LAB 7 - Calibration of Supersonic Wind Tunnel
Debanjan Manna (190255)
AE351
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- **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

- **INTRODUCTION AND THEORY:**

FORMULAE:	**LIST OF SYMBOLS:**
1. $\frac{A}{A^*} = \frac{1}{M^2}\left[\frac{2}{\gamma+1}\left(1+\frac{\gamma-1}{2}M^2\right)\right]^{\frac{\gamma+1}{\gamma-1}}$ 2. $\frac{P_0}{P} = \left(1+\frac{\gamma-1}{2}M^2\right)^{\frac{\gamma}{\gamma-1}}$	L (L1, L2…) Distance from the throat (for location1, 2, etc) A_x → Cross-sectional area at location X (e.g. 1, 2, 3…) 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

- **EQUIPMENT AND OPERATING CONDITIONS:**

The experimental setup includes:

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.

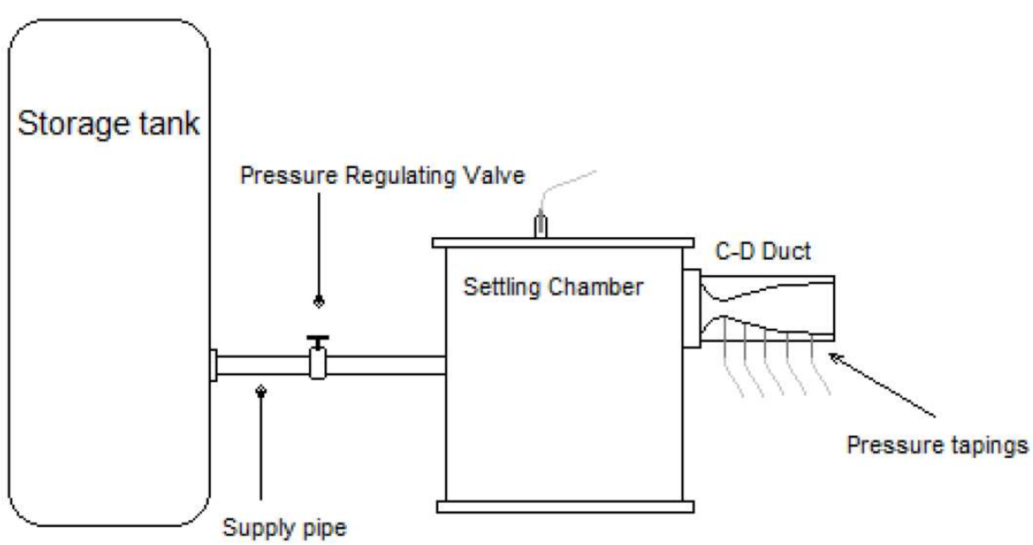
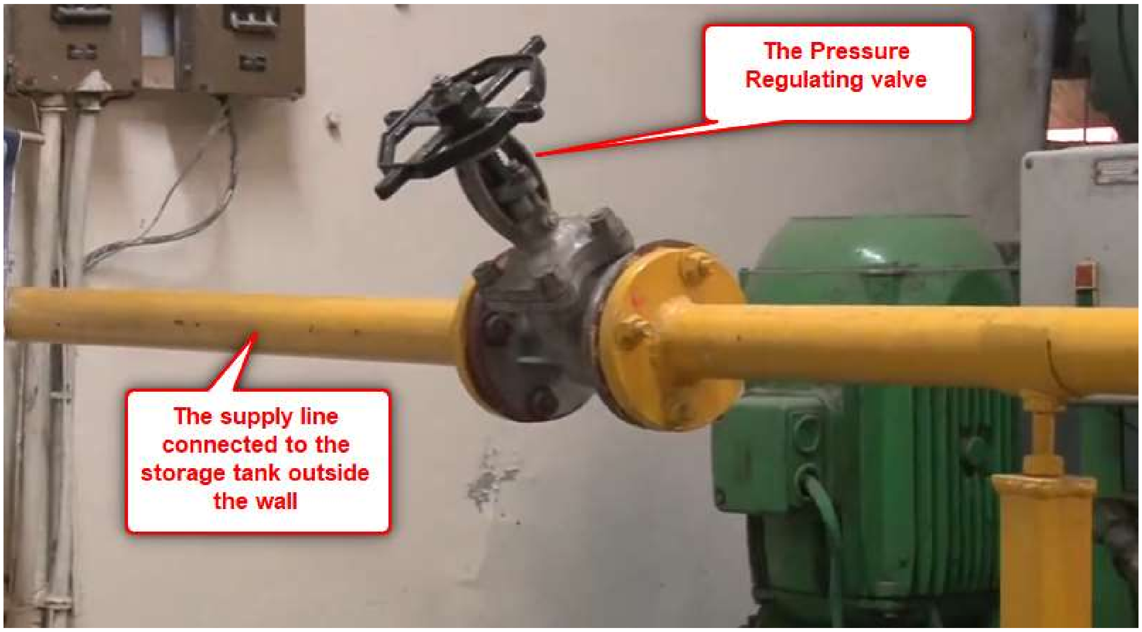


Figure 1: Wind tunnel Setup

a) Storage Tank:

It is a ***high-pressure tank used to store large volumes 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 pressurize up to a safe limit of 200 Psi.

b) Supply pipe:
It supplies air from the 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. A schematic diagram of a simple pressure regulating valve is shown below.

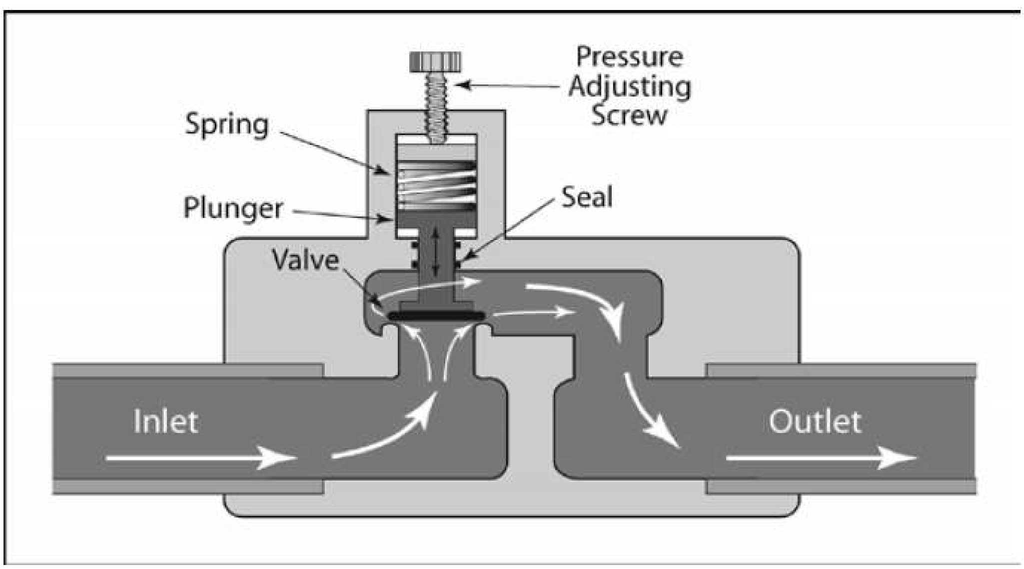
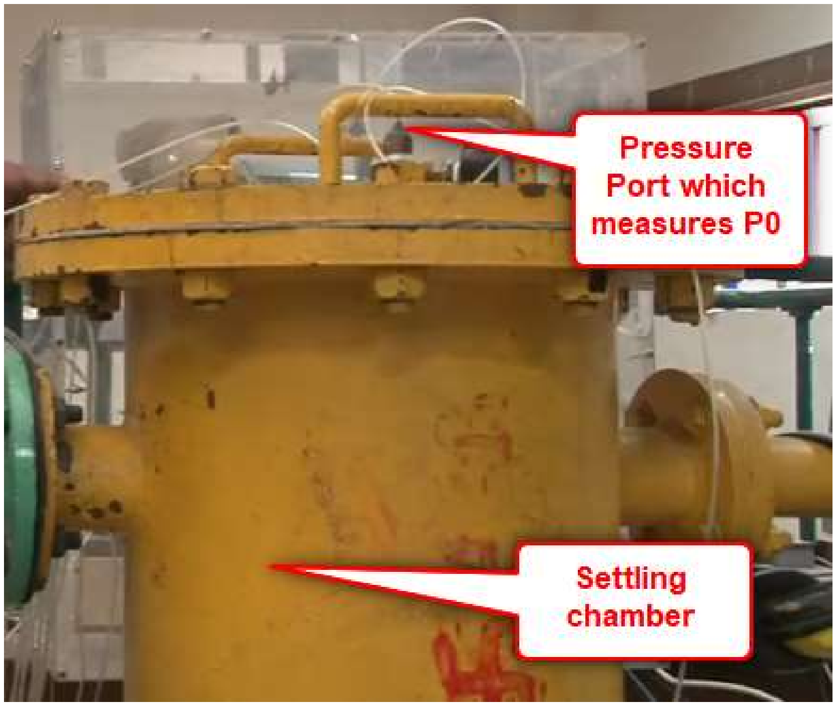


Figure 2: Pressure Reguating Valve

d) Settling Chamber:
It settles down the pressure oscillations and perturbations from the upstream and provides steady downstream conditions for the operation of the wind tunnel. **In our facility, the chamber pressure is maintained within the safe pressure of 60 Psi**.



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

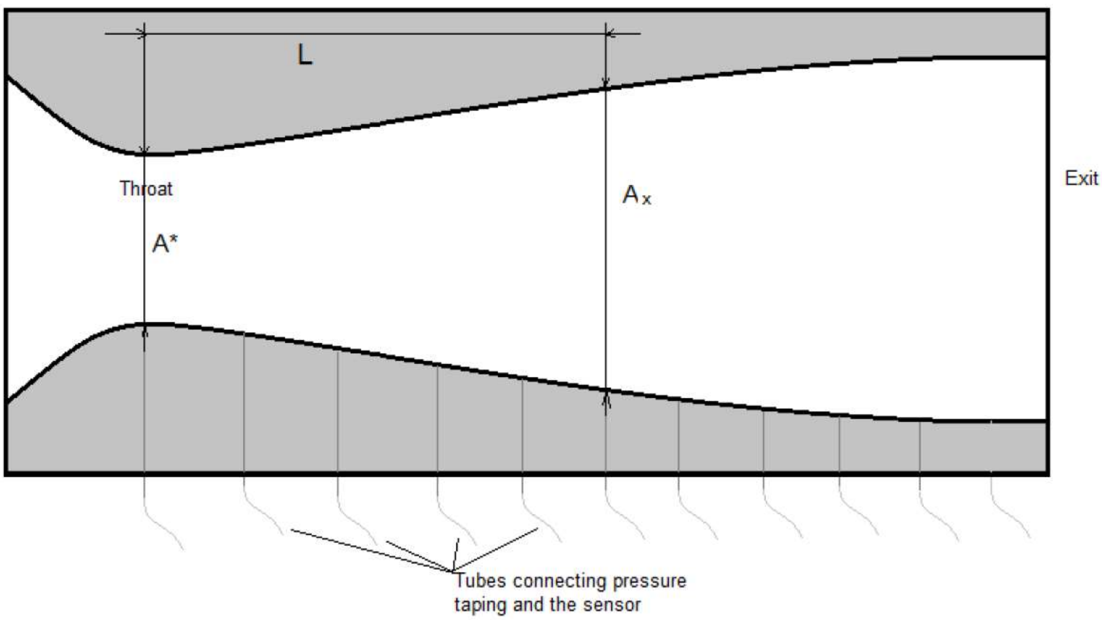
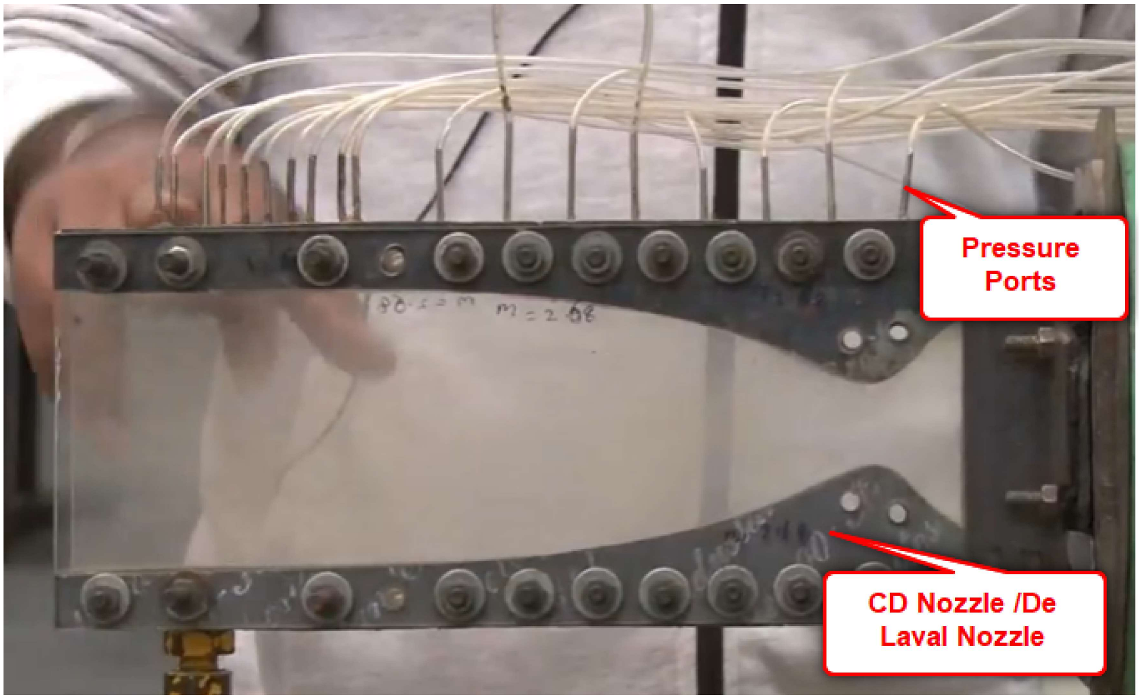


Figure 3: Convergent-Divergent Duct

It is a varying area duct of the rectangular cross-section made completely out of plexiglass. ***The sidewalls of the duct are 25mm apart.*** The top and bottom walls are contoured for area ratios ($\frac{A}{A^*}$) which expand the flow to the required test section Mach number. **Since the Mach number is a function of the area ratio in the duct, to obtain different test section Mach numbers different contours should be used.**

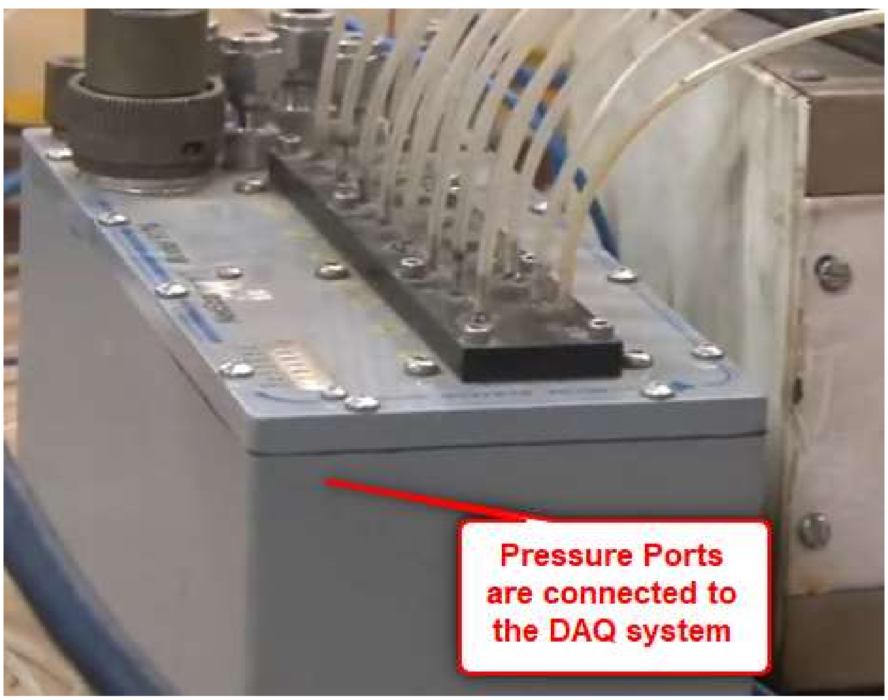
- There are tiny holes drilled at a particular location along the contour to tap out the local static pressure. The ***static pressure (P_x)*** thus obtained along with the ***settling chamber pressure (P_{sc})*** gives the local Mach number (using $\frac{P_0}{P} = (1 + \frac{\gamma-1}{2}M^2)^{\frac{\gamma}{\gamma-1}}$). ***This is the actual Mach number M_{ac} 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 the diffuser.



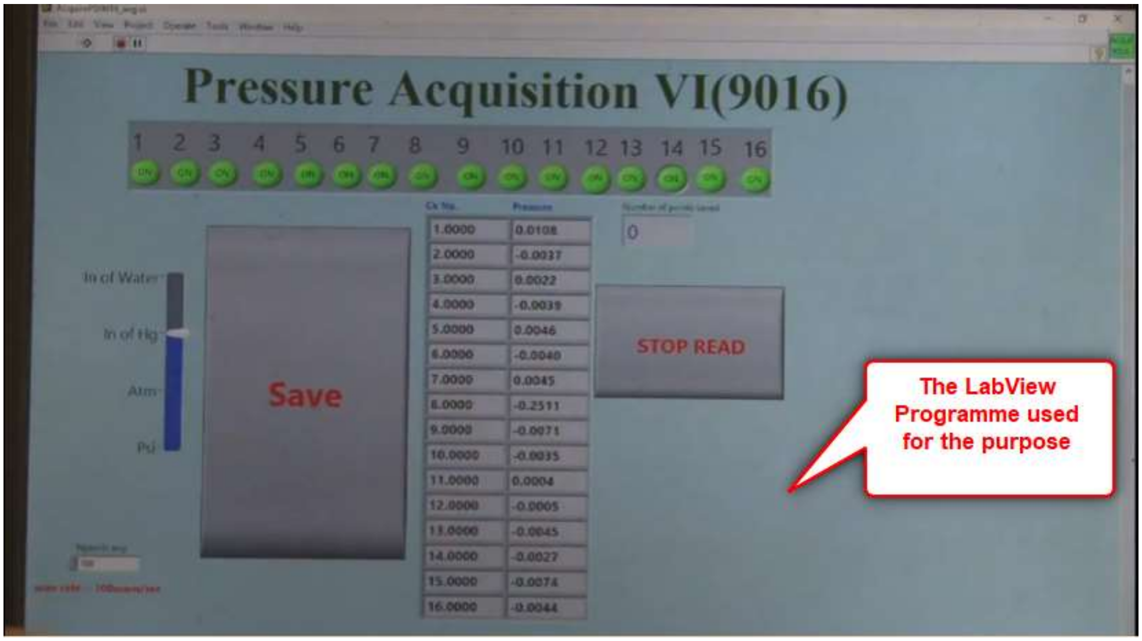
f) Pressure Ports:

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 the 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 the LabView program*.



- **PROCEDURE:**

1. Familiarize with the major components of the wind tunnel setup.
2. Familiarize with the principles of how the data is acquired and reduced to required values.
3. Slowly open the pressure regulating valve till the flow is completely supersonic inside the wind tunnel.
4. Using the LabView program take pressure measurements of the settling chamber and along the contour of the tunnel.
5. Using the 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.
6. Measure the location of the pressure ports from the throat and also find the cross-section at the same location for the tunnel contour used.
7. From the area ratios at different locations of the contour $(\frac{A}{A^*})_x$ find the isentropic Mach number M_{isen} for that area ratio from the 1st formula.

Some important Dimensions:

P_0	**60 PSI**
Standard Atmospheric Pressure	**14.6959 PSI**
Width of nozzle	**25mm**
Depth of throat	**25mm**
γ_{air}	**1.4**

Measured Data:

GUAGE PRESSURE in PSI														
P0	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	P13	P14
5.375	-6.184	-3.2896	-2.814	-1.6094	-0.6816	-0.347	-0.1434	-0.1176	-0.0318	-0.0864	-0.0172	-0.0318	-0.0294	-0.0358
9.94	-4.695	-7.184	-3.8212	-3.5826	-2.6192	-1.4648	-0.6644	-0.327	-0.1184	-0.1104	-0.0634	-0.0332	-0.025	-0.0142
15.1586	-2.6292	-9.0744	-4.6304	-4.5738	-3.826	-2.972	-1.6404	-0.8356	-0.2008	-0.2398	-0.0728	-0.0746	-0.0518	-0.0582
20.1438	-0.6858	-8.3106	-9.1292	-1.1308	-1.9964	-3.7598	-2.5976	-2.4164	-0.4546	-0.7542	-0.1694	-0.1784	-0.128	-0.1556
25.0022	1.2028	-7.5234	-8.5608	-7.1974	-2.4946	-1.9648	-5.1976	-3.359	-1.0246	-1.5498	-0.282	-0.5394	-0.1928	-0.212
30.0622	3.173	-6.6962	-7.7418	-8.054	-5.3246	-4.6784	-4.2776	-5.9128	-1.826	-2.475	-1.8018	-1.3196	-0.777	-0.2708
35.1828	5.1682	-5.8968	-6.9214	-7.3194	-8.7348	-5.4208	-4.417	-6.0972	-4.1176	-3.246	-2.2842	-2.725	-1.5574	-1.3402
40.6148	7.287	-5.0298	-6.046	-6.5364	-8.102	-8.9958	-5.136	-4.7832	-4.0336	-5.5504	-4.8908	-1.227	-2.8594	-2.729
44.9086	8.9774	-4.3464	-5.343	-5.9348	-7.5802	-9.0542	-7.5862	-3.6908	-3.558	-5.9222	-6.5034	-2.7756	-1.31	-1.9226
49.6962	10.9382	-3.5968	-4.5878	-5.2704	-6.995	-8.7012	-8.7668	-5.6036	-2.1652	-5.4602	-7.0606	-5.6648	-0.8182	-0.3568
55.3254	13.2452	-2.7088	-3.689	-4.4648	-6.3048	-8.2244	-9.4042	-8.3646	-1.8438	-2.8944	-6.1004	-5.7212	-3.7678	-2.4816
60.076	15.1628	-1.9764	-2.9308	-3.7646	-5.7184	-7.8134	-9.0846	-9.6002	-5.7588	-3.725	-1.685	-5.0104	-2.8232	-2.213
64.4112	16.8462	-1.3012	-2.263	-3.121	-5.192	-7.4386	-8.7742	-9.2934	-6.6006	-7.4636	-4.1518	-1.611	-3.755	-3.4958

Location of pressure ports in m														
x0	x1	x2	x3	x4	x5	x6	x7	x8	x9	x10	x11	x12	x13	x14
0	0.05	0.08	0.1	0.12	0.135	0.165	0.185	0.205	0.233	0.246	0.262	0.275	0.29	0.295

Depth at different locations in cm														
y0	y1	y2	y3	y4	y5	y6	y7	y8	y9	y10	y11	y12	y13	y14
7.5	3	4	5.8	6.4	6.8	7.5	7.6	7.7	7.8	7.9	7.9	7.9	7.9	7.9

- **RESULTS AND DISCUSSION :**

(a) Calculations and Plots

From 1st formula:

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

A_x → Cross Section area at Location X

Over here the CD nozzle has rectangular Cross-section area, therefore A_x = Width*(2*depth)

So the 1st formula reduces to

$$\frac{y_x}{y^*} = \frac{1}{M_{isen}^2}\left[\frac{2}{\gamma+1}\left(1 + \frac{\gamma-1}{2}M_{isen}^2\right)\right]^{\frac{\gamma+1}{\gamma-1}}$$

where y_x → depth at any location X
and y^* → depth at the throat of the CD Nozzle

From 2nd formula:

$$\frac{P_0}{P_x} = \left(1 + \frac{\gamma-1}{2}M_{ac}^2\right)^{\frac{\gamma}{\gamma-1}}$$

P_x → Pressure at location X
$M_{,ac}$ → Actual Mach number ≡ Mach number at the location X
$P_0 \approx P_{sc} \approx$ Stagnation Pressure at location X (as the flow through the)

Assumption: A_exit/A* = 3.16

Serial number	Pb/P_chamber	The A/A* value @ Normal Shock in the CD Nozzle	The Mach number Just Before the Normal Shock, M1	P_{02}/P_{01} @ Normal Shock
1	0.732	1.57	1.88	0.776
2	0.596	1.98	2.14	0.656

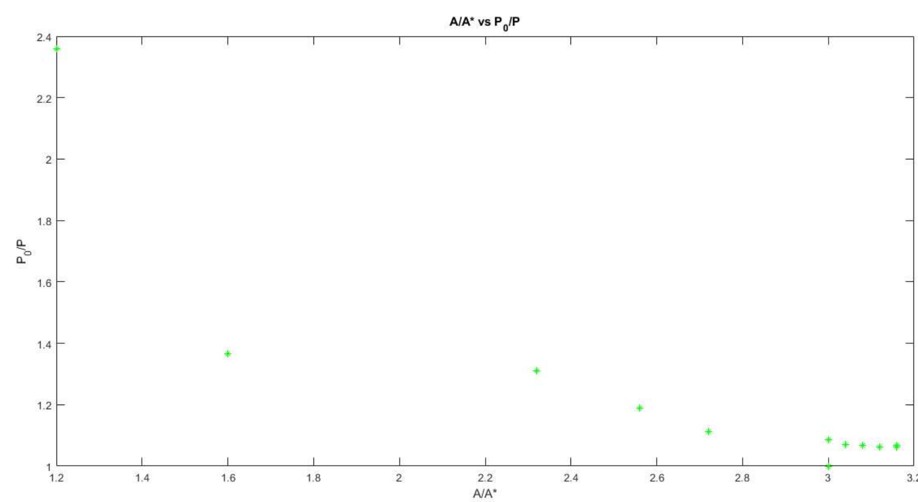
3	0.492	2.40	2.39	0.544
4	0.422	2.77	2.55	0.479
5	0.370	3.09	2.67	0.434
6	0.328	overexpanded	-	-
7	0.295	overexpanded	-	-
8	0.266	overexpanded	-	-
9	0.247	overexpanded	-	-
10	0.228	overexpanded	-	-
11	0.210	overexpanded	-	-
12	0.197	overexpanded	-	-
13	0.186	overexpanded	-	-

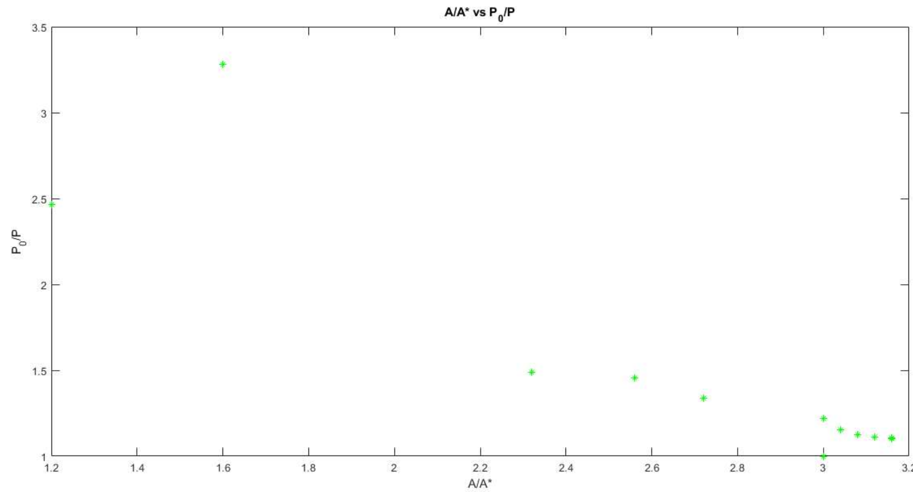
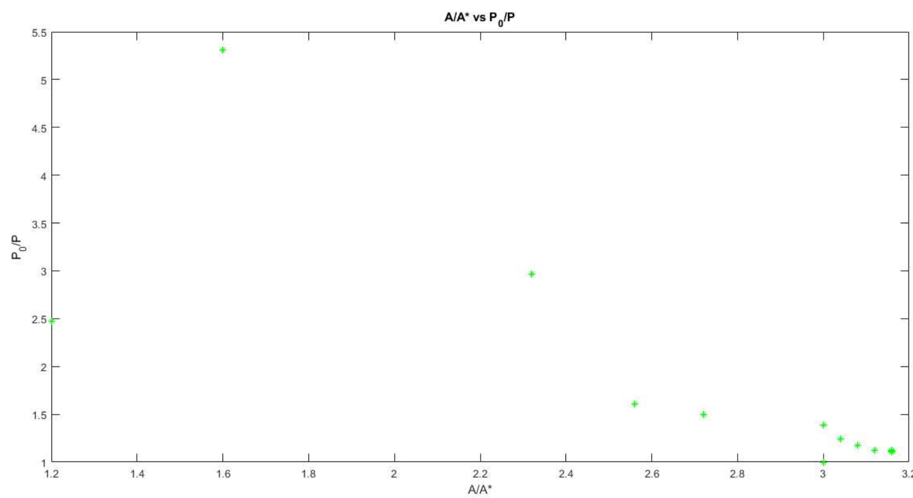
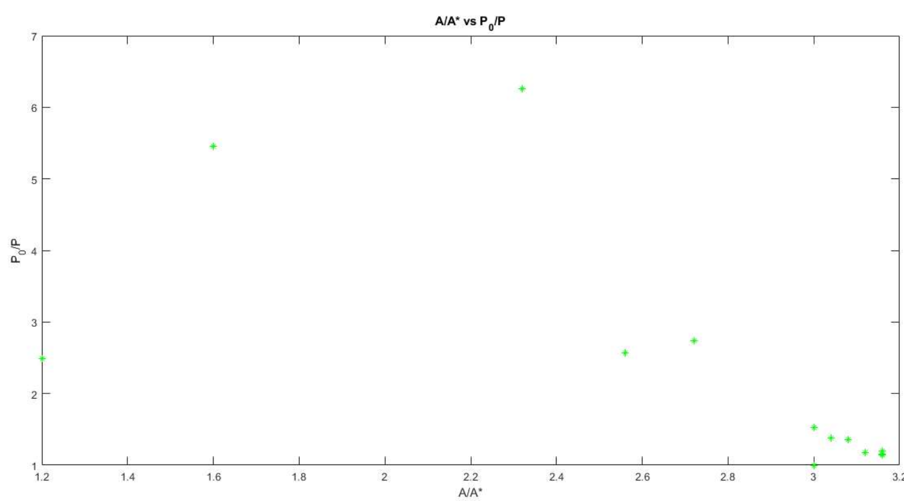
NOTE: I have calculated this table using the CD nozzle calculator of Virginia Tech

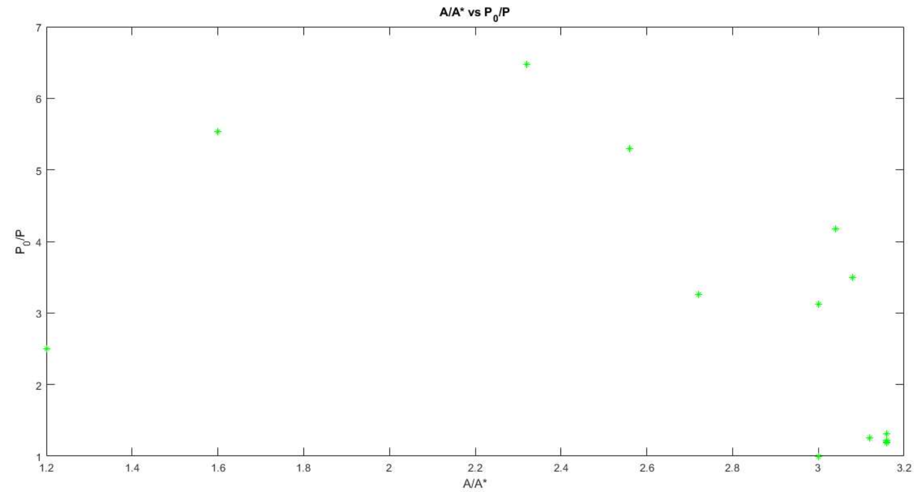
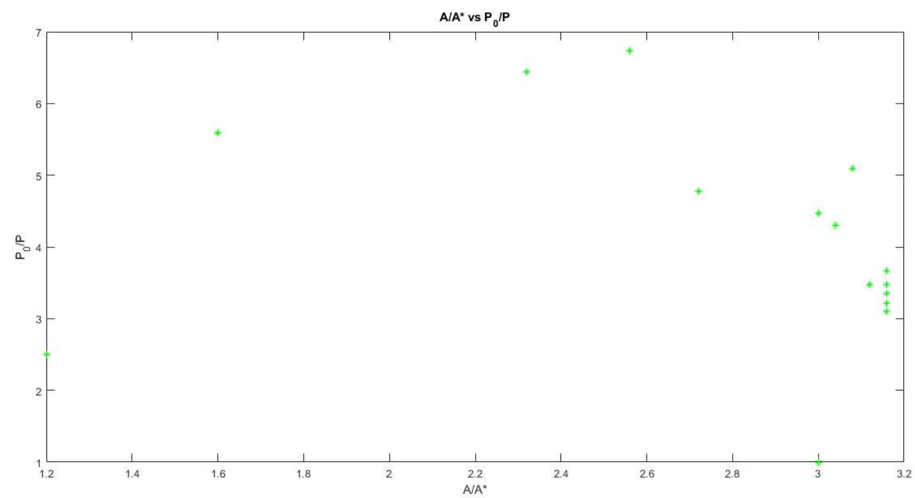
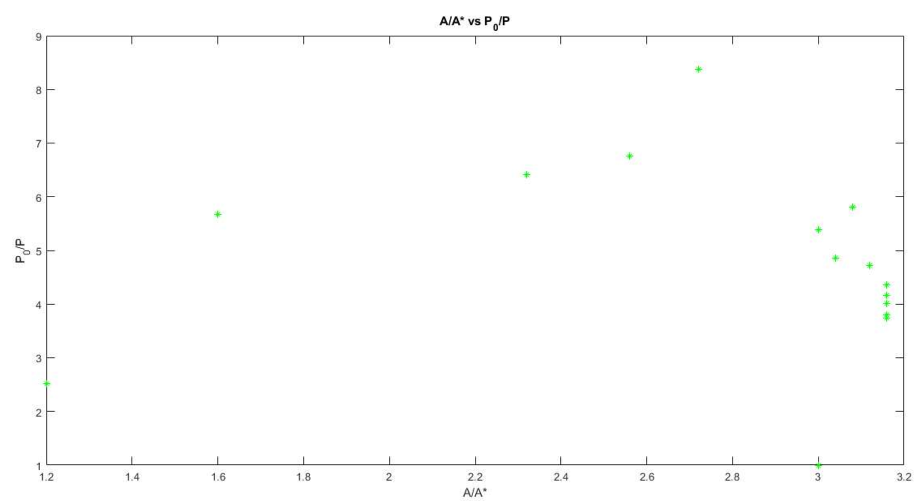
Observe that After the datapoint 5 flow remains isentropic throughout the nozzle . The Flow will have oblique shocks outside the nozzle (overexpanded flow) in those cases and therefore the P_0 value will remain same throughout in datapoints 6 to 13

i) Plot and Discuss measured Pressure Ratio (P_0/P) vs A/A^* for locations along the contour.

Area Ratio at different location : A/A* = Depth/Depth_of_throat														
x0	x1	x2	x3	x4	x5	x6	x7	x8	x9	x10	x11	x12	x13	x14
3	1.2	1.6	2.32	2.56	2.72	3	3.04	3.08	3.12	3.16	3.16	3.16	3.16	3.16

Serial Number	**The 13 cases are plotted sequentially (have incorporated Change in P0 when shock is there)**
1.	

2.	A/A* vs P_0/P P_0/P A/A* 3.5 3 2.5 2 1.5 1 1.2 1.4 1.6 1.8 2 2.2 2.4 2.6 2.8 3 3.2
3.	A/A* vs P_0/P P_0/P A/A* 5.5 5 4.5 4 3.5 3 2.5 2 1.5 1 1.2 1.4 1.6 1.8 2 2.2 2.4 2.6 2.8 3 3.2
4.	A/A* vs P_0/P P_0/P A/A* 7 6 5 4 3 2 1 1.2 1.4 1.6 1.8 2 2.2 2.4 2.6 2.8 3 3.2

5.	A/A* vs P0/P P0/P A/A* 1 2 3 4 5 6 7 1.2 1.4 1.6 1.8 2 2.2 2.4 2.6 2.8 3 3.2
6.	A/A* vs P0/P P0/P A/A* 1 2 3 4 5 6 7 1.2 1.4 1.6 1.8 2 2.2 2.4 2.6 2.8 3 3.2
7.	A/A* vs P0/P P0/P A/A* 1 2 3 4 5 6 7 8 9 1.2 1.4 1.6 1.8 2 2.2 2.4 2.6 2.8 3 3.2

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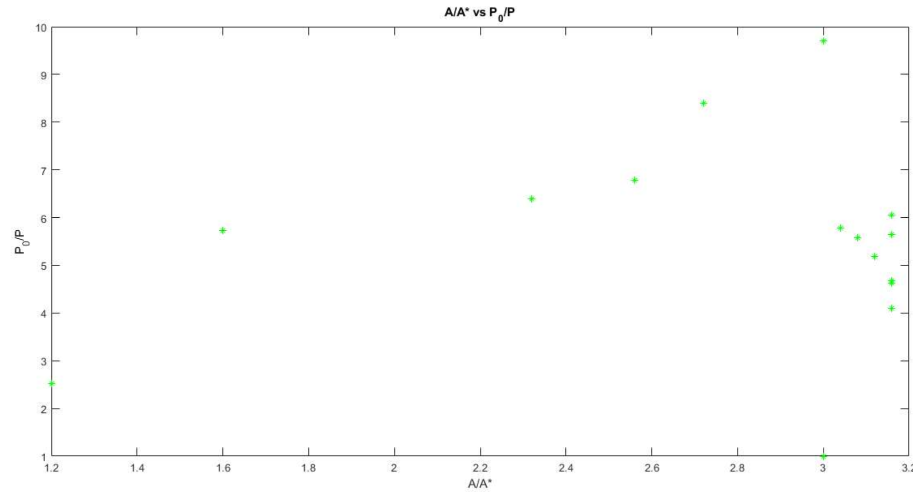
<tr><td>8.</td><td>
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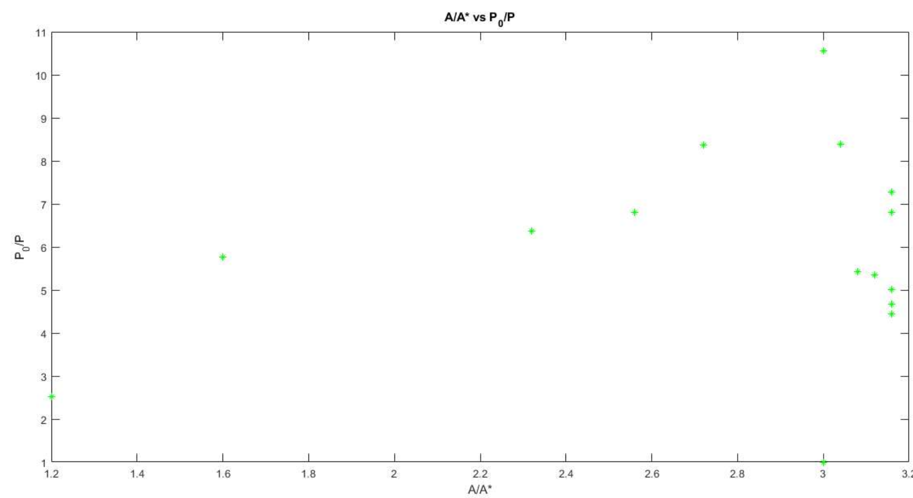
<tr><td>9.</td><td>
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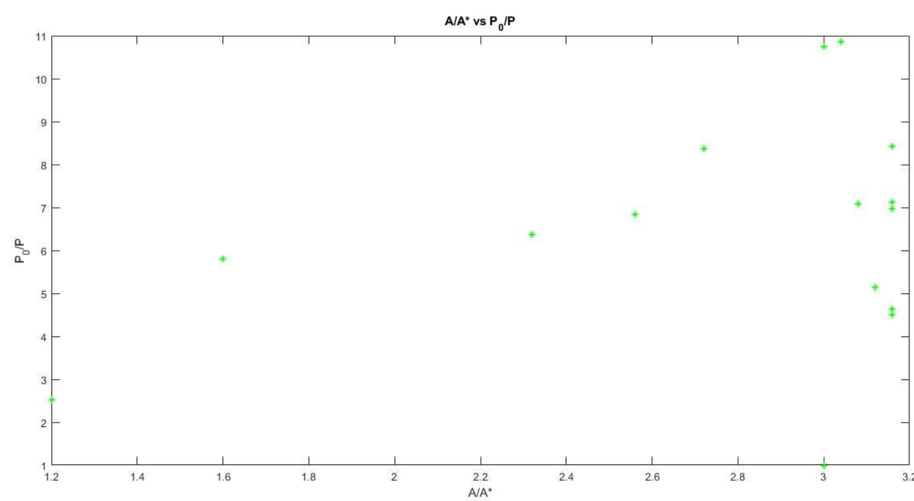
<tr><td>10.</td><td>
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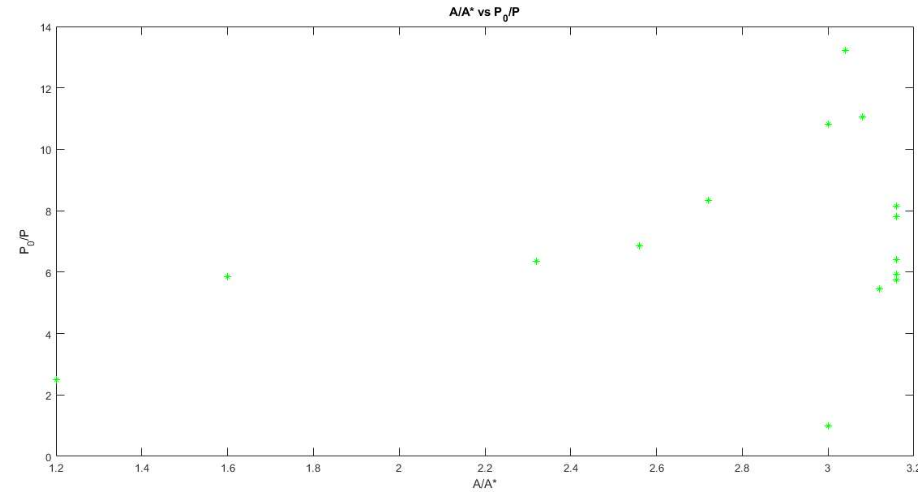
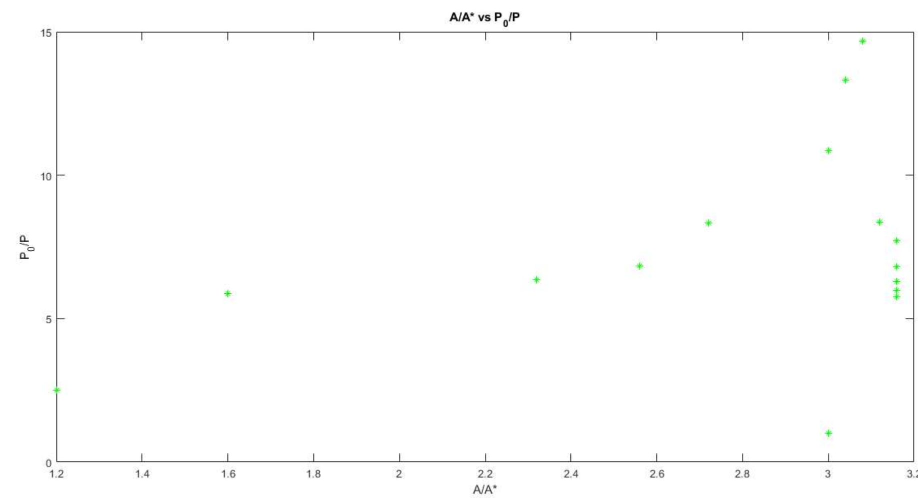
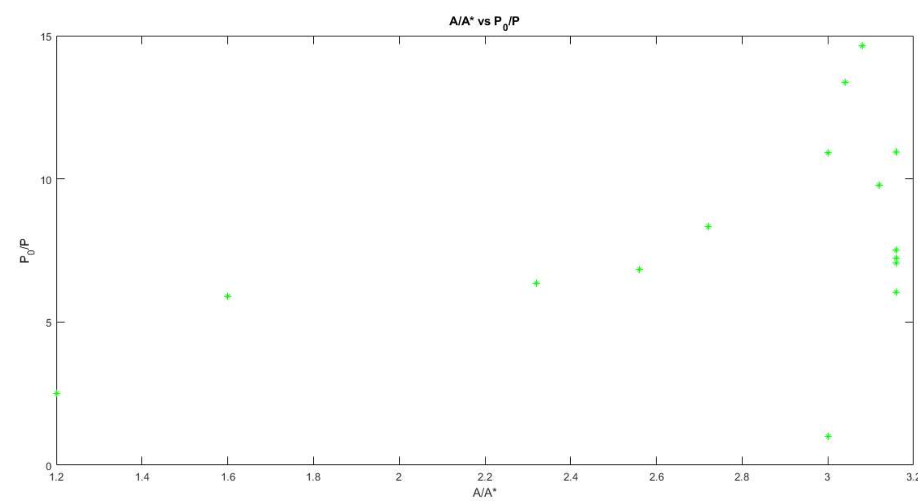
11.	
12.	
13.	

ii) Plot and Discuss M_{ac} vs A/A^* for locations along the contour

Serial number	The 13 cases are plotted sequentially (have incorporated Change in P0 when shock is there)

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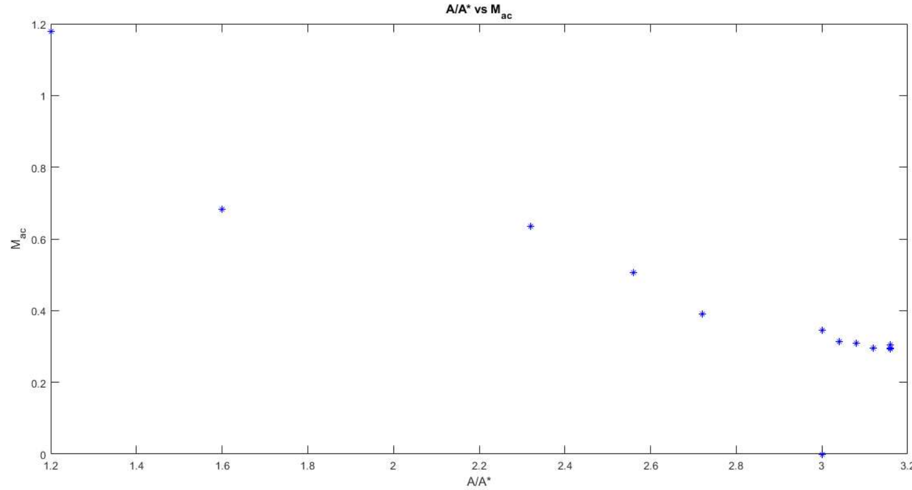
<tr><td>1.</td><td>
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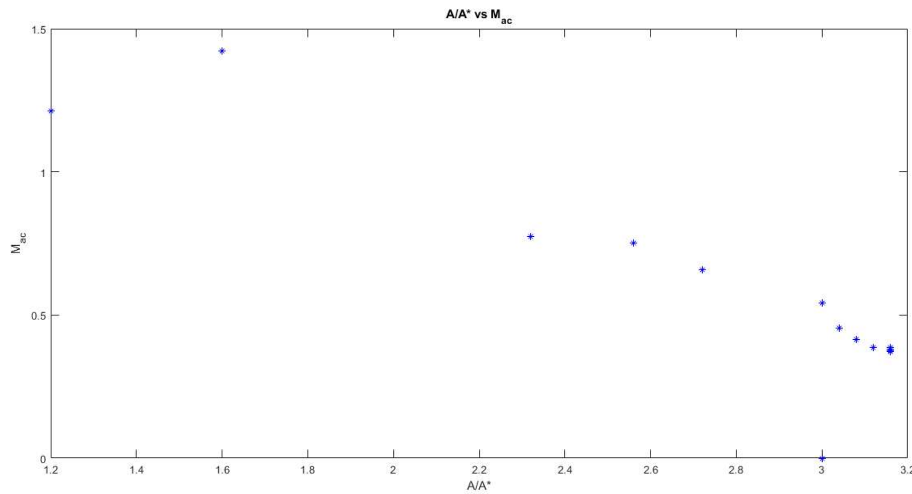
<tr><td>2.</td><td>
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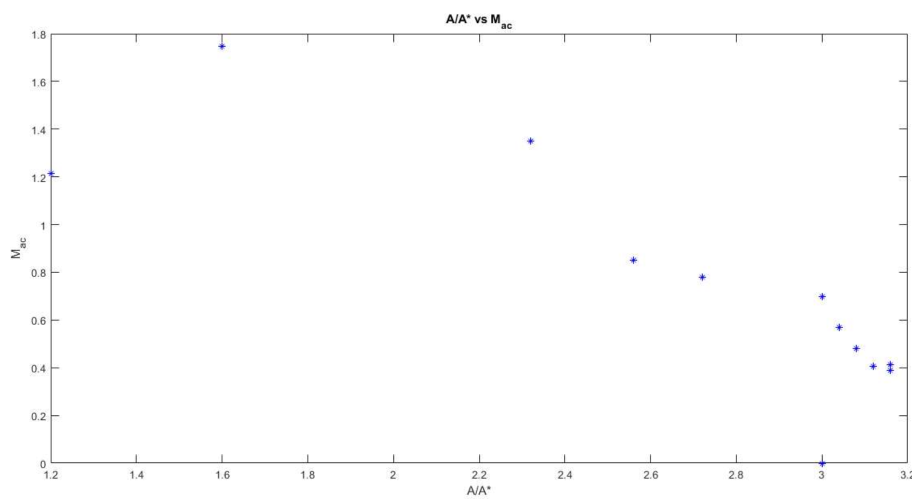
<tr><td>3.</td><td>
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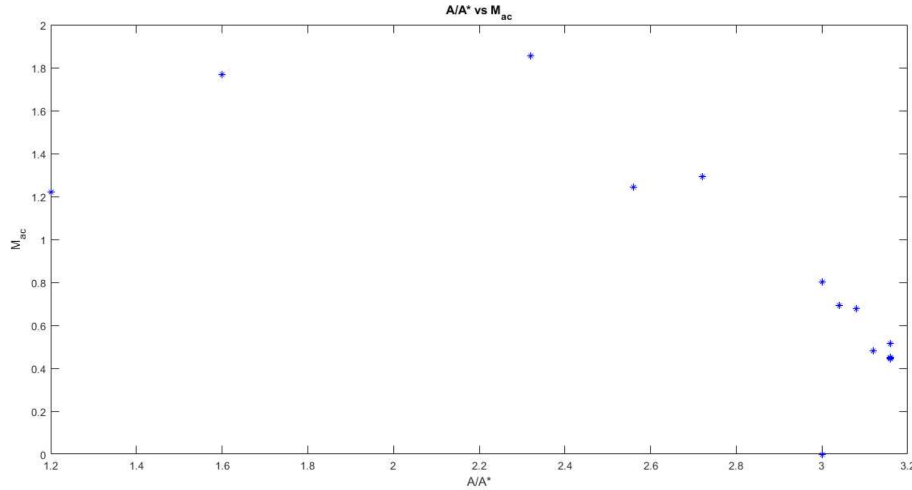
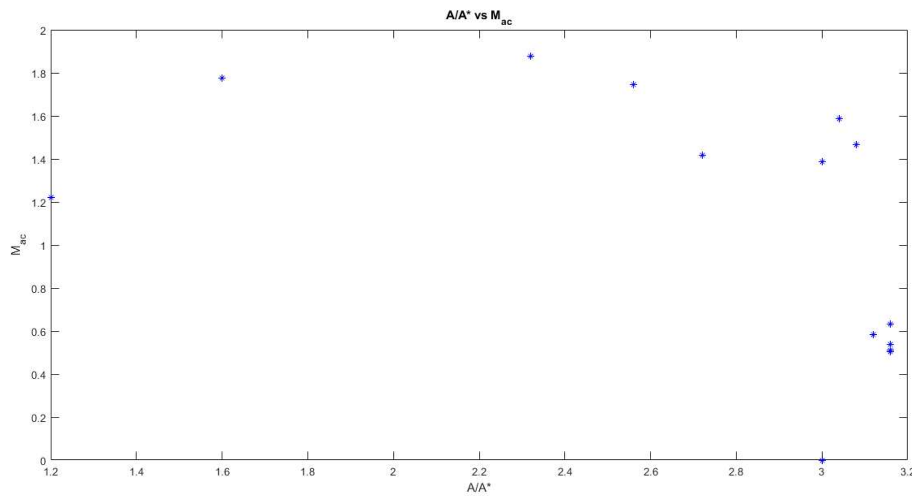
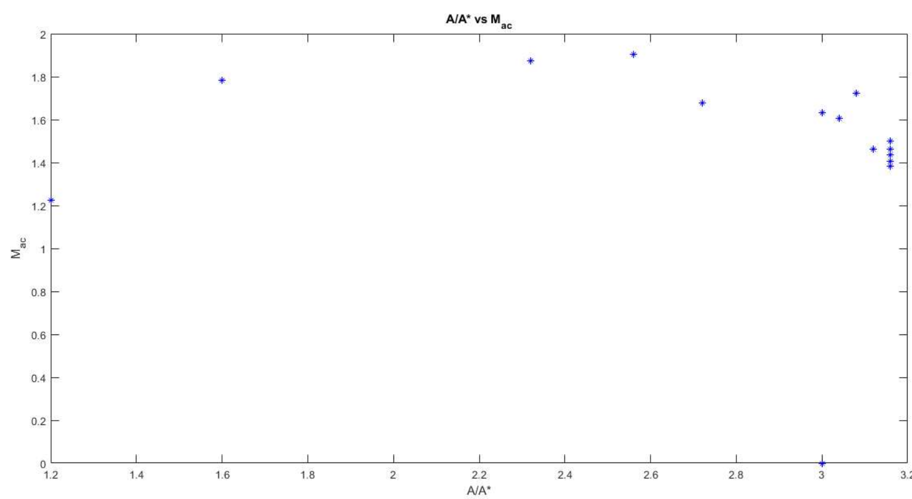
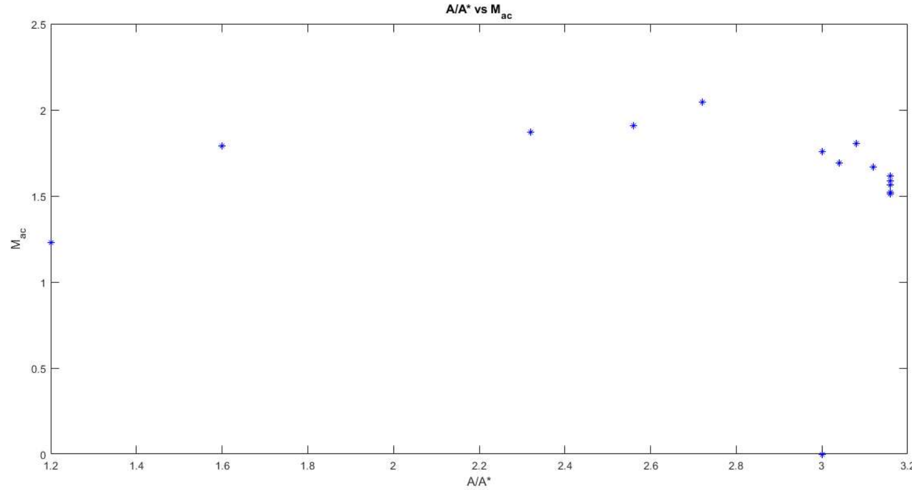
4.	A/A* vs M_{ac} → A/A* vs M_{ac} M_{ac} A/A*
5.	A/A* vs M_{ac} M_{ac} A/A*
6.	A/A* vs M_{ac} M_{ac} A/A*

7.	A/A* vs M_{ac}
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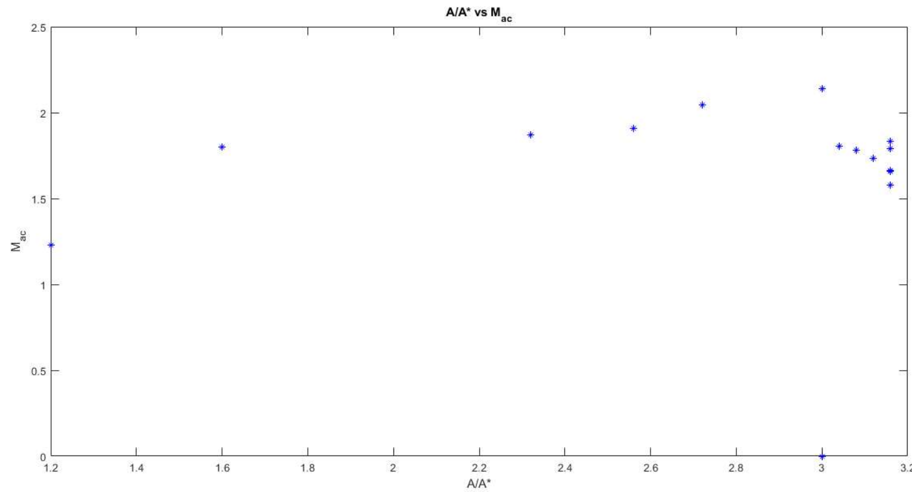
8.	A/A* vs M_{ac}
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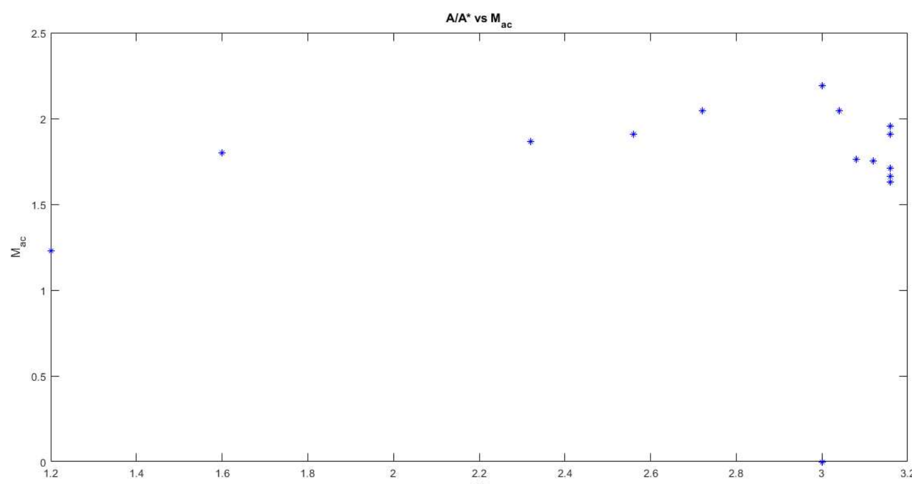
9.	A/A* vs M_{ac}
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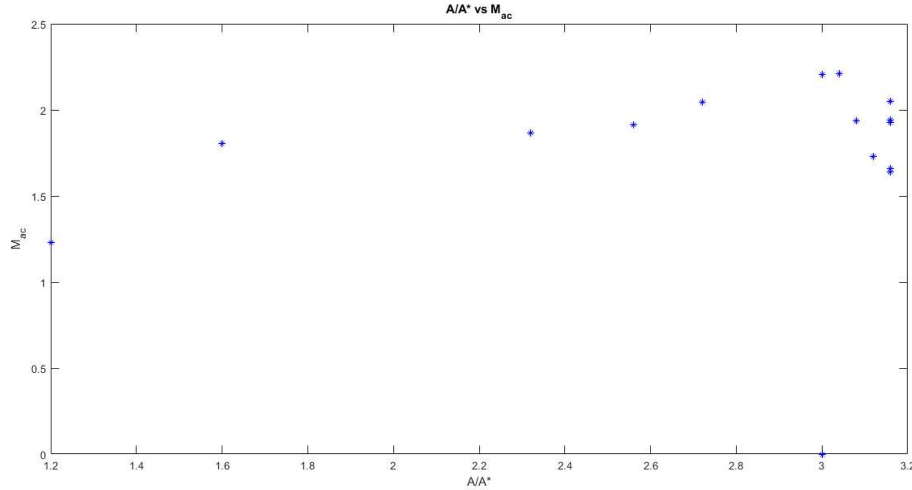
10.	A/A* vs M_{ac}
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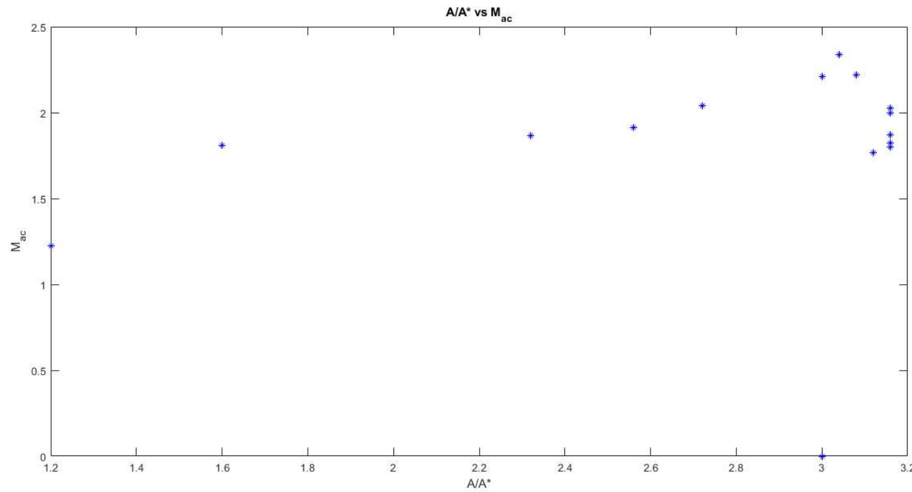
11.	A/A* vs M_{ac}
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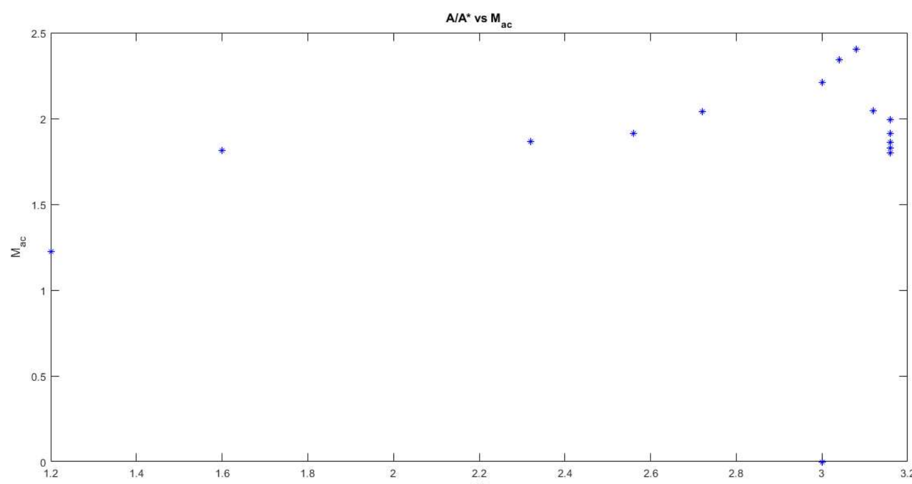
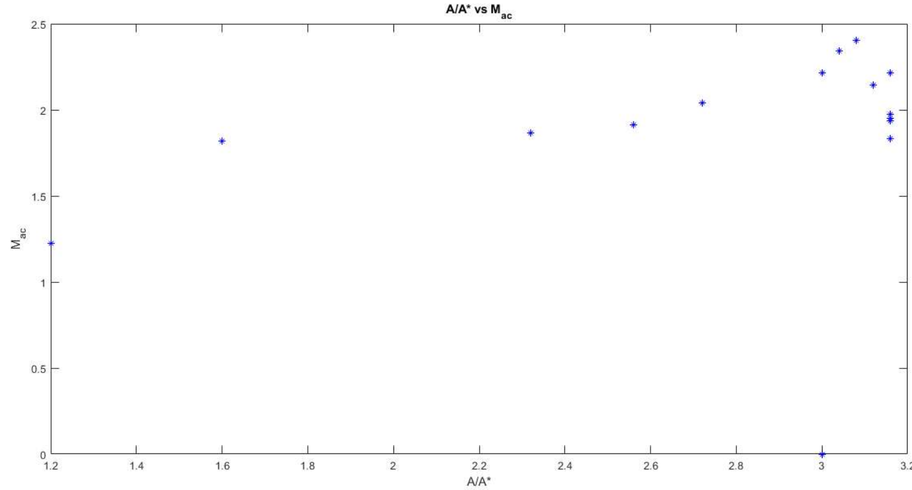
3
3.2
12.	A/A* vs M_{ac}
M_{ac}
A/A*
0
0.5
1
1.5
2
2.5
1.2
1.4
1.6
1.8
2
2.2
2.4
2.6
2.8
3
3.2

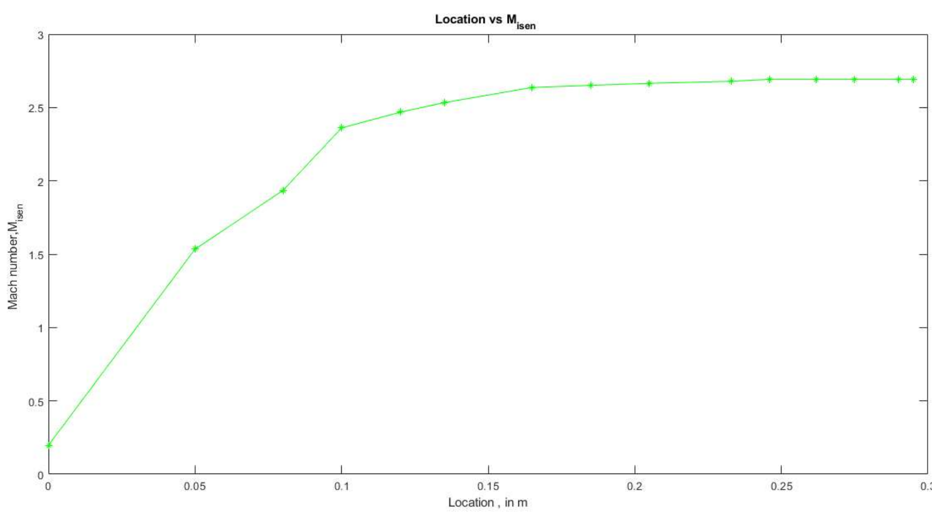
13.



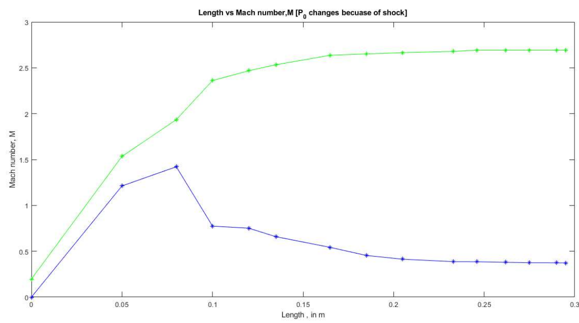
Subsonic followed by supersonic Mach number M at different location (calculated using the 1st formula)												
x0	x1	x2	x3	x4	x5	x6	x7	x8	x9	x10	x11	x12,x13,x14
0.197 2.637	0.590 1.534	0.397 1.935	0.260 2.361	0.233 2.468	0.219 2.533	0.197 2.637	0.195 2.651	0.192 2.665	0.189 2.679	0.187 2.692	0.187 2.692	0.187 2.692

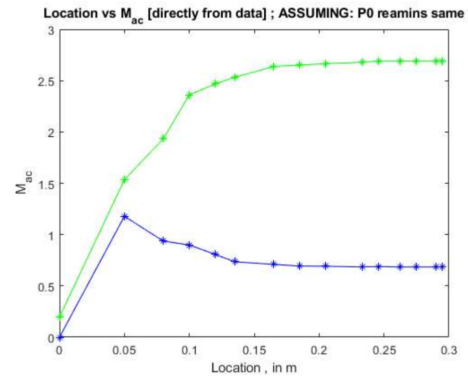
iii) Compare and discuss Isentropic Mach number (M_{isen}) distribution and Actual Mach number (M_{ac}) distribution along the length of the duct.

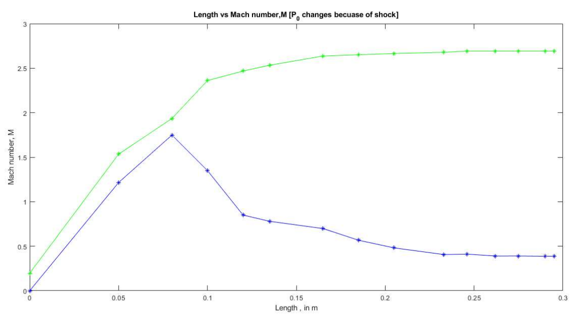
M_{isen} calculated using the Equation no. 1

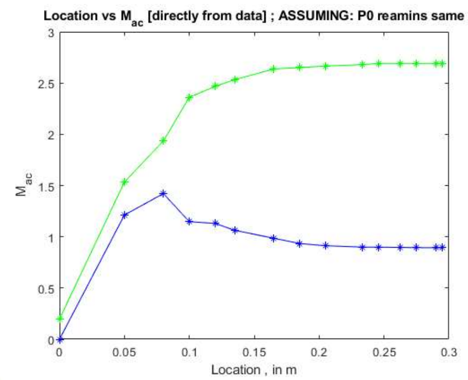


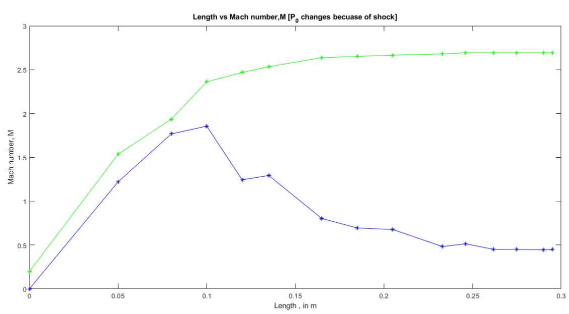
Green color → M_{isen}
Blue color → M_{ac} (calculated from experimental data; the change in P_0 is calculated separately)
The 13 cases are plotted sequentially

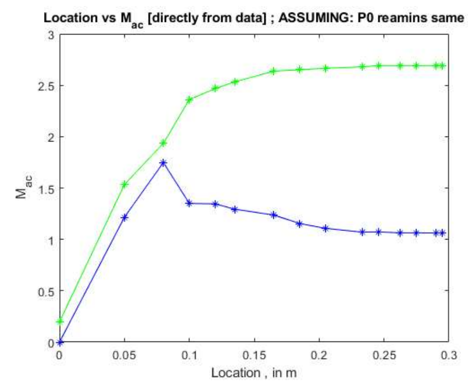

Length vs Mach number,M [P0 changes becuase of shock]
Mach number, M
Length , in m

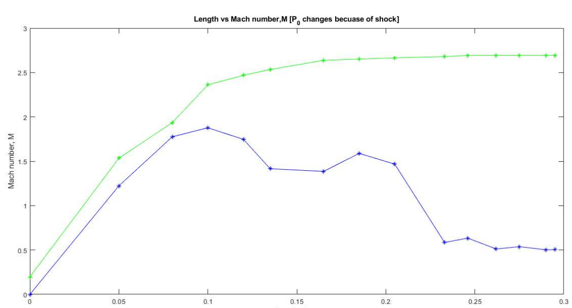

Location vs Mac [directly from data] ; ASSUMING: P0 reamins same
Mac
Location , in m

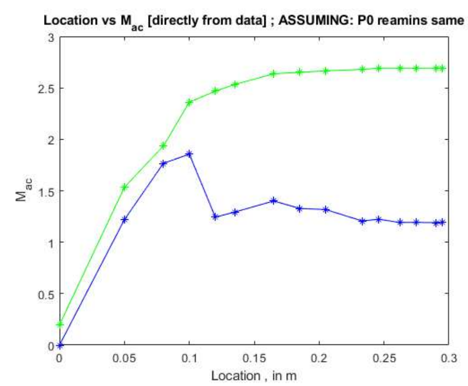

Length vs Mach number,M [P0 changes becuase of shock]
Mach number, M
Length , in m

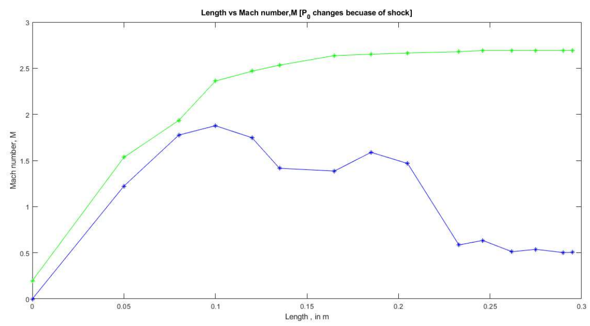

Location vs Mac [directly from data] ; ASSUMING: P0 reamins same
Mac
Location , in m

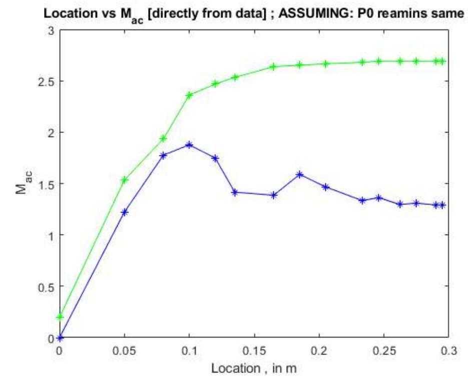

Length vs Mach number,M [P0 changes becuase of shock]
Mach number, M
Length , in m

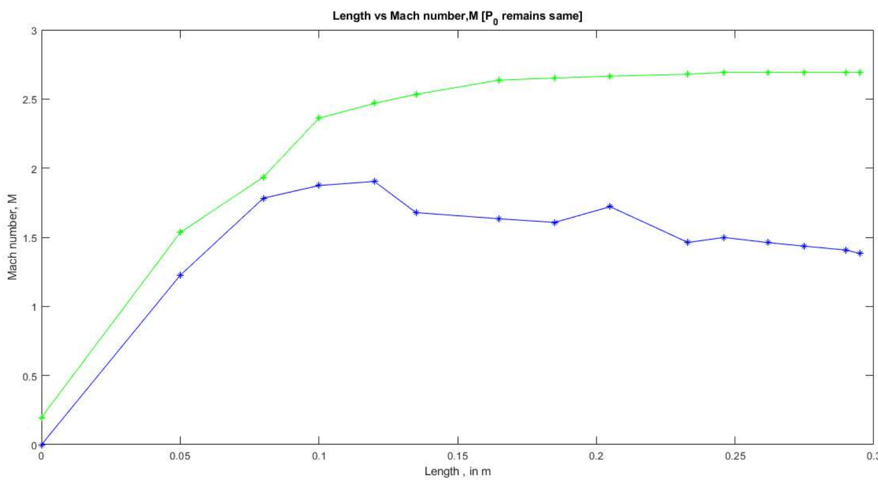

Location vs Mac [directly from data] ; ASSUMING: P0 reamins same
Mac
Location , in m

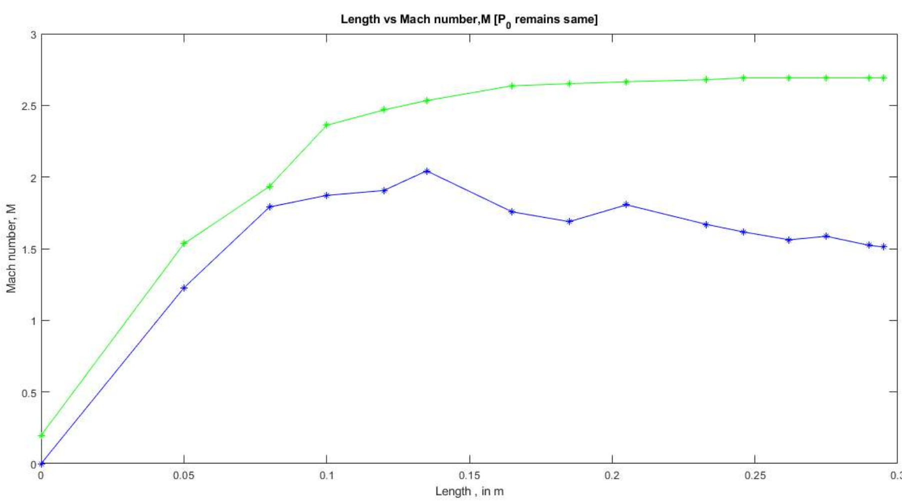

Length vs Mach number,M [P0 changes becuase of shock]
Mach number, M
Length , in m

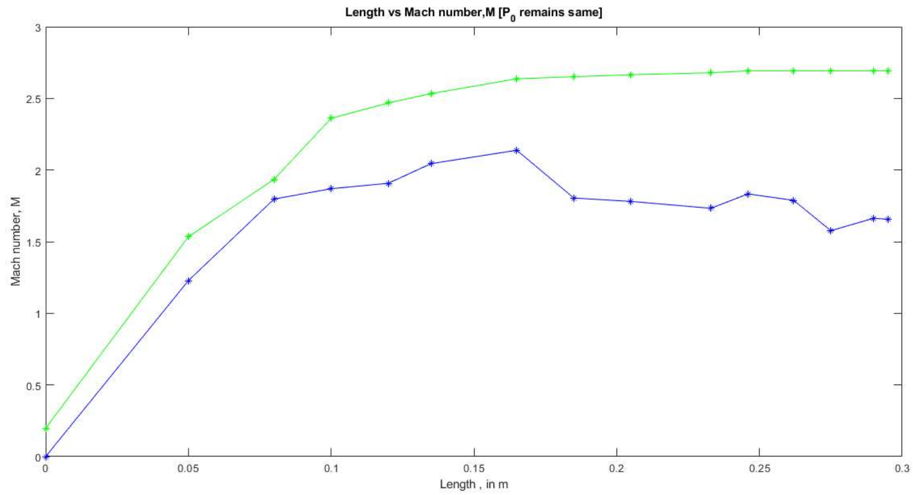

Location vs Mac [directly from data] ; ASSUMING: P0 reamins same
Mac
Location , in m

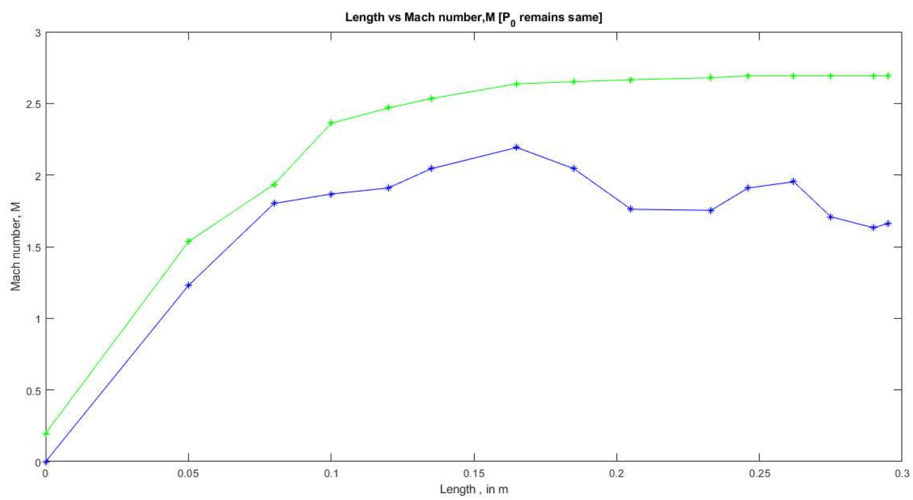

Length vs Mach number,M [P0 changes becuase of shock]
Mach number, M
Length , in m
0
0.5
1
1.5
2
2.5
3
0.05
0.1
0.15
0.2
0.25
0.3

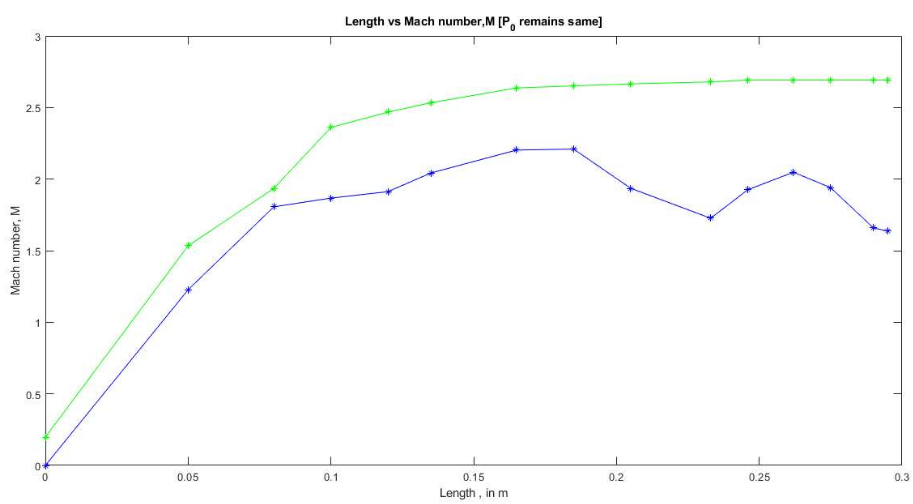

Location vs Mac [directly from data] ; ASSUMING: P0 reamins same
Mac
Location , in m
0
0.5
1
1.5
2
2.5
3
0.05
0.1
0.15
0.2
0.25
0.3

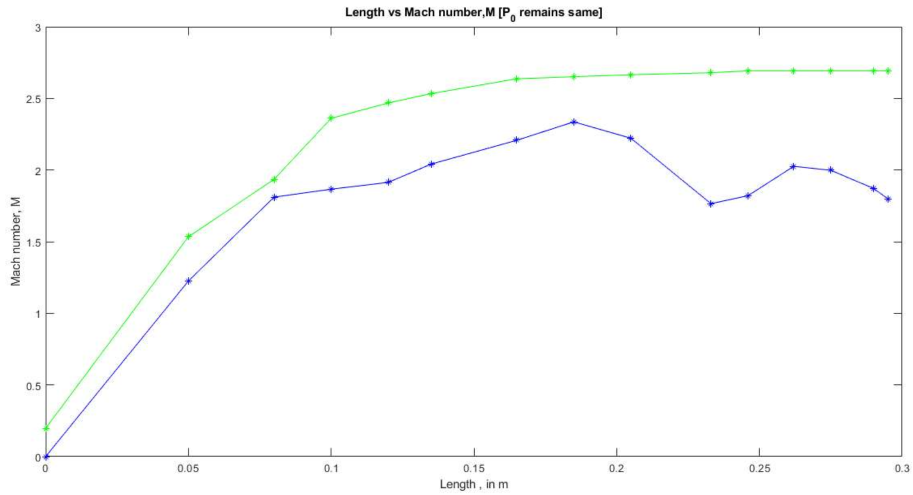

Length vs Mach number,M [P0 remains same]
Mach number, M
Length , in m
0
0.5
1
1.5
2
2.5
3
0.05
0.1
0.15
0.2
0.25
0.3

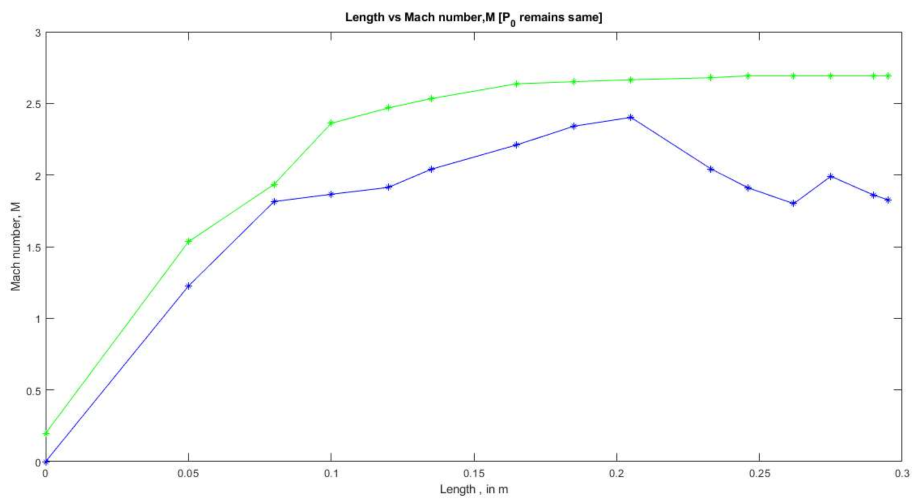

Length vs Mach number,M [P0 remains same]
Mach number, M
Length , in m
0
0.5
1
1.5
2
2.5
3
0.05
0.1
0.15
0.2
0.25
0.3

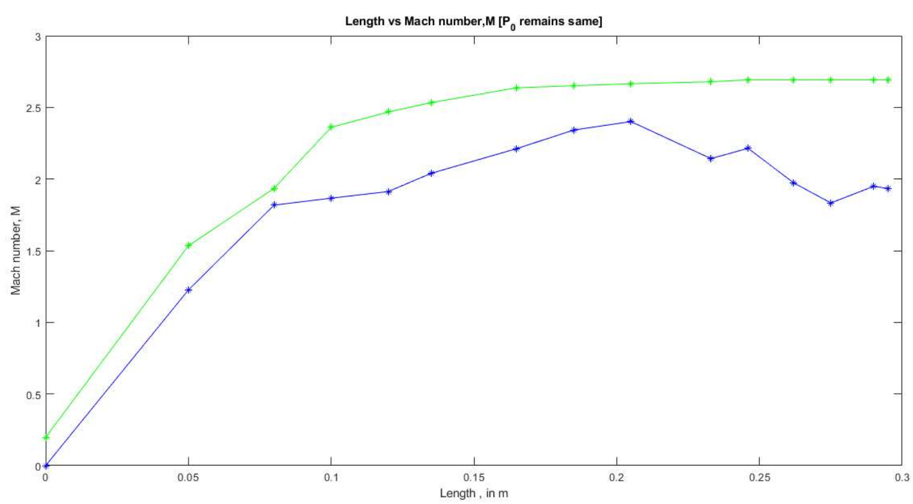

Length vs Mach number,M [P_0 remains same]
Mach number, M
Length , in m
0
0.5
1
1.5
2
2.5
3
0
0.05
0.1
0.15
0.2
0.25
0.3


Length vs Mach number,M [P_0 remains same]
Mach number, M
Length , in m
0
0.5
1
1.5
2
2.5
3
0
0.05
0.1
0.15
0.2
0.25
0.3


Length vs Mach number,M [P_0 remains same]
Mach number, M
Length , in m
0
0.5
1
1.5
2
2.5
3
0
0.05
0.1
0.15
0.2
0.25
0.3



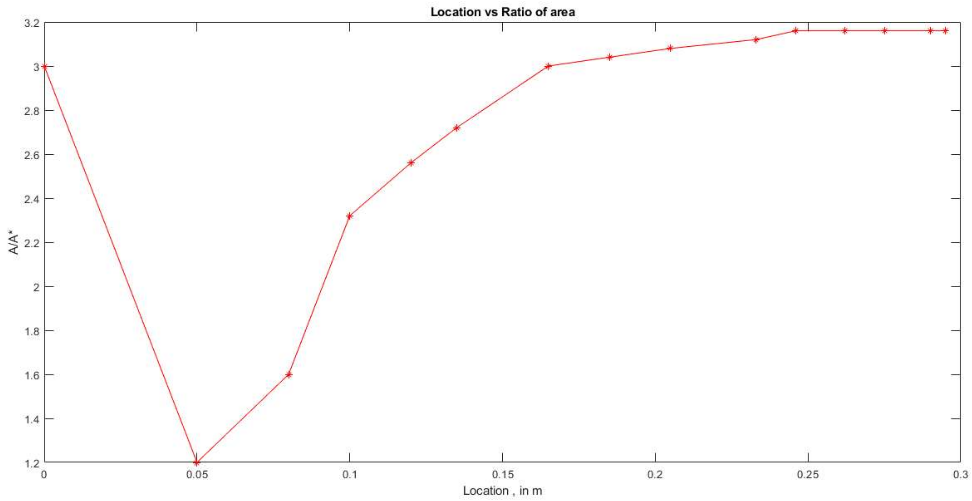




iv) Discuss what you have understood from this experiment.

- Normal Shocks are formed within the CD nozzle only in cases 1 → 5
- For cases 6 →13 The flow (in theory) should be isentropic throughout the nozzle.
- There is considerable loss of entropy even in cases 6→13 , this is because practically every isentropic process will involve some losses in entropy because of irreversibility.

- The approximate location of Normal shock can be obtained in cases 1→ 5



Serial number	Pb/P_chamber	The A/A* value @ Normal Shock in the CD Nozzle	Location of Normal Shock
1	0.732	1.57	~0.08m
2	0.596	1.98	~0.09m
3	0.492	2.40	~0.11m
4	0.422	2.77	~0.14m
5	0.370	3.09	~0.21m
6	0.328	overexpanded	-
7	0.295	overexpanded	-
8	0.266	overexpanded	-
9	0.247	overexpanded	-
10	0.228	overexpanded	-
11	0.210	overexpanded	-
12	0.197	overexpanded	-
13	0.186	overexpanded	-

Sources of Error:

1. Do not exceed the pressure limits of the settling chamber.
2. Make sure that there are no loose parts and there are no objects placed inside the duct.
3. Make sure that the pressure ports are not blocked by dust or any other materials.

- **Conclusion :**
  1. Normal Shocks are formed within the CD nozzle only in cases 1 → 5
  2. For cases 6 →13 The flow (in theory) should be isentropic throughout the nozzle.
  3. There is considerable loss of entropy even in cases 6→13 , this is because practically every isentropic process will involve some losses in entropy because of irreversibility.
- **Reference :**

- Pictures from Google, Lectures and Lecture Notes of AE351 (Lab7)
- http://www.dept.aoe.vt.edu/~devenpor/aoe3114/calc.html
- http://www.dept.aoe.vt.edu/~devenpor/aoe3114/CD%20Nozzle%20Sim/index.html

- **Appendix :**

```
%% Pressure in PSI || Location of pressure ports in m || Depth at different locations
in cm
% All data in the experiment

Pressure = [5.375 -6.184 -3.2896 -2.814 -1.6094 -0.6816 -0.347 -0.1434 -0.1176 -0.0318
-0.0864 -0.0172 -0.0318 -0.0294 -0.0358;
   9.94 -4.695 -7.184 -3.8212 -3.5826 -2.6192 -1.4648 -0.6644 -0.327 -0.1184 -0.1104
-0.0634 -0.0332 -0.025 -0.0142;
   15.1586 -2.6292 -9.0744 -4.6304 -4.5738 -3.826 -2.972 -1.6404 -0.8356 -0.2008
-0.2398 -0.0728 -0.0746 -0.0518 -0.0582;
   20.1438 -0.6858 -8.3106 -9.1292 -1.1308 -1.9964 -3.7598 -2.5976 -2.4164 -0.4546
-0.7542 -0.1694 -0.1784 -0.128 -0.1556;
   25.0022 1.2028 -7.5234 -8.5608 -7.1974 -2.4946 -1.9648 -5.1976 -3.359 -1.0246
-1.5498 -0.282 -0.5394 -0.1928 -0.212;
   30.0622 3.173 -6.6962 -7.7418 -8.054 -5.3246 -4.6784 -4.2776 -5.9128 -1.826 -2.475
-1.8018 -1.3196 -0.777 -0.2708;
   35.1828 5.1682 -5.8968 -6.9214 -7.3194 -8.7348 -5.4208 -4.417 -6.0972 -4.1176 -3.246
-2.2842 -2.725 -1.5574 -1.3402;
   40.6148 7.287 -5.0298 -6.046 -6.5364 -8.102 -8.9958 -5.136 -4.7832 -4.0336 -5.5504
-4.8908 -1.227 -2.8594 -2.729;
   44.9086 8.9774 -4.3464 -5.343 -5.9348 -7.5802 -9.0542 -7.5862 -3.6908 -3.558 -5.9222
-6.5034 -2.7756 -1.31 -1.9226;
   49.6962 10.9382 -3.5968 -4.5878 -5.2704 -6.995 -8.7012 -8.7668 -5.6036 -2.1652
-5.4602 -7.0606 -5.6648 -0.8182 -0.3568;
   55.3254 13.2452 -2.7088 -3.689 -4.4648 -6.3048 -8.2244 -9.4042 -8.3646 -1.8438
-2.8944 -6.1004 -5.7212 -3.7678 -2.4816;
   60.076 15.1628 -1.9764 -2.9308 -3.7646 -5.7184 -7.8134 -9.0846 -9.6002 -5.7588
-3.725 -1.685 -5.0104 -2.8232 -2.213;
   64.4112 16.8462 -1.3012 -2.263 -3.121 -5.192 -7.4386 -8.7742 -9.2934 -6.6006 -7.4636
-4.1518 -1.611 -3.755 -3.4958]+14.6959;

% location in m
Location = [0 0.05 0.08 0.1 0.12 0.135 0.165 0.185 0.205 0.233 0.246 0.262 0.275 0.29
0.295];

% Depth in cm
Depth = [7.5 3 4 5.8 6.4 6.8 7.5 7.6 7.7 7.8 7.9 7.9 7.9 7.9 7.9];

% depth of throat in cm
Depth_throat = 2.5;

% gamma of air
gamma = 1.4;
% atmospheric pressure in PSI
P_atm = 14.6959;

%tiledlayout(2,2)

%% plot of A/A* vs Location
RatioOfArea = Depth./Depth_throat;

%nexttile;
plot(Location,RatioOfArea,'-*r');
xlabel("Location , in m");
ylabel("A/A*");
title("Location vs Ratio of area");
```

```
%% calculation of pressure Ratio from the Experimental data

RatioOfPressure = zeros(13,15);
for j=(1:1:15)
   RatioOfPressure(:,j) = (Pressure(:,j)./Pressure(:,1));
end


%% when flow is choked
% the distribution of M wrt position

% M_1: Mach number calculated using the 1st formula (subsonic ; Supersonic
solution)

M_1 = [0.197 0.590 0.397 0.260 0.233 0.219 0.197 0.195 0.192 0.189 0.187 0.187 0.187
0.187 0.187;
      2.637 1.534 1.935 2.361 2.468 2.533 2.637 2.651 2.665 2.679 2.692 2.692 2.692
2.692 2.692];

M_1_plot = [M_1(1,1),M_1(2,2:end)];

%nexttile;
plot(Location,M_1_plot,'-*g');
xlabel("Location , in m");
ylabel("Mach number,M [calculated from 1st formula]");
title("Location vs M [choked flow]");

%nexttile;

% Pressure ratio calculated for the above Mach no. distribution

PressureRatio_Choked = zeros(13,15);

for i=(1:1:13)
   PressureRatio_Choked(i,:) =  1./((1+(gamma-1)/2 *
M_1_plot.^2).^(gamma/(gamma-1)));
end

plot(Location,PressureRatio_Choked(1,:),'-*g');
xlabel("Location , in m");
ylabel("Pressure Ratio P/P_0 [calculated from Mach no. obtained from 1st
formula]");
title("Location vs P/P_0 [choked flow]");

%% plot of Pressure Ratio from Experimental data
%nexttile;
Pb_ratio=P_atm./Pressure(:,1);

plot(Location,RatioOfPressure(1,:),'-*b');
xlabel("Location , in m");
ylabel("P_x/P_0");
title("Location vs Px/P0 [directly from data] ; ASSUMPTION: P0 reamins same");

plot(Location(1,15),Pb_ratio(1,1),'og');

plot(Location,PressureRatio_Choked(1,:),'-*g');

plot(Location,M_1_plot,'-*g');
xlabel("Location , in m");
ylabel("Mach number,M_{isen} ");
title("Location vs M_{isen} ");

plot(Location,PressureRatio_Choked(1,:),'-*g');
```

```
xlabel("Location , in m");
ylabel("Pressure Ratio P/P_0 [isen]");
title("Location vs P/P_0 [isen]");

plot(Location,RatioOfArea,'-*r');
xlabel("Location , in m");
ylabel("A/A*");
title("Location vs Ratio of area");
%%
P_02 = [0.776; 0.656; 0.544; 0.479; 0.434; 1; 1; 1; 1; 1; 1; 1; 1].* Pressure(:,1);

RatioOfPressure = zeros(13,15);
for j=(1:1:15)
   RatioOfPressure(:,j) = (Pressure(:,j)./Pressure(:,1));
end

for j=(3:1:15)
   RatioOfPressure(1,j) = (Pressure(1,j)./P_02(1,1));
end

for j=(4:1:15)
   RatioOfPressure(2,j) = (Pressure(2,j)./P_02(2,1));
end

for j=(5:1:15)
   RatioOfPressure(3,j) = (Pressure(3,j)./P_02(3,1));
end

for j=(7:1:15)
   RatioOfPressure(4,j) = (Pressure(4,j)./P_02(4,1));
end

for j=(10:1:15)
   RatioOfPressure(5,j) = (Pressure(5,j)./P_02(5,1));
end

i=13;
Mac = (((1./RatioOfPressure(i,:)).^((gamma-1)/gamma) - 1 ).*(2/(gamma-1))).^0.5;

plot(RatioOfArea,Mac,'*b');
xlabel("A/A*");
ylabel("M_{ac}");
title("A/A* vs M_{ac}");
```

****