This document provides the Abstract & Introduction of my M Tech Thesis titled 'Atomization of Impinging Liquid Jets in Supersonic Flow'

Abstract

Human's desire to travel in supersonic speed can be accomplished by Scramjet engines. But the small residence time available for mixing and combustion of fuel and air in Scramjets act as major stumbling block in the technological development. Numerous studies were done on gaseous fuel though they cause problem in storage and availability, and relatively the studies on liquid injection in Scramjets are limited. The limitation in carrying out exhaustive and time consuming experiment and the high time consuming Large Eddy (LES) simulations reduced the number of models that can be tested. The current work focus on impinging liquid jet injector that is employed in a back ward facing step in a supersonic flow. The work also utilizes the intelligent concept of deep learning to optimize the injection strategies and methodologies adopted in the current study.

Due to angled injection, the fuel streams coming from both injectors produce an elliptical liquid sheet perpendicular to the plane of impingement. The interaction of this sheet and supersonic air-stream produce sized particles which was visualized using various laser based techniques like Laser Shadowgraphy and Particle Master Shadowgraphy and PDPA. Mie-Scattering and Schileren visualization was also carried out to study the mixing characteristics. The results shows, high level of mixing and the formation of very fine droplets. Five impinging angles ranging from 0 to 60 degrees and six jet momentum ratios were studied. It was clearly observed that impinging angle had a direct influence on the penetration height as well as droplet diameter.

Scramjets at supersonic speed is affected from inefficient mixing in combustion-chamber, but with optimal configuration, mixing can be made efficient. To get optimal configuration an analytical approach is proposed with prediction of optimal parameters using Neural Networks. In this proof of concept approach, deep learning is used to learn mappings from experimental images to obtain penetration height& spread area. The various other parameters like mixing efficiency, combustion efficiency which have direct impact on improved mixing and flame stabilization to obtain the design of a scramjet combustor with optimum working condition could also be attempted in future studies.

Chapter 1

Introduction

1.1 Introduction

Launch vehicles use propellants consisting of oxidiser and fuel to derive energy through combustion. Instead of carrying large amount of oxidizer, the atmospheric air can be utilised for combustion. This forms the basis of air breathing propulsion. Air breathing propulsion is a solution for a powered long return cruise flight necessary for reusable launch vehicles. The utilization of atmospheric air for combustion involves challenges as the launch vehicle speeds through atmosphere at supersonic speeds. This calls for the development of ramjet or scramjet (supersonic combustion ramjet) technologies. Of the different air breathing engines the turbojet can operate efficiently up to a Mach number of 3. For an operating Mach number greater than 3, Ramjet is usually proposed. But it cannot fly above Mach number 5. This is due to the drastic drop in efficiency occurring because of the deceleration of incoming supersonic stream to subsonic speed. This leads to large pressure loss in the system. Hence supersonic combustion is a solution for the aforementioned problem. This can be achieved through Scramjet engine. But the small residence time available for mixing and combustion of fuel and air in Scramjets acts as the major stumbling block in the technological development. Hence for improved combustion, the mixing efficiency and flame stabilisation should be optimized.

A large number of studies were done on mixing enhancement of gaseous fuels like Hydrogen because of its superiority in combustion performance. However the lower energy density may result in aerodynamically unattractive vehicle [Table1.1]. Other than that cryogenic propellants poses many transportation and safety issues. Moreover the cost and availability limit the usage of Hydrogen fuel for special applications [2]. Thus there is a need to use hydrocarbon liquid fuels, due to the ease of storage and availability and also logistics and cost consideration.

However the liquid fuelled supersonic combustors are imparting many technical challenges compared to gaseous fuels. This include [3]:

1. A deeper fuel penetration into the air stream for better mixing;
2. Generation of smaller liquid fuel droplets for faster evaporation;
3. Appropriate flame stabilization mechanism for piloting and sustaining combustion;
4. A substantial reduction in drag losses associated with processes of mixing and flame holding

Optimisation of various designs or models of Scramjet is always a challenging issue. This can be addressed by modern day technology like Deep Learning. In this method using a network of neurons and deep layer features, images or data set are extracted to provide an optimised design parameters.

1.2 Motivation

Almost 60 years of research and development in different configurations of gaseous fuelled Scramjets, made the development of a Scramjet engine (X-51A Waverider) which can fly for a duration of 200 seconds. But through out these years research on liquid fuelled injection were limited as compared to their gaseous counter parts. Even though many configuraions were tested for gaseous injection scheme, only few organisations/institutes attempted various schemes in liquid injection. Further more all hydrocarbon launch vehicle concepts provide a 3-4% of improved payload fraction compared to present shuttle class vehicles [4].

In the study, it is proposed to exploit the advantages of a Backward Step Doublet impinging injector in order to solve the above mentioned 4 challenges. Parallel injection to the main flow reduces the drag and formation of strong shocks as compared to transverse injection. But penetration, formation of fine droplets and mixing will be relatively low in the case of parallel injection. Hence to increase the mixing performance, doublet injection was selected. In doublet injection the impinging jets produces an elliptical liquid sheet perpendicular to the plane of impingement. This sheet increases the penetration height and the impact waves formed during impingement reduces the breakup length and accelerates the spray formation. This forms the basis for selecting this type of an injector.

Even there are number of configurations in Scramjet combustion, it is very difficult to achieve an optimised design due to the difficulties associated with experimentation and computational facilities. Hence in this study a proof of concept was attempted to identify an optimised design configuration using Artificial Intelligence. All this forms the basis of motivation for the present study.

Table 1.1: Aviation Fuel Properties[2]

Sl. No.	Fuel	Freeze point (°C)	Net heating value (kJ/m^3)	Cost* ($/liter)
1	Hydrogen	-259.2	8133	16.33
2	JP-7	-44	34,423	0.8
3	JP-8	-50	34,674	0.24
4	JP-10	-79	39,441	2.94

*Price paid by U.S. Air Force in 1998