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Editorial:

Mixing and combustion in supersonic/hypersonic flows

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Under the guidance of the major two-period research program of the National Natural Science Foundation of China, the hypersonic technique has steadily matured. Further development of its core component—the airbreathing hypersonic propulsion system, and of some novel concepts of the combined cycle engine, is needed urgently to meet the power requirements of single/two-stage-to-orbit manned spacecraft and hypersonic aircraft, such as the SR-72 (Fig. 1). However, the resident time of the high-speed flow in the scramjet combustor is very limited, only a few milliseconds, and the generation of useful thrust through additional heat at such high speeds is still a challenging task (Huang et al., 2019). Therefore, many mixing augmentation devices have been proposed and investigated, as well as flame propagation and stabilization mechanisms in the supersonic or hypersonic flow (Huang et al., 2018). Fig. 2 shows the operational process in an airbreathing hypersonic propulsion system. The developed computational fluid dynamics (CFD) approaches, such as the efficient WENOCU4 developed by Li et al. (2020), have contributed greatly to ground experimental testing, especially of approaches with high-order accuracy.

In this special issue, we invited primary scientists on the leading edge in this field and with recent high impact research to share their expertise and perspectives. The collected papers cover various topics, such as shock wave/turbulence boundary layer interaction control, mixing, ignition, and flame stabilization in scramjet combustors, and mode transition in rotating detonation engines.

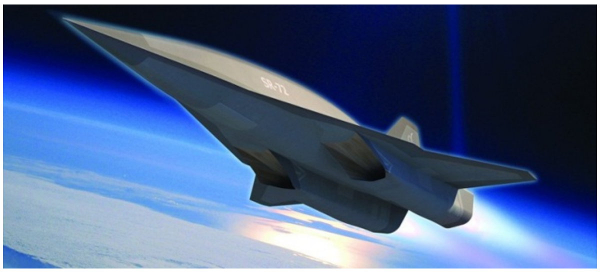

Fig. 1 Schematic diagram of the hypersonic aircraft SR-72

Shock wave/boundary layer interaction is a common phenomenon which occurs in the internal and external flow fields of hypersonic vehicles. Zhang et al. (2020) evaluated numerically the influences of the bleed hole diameter, depth, and boundary layer thickness on the bleed mass flow rate of a porous array bleed system in a hypersonic inlet, and explored its potential physical mechanism. Hou et al. (2020) investigated self-excited oscillation in an isolator with background waves by means of a wind tunnel experiment. High-frequency pressure measurements were used to capture dynamic pressure data, and the high-speed Schlieren technique to visualize the flow field. A strong interaction between the shock wave train and the boundary layer was observed. Fig. 3 shows a schematic diagram of the mechanism of shock train self-excited oscillation in the isolator (Hou et al., 2020). Jiang et al. (2020) studied the hypersonic shock wave/turbulent boundary layer interaction control induced by magnetohydrodynamic (MHD) plasma actuators. A novel parameter based on

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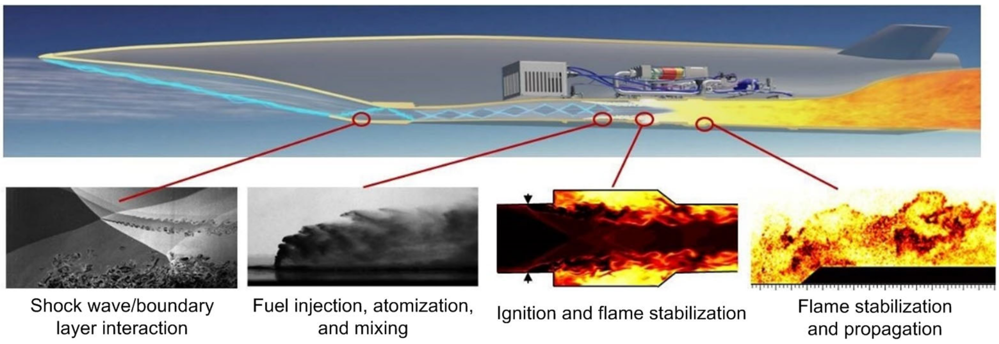

Fig. 2 Operational process in an airbreathing hypersonic propulsion system

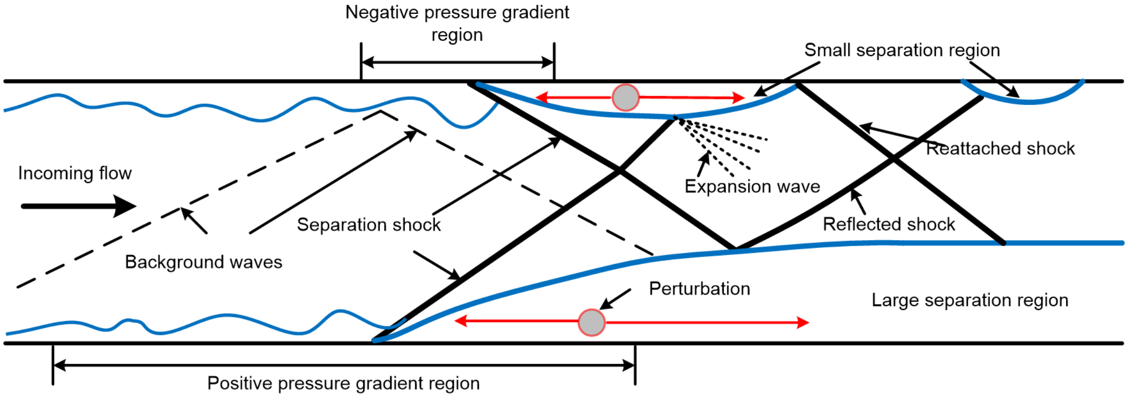

Fig. 3 Schematic diagram of the mechanism of shock train self-excited oscillation in an isolator (Hou et al., 2020)

Lorentz force acceleration is proposed to predict control efficiency. The largest separation length reduction can be obtained when the magnetically accelerated plasma is placed inside an isobaric dead-air region.

In relation to fuel injection, flame stabilization, and mode transition, Zhao et al. (2020) used nanoparticle planar laser scattering (NPLS) and stereo-particle image velocimetry (SPIV) technology to investigate the flow field properties of a jet in supersonic crossflow (JISC). They installed a vortex generator (VG) upstream of the jet orifice, and evaluated the influence of the distance between the vortex generator and the jet orifice on the flow field structures. Two flow modes were observed, and the penetration depth was increased by the vortex generator. Sun et al. (2020) investigated the ignition process in a 2D ethylene-fueled supersonic combustor with a single rear-wall-expansion cavity by means of a large eddy simulation approach based on OpenFOAM. Two flame extinguishing modes were identified, namely blow out and flow dissipation. They found that the movement routine of the initial flame has a great impact on the ignition process, and both increasing the equivalence ratio and optimizing the ignition site in the cavity are beneficial for the ignition process. Shi et al. (2020) studied the flame stabilization in a kerosene-fueled scramjet combustor through Schlieren, flame luminosity, and wall pressure measurement. The equivalence ratio of pilot hydrogen has a great impact on the ignition of the kerosene, as well as the unstable combustion phenomenon. Yan et al. (2020) developed a free radical cracking model to predict the burning rate of nitrate ester plasticized polyether (NEPE) propellants. The combustion characteristics of four kinds of NEPE propellants with different compositions and grain size distributions were studied to assess the accuracy of the developed model. Lei et al. (2020a) established the relationship between the number of detonation waves and the evolution process of the flow field in a rotating detonation engine through a numerical analysis. A parameter was proposed to predict the evolution of the flow field to control the operational mode in the rotating detonation engine experiment. They also proposed a fuel injection scheme, namely stratified injection, to improve the propulsion performance and stability of the rotating detonation engine. This enables a greater gain in self-pressure and a reduction in the generation of entropy (Lei et al., 2020b). With these enhancements, the specific impulse of the engine was improved by 16%, and its average temperature was reduced by 19.1%.

In hypersonic vehicles, there are some crucial components associated with the propulsion system which are also considered in this special issue. In the design of the thermal protection system, Shen et al. (2020) proposed a combined opposing jet and platelet transpiration cooling blunt nose, and investigated numerically the influence of the angle of attack on its heat flux reduction. The windward recompression shock wave increases the local temperature and strengthens the heat transfer. The opposing jet fails in thermal protection when the angle of attack reaches a critical value, and the transpiration gas can strengthen the windward cooling efficiency. For the novel design concept of a waverider vehicle, Chen SH et al. (2020) developed an osculating cone waverider by using the planform leading-edge profile curve to design the planform shape of the vehicle. The influences of the sweep and dihedral angles on the lift-to-drag ratio and the lateral static stability were evaluated numerically. They found that the dihedral angle is more important for the lateral stability of a waverider. To obtain the optimum design of a liquid-liquid pintle injector, Zhou et al. (2020) studied the primary breakup in a liquid-liquid pintle injector element at different radial jet velocities. They investigated the impingement morphology, the formation of the primary breakup spray half cone angle, the pressure distribution, the liquid diameter distribution and the liquid velocity distribution, and different kinds of ligament breakup patterns caused by aerodynamic force and surface tension on the axial sheet. Chen K et al. (2020) compared the performance of three classical geomagnetic matching aided navigation algorithms, namely the geomagnetic contour matching (MAGCOM), iterative closest contour point (ICCP), and Sandia inertial magnetic aided navigation (SIMAN) algorithms, to assess their applicability to hypersonic vehicle navigation. They found the SIMAN algorithm to be the best, as it can achieve better stability and better positioning accuracy.

We believe this special issue has provided a unique opportunity for researchers to present and discuss recent advances in hypersonic techniques. We hope that these investigations will attract the attention of scholars and provoke some new ideas in the engineering implementation of large scale airbreathing propulsion systems. Further, we expect these cutting-edge articles will promote discussion among established scientists and provide benefits for the journal readers.

Contributors

Wei HUANG wrote the manuscript. Jun-tao CHANG and Li YAN provided suggestions.

Conflict of interest

Wei HUANG, Jun-tao CHANG, and Li YAN declare that they have no conflict of interest.

References

Chen K, Liang WC, Liu MX, et al., 2020. Comparison of geomagnetic aided navigation algorithms for hypersonic vehicles. *Journal of Zhejiang University-SCIENCE A (Applied Physics & Engineering)*, 21(8):673-683. https://doi.org/10.1631/jzus.A1900648

Chen SH, Liu J, Huang W, et al., 2020. Design methodology of an osculating cone waverider with adjustable sweep and dihedral angles. *Journal of Zhejiang University-SCIENCE A (Applied Physics & Engineering)*, 21(9):770-782. https://doi.org/10.1631/jzus.A2000020

Hou WX, Chang JT, Kong C, et al., 2020. Experimental study and analysis of shock train self-excited oscillation in an isolator with background waves. *Journal of Zhejiang University-SCIENCE A (Applied Physics & Engineering)*, 21(8):614-635. https://doi.org/10.1631/jzus.A2000042

Huang W, Du ZB, Yan L, et al., 2018. Flame propagation and stabilization in dual-mode scramjet combustors: a survey. *Progress in Aerospace Sciences*, 101:13-30. https://doi.org/10.1016/j.paerosci.2018.06.003

Huang W, Du ZB, Yan L, et al., 2019. Supersonic mixing in airbreathing propulsion systems for hypersonic flights. *Progress in Aerospace Sciences*, 109:100545. https://doi.org/10.1016/j.paerosci.2019.05.005

Jiang H, Liu J, Luo SC, et al., 2020. Hypersonic flow control of shock wave/turbulent boundary layer interactions using magnetohydrodynamic plasma actuators. *Journal of Zhejiang University-SCIENCE A (Applied Physics & Engineering)*, 21(9):745-760. https://doi.org/10.1631/jzus.A2000025

Lei ZD, Chen ZW, Yang XQ, et al., 2020a. Operational mode transition in a rotating detonation engine. *Journal of Zhejiang University-SCIENCE A (Applied Physics &*

Engineering), 21(9):721-733.
https://doi.org/10.1631/jzus.A1900349

Lei ZD, Yang XQ, Ding J, et al., 2020b. Performance of rotating detonation engine with stratified injection. *Journal of Zhejiang University-SCIENCE A (Applied Physics & Engineering)*, 21(9):734-744.
https://doi.org/10.1631/jzus.A1900383

Li L, Wang HB, Zhao GY, et al., 2020. Efficient WENOCU4 scheme with three different adaptive switches. *Journal of Zhejiang University-SCIENCE A (Applied Physics & Engineering)*, 21(9):695-720.
https://doi.org/10.1631/jzus.A2000006

Shen BX, Liu HP, Liu WQ, 2020. Influence of angle of attack on a combined opposing jet and platelet transpiration cooling blunt nose in hypersonic vehicle. *Journal of Zhejiang University-SCIENCE A (Applied Physics & Engineering)*, 21(9):761-769.
https://doi.org/10.1631/jzus.A1900514

Shi W, Tian Y, Zhang WZ, et al., 2020. Experimental investigation on flame stabilization of a kerosene-fueled scramjet combustor with pilot hydrogen. *Journal of Zhejiang University-SCIENCE A (Applied Physics & Engineering)*, 21(8):663-672.
https://doi.org/10.1631/jzus.A1900565

Sun YC, Cai Z, Wang TY, et al., 2020. Numerical study on cavity ignition process in a supersonic combustor. *Journal of Zhejiang University-SCIENCE A (Applied Physics & Engineering)*, in press.
https://doi.org/10.1631/jzus.A1900419

Yan XT, Xia ZX, Huang LY, et al., 2020. Numerical and experimental study on the combustion of NEPE propellants. *Journal of Zhejiang University-SCIENCE A (Applied Physics & Engineering)*, in press.
https://doi.org/10.1631/jzus.A1900668

Zhang BH, Zhao YX, Liu J, 2020. Effects of bleed hole size on supersonic boundary layer bleed mass flow rate. *Journal of Zhejiang University-SCIENCE A (Applied Physics & Engineering)*, 21(8):652-662.
https://doi.org/10.1631/jzus.A1900507

Zhao YH, Liang JH, Zhang SP, et al., 2020. Experimental investigation on flow characteristics of a transverse jet with an upstream vortex generator. *Journal of Zhejiang University-SCIENCE A (Applied Physics & Engineering)*, 21(8):636-651.
https://doi.org/10.1631/jzus.A1900392

Zhou R, Shen CB, Jin X, 2020. Numerical study on the morphology of a liquid-liquid pintle injector element primary breakup spray. *Journal of Zhejiang University-SCIENCE A (Applied Physics & Engineering)*, 21(8):684-694.
https://doi.org/10.1631/jzus.A1900624

中文概要

题　目： 超/高超声速气流中的混合与燃烧

概　要： 在国家自然科学基金两期重大研究计划的指导下，高超声速技术越来越成熟，尤其是它的核心组成部分——吸气式高超声速推进系统。为了满足单级/两级入轨可重复使用飞行器以及高超声速飞机对动力装置的需求，非常有必要发展一些新概念组合循环发动机方案。但是，由于高速气流在超燃冲压发动机燃烧室内的滞留时间非常有限，只有毫秒量级，所以在如此快的流速下通过加热来获取有用推力仍然极具挑战性。为此，学者们提出了许多混合增强措施，包括超/高超声速气流中的火焰传播与稳定机制。本专辑收集了相关科研人员在设计理论、数值仿真、地面风洞试验等方面取得的一批核心技术成果，包括激波/湍流边界层干扰控制，隔离段中激波串与湍流边界层之间的强干扰，超燃冲压发动机燃烧室中的混合、点火与火焰稳定，以及旋转爆震发动机中的模态转换等。这些研究对大尺度发动机的工程化具有重要的参考价值。

关键词： 混合；燃烧；超/高超声速气流；模态转换；激波/边界层干扰

Introducing Guest Editor-in-Chief and Guest Editors:

Guest Editor-in-Chief

Dr. Wei HUANG has been the Editorial Board Member of the *Journal of Zhejiang University-SCIENCE A (Applied Physics & Engineering)* since 2018. He has been the Editorial Board Member of the *Chinese Journal of Aeronautics* and *Aero Weaponry* since 2019.

Dr. Wei HUANG is an Associate Professor at the National University of Defense Technology, China, and has been a member of the American Society of Mechanical Engineers since 2011. He was the recipient of the 2013 National Doctoral Dissertation Award, and one of the recipients of two first-class prizes in Natural Science of Hunan Province and two second-class Military Progress Prizes in Science and Technology, China. He is also an active expert on aerospace engineering in China, and in 2018 and 2019 was awarded first place among the Most Cited Chinese Researchers for his exceptional research performance in the field of aerospace engineering.

Dr. HUANG received his BS and PhD degrees from the National University of Defense Technology in 2005 and 2010, respectively. He is a researcher with over 35 invention patents, four (co)authored academic books, and over 140 technical papers published in international journals and conference proceedings. He is active in major international conferences related to aerospace engineering, and a regular reviewer for over 30 international journals. His research interests are in integrated design of hypersonic vehicles, multidisciplinary design optimization, supersonic mixing and combustion, flow control techniques, intelligent control, and hypersonic aerodynamics and thermodynamics. His findings have been successfully applied to the development of a low cost hypersonic vehicle testbed for fundamental research in China.

Guest Editors

Dr. Jun-tao CHANG is a Professor of Power Mechanism and Engineering (since 2015) at the Harbin Institute of Technology, China. He received his BS degree in 2002 and his PhD degree in 2008 in Power Mechanism and Engineering from the same Institute. He won the National Natural Science Excellent Youth Fund and the third XINGZHOU Award in 2017, the Wu Zhonghua Outstanding Young Scholar Award, and was among the Most Cited Chinese Researchers for his exceptional research performance in aerospace engineering in 2019. His current research interests focus on instability mechanisms and control of scramjets, airbreathing engine control, and the interaction mechanism between flow and combustion in scramjets. He has published over 130 peer-reviewed articles.

Dr. Li YAN is an Associate Professor of Science and Technology on Scramjet Laboratory, National University of Defense Technology, China, from where she received her PhD degree in 2006. She is a recipient of one first-class prize in Natural Science of Hunan Province and two second-class Military Progress Prizes in Science and Technology, China. Dr. YAN is a researcher with three coauthored academic books, and over 70 technical papers published in international journals and conference proceedings. Her current research interests focus on the overall design and optimization of aircraft, and the theory and application of multidisciplinary design optimization.