NUMERICAL STUDY OF SCRAMJET INLET FLOW CONTROL BY CONSTANT ENERGY DEPOSITION

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ABSTRACT

In previous years, significant progress has been achieved in the design of high-speed vehicles. A design propulsion system that is effective in supplying the necessary force to advance an aircraft travelling through the air is one of the major problems that has yet to be solved. The primary goal of this study was to explore the impact of laser energy deposition at scramjet propulsion inlets with throttling for high-speed flow. This research was conducted on a two-dimensional double ramp at free-stream Mach numbers 4, 5, and 6 with attack angles ranging from -10° to 10°. The application of heat source and throttling devices was simulated. The results of shocks reflected from the external compression part intersecting with the cowl edge axis were used to determine the locations of heat sources. Previous experimental work was used to validate the results. The impact of the shockwave on the cowl inlet is significantly altered. As Mach number increase, the shockwave reflected inside isolator while as the angle of attack increases, the shockwave reflected outside isolator. Mach number and angle of attack have a significant influence on Total Pressure Efficiency (TPE), Kinetic Energy Efficiency (KEE), Compression Process Efficiency (CPE), Total Pressure Recovery (TPR), and Flow Distortion (FD). The CPE and KEE both increases in average of 0.73 and 0.81 from a rise in the AoA. With the inclusion of a heat source, the shock wave reflects within the isolator but outside the isolator without a heat source, influencing flow behavior and hence intake operation. It implies that heat source energy was more significant in steady-state conditions, but heat source sizes were more relevant in transient-state conditions. It has been revealed that the heat source and throttling device have a significant influence on the operation of its intake.

ABSTRAK

Kebelakangan ini, kemajuan ketara dicapai dalam reka bentuk kenderaan berkelajuan tinggi. Reka bentuk sistem pendorong yang berkesan dalam membekalkan daya yang diperlukan untuk memajukan pesawat yang bergerak melalui udara adalah salah satu masalah utama yang masih belum diselesaikan Matlamat utama kajian ini adalah untuk meneroka kesan pemendapan tenaga laser pada salur masuk pendorong scramjet dengan pendikit untuk aliran berkelajuan tinggi. Penyelidikan ini dijalankan pada tanjakan dua dimensi pada aliran bebas nombor Mach 4, 5, dan 6 dengan sudut serangan antara -10° hingga 10°. Aplikasi sumber haba dan peranti pendikit telah disimulasikan. Hasil gelombang kejutan yang dipantulkan daripada bahagian mampatan luaran yang bersilang dengan paksi tepi tudung digunakan untuk menentukan lokasi sumber haba. Data eksperimen kajian lepas digunakan untuk pengesahan. Kesan gelombang kejutan pada salur masuk tudung scramjet berubah dengan ketara. Apabila nombor Mach meningkat, gelombang kejutan memantulkan pengasing di dalam manakala apabila sudut serangan meningkat, gelombang kejutan memantulkan pengasing di luar. Nombor mach dan sudut serangan mempunyai pengaruh yang signifikan terhadap Kecekapan Tekanan Keseluruhan, Kecekapan Tenaga Kinetik, Kecekapan Proses Mampatan, Pemulihan Tekanan Jumlah dan Herotan Aliran. *CPE* dan *KEE* kedua-duanya meningkat secara purata 0.73 dan 0.81 daripada kenaikan dalam sudut serangan. Dengan kemasukan sumber haba, gelombang kejutan memantul dalam pengasing, tetapi di luar pengasing tanpa sumber haba, mempengaruhi tingkah laku aliran dan operasi pengambilan. Menunjukkan bahawa tenaga sumber haba adalah ketara dalam keadaan mantap, tetapi saiz sumber haba ketara dalam keadaan sementara. Telah didedahkan bahawa sumber haba dan peranti pendikit mempunyai pengaruh yang penitng ke atas operasi pengambilannya.

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APPROVAL

The Examination Committee has met on **18 January 2023** to conduct the final examination of **Nurfathin Binti Zahrolayali** on his degree thesis entitled **'Numerical Study of Scramjet Inlet Flow Control by Constant Energy Deposition'.**

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LIST OF ABBREVIATIONS

AFC	-	Active Flow Control
AIP	-	Aerodynamic Interface Plane
AOA	-	Angle of Attack
APJ	-	Alternating Pulsed Jet
CFD	-	Computational Fluid Dynamics
CFJ	-	Co-Flow Jet
CFL	-	Courant–Friedrichs–Levy
CRM-HL	-	Common Research Model High-lift
CV	-	Corner Vortex
DRSWJ	-	Double-Row Sweeping Jet
FC	-	Flow control
FD	-	Flow Distortion
HELP	-	High-Efficiency Low Power
HSST	-	High Supersonic Tunnel
LES	-	Large Eddy Simulation
MHD	-	Magneto-Hydrodynamic
MVG	-	Micro-Vortex Generator
N-S	-	Navier-Stokes
PFC	-	Passive Flow Control
PSJA	-	Plasma Synthetic Jet Actuators
RANS	-	Reynolds Averaged Navier-Stokes
RSM	-	Reynolds Stress Model
SST	-	Shear Stress Transport
SSV	-	Surface Separation Vortex
STEP	-	Spanwise Traversing Electro-Pneumatic
STJ	-	Steady Jet
SWBLI	-	Shock-wave Boundary Layer Interaction
SWJ	-	Sweeping Jet
TPR	-	Total Pressure Recovery

TR	-	Throttling ratio
UPNM	-	Universiti Pertahanan Nasional Malaysia
VG	-	Vortex Generator
VGJ	-	Vortex Generating Jet

LIST OF SYMBOLS

L/W	-	Length-to-Width ratio
M	-	Mach number
C_μ	-	Momentum coefficient
P_∞, P_O	-	Stagnation pressure (MPa)
T_∞, T_O	-	Stagnation temperature (K)
q	-	Heat generation rate (Wm^{-3})
D	-	Diameter (mm)
κ-ω	-	k-omega
ρ	-	Density (kgm^{-3})
t	-	Time taken (ms)
u_i, u_j	-	Velocity vector
q_j	-	Heat flux (Wm^2)
τ_{ij}	-	Compressible viscous stress tensor
E	-	Total energy per unit mass (J/kg)
p	-	Static pressure (kPa)
P/P_{amb}	-	Pressure ratio
y^+	-	Dimensionless y-distance to wall surface
C_f	-	Coefficient fraction factor
x/L	-	Averaged time and spanwise distributions (mm)
π_C	-	Total Pressure Efficiency
$\eta_{KE\ (ad)}$	-	Kinetic Energy Efficiency
$\eta_{C(ad)}$	-	Compression Process Efficiency
γ	-	Specific heat ratio
P_{t0}	-	Pressure at Station 0 (kPa)
P_{t3}	-	Pressure at Station 3 (kPa)
T_{t3}	-	Temperature at Station 3 (K)
$A_{t,plug}$	-	Area of the plug (mm^2)
$A_{isolator}$	-	Cross-sectional area of the isolator (mm^2)

$P_{t,max}$	-	Maximum total pressures (kPa)
$P_{t,min}$	-	Minimum total pressures (kPa)
$P_{t,avg}$	-	Average total pressure (kPa)

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Background

Hypersonic vehicles are frequently explored due to their benefits of fast speed and high flight altitude. Although jet propulsion systems may fly at great speeds, the substantial oxidizer required on board sets a restriction on the amount of usable cargo they can transport. Little payloads with large aircraft result in high costs, as a result, an approach is necessary. The necessity of an oxidizer can be eliminated by using an air-breathing propulsion system, and thus the scramjet engine is indeed the best form of air breathing engine at hypersonic aircraft mode.

Controlling the flow is critical. Flow control (FC) is required to controlling the unstable internal flow. It has received a lot of attention in the regulation of shock waves in hypersonic flow to minimize wave drag or protect the aircraft. This study focuses on enhancing the performance of the scramjet engine's intake by active flow control in hypersonic flows.

A significant progress in the design of high speed vehicles has been achieved over the past several decades. However, one of the critical design issues remain unresolved are efficient propulsion system. Typically, flow control in high speed at inlet is critical. At high speed a mixed compression inlet is use to decelerate the flow to a subsonic Mach number at the compressor face. The mixed compression is characterized by a series of oblique shocks, followed by an approximately normal terminal shock downstream of the geometric throat. The terminal shock is unstable to small disturbances if perturbed to a position upstream of the geometric throat leading to expulsion of the terminal shock out the inlet entrance and consequent severe reduction in total pressure recovery. This phenomenon is known as inlet unstart. Therefore, maintaining control of the terminal shock downstream of the geometric throat is critical. Maximizing total pressure recovery at the compressor face implies locating the terminal shock as close to the geometric throat as possible where the Mach number immediately ahead of the terminal shock is the lowest. Therefore, a method for controlling the location of the terminal shock in the presence of disturbances is important.

The scramjet engine's intake is where it compresses and progressively lowers the flow of hypersonic or supersonic air coming in. The isolator, which links the intake and supersonic combustor, slows the flow even further and prevents disruption from the combustor from reaching the intake. Via combustion processes, the combustor provides the flow with heat energy. In order to provide thrust and enable hypersonic take-off, the exit nozzle's divergent flow increases the supersonic flow.

The fundamental overview of flow control as well as its role in the scramjet propulsion system is presented in Chapter 1. The principles of aerodynamic flow control, including both passive and active flow control, are covered in depth in Chapter 2. This chapter further includes analyses of the active flow control with an emphasis on hypersonic flow. The model of a generic scramjet inlet-isolator in this work project was done using a comprehensive procedure, which is presented in Chapter 3. After that, Chapter 4 presents the internal flow behaviour and inlet performance. The chapter 5 summarizes the entire findings of the present study. As a way to wrap up the work, this chapter also discusses areas for enhancement and prospective future research.

1.2 Problem Statement

Significant improvement has been achieved in the development of high-speed vehicles in recent years. However, one of the primary design issues that have yet to be addressed is an efficient propulsion system. The purpose of this study is to maximize engine performance by using the Active Flow Control (AFC). The vast of the major scramjet engine issues that require critical intervention are focused on the intake compression and pre-combustion systems. Shockwave boundary layer interactions (SWBLI), boundary layer transition, shock-shock interaction, boundary layer detachment, and several others are examples of intake flow features that require attention.

In order to efficiently compressing airflow and facilitate supersonic flow towards the compressor, the scramjet engine's intake part must accomplish several tasks. Scramjet avoids the issues by keeping stream velocity enabling supersonic burning. Since supersonic speeds performed engine operation eliminates the requirement for a converging-diverging intake and exit, improving the work flow. Given that a scramjet uses solely oblique shock waves during compression, its intake is often significantly longer unlike as ramjet.

The variable geometry devices used on the Rolls Royce/Snecma Olympus Concorde engine system were integrated into the Flow Control (FC) at the supersonic inlet. Although this technology is acceptable, the inherent inertia in these mechanical devices reduces their efficiency in high-speed engine controls. At higher Mach numbers, the total pressure loss and input trajectory become more severe, necessitating the use of a mixed compression inlet. To lower the flow of the compressor to a subsonic Mach number, the mixed compression intake combines external and internal compression. Furthermore, unstable aspects of internal flow throughout the combustion process influence the flow field. As a result, in the presence of throttling devices, controlling the flow by is critical.

Laser energy deposition was proven to enhance energy efficiency when pressure recovery was utilised as an input for a hypothetical propulsion system. The subject of fascination for this study is laser energy deposition. The off-design location of the laser energy deposition are assumed in being circular in form. In order to produce thermal bubbles in the stream, the basic idea would be to employ laser energy deposition. The plasma density is reduced as a consequence of the expansion and dissipation processes, and the pressure is equalised with the ambient air flow to produce a contact surface. This low density zone is thus referred as a thermal bubbles. A blast wave is produced by the extreme pressure and temperature at the emission area. Because of the localised reduction in Mach number inside the heat source low-density zone, a supersonic flow shock wave is lessened, thus reduces drag. This utilisation is concerned in the interactions between the laser discharge and the shock pattern which is the Shockwave Boundary Layer Interaction (SWBLI).

1.3 Objective

The purpose of this research is to analyze the flow at the inlet isolator utilizing active flow control of laser energy deposition on a two-dimensional double ramp at free-stream Mach numbers 4, 5, and 6 with attack angles ranging from -10° to 10°. The application of heat source at different diameter and energy with throttling ratio (0.4, 0.5, 0.6) was simulated. To reach the goal of this study, there are three key objectives:

(a) To validate the SWBLI of the hypersonic inlet isolator with experiment work.

(b) To investigate characteristics of the SWBLI at various sizes and power of heat source with throttling.

(c) To determine the performance of the hypersonic inlet isolator with heat source and throttling.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

It is crucial to investigate both the prior and current literature on the subject at hand since these sources were utilized to spot discrepancies, deficiencies in the literature, and issues with earlier research. The scope of aerodynamic flow control in Subsonic, Transonic, Supersonic and Hypersonic flow will be reviewed in this chapter initially. After that, active flow control will be covered, with a particular emphasis on the hypersonic flow control technique and the significance of shock-wave boundary layer interaction (SWBLI).

2.2 Aerodynamic flow control

High-speed vehicle technology has advanced tremendously in recent years. One of the key design challenges that have remained to be tackled is the development of an economical aerodynamic vehicle. As a response, flow management is vital to resolving the problem. Shock-wave Boundary Layer Interaction (SWBLI) is the engagement between a boundary layer and a shock wave that causes detachment, periodic flow patterns, heat exchange localization, and pressure gradients. SWBLI are