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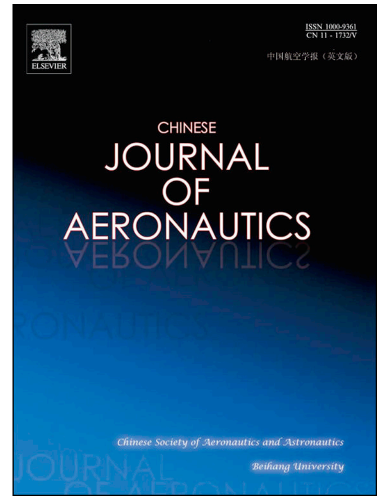

Full Length Article

Detached-eddy simulation of supersonic flow past a spike-tipped blunt nose

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PII:	S1000-9361(18)30228-0
DOI:	https://doi.org/10.1016/j.cja.2018.06.016
Reference:	CJA 1094

To appear in: *Chinese Journal of Aeronautics*

Received Date:	26 February 2018
Revised Date:	12 April 2018
Accepted Date:	22 May 2018

Please cite this article as: Y. Xue, L. Wang, S. Fu, Detached-eddy simulation of supersonic flow past a spike-tipped blunt nose, *Chinese Journal of Aeronautics* (2018), doi: https://doi.org/10.1016/j.cja.2018.06.016

Chinese Journal of Aeronautics xx (2018) xx-xx

Contents lists available at ScienceDirect

Chinese Journal of Aeronautics

journal homepage: www.elsevier.com/locate/cja

Detached-eddy simulation of supersonic flow past a spike-tipped blunt nose

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Received 26 February 2018; revised 12 April 2018; accepted 22 May 2018

Abstract

Space vehicle in atmosphere travels mostly at supersonic speed and generates a very strong bow shockwave around its blunt nose. Oblique shock and conical separated flow zone generated by a forward disk-tip spike significantly reduce the drag by reducing the high pressure area on the blunt nose. This study employs improved delayed detached eddy simulation to investigate the characteristic flow structures around a spike-tipped blunt nose at Mach number of 3 and Reynolds number (based on the blunt-body diameter) of $2.72\ 10^{8}$. The calculated time-averaged quantities agree well with experimental data. Characteristic frequencies in different flow regions are extracted using fast Fourier transform. It is found that two distinct instability modes exist: oscillation mode and pulsation mode. The former is related to the foreshock/turbulence interaction with non-dimensional frequency at around 0.004. The latter corresponds to the interaction between turbulence and shock structures around the blunt nose, with a typical coherent structure shedding frequency at 0.092.

Keywords: Spike-tipped blunt vehicle; Supersonic flow; Detached-eddy simulation; Drag reduction; Oscillation mode; Pulsation mode

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1. Introduction[1]

Blunt body vehicle flying at supersonic speed leads a very strong bow shockwave at the upstream around its blunt nose. The shockwave generates both high drag and heat to the blunt nose. This may damage the nose and equipment it carries. A disk-tip spike is able to generate an oblique shockwave at a distance away from the blunt body and a conical separated flow zone between the disk and blunt nose. As a result, disk-tip spike can significantly reduce drag by reducing the high pressure area on blunt nose[1].

However, the formation of shear layer and recirculation zone in between the spike and blunt nose introduces additional unsteadiness into the flow field, as first reported in measurements in 1950s[2-4]. Bogdonoff [4] first observed that there exist two typical instability modes in such flows: the oscillation mode corresponding to the foreshock/turbulence interaction and the pulsation mode related to the interaction between turbulence and shock structures around the blunt nose, as illustrated in Fig. 1. The mechanism of oscillation mode was explained by Feszty et al.[5] through theoretical analyses while the one of pulsation mode was described based on several hypotheses[6, 7].

In 2011, Ahmeda and Qin reviewed the progress and state of the aerothermodynamics of spiked supersonic/hypersonic vehicles[8]. They claimed that compared to the large amount of literature on parametric studies for engineering applications, numerical investigations on detailed flow physics were relatively rare. To date, the numerical simulation techniques are limited to steady or unsteady Reynolds-Averaged Navier-Stokes (RANS) methods[9].