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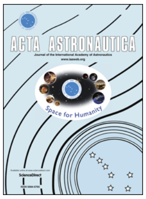

Experimental study of mixing enhancement using pylon in supersonic flow

Manmohan Vishwakarma, Aravind Vaidyanathan*

Indian Institute of Space Science and Technology, Thiruvananthapuram, 695547 Kerala, India

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ABSTRACT

The Supersonic Combustion Ramjet (SCRAMJET) engine has been recognized as one of the most promising air breathing propulsion system for the supersonic/hypersonic flight mission requirements. Mixing and combustion of fuel inside scramjet engine is one of the major challenging tasks. In the current study the main focus has been to increase the penetration and mixing of the secondary jet inside the test chamber at supersonic speeds. In view of this, experiments are conducted to evaluate the effect of pylon on the mixing of secondary jet injection into supersonic mainstream flow at Mach 1.65. Two different pylons are investigated and the results are compared with those obtained by normal injection from a flat plate. The mixing studies are performed by varying the height of the pylon while keeping all other parameters the same. The study mainly focused on analyzing the area of spread and penetration depth achieved by different injection schemes based on the respective parameters. The measurements involved Mie scattering visualization and the flow features are analyzed using Schlieren images. The penetration height and spread area are the two parameters that are used for analyzing and comparing the performance of the pylons. It is observed that the secondary jet injection carried out from behind the big pylon resulted in maximum penetration and spread area of the jet as compared to the small pylon geometry. Moreover it is also evident that for obtaining maximum spreading and penetration of the jet, the same needs to be achieved at the injection location.

1. Introduction

Over the past several years there has been considerable effort to explore the options for using air breathing engines for reusable launch vehicles as well as for high speed military applications. For the turbojet/fan engines that typically operate within the 0.6–3 Mach number range, the thermodynamic process involving compression is achieved through compressors and fans that in turn are driven by the turbines. However for Mach number range of 2.5–5 the turbojet/fan engines significantly underperform due to the highly inefficient operation of compressors and fans. Moreover at higher Mach numbers the blockage caused due to the mechanical structure of the compressors, fans and turbines will lead to increased drag and high structural loads. Thus for Mach 2.5–5 the air breathing engine is typically designed with no moving parts and is referred to as Ramjet engine. In the Ramjet engine the ramming effect of the jet substitutes the compression process achieved through compressor in a turbojet/fan engine, and the combustion of fuel and air is carried out at very low subsonic speeds. The high enthalpy fluid is then expanded through a CD nozzle to supersonic speeds and thrust is generated. Since the inlet supersonic stream is decelerated to very low subsonic speeds in a Ramjet engine, there occurs a significant rise in the static temperature of the stream. The combustion of fuel causes further increase

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* Corresponding author. Tel.: +91 471 256 8435; fax: +91 471 256 4806.
E-mail address: aravind7@iist.ac.in (A. Vaidyanathan).

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List of abbreviations and symbols:

FP	Flat Plate
SP	Small Pylon
MP	Medium Pylon
BP	Big Pylon
M	Mach number
L	length of cavity (unit: mm)
D	depth of cavity (unit: mm)
Xi	distance between injection and pylon (unit: mm)
h	height of pylon (unit: mm)
l	length of pylon (unit: mm)
x	stream wise axis
y	transverse axis
z	span wise axis
P	pressure (unit: bar)

Greek letters

Θ	pylon wedge angle (unit: degree)
Υ	specific heat ratio

Subscripts

inj	injection

in static temperature and can result in thermo-structural damage of the engine as well as endothermic dissociation of nitrogen molecule. Moreover the deceleration of the supersonic stream from Mach 5 to low subsonic speeds drastically contributes to the stagnation pressure loss too. Thus for Mach numbers above 5 deceleration of jet to $M \ll 1$ will lead to zero or negative thrust owing to high stagnation pressure loss and endothermic dissociation that significantly decreases the static enthalpy of the jet.

Thus for flight Mach numbers above 5 it is required to decelerate the inlet stream to only low supersonic Mach numbers in the combustor, add energy through combustion and expand the jet through the nozzle for generating thrust. In doing so, not only the stagnation pressure loss is minimized but also the static temperature rise could be kept below the prescribed limits. The air breathing engines for which the combustion and energy addition takes place at low supersonic Mach numbers of 1.5–3 is referred to as Supersonic Combustion Ramjet (SCRAMJET). However the processes involving uniform mixing of fuel and air, ignition of the combustible mixtures, and flame stabilization in Mach 2 stream pose as the major challenges as the residence time available for the mainstream flow in the combustor is of the order of milliseconds. Thus for smooth functioning of the SCRAMJET engine efficient mixing schemes are to be adopted for maximum penetration and spreading of the fuel jet into the core of the supersonic mainstream within the available residence time in the combustor. As the air is at supersonic speed the mixing and spreading of fuel inside a combustor chamber is a challenge due to the very short residence time. In pursuit of mixing enhancement, considerable efforts have been invested both experimentally as well as computationally. In a study by Bogdanoff [1], the author explains about the different techniques to enhance the mixing of fuel. The study consisted of different injection methods like normal injection from combustor wall, slot injection parallel to the flow, injection from struts and rear of ramps etc. In a numerical study by Jin et al. [2] the effect of three dimensional (3D) side wall compression inlets and the effect of inlet distortion on flow field, mixing and combustion process is examined in detail. It is found that the bow shock before the upstream injection impinges on the lower wall, resulting in higher static pressure rise. Even though pressure distribution along the upper and lower wall are almost the same after the combustion zone in cavity, the presence of shock train system leads to asymmetries in the flow. In a computational study by You et al. [3], the authors have identified the following processes associated with normal injection: detached normal shock in main flow, a small three dimensional barrel shock terminated by Mach disk for secondary jet and the flow with omega vortices in horse shoe shape around the secondary injection. From their study it is inferred that the momentum flux ratio is the main parameter for determining the flow pattern around the injection hole. The study by Schitz and Billig [4] also revealed that the momentum flux ratio is an important parameter for the penetration in the main stream with the effective back pressure playing a major role in the penetration of the jet. The effective back pressure is the average pressure surrounding the jet region. For optimum penetration it is identified that the effective back pressure should be equal to the static pressure of the main stream jet. In a computational study by Schetz et al. [5] the complex structure of normal injection in supersonic flow is observed and the vortical structure generated due to interaction of shock and flow are identified to be responsible for the mixing of fuel in supersonic flow. In a numerical study by Yan et al. [6] on non-reacting and reacting flow, the wall pressure distribution, separation length due to secondary injection and penetration height are analyzed, and compared with the experimental results for transverse injection. It is observed that the pressure ratio of jet to crossflow affects the pressure distribution upstream, and small molecular weight of fuel are identified to promote the mixing of fuel and air. Moreover the recirculation zone that forms upstream due to jet and cross flow interaction is identified to increase the flame holding capability of the flow during combustion. In a study by Timnat et al. [7], for oblique injection, the pressure loss is found to be relatively low as the strength of the shock is reduced as compared to the bow shock associated with normal injection. However as the angle is increased to 30°–60°, the vortices formation is found to be reduced whereas the penetration into the main flow is found to increase. In an experimental and computational study by Aso et al. [8], the effect of of different injection schemes in supersonic stream has been studied, and it has been found that the injection with 30° and 150° is superior to the 90° case; however they also observed