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ANALYSIS OF FLOW CHARACTERISTICS OF DE LAVAL NOZZLE

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Abstract

The work's primary aim is to examine the performance and flow characteristics of a convergent divergent nozzle, as well as to compare numerical data using various approaches." We investigated the location and strength of the normal shock wave in the divergent region of the nozzle under various operating conditions and with various nozzle geometries in this paper**.**

Keywords: Mach number, Sub-sonic, Super-sonic, Sonic, Compressible flow, Throat.

1. Introduction

A nozzle is a relatively simple device that consists of a specifically formed tube that allows hot gases to flow through it. However, the mathematics that describes the nozzle's operation necessitates some thought. Nozzles are available in a wide range of forms and sizes. A fixed geometry convergent nozzle is common on simple turbojets and turboprops. A co-annular nozzle is commonly used in turbofan engines. The core flow exits the central nozzle, while the annular nozzle exits the fan flow. The mixing of the two flows increases thrust, and these nozzles are also quieter than convergent nozzles.

A variable geometry convergent-divergent CD nozzle is required for afterburning turbojets and turbofans. The flow in this nozzle first converges down to the smallest area, or throat, before expanding via the divergent segment to the right exit. These nozzles are heavier than fixed geometry nozzles because of the variable geometry, however variable geometry allows more efficient engine running across a larger airflow range than a conventional fixed nozzle. Nozzles are also used in rocket engines to accelerate hot exhaust and generate thrust. A fixed geometry CD nozzle is used in rocket engines, having a significantly greater divergent section than is required for a gas turbine.

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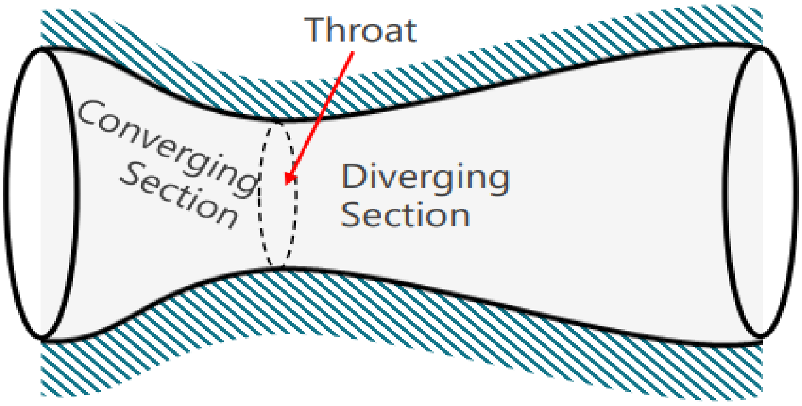

Figure1 CD Nozzle profile

2. Problem in flow by De-Laval Nozzle

A propagating disturbance is a shock wave (sometimes known as a shock front or simply "shock"). It transports energy and can propagate via a media (solid, liquid, or gas) or, in some situations, through a field such as the electromagnetic field in the absence of a material medium. Shock waves are defined by a sudden, practically discontinuous shift in the medium's characteristics. The pressure, temperature, and density of the flow all climb extraordinarily quickly through a shock. An expansion fan is used to create supersonic flow expansion. A shock wave travels at a faster rate through most medium than a regular wave.

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During the flow through CD Nozzle there have some number of concept and assumption while analysing the fluid flow. The following assumptions are listed below:
For analysis,

- The gas to be ideal.
- The gas flow is isentropic. Subsequently the stream is reversible (frictionless and no dissipative misfortunes), and adiabatic
- The gas flow is constant and steady during the period of the propellant burn.
- The gas flow is asymmetric along a straight line from inlet to exhaust gas exit.
- The flow is compressible at very high velocities (Mach number > 0.3).

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3. Analytical Approach

In this phase the analytical approaches has follow to find out the location of shock in CD nozzle. There are set of formula to determine the approximate location of shock.

STEP 1: To find the pressure ratio that will produce shock in the divergent portion of the nozzle.

STEP 2: Determine exit Mach number (M_e)

$$(Me)^2 = \frac{-1}{\gamma-1} + \sqrt{\left(\frac{1}{\gamma-1}\right)^2 + \left(\frac{2}{\gamma-1}\right)\left(\frac{2}{\gamma+1}\right)\left(\frac{2}{\gamma+1}\right)^{\frac{\gamma+1}{\gamma-1}}\left(\frac{P_{01}}{P_e}\right)^2\left(\frac{A_t}{A_e}\right)^2}$$

STEP 3: Use Me to determine $\frac{P_e}{P_{02}}$

$$\frac{p_{02}}{p_e} = \left(1 + \frac{Y-I}{2}M_e^2\right)^{\frac{y}{y-I}}$$

STEP 4: Since $M_e<1$, $P_e= P_b$

$$\frac{p_{02}}{P_{01}} = \frac{p_b}{P_{01}} * \frac{p_{02}}{p_e}$$

STEP 5: Determine M_1, by using the value of $\frac{P_{02}}{P_{01}}$

$$\frac{p_{02}}{p_{01}} = \left(\frac{\frac{y+1}{2}M_1^2}{1+\frac{y-1}{2}M_1^2}\right)^{\frac{y}{y-I}}\left[\frac{1}{\frac{2y}{y+1}M_1^2 - \frac{y-1}{y+1}}\right]^{\frac{1}{Y-1}}$$

STEP 6: Determine Shock Location $\frac{A_S}{A_t}$

$$\frac{A_s}{A_t} = \frac{1}{M_1}\left[\left(\frac{2}{y+1}\right)\left(1+\frac{y-1}{2}M_1^2\right)\right]^{\frac{y+1}{2(Y-1)}}$$

STEP 7: Determine Shock Strength

$$\frac{p_y - p_x}{p_x} = \left[\frac{2y}{y+1}(M_1^2 - 1)\right]$$

STEP 8: Determine Temperature Ratio across the shock

$$\frac{T_2}{T_1} = \frac{\left(1 + \frac{y-1}{2} M_1^2\right)\left(\frac{2y}{y-1} M_1^2 - 1\right)}{\left(\frac{(y+1)^2}{2(y-1)}\right) M_1^2}$$

STEP 9: Determine Pressure Ratio across the shock

$$\frac{p_2}{p_1} = \frac{2y M_1^2}{y+1} - \frac{y-1}{y+1}$$

STEP 10: Determine density ratio across the shock

$$\frac{\rho_2}{\rho_1} = \frac{(y+1) M_1^2}{(y-1) M_1^2 + 2}$$

4. Numerical (Mat Lab) Method

The mat lab is one of the most useful and interactive numerical analysis software which is based on the mathematical formulation and programing method for analysis of any liner and nonlinear problem. In our case the input is the area ratio of throat and exit area of nozzle along with initial pressure ratio. Based on the input and boundary condition the program is developed to find out the shock location and after shock in divergent location.

Input

Ae/At=1.53

Pe/Po =.75

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Output

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y=1.40 Ae/At=1.530 P_e/P_o=0.75

M_e = 0.492512

P_{02}/P_e = 1.180346

P_{02}/P_{01} = 0.885259

M_1 = 1.627000

A_s/A_t = 1.272489

$(P_y-P_x)/P_x$ = 1.921650

T_2/T_1 = 1.406696

P_2/P_1 = 2.921650

Rho_2/Rho_1 = 2.076959

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5. Result of CD Nozzle

Table 1 Comparison Between Analytical And Numerical Method

Properties	Analytical Method	Matlab Result
M_e	0.49	0.49251
P02/P01	0.8838	0.88526
M_1	1.63	1.627
T_2/T_1	1.41	1.4067
P_2/P_1	2.93	2.92165
A_s/A_t	1.274	1.27249
$(P_y-P_x)/P_x$	1.922	1.92165

The results tabulated above are for nozzle geometry with an area ratio of 1.53, working fluid is air with specific heat ratio $\gamma = 1.4$. For this area ratio the range of pressure ratio between which shock will produce inside the nozzle, i.e. range of pressure ratio between 1st and 2nd critical point varies from 0.881 to 0.6093. All the operating pressure ratio between this pressure ranges will generate a shock wave in the divergent portion of the convergent divergent nozzle. Both method shows vary good agreement and close to each other so we can say that the approach is moving in the right direction to find out the shock location in divergent area.

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