Development of Intake System of Subsonic and Supersonic Ramjet Engine
Dhvanil S. Joshi1 Deep S. Patel2 Dhaval K. Esotiya3
1,2,3Department of Automobile Engineering
1,2,3Indus University, Ahmedabad, Gujarat, India

Abstract—Intake system of Ramjet Engine plays important role in the development of Ramjet engine since it is required to meet the function of Compressor for the gas turbine. These engines are normally designed for supersonic speeds. However authors have designed, analyses and also developed the intake system for subsonic Ramjet engine for Mach 0.5 and also Supersonic Engine at March 2.8. Several papers are available for supersonic design but authors are not able to put their hand on subsonic intake system for Ramjet engine. This paper provides the design and development of a 2D rectangular geometry of suction system for Ramjet engines. The design is further verified by simulating 2D CFD using Ansys software.

Key words: Ramjet, Subsonic, Supersonic, Oblique Shockwave, Normal Shockwave, CFD, Pressure

I. INTRODUCTION
Ramjet engine is one of the several air breathing engines which are developed for space applications. The main components of the engine consist of a inlet system which works as diffuser, a combustion chamber and an exhaust nozzle. The inlet system of Ramjet engine transforms the velocity head of incoming flow to static pressure head. It means the suction system of ramjet engine is basically has the function of compressor of gas turbine. The system configuration of subsonic inlet (M<1) and supersonic inlet (2<M<5) are different from one another. Subsonic intake (diffuser) system mostly consists of simple rectangular pipe system where shock takes place at the end of pipe. Supersonic system provides one or more oblique shock waves within the system and also a strong normal shock, to slow down the airflow to a subsonic velocity at the exit of the intake system. The oblique shock is formed by a cone shaped spike in the diffuser which project from the inlet opening. The rectangular supersonic intake is provided with a slope to generate an oblique shock at high speed.

The main process in the ramjet engine include compression of inlet fluid by the inlet-diffuser, followed by fuel combustion in super charged combustion chamber. The potential energy of the hot and compressed gases are converted into kinetic energy in the exhaust nozzle to provide the required thrust from the engine.

Ramjet engines are designed to perform the tasks which include 1) collecting the atmospheric air. 2) Compress it through diverging tube (M<1) and also through a series of oblique and also normal shock (M>1). 3) Deliver the compressed air flow to the ramjet combustion chamber at M<1. 4) Flow high pressure gasses through exhaust nozzle to provide required thrust.

II. DESCRIPTION
A subsonic diffuser is represented by an expanding tube whose forward edge has smooth outlines. To prevent disruption of the stream, a special aerodynamic form has been imparted to the diffuser lip. The relation of areas ratio of subsonic diffusers is always less than one.

\[
\frac{a_1}{a_2} < 1
\]

In case of air intake at supersonic velocity, energy loss in the diffuser with normal shock wave at the inlet become large and also the pressure recovery factor becomes small. Therefore, the losses during the deceleration of the flow are decreased by replacing the powerful normal shock wave at the diffuser inlet by a system of weaker oblique shock waves, and ending with a weak normal shock wave. Such system makes the energy losses in the configuration of successive shock waves, which lead to subsonic velocity, are less than in a single normal shock wave.

Therefore, the diffuser is provided with a rectangular slope to form oblique shock waves, which projects from inlet opening.

III. GOVERNING EQUATIONS
The Bernoulli’s equation is used for subsonic flow and density of fluid is considered constant even if variation of pressure takes place during the flow of fluid. Therefore, the fluid flow is considered incompressible.

\[
\frac{v^2}{2} + gz + \frac{p}{\rho} = \text{const}. 
\]

V is flow velocity
\(g\) is acceleration due to gravity
\(z\) is elevation point above reference line
\(P\) is flow pressure
\(\rho\) is density

IV. SUBSONIC INLET
The geometry of conical diffuser is determined by two measure parameters: The first parameter is conical angle ‘\(\alpha\)’ which is shown in the given figure and the ratio of outlet to inlet area ‘\(G\)’. The literature survey gave us the conclusion that for subsonic flow the most advantageous expansion angle is of order of 10-15°and the cross-section area ratio is 3 to 4. The decrease in cone angle increases the length of diffuser and therefore increases the construction weight of diffuser. It is required that the flow should not separate from the sides to avoid eddies formation. Considering these aspects, we selected 15° cone angle and inlet diameter d1=4cm, outlet diameter d2=7cm
From the geometry of the figure, the length variation is given by

\[ L = \frac{d_2 - d_1}{2 \tan \frac{\alpha}{2}} \]

Considering, the density of air is constant, the Bernoulli’s equation is used to estimate the increase in static pressure with the length of diffuser.

\[ P_2 - P_1 = \rho \frac{V_1^2}{2g} (1 - \frac{a_1^2}{a_2^2}) \]

\[ P_2 - P_1 = \rho \frac{V_1^2}{2g} (1 - \frac{d_1^2}{d_2^2}) \]

\[ P_2 - P_1 = \rho \frac{V_1^2}{2g} \left( 1 - \frac{1}{\left(1 + \frac{2 \tan \frac{\alpha}{2}}{d_1}\right)^4} \right) \]

From the graph we seen that pressure recovery occurs basically in front portion of diffuser. Following output from the Ansis software also provide the pressure variation along the length of the diffuser.

V. SUBSONIC INLET 2

The deceleration of flow in this type of diffuser occurs in such a manner that pressure rise is uniform along the entire length.

\[ \frac{dP}{dL} = \text{grad} \, P = \text{const.} \]

The relation between the acceleration of the flow \( \dot{\alpha} \) and the pressure gradient \( \frac{dP}{dL} \) is expressed by

\[ \frac{dP}{dL} = -\frac{P}{g} \dot{\alpha} \]

The minus sign indicated that the direction of acceleration toward decreasing pressure. In this type of diffuser the product of the acceleration and density is constant along the length of diffuser. Assuming the density of flow is constant, we find the relation between the length of diffuser and its diameter, so deceleration of flow is constant. Following output from the Ansis software also provide the pressure variation along the length of the diffuser.
VI. SUPERSONIC INLET I

The inlet system for supersonic flow is configured for the Mach No. = 2.8 and figure shows over all configuration. There are two oblique shockwaves. First the flow turnings at 16° and due to reflective shock wave flow become again horizontal. There is a normal shock at following output from the Ansys software also provide the pressure variation along the length of the diffuser.

A supersonic flow at Mach number M is flowing from left to right. We will call the free stream region zone "1" as shown in red. The flow encounters a wedge "Z" and generates a shock wave with the conditions downstream of this shock noted as zone "2". The flow in zone "2" is parallel to wedge "a" and the conditions are specified by the oblique shock relations given on another page. The shock wave then strikes a solid wall and reflects from the wall generating a new shock. The flow downstream of the reflected shock is denoted as zone "3". Since the flow in zone "2" is parallel to wedge "Z", it strikes the solid wall at angle "Z" as shown by the white dashed line. The flow in zone "3" is parallel to the solid wall and the conditions in zone "3" are given by the oblique shock relations with the upstream conditions being the conditions in zone "2". The reflected shock will itself reflect from the wedge producing a "train" of shock waves in the duct formed by the wedge and the solid wall. Across each shock and reflection the Mach number of the flow is decreased. Eventually, the Mach number in some zone becomes too low to support an oblique shock and a terminal, normal shock is formed.

A. Oblique Shock Wave

<table>
<thead>
<tr>
<th>Sr.N o.</th>
<th>$M_1$</th>
<th>$\Theta$</th>
<th>$\beta$</th>
<th>$p_2/p_1$</th>
<th>$p_2/p_1$</th>
<th>$T_2/T_1$</th>
<th>$M_2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2.8</td>
<td>1</td>
<td>35</td>
<td>2.830</td>
<td>2.036</td>
<td>1.389</td>
<td>2.05</td>
</tr>
<tr>
<td>2</td>
<td>2.05</td>
<td>3</td>
<td>45.3</td>
<td>2.331</td>
<td>1.78</td>
<td>1.295</td>
<td>1.45</td>
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</tbody>
</table>

B. Normal Shock Wave

<table>
<thead>
<tr>
<th>$M_1$</th>
<th>$p_2/p_1$</th>
<th>$p_2/p_1$</th>
<th>$T_2/T_1$</th>
<th>$M_2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.45</td>
<td>2.286</td>
<td>1.7761</td>
<td>1.287</td>
<td>0.719</td>
</tr>
</tbody>
</table>
VII. CONCLUSION

Inlet system for subsonic and supersonic inlet design is a challenging task due to complex gas dynamics and computation limitations. Ram jet performance depends on optimized design of intake diffuser. Subsonic diffuser creates a very low pressure at such a low speed and therefore it is used for small capacity subsonic speed ramjet engines. Subsonic diffuser is also not creating high pressure at supersonic speed (2.8M) which calls for design of high speed supersonic intake. In a constant pressure gradient diffuser also the pressure increase is not significant. Supersonic diffuser create high pressure at high speed so supersonic diffuser are used in Ramjet engines to create high thrust at high speed.

REFERENCES