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ORIGINAL ARTICLE

Numerical study of the oscillations induced by shock/shock interaction in hypersonic double-wedge flows

Z. M. Hu · R. S. Myong · C. Wang · T. H. Cho · Z. L. Jiang

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Abstract In this paper, the shock pattern oscillations induced by shock/shock interactions over double-wedge geometries in hypersonic flows were studied numerically by solving 2D inviscid Euler equations for a multi-species system. Laminar viscous effects were considered in some cases. Temperature-dependent thermodynamic properties were employed in the state and energy equations for consideration of the distinct change of the thermodynamic state. It was shown that the oscillation results in high-frequency fluctuations of heating and pressure loads over wedge surfaces. In a case with a relatively lower free-stream Mach number, the shock/shock interaction structure maintains a seven-shock configuration during the entire oscillation process. On the other hand, the oscillation is accompanied by a transition between a six-shock configuration (regular interaction) and a seven-shock configuration (Mach interaction) in a case with a higher free-stream Mach number. Numerical results also indicate that the critical wedge angle for the transition from a steady to an oscillation solution is higher compared to the corresponding value in earlier numerical research in which the perfect diatomic gas model was used.

Keywords Shock/shock interaction · Oscillation · Hypersonic · Double-wedge · Numerical study

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Z. M. Hu · R. S. Myong (✉) · T. H. Cho
Research Center for Aircraft Parts Technology,
School of Mechanical and Aerospace Engineering,
Gyeongsang National University, Jinju 660-701, South Korea
e-mail: myong@gnu.ac.kr

Z. M. Hu
e-mail: bighumin@126.com

C. Wang · Z. L. Jiang
LHD, Institute of Mechanics, Beijing 100080, China

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1 Introduction

Shock/shock interactions in hypersonic flows can induce extremely high heating and pressure loads on the surface of an aircraft. Within the human's attempts to manned hypersonic flight, for example, unforeseen shock interactions caused airframe damage to an X-15. In February 1, 2003, damage to the thermal protection system (TPS) led to a structural failure in the left wing and the ultimate disaggregation of the USA space shuttle upon its re-entry. During this accident, shock/shock interaction was likely to be one of the factors that had caused the vulnerability of the aircraft. Shock/shock interactions are also important and fundamental issues occurring in the inlet flows of a hypersonic air-breath Scramjet with a multi-ramp shock-compression-driven intake. Damage to the ventral fin of the X-15 caused by shock/shock interaction phenomena was defined as one of unknown unknowns by Bertin and Cummings in [1,2] in the development of hypersonic vehicles before the X-15A accident. Unknown unknowns can have drastic consequences on the survival of the vehicle or the crew and lead to unacceptable increases in the costs of developing the vehicles [1]. As one of the key research issues in this area, numerous studies of shock/shock interactions can be found in literature [3–8].

Edney [3] used shock polar diagrams and classified the interactions of oblique shock waves and bow shocks on a cylinder. Through his experimental research, it was realized that abnormally high heating and pressure loads can be induced by shock/shock interactions on hypersonic vehicles and small changes in the geometry can lead to large changes in the overall flow structure. Olejniczak et al. [4] numerically studied shock interactions on double-wedge-like geometries.