Numerical study of an Aerospike Nozzle in Retropropulsion

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Abstract

The primary motivation of this numerical study is to explore the feasibility of drag enhancement using aerospike nozzle in retropropulsion at hypersonic flow. A contoured aerospike nozzle with exit Mach 3.0 have been attached to a 140° spherical cone re-entry body shape for retro-propulsion. The two-dimensional axi-symmetric unsteady RANS numerical simulations are performed in freestream flow of hypersonic Mach number 7 using SU2 code. In order to compare the performance of the aerospike nozzle with circular and annular counter-flow jets, the exit of the annular nozzle and the circular nozzle have been modelled on the 140° spherical cone body as well. All three nozzles are simulated with thrust coefficient 1 in preliminary study. It was found that aerospike nozzle in retropropulsion provides a +14% drag enhancement (w.r.t blunt nose without retropropulsion) due to it's contoured surface compared to +4% of annular and −11% drag reduction for circular nozzle. The full paper will attempt to access the performance of the aerospike nozzle at higher thrust coefficients as well as a range of Mach numbers.

1 Introduction

The simplicity in integration retropropulsion coupled with the maturity level in propulsion technology makes it one of the attractive techniques for EDL. However, the interaction of rocket plumes with freestream hypersonic or supersonic regimes can be highly complex and may lead to reduced aerodynamic deceleration. The disturbance or pushing back the bow shock at the stagnation region due to interaction of counter-flow jet and the creation of low pressure re-circulation regions on the outskirts of a blunt body can lead to an overall reduction in aerodynamic drag levels. The circular nozzle at the center of a blunt body has been studied extensively for drag and aerodynamic heating reduction at hypersonic and high supersonic flows [1]. However, the configuration of different peripheral counter-flow jet have been found to preserve and slightly augment the aerodynamic drag in supersonic [2] or hypersonic flows[4]. The circular supersonic nozzle with fixed exit area can operated optimally at the design altitude and the exit jet may behave overexpanded or underexpanded based on pressure at different altitude. The working principle and flow field of different altitude adaptive advanced nozzles have been discussed by Hagemann et al.[3]. The premise of the current study is that it may be better to use altitude adaptive advanced nozzle during the all propulsive EDL phases, with a single nozzle capable to working at all the altitude. The current study is focused on performance and flow interaction of an aerospike nozzle against the hypersonic flow. The primary objectives of the study are: 1) Develop an understanding of the the flow-field interaction between the incoming hypersonic flow and the aerospike nozzle jet exit, 2) Compare the performance of the aerospike nozzle with annular and circular nozzles for different thrust coefficient C_T and over a range of Mach numbers.

2 Preliminary Results and Full Paper Content

In this preliminary study, 140° spherical cone blunt nose without any jet, central counter-flow jet, annular counterflow jet and aerospike retro jet have been simulated. The 2D axi-symmetric unsteady compressible Reynolds Averaged Navier Stokes Equations with $k-\omega$ Turbulence Model have been solved using the Stanford University Unstructured (SU^2) solver. Fig. 1a and 1b shows the computational domain & multizone grid generated for aerospike integrated blunt nose. The inlet boundary condition is defined as freestream hypersonic Mach 7 conditions of the Kashiwa Hypersonic Wind Tunnel test-section. The retro nozzle exit conditions are based on $C_T = 1$ for this preliminary study.

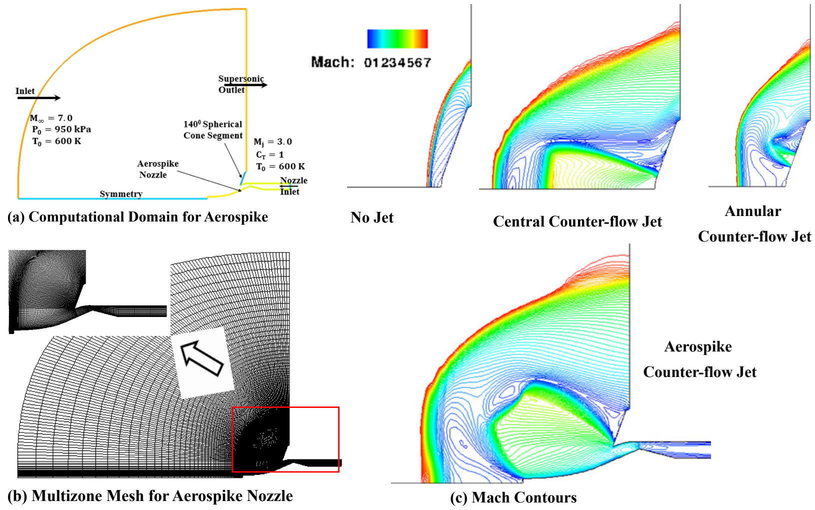

Figure 1: (a) Computational Domain for Aerospike Nozzle attach to 140° blunt cone, (b) Single Zone grid for No jet, central jet ON and annular jet ON cases, (c) Multi-zone grid for Aerospike Nozzle with blunt cone (d) Zoomed View of Aerospike Nozzle

Table 1: Computed Total Axial Force $C_A = C_D + C_T$(assuming ideal $C_T = 1$)

S.No.	**Case**	**Components**	**Total** (C_A)
1.	No Jet	$C_D = 1.23$, $C_T = 0$	1.23
2.	Circular Counter-flow Jet	$C_D = 0.09$, $C_T = 1.0$	1.09
3.	Annular Counter-flow Jet	$C_D = 0.28$, $C_T = 1.0$	1.28
4.	Aerospike as Retro	Lower Contour: $C_D = 0.681$, Upper Cowl: $C_D = -0.282$, $C_T = 1.0$	1.40

The drag force on the segment of blunt body have been computed in all four cases and total axial forces have been compared as shown in Table 1. It can be seen that performance of the aerospike nozzle in retropropulsion is better in comparison to central or annular jets. The flow-field for all four cases is shown in Figure 1c. The full paper will explore the improved design of the upper cowl, so that further increase in drag can be achieved. With improved design, the parametric study for higher thrust coefficients (C_T) and a range of Mach numbers will be performed.

References

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