute Pressure, Gauge Pressure and Differential Pressure.
2. Explain difference between Piezoresisitive strain, Capacitive, Electromagnetic, Piezoelectric, Optical, pressure sensing technology.
3. Explain in brief about Orifice meter, Nozzle meter, Venturi meter, Pitot probe.
4. Plot the data points and the calibration equation for all the sensors indicating the equations representing them.
5. Plot the variation of C_d with $\dot{m}$ and pressure drop, across flow meter in the same plot. Use different plots for different flow meter.
6. Plot the velocity profile at the exit of Pipe.
7. Comment on the nature of the results and explain inconsistencies, if any.

Appendix:

Dimensions of Flow Meter

	Orifice	Nozzle	Venturi	
			Outer Dia	Throat Dia
Diameter	50mm	48mm	82.61mm	43.4mm

Experiment 2

Experimental investigations on premixed LPG-air flame

LIST OF SYMBOLS:

ϕ - Equivalence Ratio.

R - Universal Gas Constant.(J/kg.K)

$\dot{Q}_{actual}$ - Actual Flow rate. (m^3/s)

$\dot{Q}_{indicated}$ - Indicated Flow rate. (LPM)

ρ_{actual} - Density of metered fluid medium. (kg/m^3)

ρ_{scale} - Density of air medium in rotameter. (kg/m^3)

P_{guage} - Control line supply pressure.(psi)

P_{atm} - Local atmospheric pressure noted from barometer. (cm.Hg)

S_u - Burning Velocity

T - Local atmospheric temperature. (°C)

P_0 - Reference Pressure. (Pa)

OBJECTIVE:

1) To determine 2-D temperature parallel to the flame front.

2) Spectroscopic analysis using Avast spectrometer.

3) Qualitative analysis using Shadow graphic techniques.

DESCRIPTION OF EXPERIMENT:

Fine gage S-Type thermocouples are made of Pt-10%Rh/Pt, which are used when fast, accurate temperatures are required. The dia-meter of these wires are of 0.125mm and the response time are of 0.08secs, these fine wire diameters enable accurate temperature measurements, keeping the heat transfer at the point of contact to the flame and thermocouple minimum. In addition to that, the fine junction permits accurate pin-pointing of the measured values.

To calibrate this S-Type thermocouple a Nagman's Temperature calibrator, is used which is of Model 1200HN is a semi-portable, multi hole, dry block type, high Temperature Calibrator which can generate temperature upto to 1200K, consequently a voltage is generated by given temperature.(seebeck effect).

To investigate the temperature at various uniformly distributed points, with S-Type of thermocouple over a simple burner which provide pre-mixed flames. Rotameters were used to measure the flow rates where the air and fuel are fed through the rotameters with a prescribed pressure and the discharge is being controlled by needle valve at the exit. The air was supplied from a single piston engine compressor.

A constant deviation Spectrometer (CDS) is used to measure radical emission intensities. These emissions with their ratios were then related with the equivalence ratio. To find relation between each radical intensity ratio and the equivalence ratio.

To calculate the Burning velocity using Gouy's Method, for which calculate the flame area by using digital photographs,

Shadow graph images were procured from the flame over the burner with low intensity Diode-pumped-Solid-State LASER which is operating with 220V AC at 50Hz, which can generate a beam of 100mw. The laser beam is passed through a double concave lens with a minimum focal length(2.5cm) so that light from LASER beam spreads and shoots out on the screen, from which the photographs are been captured using a Digital Camera.

PRECAUTIONS:

1) Turn on the compressor, and then the LPG cylinder. LPG cylinder knob should be completely turned on to avoid pressure losses in the feed line.

2) To avoid spilling of gas (LPG), ignite the burner and then set the required flow rate in the rotameters.

3) While turning on the LASER, make sure that the fan is turned on, than turn on the key and then switch on the LASER. Turn off the laser similarly.

4) While moving the traverse, don't touch the thermocouple, as it the most delicate part of the experimental setup.

5) Turn off the LPG cylinder first, and then the compressor.

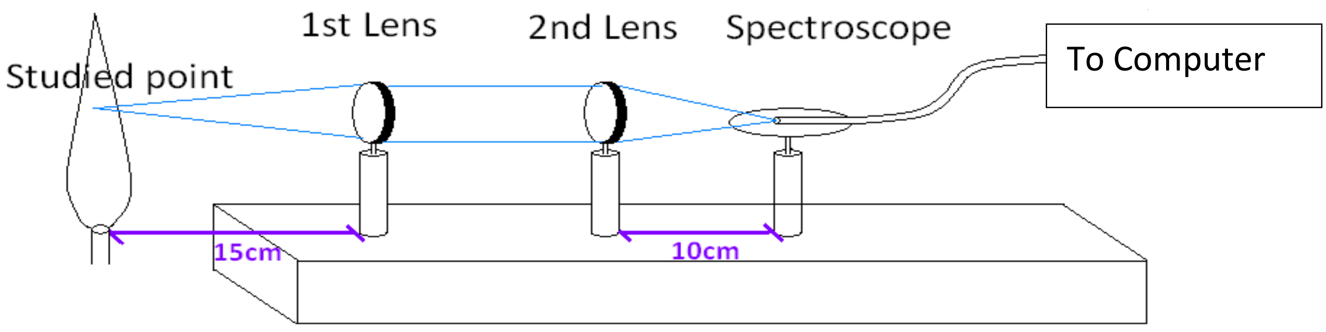


Fig.1: Experimental Setup for Spectroscopic Analysis

PROCEDURE:

1. Before starting the experiment, familiarize yourself with various components of test set as well as the instruments used for experimentation.

2. Familiarize with the basic principles of how the data is acquired using and reduced to the required values.

3. Note down the ambient temperature and pressure.

4. When the compressor and the LPG-cylinder is turned on note down the gauge pressures from the control line.

5. To understand the nature of flame, the equivalence ratio was varied right from the Fuel rich premixed flame to stoichiometric AFR to Fuel lean Premixed Flame.

6. At an unique equivalence ratio (ϕ=0.95), input a grid format, and move the traverse 2-Diamentially along with the coordinates as given in the grid, measuring the temperature on those points.

7. Take shadowgraphic images using digital camera at the equivalence ratio (ϕ=0.95)

8. At a point 3cm above the Burner Rim, fix the thermocouple and vary the equivalence ratio.

9. At the same point, using a stroboscope get the intensity of radicals with the change in varying equivalence ratio.

FORMULAE:

a) **For Adiabatic Flame temperature.**

$$q = mc_p(\Delta T)$$

b) **Rotameter Calculations.**

$$\frac{Q_{actual}}{Q_{scale}} = \sqrt{\frac{\rho_{scale}}{\rho_{actual}}}$$

$$\dot{m}_{actual} = \rho_{actual}\,\dot{Q}_{actual}$$

$$\dot{m}_{actual} = \dot{Q}_{scale}\,\rho_{actual}$$

$$\dot{m}_{actual} = \dot{Q}_{scale}\sqrt{\rho_{scale} * \rho_{actual}}$$

$$\rho_{scale} = \frac{P_{atm}}{R*T}$$

$$\rho_{actual} = \frac{(P_{guage} + \text{Patm})}{R*T}$$

The Total Mass flow rate is

$$\dot{m}_{actual} = \dot{Q}_{scale}\sqrt{\rho_{scale} * \rho_{actual}}$$

$$\dot{Q}_{\text{scale}} = \frac{\dot{Q}indicated}{60{,}000}\ (\text{kg/s})$$

c) **Burning Velocity Calculations:**

Let Area of the burner mouth = A_o (Dia = 10mm)

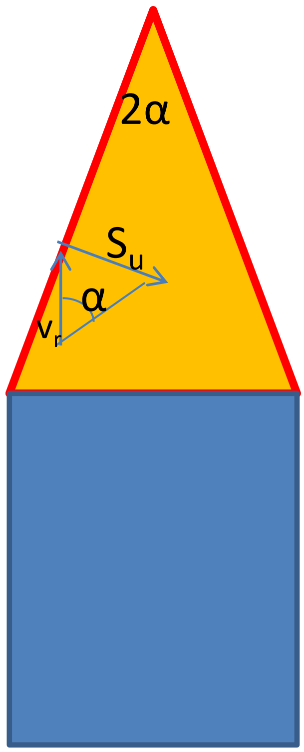


Fig. 2: Element of Flame Front
V_r = Gas velocity at radius r, S_u = Burning Velocity, 2α = Cone Angle

The average flow velocity in the burner mouth = V_o

The total Volume flow of gas = $A_o * V_o$

Let total Area of the flame front, A_f moving with

Velocity V_o

$$A_o * V_o = A_f * S_u$$

To Measure the surface of the Flame Front AB

- Divide it into number of sections of equal height. From Flame Photographs.

The surface area of the section AF = π s $(r_1 + r_2)$

Where s is distance of AF

- If α is the half cone angle, s = h/cosα
- The area AFGC = ½ s $((r_1 + r_2)$
- The AFBGC = $\sum$ ½ s_n $(r_n + r_{n+1})$

Multiplying by 2π, flame area is calculated.

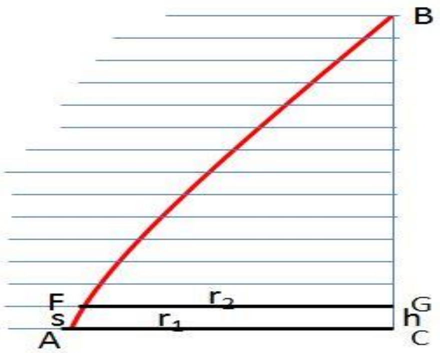


Fig. 3: Method to calculate Flame Area

RESULTS AND DISSCUSSIONS:

1) A 2-D Temperature contour plot must be plotted, with x and y axis as per the grid generated, along the direction parallel to the flame front.(Hint: Use TEC-PLOT 360, Triangulate)

2) In Shadow-graphic images, by using image processing in Matlab get the point of maximum density, which is a function of the maximum temperature.(Qualitatively compare with the maximum temperature with 2-D Temperature contour plot)

3) Plot Temperature vs. equivalence ratio (ϕ) at a position 3cm above the burner rim.

4) At the same position obtain various intensities by varying the equivalence ratio (ϕ), at a specific (ϕ) at ϕ =0.95.

5) By using Energy balance equation, theoretically calculate adiabatic flame temperature at equivalence ratio (0.95).

6) Calculate the Flame Area, and the burning velocity using Gouy's Method, for one particular Equivalence Ratio.

APPENDIX:

Chemical composition of LPG gas (Approx.)

Propane	C_3H_8	44.7
Isobutane	C_4H_{10}	54.8
Ethane	C_2H_6	0.7
Avg. Mol Wt.		51.57

Heating Value for LPG is 46.1MJ/kg.

Stoichiometric fuel air ratio = 0.0643 Kg of LPG/Kg of air.

Average specific heat values for gases

O_2	52.24	KJ/Kg-Mol
N_2	51.26	KJ/Kg-Mol
CO_2	78.80	KJ/Kg-Mol
H_2O	65.80	KJ/Kg-Mol

The CDS measured radiations in a range from 200 to 750nm. In this region, several peaks could be observed. Flame emission wavelength for common radicals and products are as follows:

- CH 420-440nm
- C_2 460-475nm / 510-516nm
- CN 359nm / 386nm
- H_2O Broadband around 600nm
- CO_2 Broadband
- OH 300-320nm

References

1) R Gupta, V Garg, Dr A Kushari. "Spectroscopic Analysis of a Premixed LPG-air Flame.", IITK, Kanpur 208 016, 2004.
2) "FLAMES Their structure, Radiations and Temperature", Gaydon,A.G., Wolfhard H.G., Chapman & Hall LTD.
3) Combustion, Flames & Explosions of Gases, Bernard Lewis, Guenther von Elbe, Ph.D
4) Dinesh Kumar.S.J., "Experimental Investigations of LPG-Air Pre-mixed Flames", M.E Thesis, Birla Institute of Technology, Ranchi.

Experiment 3

High-speed Flow Visualization using Shadowgraph and Schlieren technique

(a) Schlieren Flow Visualization

List of symbols

Po - Stagnation pressure

T_0 - Stagnation temperature

Pa - Ambient Pressure

NPR – Nozzle Pressure Ratio

Objective:

To study the shock structure on the solid body using Schlieren visualization technique.

Apparatus:

Supersonic wind tunnel: The schematic of blow down tunnel is shown in figure 1. In general Blow down tunnels is used to test the models from high subsonic to supersonic flow conditions. De Laval nozzle is used to generate desired Mach number in the test section. The test section with size 225mm x 175mm is placed at the end of a de Laval nozzle. Basically, the Mach number in the test section is determined by pressure and temperature in the settling chamber and the area ratio between the test sections on the nozzle throat. The test models are fixed in the test section by using a support. The air is pumped into a closed high pressure tank upstream of the settling chamber. At the same time, air is pumped out of a closed low pressure chamber downstream of the test section. As the flow expands in the nozzle, the pressure decreases and any moisture in the tunnel may condense and liquefy in the test section. To avoid condensation, air is brought into the tunnel through a dryer bed. A second throat is used downstream of the test section to shock down the supersonic flow to subsonic before entering the low pressure chamber or silencer.

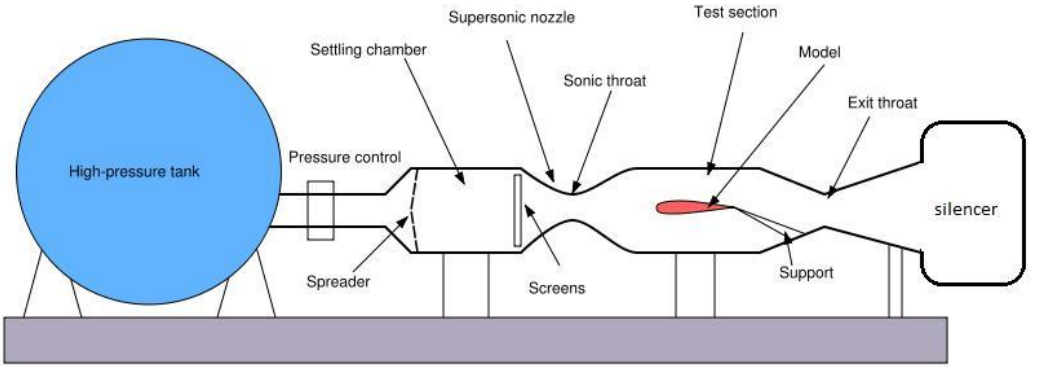


Figure1. Schematic representation of supersonic wind tunnel

Nozzle:

The schematic of de Laval nozzle is shown in figure 2.

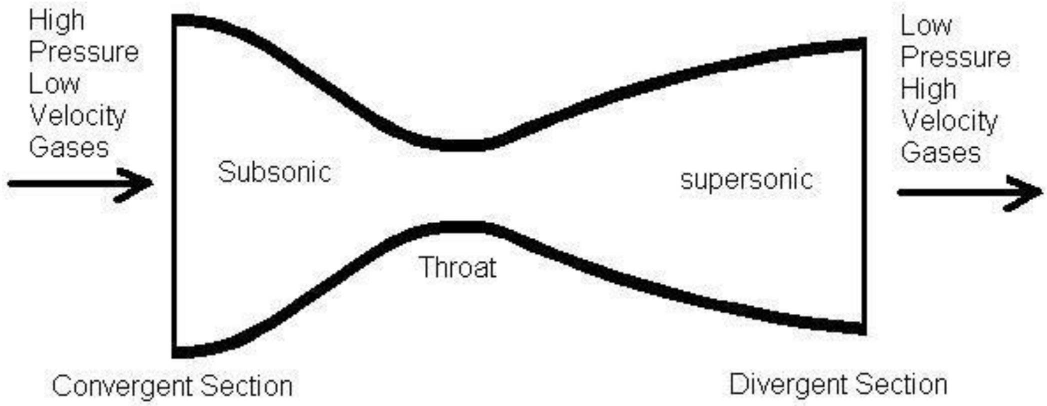


Figure 2. Schematic of de Laval Nozzle

Light source and mirrors:

a. 5W Laser is used as light source. In general small intense halogen lamp is sufficient.
b. Two parabolic mirrors of 200 mm diameter and thickness of the mirror glass about 25 mm.

Focusing Lens & Knife edge: This lens is positioned in the Schlieren system in such a way that a flow field is focused on the screen. An ordinary double convex is used. Any straight, sharp edged opaque object mounted on an adjustable stand will be sufficient to serve as a knife edge.

Electronic pressure scanners: The pitot pressure sensed by the probe was measured using a PSI model 9016, 16- channel pressure transducer. The model 9016 transducer is capable of measuring pressures up to 300 psi, which is approximately 20 atm. The accuracy of the transducer (after re-zero calibration) is specified to be ± 0.15% full scale. Also, transducer offset errors were eliminated by performing a re-zero calibration prior to every run.

Scanner support module: The application software developed using the Lab VIEW links the host computer to the pressure scanner via TCP/IP communication. The application software performs all the required functions like initialize, reset, and re- zero calibration and read pressure.

Precautions:

1. In the test section constant conditions need to be provided by controlling a pressure regulator valve.

2. Knife-edge needs to be aligned properly to obtain sharp images of the flow field.

3. Do not block the laser while it is on.

Procedure:

Familiarize with the general layout and major components of the wind tunnel and Schileren system.

The stagnation pressure (Po), temperature (T_0) and nozzle area ratio (A/A*) will determine the Mach number (from isentropic relations) in the test section of wind tunnel. The settling chamber total pressure (Po), maintained constant during a run by controlling the pressure regulating valve.

Light from a source is collimated by the first lens and then passed through the test section. It is then brought to a focus by the second lens and projected on the screen. At the focal point of the second lens, where the image of the source is formed, a knife edge is introduced to cut off part of the light. The screen is made to be uniformly illuminated by the portion of the light escaping the knife edge, by suitably adjusting it to intercept about half the light when there is no flow in the test section. The arrangement of Schlieren technique is shown in figure 3.
Obtain the visualized images on the screen for a given Mach number using a camera.

Principle:

Illumination of the picture on the screen is proportional to the first derivative of the density

Results & Discussion:

1. Explain the shock structure on the solid body.

2. Comment on the nature of the shocks and explain inconsistencies, if any.

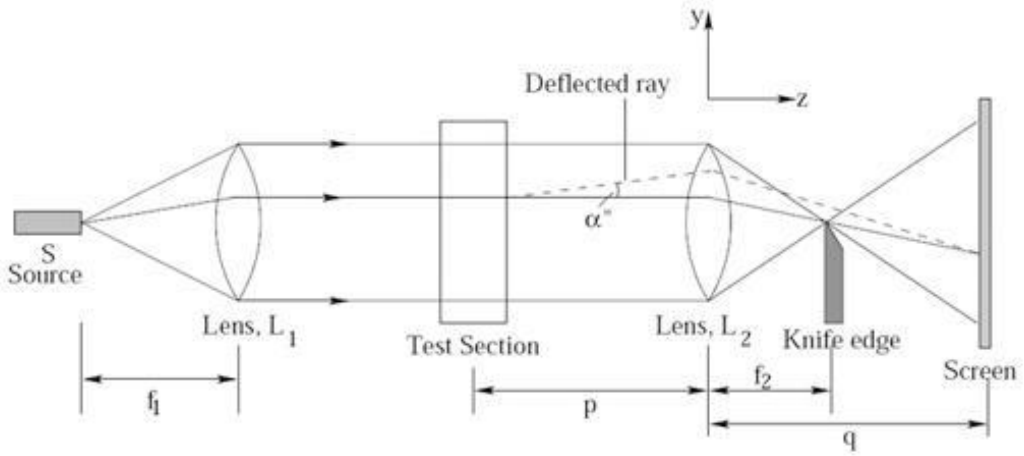


Figure 3. Schematic representation of Schlieren system

(b) Shadowgraph Visualization Technique

List of symbols

P_0 - Stagnation pressure

T_0 - Stagnation temperature

Pa - Ambient Pressure

NPR – Nozzle Pressure Ratio

Objective:

To study the shock structure on the solid body using shadowgraph visualization technique.

Apparatus:

Supersonic wind tunnel:

The schematic of blow down tunnel is shown in figure 1. In general Blow down tunnels is used to test the models from high subsonic to supersonic flow conditions. De Laval nozzle is used to generate desired Mach number in the test section. The test section with size 225mm x 175mm is placed at the end of a de Laval nozzle. Basically, the Mach number in the test section is determined by pressure and temperature in the settling chamber and the area ratio between the test sections on the nozzle throat. The test models are fixed in the test section by using a support. The air is pumped into a closed high pressure tank upstream of the settling chamber. At the same time, air is pumped out of a closed low pressure chamber downstream of the test section. As the flow expands in the nozzle, the pressure decreases and any moisture in the tunnel may condense and liquefy in the test section. To avoid condensation, air is brought into the tunnel through a dryer bed. A second throat is used downstream of the test section to shock down the supersonic flow to subsonic before entering the low pressure chamber or silencer.

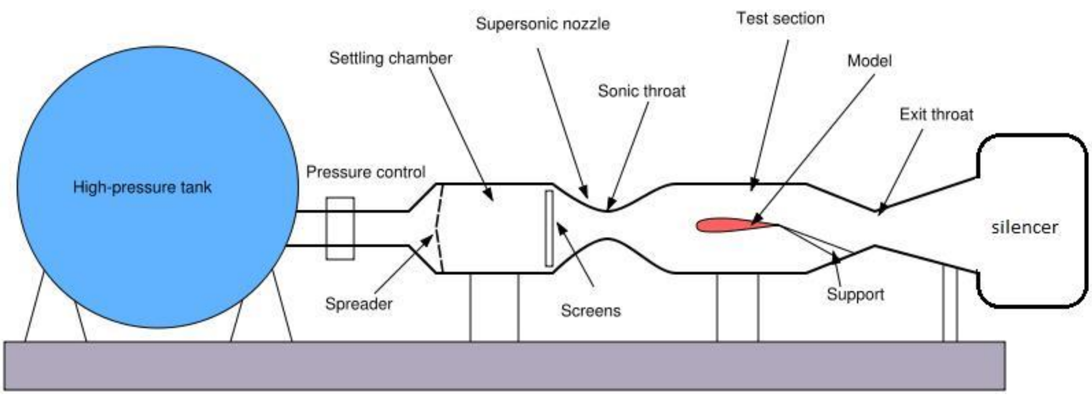


Figure1. Schematic representation of supersonic wind tunnel

Nozzle:

The schematic of de Laval nozzle is shown in figure 2.

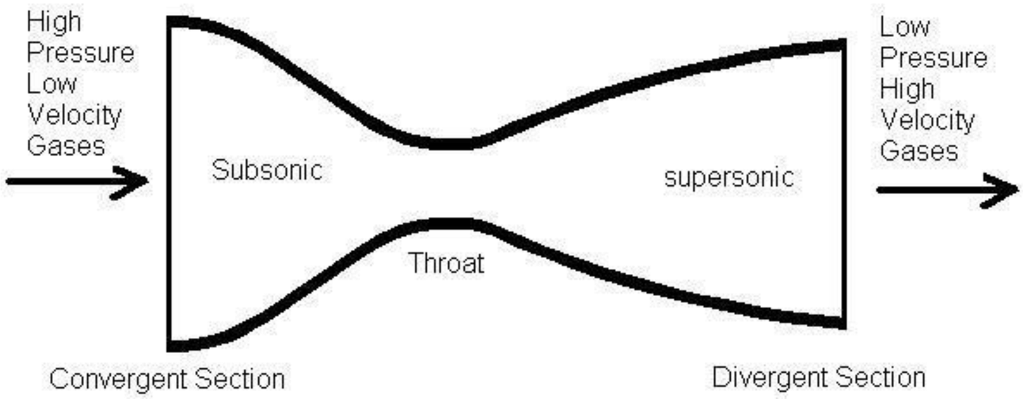


Figure 2. Schematic of de Laval Nozzle

Light source and mirrors:

5W Laser is used as light source. In general Helium spark arc light source and 150 mm diameter concave mirror is sufficient.

Electronic pressure scanners: The pitot pressure sensed by the probe was measured using a PSI model 9016, 16- channel pressure transducer. The model 9016 transducer is capable of measuring pressures up to 300 psi, which is approximately 20 atm. The accuracy of the transducer (after re-zero calibration) is specified to be ± 0.15% full scale. Also, transducer offset errors were eliminated by performing a re-zero calibration prior to every run.

Scanner support module: The application software developed using the LabVIEW links the host computer to the pressure scanner via TCP/IP communication. The application software performs all the required functions like initialize, reset, and re- zero calibration and read pressure.

Precautions:

1. In the test section constant conditions need to be provided by controlling a pressure regulator valve.

2. Screen need to be placed close to the test section to have proper visibility of image.

3. Do not block the laser while it is on.

Procedure:

Familiarize with the general layout and major components of the wind tunnel and shadowgraph system. The stagnation pressure (Po), temperature (T_0) and nozzle area ratio (A/A*) will determine the Mach number (from isentropic relations) in the test section of wind tunnel. The settling chamber total pressure (Po), maintained constant during a run by controlling the pressure regulating valve.

The light source was collimated by the condenser lens and then brought to the concave mirror. The parallel beam from the mirror was made to pass through the jet flow field and projected on the screen. The photographs of shadowgraph images of shock-train on the screen were taken directly by using a camera. The arrangement of mirror and light source are shown in Figure 3.
Obtain the visualized images on the screen for a given Mach number using a camera.

Principle:

Illumination of the picture on the screen is proportional to the second derivative of the density

Results & Discussion:

1. Explain the wave structure on the solid body and explain.

2. Comment on the nature of the wave structure and explain inconsistencies, if any.

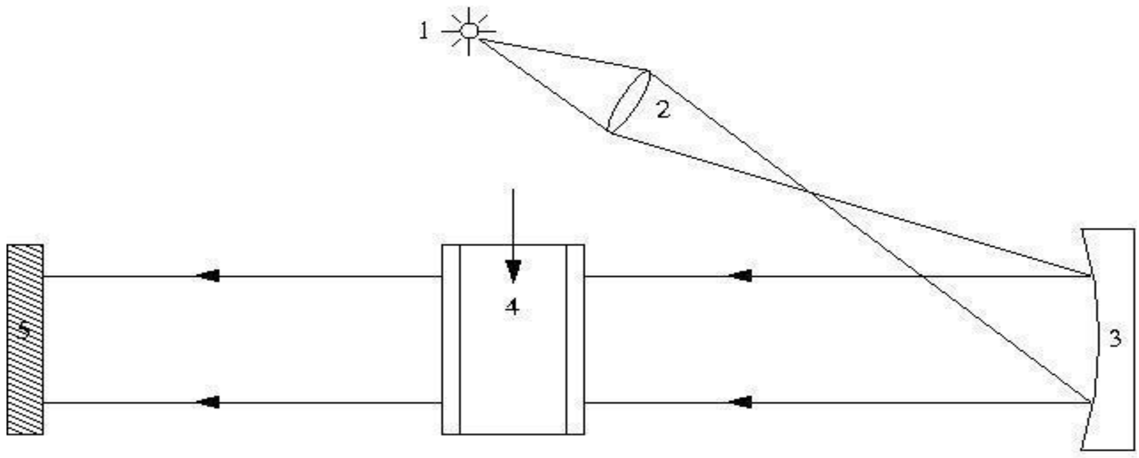


Figure 3. Schematic diagram of shadowgraph system

1. Light source

2. Condenser lens

3. Concave mirror

4. Test Section

5. Screen

Experiment 4
Calibration of Supersonic Wind Tunnel

List of Symbols:

L (L1, L2…)	Distance from throat (for location1, 2, …)
A_X	Cross sectional area at location X (e.g. 1, 2, …)
A*	Cross section 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) $$\frac{A}{A^*} = \frac{1}{M^2}\ \frac{2}{\gamma+1}\ \ 1+\frac{\gamma-1}{2}M^2\ ^{\frac{\gamma+1}{\gamma-1}}$$

2) $$\frac{P_0}{P} = \ 1+\frac{\gamma-1}{2}M^2\ ^{\frac{\gamma}{\gamma-1}}$$

Objective:

1) To calibrate the supersonic wind tunnel

2) 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.

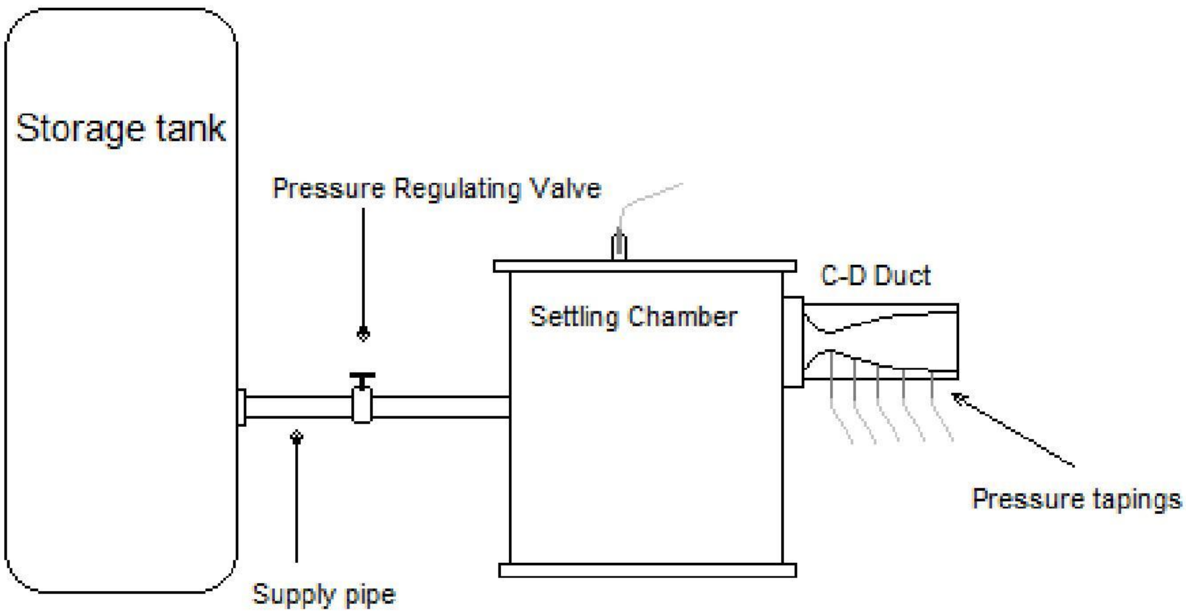


Figure 1: Wind tunnel Setup

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 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 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.

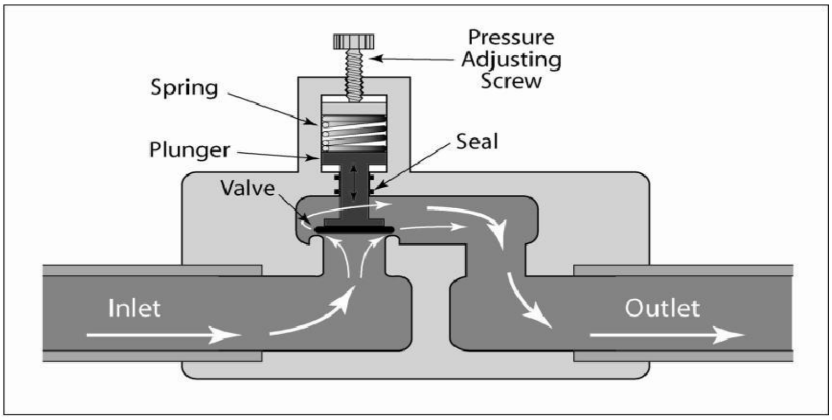


Figure 2: Pressure Regulating Valve

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 of 60 Psi.

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

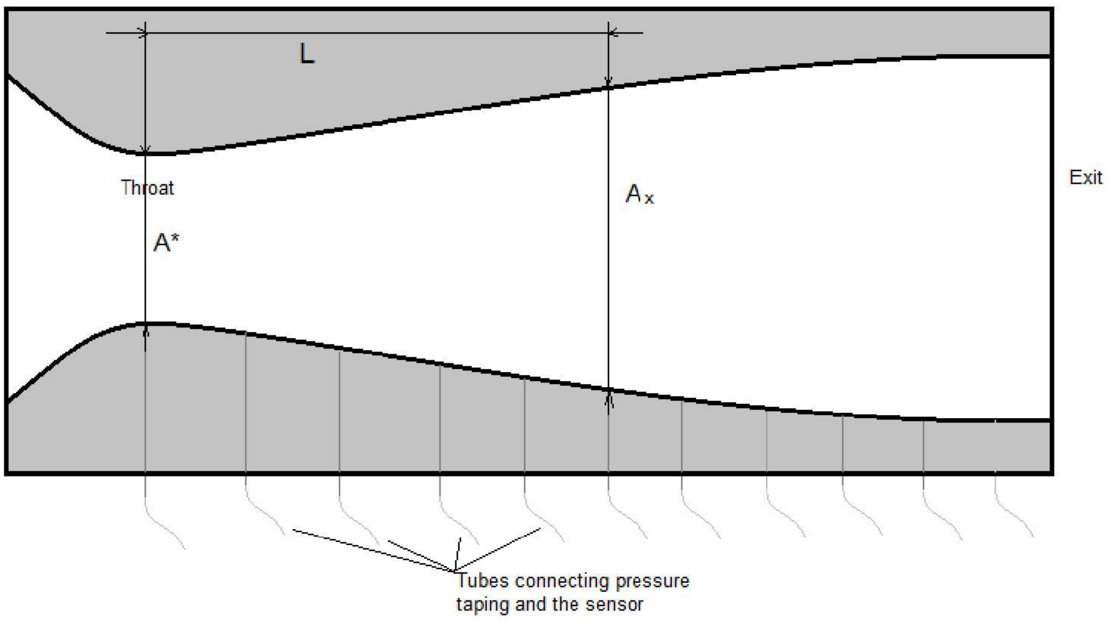


Figure 3: Convergent-Divergent Duct

It is a varying area duct of rectangular cross section made completely out of Plexiglas. The side walls of the duct are 25mm apart. The top and bottom walls are contoured for 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 should be used.

There are tiny holes drilled at particular location along the contour to tap out 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 2nd formula). This is the actual Mach number Mac at that location.

The test piece or the model is kept 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 dusts or any other materials.

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 measurements of the settling chamber and along the contour of the tunnel.
Using 2nd formula, find the 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 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 ($M_{isentropic}$) distribution and actual Mach number (M_{actual}) 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.