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Fabrication of an Experimental Setup to Study the Flow through a Convergent-Divergent Nozzle

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Abstract: ***Nozzle is a flow passage of varying cross sectional area. It is the most important and basic piece of engineering hardware associated with propulsion and the high speed flow of gases. This is intended to visualize the flow through this type of nozzle at a range of conditions. The usual configuration for a converging diverging (CD) nozzle is shown. Gas flows through the nozzle from a region of high pressure (usually referred to as the chamber) to one of low pressure (referred to as the ambient). The chamber is usually big enough so that any flow velocities here are negligible. The pressure here is denoted by the symbol P. Gas flows from the chamber into the converging portion of the nozzle, past the throat, through the diverging portion and then exhausts into the ambient as a jet. The ambient pressure at different cross sectional position of the nozzle is referred as the 'back pressure' and given the symbol P_b. An experimental setup is designed to measure the P_b for a fixed value of P and a plot between the axial length versus pressure ratio is plotted which shows the flow behaviour at different chamber pressures. The axial length is taken from the nozzle throat. Bourdon pressure gauges are used to measure the pressure the bourdon gauges are stationary and the nozzle is moving axially with the help of rotating spindle attached to it.***

Keywords: ***Cylindrical flow passage, Back pressure, CD nozzle, ambient pressure.***

1. Introduction

A nozzle is a device designed to control the direction or characteristics of a fluid flow (especially to increase velocity) as it exits (or enters) an enclosed chamber or pipe via an orifice. A nozzle is often a pipe or tube of varying cross sectional area and it can be used to direct or modify the flow of a fluid (liquid or gas). Nozzles are frequently used to control the rate of flow, speed, direction, mass, shape, and or the pressure of the stream that emerges from them [1]. Steady flow of a gas through a nozzle which has a varying cross sectional area i.e. Compressible gas flows through a nozzle whose cross-sectional area is varying, occur in many engineering devices, e.g., in the nozzle of a rocket engine and in the blade passages in turbo machines. It will be assumed that the flow can be adequately modelled by assuming it to be One-dimensional at all sections of the nozzle, i.e., quasi-one-dimensional flow will be assumed. It will also be assumed in studying the effects of changes in area on the flow that

The flow is isentropic everywhere except through any shock waves that may occur in the flow [2]. The term compressible flow is routinely used to define variable density flow which is in contrast to incompressible flow, where the density is assumed to be constant throughout. In many cases, these density variations are principally caused by the pressure changes from one point to another. Physically, the compressibility can be defined as the fractional change in volume of the gas element per unit change in pressure. It is a property of the gas. [3] According to the assumptions introduced, are valid only for isentropic flow, since the variation of the density is assumed to be isentropic. Mach number and pressure distribution can be determined for an area distribution prescribed in the stream wise direction. The flow in the nozzle solely depends on the pressure in the exit cross section.[4] This assumption is Usually quite adequate since the effects of friction and heat transfer are usually restricted to a thin boundary layer in the types of flows here being considered and their effects can often be ignored. [2]

2. Flow Behaviour in a Convergent–Divergent Nozzle

The operating characteristics of nozzles it will be assumed that the nozzle is connected to an upstream chamber in which the conditions, i.e., the upstream stagnation conditions, are kept constant while the conditions in the downstream chamber into which the nozzle discharges are varied. The pressure in the downstream chamber is termed the back pressure. The nature of the flow can be explained by considering how the flow in the nozzle changes as the back pressure P_b is decreased [2]. When the gas exits the nozzle at supersonic speeds, it undergoes several flow phenomena depending on the nozzle pressure ratio [8]. The flow regimes are then as shown in Figure (1) [9] It shows the flow through the nozzle when it is completely subsonic (i.e. nozzle isn't choked). The flow accelerates out of the chamber through the converging section, reaching its maximum (subsonic) speed at the throat. The flow then decelerates through the diverging section and exhausts into the ambient as a subsonic flow. Lowering the back pressure in this state increases the flow speed everywhere in the nozzle. Further lowering P_b results in flow pattern is exactly the same as in subsonic flow, except that the flow speed at the throat has just reached Mach equal to one.

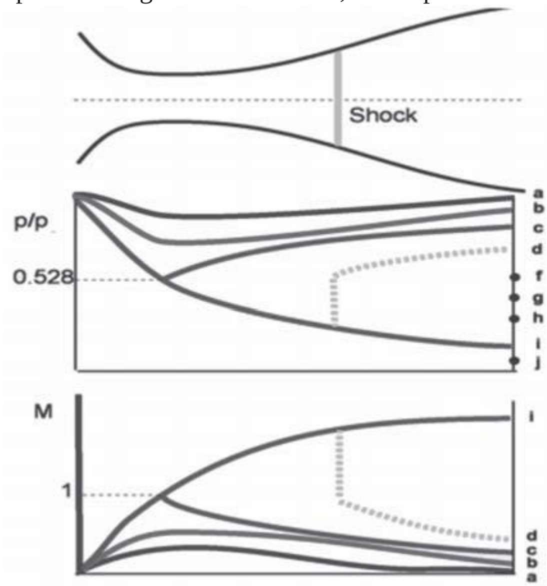

Fig. 1 Flow through Convergent Divergent Nozzle

3. Experimental Facilities

The aim of this laboratory experiment is to study the behaviour of supersonic gas flow. To complete the work successfully we need to understand the properties of supersonic flow as well as equipment and techniques required to perform measurement of this flow.

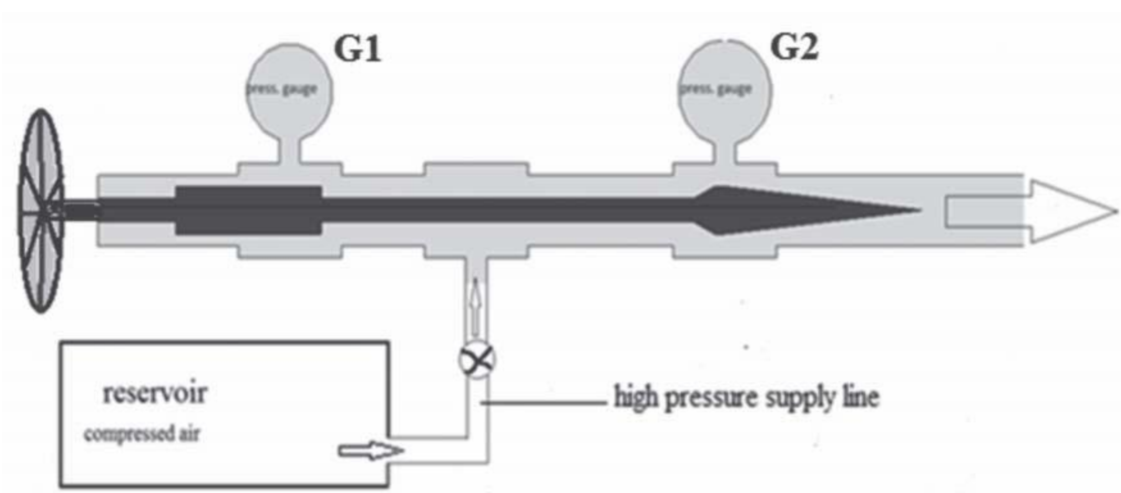

Fig 2. Schematic of Equipment Connections

4. Arrangements

The setup (fig 2) is made to study the flow through convergent divergent nozzle.

Type of pressure gauge-Bourdon stationary pressure gauge

Type of nozzle - Axially moving, manually operated

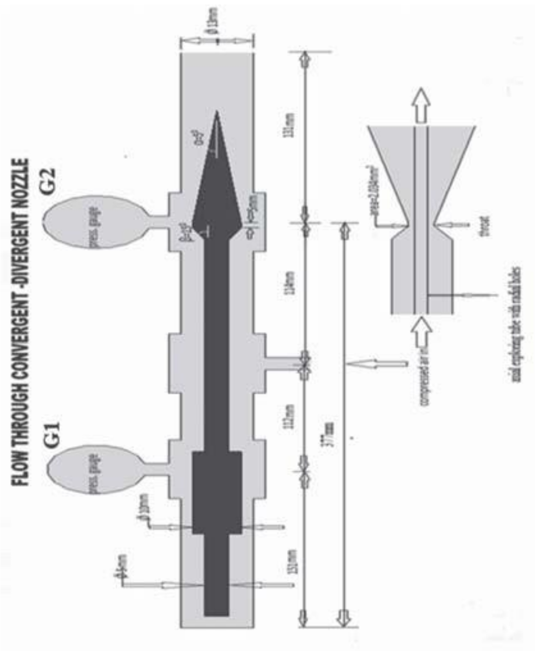

Fig. 3 Convergent- Divergent Nozzle

5. Experimental Procedure:

The above setup is developed to study the flow of air through convergent divergent nozzle. The high-pressure gas supply line is attached via a manually operated valve to the converging-diverging two-dimensional nozzle. A cylindrical tube containing the bourdon pressure gauge mounted at two different locations, one is at upstream flow station and other at the downstream position. Using this pressure gauge, static pressure variation along the nozzle length can be determined. The static pressure to stagnation pressure ratio at any point along the channel can be measured. Once the valve is open to give sufficient upstream stagnation pressure, as indicated by the bourdon gauge G1. the downstream pressure at different cross section of the nozzle can be read out on the bourdon pressure gauge G2 mounted on the downstream flow. The position of the nozzle cross section can be changed by manually operated axial which can be moved with the rotation of spindle.

Once the upstream pressure is fixed the downstream pressure at different locations is measured. And measure the ratio of downstream pressure to the upstream pressure is measured. Different pressure ratios give different mass flow rate and different values of flow velocity at different locations. Nozzle will choke giving Mach 1 flow at the throat. Downstream of the throat (area A*) the flow Mach number will depend primarily on the area ratio of the channel (A/A*) and a supersonic flow.

Nozzle specifications:

Throat area $A^* = \frac{\pi}{4}(13^2 - 12.9^2)$ mm^2
$= 2.034$ mm^2

Maximum Area ratio $= \dfrac{\frac{\pi}{4}(13^2)}{2.034}$ = **65.25**

6. Static Pressure Recordings

Absolute Ambient Lab conditions
Absolute pressure in lab = **1.003kgf/cm^2**
Temperature = **29^{0}c**
Table 1.
Pressure Recording at Each Nozzle locations

STATIONS	0	1	2	3	4
POSITIONS(mm)	-5	0	5	10	15
UPSTREAM PRESSURE absolute (kgf/cm^2)P	pressure at different nozzle stations(P_b) kgf/cm^2				
2	1.8	1.8	1.8	1.2	1
3	2.9	2.8	2.8	2.2	1
4	3.9	3.9	3.9	3.0	1
5	5.0	5.0	5.0	3.8	1.28
6	6.0	6.0	5.0	4.6	1.8
11	11.2	11.2	11.2	9.0	3.4

Table 2.
Pressure ratio versus axial length recordings

STATIONS	0	1	2	3	4
POSITIONS (mm)	-5	0	5	10	15
UPSTREAM PRESSURE absolute (kgf/cm^2) P	Pressure ratio P_b/P				
2	0.9	0.9	0.9	0.6	0.5
3	0.96	0.933	0.933	0.733	0.33
4	0.975	0.975	0.975	0.75	0.25
5	1.0	1.0	1.0	0.76	0.256
6	1.0	1.0	1.0	0.767	0.3
11	1.02	1.02	1.02	0.818	0.309

7. Results

Plot of pressure ratio versus axial length from throat based on the above experimental data is as follows.

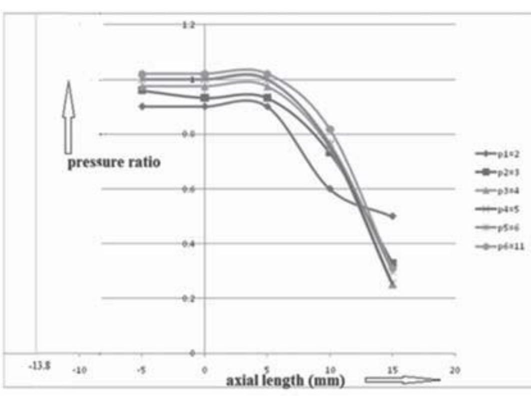

Fig. 4 Pressure Ration Versus Axial Length

The pressure ratio versus axial length is plotted as shown, for different upstream pressures p_1, p_2, p_3, p_4, p_5 and p_6 as the upstream pressure increases the pressure ratio at the throat increases. And on moving along the axial direction the pressure ratio decreases for just chocked condition at the throat the required pressure ratio is 0.5283 the pressure ratio above this shows the subsonic flow and below the flow is supersonic. When the chocked condition at the throat is reached the mass flow rate is maximum. On further reduction of the pressure ratio no mass flow rate is increased, the shock wave formation takes place along downstream the measurement of pressure is made by the bourdon pressure gauge which might be contained some measurement error therefore for the correct measurement the pressure transducer can be used so that high frequency shock wave formation can be located.

The manually operated spindle introduce some scale reading differences which does not locate the correct nozzle cross section position this gives the differences in pressure ratios and the positions of shock waves cannot be located exactly.

References

[1] Khan, A. A. ; Shembharkar, T. R., (2008) ,"Viscous flow analysis in a convergent-divergent nozzle", Proceedings of the International Conference on Aerospace Science and Technology 26 - 28 June 2008, Bangalore, India,.

[2] Patrick H. O. ; William E. C. (1997), "Compressible Fluid Flow", The Mcgraw-Hill companies, INC..

[3] Kreith, F.; Berger, S.A.; et. al. (1999) , "Fluid Mechanics", Handbook, Ed. Frank Kreith Boca Raton: CRC Press LLC,.

[4] Krause, E ; Aachen, R, (2005) "Fluid mechanics with problems and solutions and an aerodynamic laboratory " Aerodynamics Institute, Germany ,ISBN 3-540-22981-7 Springer Berlin Heidelberg New York.

[5] Ekanayake, E. M. S. ; Gear, J. A. Y. Ding (2010) , " Flow simulation of a two dimensional rectangular supersonic convergent divergent nozzle" ANZIAM J. 51n (EMAC2009) PP.C377-C392,.

[6] Kirk, D. R., "Gas Turbine Engine Nozzles" mae 4261: air-breathing engines Mechanical and Aerospace Engineering Department Florida Institute of Technology.

[7] Nicholas J. Georgiadis, Teryn W. DalBello , Charles J. Trefny , and Albert L. Johns, (2006) "Aerodynamic Design and Analysis of High Performance Nozzles for Mach 4 Accelerator Vehicles " T44th AIAA Aerospace Sciences Meeting and Exhibit 9 - 12 January, 2006 Reno, Nevada