AS3510 Normal Shock in CD Nozzle

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In this lab, compressible gas flow through a piping system consisting of a critical flow CD nozzle, pressure gauges, flow meters, Suction Compressor was observed. Consider the flow in a convergent-divergent nozzle. The upstream stagnation conditions are assumed constant. The pressure in the exit plane of the nozzle is denoted by P_e. The nozzle discharges to the backpressure P_b. When a flowing fluid at a given pressure and temperature passes through a constriction (such as the throat of a convergent-divergent nozzle) into a lower pressure environment (Pb) the fluid velocity increases. Initially, in subsonic upstream conditions, the conservation of mass principle requires the fluid velocity to increase as it flows through the smaller cross-sectional area of the constriction. At the same time, the venturi effect causes the static pressure, and therefore the density, to decrease at the constriction. Thus Choked flow is achieved, on further reduction of the backpressure, the flow upstream of the throat does not respond. However, if the backpressure is reduced further, the flow initially becomes supersonic in the diverging section, but then adjusts to the backpressure by means of a normal shock standing inside the nozzle.

In such cases, the position of the shock moves downstream as P_b is decreased, and for curve, the normal shock stands right at the exit plane.

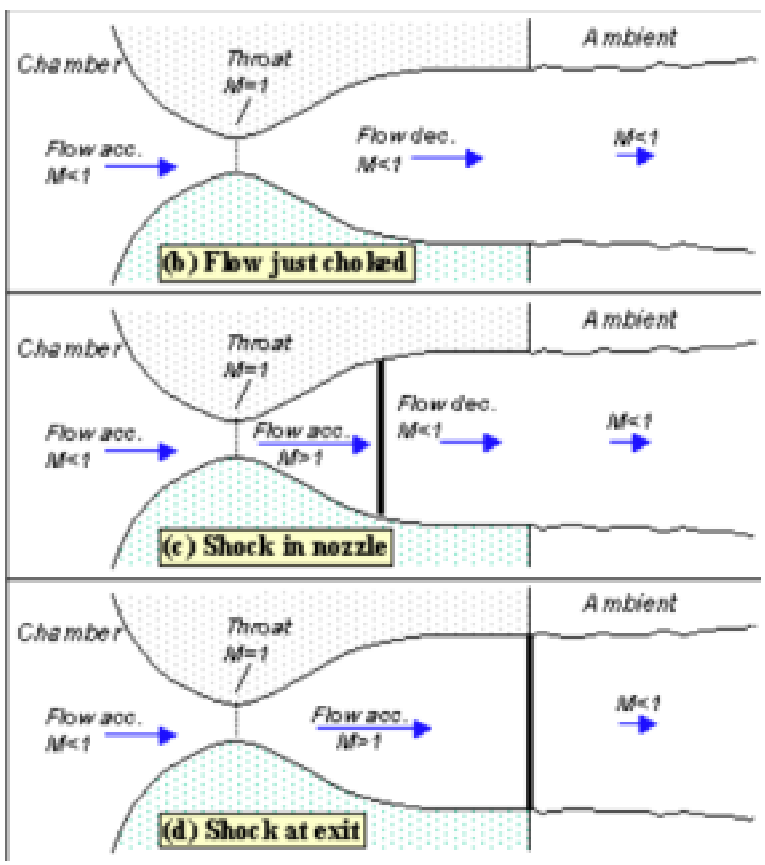

Figure 1: Transition of shock from Choked to at nozzle condition

In the above figure we can see how as we decrease the downstream pressure from the choked condition the shock moves from the throat to the exit of Nozzle. In order to compensate for the supersonic flow condition due to loss in downstream pressure, the Normal Shock forms inside the divergent portion of the Nozzle which moves towards the exit as the pressure drops.

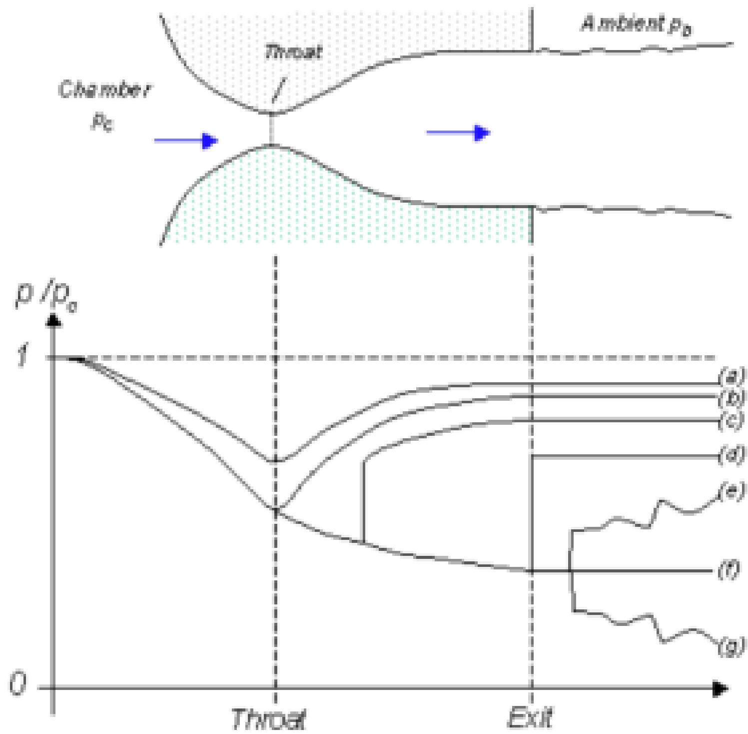

Figure 2: Pressure Ratio variation with shock position

(a) Flow through the nozzle when the flow is completely subsonic

(b) Choked Flow: Constraining condition on the nozzle as the flow accelerates and the throat reaches Mach 1.

(c) Supersonic flow just beyond the throat as the pressure P_b dropped further and a Normal Shock formed.

(d) At this point, the pressure P_b has been dropped enough that the normal shock reached the exit of the divergent portion of the nozzle.

(e) The points below this are for over-expanded and under-expanded cases.

Experimental Setup

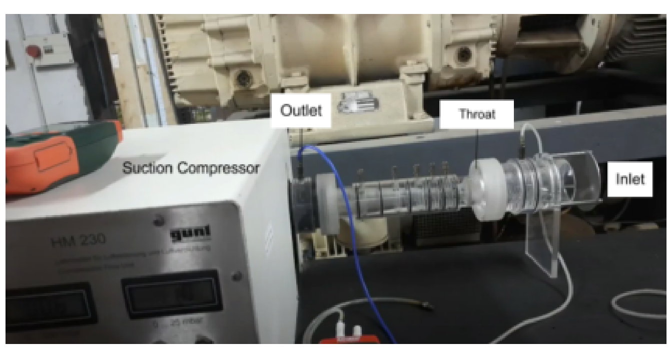

Figure 3: Experimental Setup The Setup is comprised of a Suction compressor attached to the outlet of the CD Nozzle with the inlet of the Nozzle open to the atmosphere. In this manner, the inlet pressure and temperature are constant while we are able to control the outlet pressure (Pb). We have a pressure probe attached to the throat of the nozzle and at the outlet, we also have a probe to measure the inlet velocity.

In order to find the pressure ratio variation with mass flow rate, we decrease the downstream pressure for the atmospheric pressure until the choked flow is observed.

Dimensions of the CD Nozzle:

- Inlet Diameter: 34 mm
- Outlet Diameter: 30.4 mm
- Throat Diameter: 12 mm
- Density of air: 1.225 kg/m3
- Atmospheric Pressure: 1.01325 bar
- γ : 1.4

Divergent Section Geometry:

- Throat Diameter: 12 mm
- Exit Diameter: 30.4 mm
- Senors:
  - Sensor 1: 12 mm
  - Sensor 2: 14.2 mm
  - Sensor 3: 17.6 mm
  - Sensor 4: 22.6 mm
  - Sensor Exit: 30.2 mm

Procedure

The experiment is conducted on the pre-assembled system of a suction compressor and CD Nozzle. There are five sensor slots on the divergent section of the nozzle, all of these are present at the different thicknesses of the divergent section and one of them is at the exit.

- We will be setting the backpressure P_b at a point below choked pressure condition such that a normal shock forms in the nozzle.
- Take a reading at all four sensors on the divergent section and record the gauge pressure in Millie bar pressure.
- Repeat for another P_b value and record again at all points.

Results

Sensors (mm)	P_{b1} = 98.125kPa	P_{b2} = 79.525kPa
12	80.625	55.625
14.2	91.125	51.525
17.6	95.525	70.225
22.6	97.025	76.825
30.2	97.725	79.225

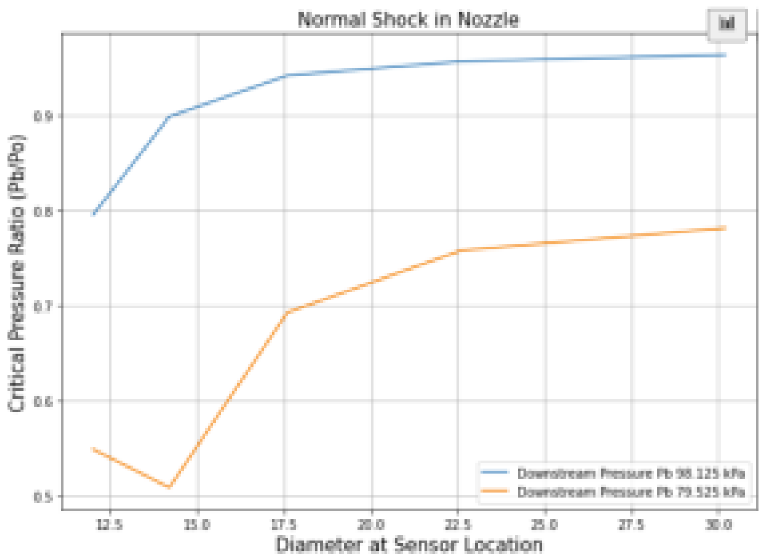

Figure 4: Normal Shock in Divergent Section of Nozzle Data Plot

From the above figure we can see for the orange plot there is a sudden drop in the pressure ratio at sensor 2 (14.2 mm). So we can see that the flow between sensors 1 and 2 is supersonic and a shock is present between sensor 2 and while the blue plot continuously increases and plateaus as we travel down the divergent section of the nozzle. Thus we can see that the normal shock is probably present between sensors 1 and 2.

Conclusion

From the above calculation we can see for the orange plot where the exit pressure ratio is 0.785. We notice from the plot that the normal shock is present between sensor 2 and sensor 3.

Thus the area ratio of the shock location *experimentally* is between [1.4, 2.151].

Through calculation we got the *theoretical value* of area ratio at shock location is $\frac{A}{A^*} = 1.49$.

For the blue plot where the exit pressure ratio is 0.968. we notice from the plot that the normal shock is present between sensor 2 and sensor 3

Thus the area ratio of the shock location *experimentally* is between [1, 1.4].

Through calculation we got the *theoretical value* of area ratio at shock location is $\frac{A}{A^*} = 1.079.\ 6$