NUMERICAL STUDIES ON COMBUSTION ENHANCEMENT BY ABLATIVE STRUT IN A SCRAMJET COMBUSTOR

Yincheng Guo [*], Haijun Li [*], C.K. Chan [**, a)]
[*]*Department of Engineering Mechanics, School of Aerospace, Tsinghua University*
Beijing, 100084, China
[**]*Department of Applied Mathematics, The Hong Kong Polytechnic University*
Hung Hom, Kowloon, Hong Kong

Summary In order to enhance fuel-air mixing and promote combustion efficiency, a novel scramjet combustor with assembled struts is proposed by arranging an ablative strut downstream of the fuel injector strut. Compared with the scramjet combustor with only a fuel injector strut, total pressure loss increases slightly in the combustor with assembled struts, while fuel-air mixing and combustion efficiency are improved in the scramjet combustor with assembled struts. Specific impulse of the scramjet combustor with assembled struts also increases due to the improvement of combustion efficiency.

INTRODUCTION

Due to its high specific impulse, scramjet combustor is the most efficient propulsion system in the hypersonic flight regime. At flight speeds beyond Mach 6, air entering the combustor is supersonic to avoid excessive dissociation of both nitrogen and oxygen gases. Consequently, the time available for fuel injection, fuel–air mixing, and combustion is extremely short and in the order of millisecond. Two important problems in scramjet combustors are fuel-air mixing and combustion enhancement. In recent years, there are mainly two methods for fuel injection in supersonic combustors; namely wall injector [1, 2], where fuel is injected through the wall, and strut injector [3, 4], which is located at the channel axis and directly inject the fuel into the core of the air stream.

To improve performance of the scramjet combustor, a novel scramjet combustor is proposed by arranging an ablative strut with the fuel injector. In the scramjet combustor, the first strut is arranged in the isolator with constant cross-sectional area for fuel injection, and the second strut is arranged in the combustor with an expansion area for fuel-air mixing and combustion enhancement. As the second strut is located in the high temperature region, ablative material has to be used. In this study, effect of the ablative strut on performance of a scramjet combustor is investigated.

THE SCRAMJET COMBUSTOR

The scramjet combustor considered in the present study is based on the model proposed by the Institute for Chemical Propulsion of the German Aerospace Center [5]. Fig.1 shows a sketch of the combustor with relevant dimensions for the simulation. The combustion chamber consists of a one-sided divergent channel with base cross section of 45-50 mm. Inlet air (23.2% O_2, 73.6% N_2, 3.2% H_2O in mass) enters the isolator with constant cross-sectional area at Ma = 2. Hydrogen is injected parallel to the air stream at the base of a wedge. The ablative strut is arranged downstream of the fuel injector strut with similar shapes.

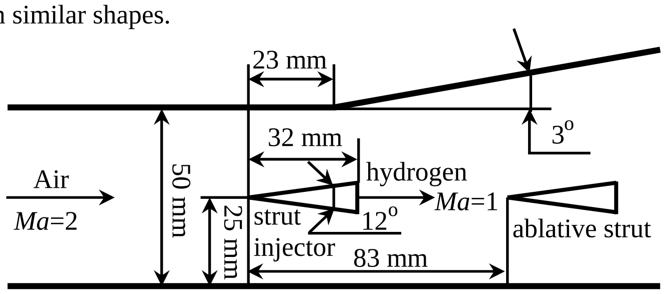


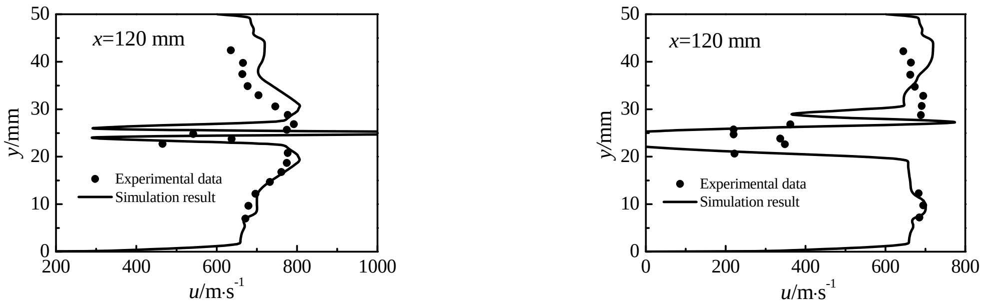
Fig.1 Configuration of the scramjet combustor

RESULTS AND DISCUSSION

Initially, numerical simulation is carried out in the scramjet combustor only with a fuel injector strut. Fig.2 shows the profiles of predicted streamwise velocity as compared with experimental data [5] at a streamwise location. Simulations agree well qualitatively as well as quantitatively with experimental data. To investigate the fuel-air mixing efficiency and combustion efficiency, numerical simulations of non-reacting and reacting flows in the scramjet combustor with an ablative strut and a fuel injector strut are carried out. Fig.3 shows the mixing efficiency in the combustor. Numerical results show that at the end of the scramjet combustor, fuel-air mixing efficiency increases from 87.4% with only a fuel injector strut to 97.9% with the novel scramjet combustor with assembled struts. The enhanced fuel-air mixing improves combustion efficiency. In addition, as the ablative strut is located in the combustion region, its surface temperature is 1800 K, which is the boundary condition for our simulation, the high

a) Corresponding author. Email: ck.chan@polyu.edu.hk

temperature also be acts as an igniter as well as a flame holder. Simulated result of combustion efficiency is only 49.7% at the end of the scramjet combustor with only a fuel injector strut. However, for the scramjet combustor with assembled struts, combustion efficiency is increased to 63.8% at the end of the scramjet combustor.



(a) non-reacting flow (b) Reacting flow

Fig.2 Velocity distributions in the scramjet combustor

A disadvantage of the scramjet combustor with assembled struts is the increase in total pressure loss due to the ablative strut. Fig.4 shows the predicted total pressure recovery coefficient in the scramjet combustors. Compared with the scramjet combustor with only a fuel injector strut, the total pressure recovery coefficient decreases by 4.8% at the end of the scramjet combustor. However, the specific impulse of the scramjet combustor increases by 9.7% due to improvement of combustion efficiency in the scramjet combustor. Hence, general performance of the scramjet combustor with assembled struts is improved.

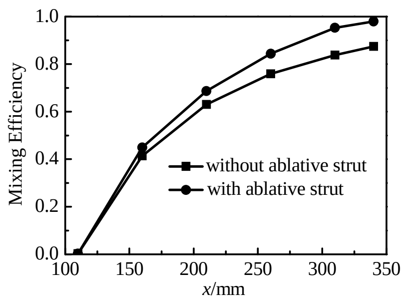


Fig.3 Mixing efficiency in the combustor

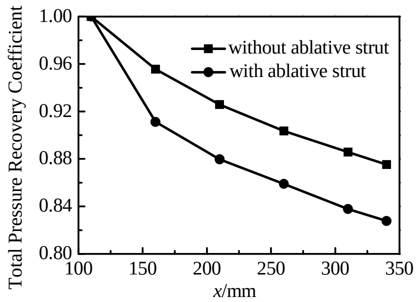


Fig.4 Total pressure recovery coefficient distribution

CONCLUSIONS

By arranging an ablative strut downstream of the fuel injector strut, a novel scramjet combustor is proposed that improves fuel-air mixing and combustion efficiency. Compared with scramjet combustor with only a fuel injector strut, the fuel-air mixing efficiency increases by 10.5% at the end of scramjet combustor with assembled struts. Numerical results show that high temperature of the ablative strut surface enhances ignition of fuel-air mixture and flame stabilization. Combustion efficiency is increased from 49.7% for the scramjet combustor with only a fuel injector strut to 62.8% for the scramjet combustor with assembled struts. Although total pressure loss increases in the scramjet combustor with assembled struts, general performance characteristics of the scramjet combustor with assembled struts increases due to improvement of combustion efficiency.

ACKNOWLEDGEMENTS

This work was partially supported by National Natural Science Foundation of China under Grant No.51176099, a grant from the AMSS-PolyU Joint Research Institute for Engineering and Management Mathematics (Project Account Code 1-BA05) and the Research Committee of The Hong Kong Polytechnic University (Grant No. 1-ZV6Q).

References

[1] Belanger J., Hornung H.: Transverse Jet Mixing and Combustion Experiments in Hypervelocity Flows. *Journal of Propulsion and Power* **12**(1):186-192, 1996.

[2] Ben-Yakar A., Hanson R. K.: Cavity Flame-Holders for Ignition and Flame Stabilization in Scramjets: An Overview. *Journal of Propulsion and Power* **17**(4):869-877, 2001.

[3] Strickland J., Selerland T., Karagozian A. R.: Numerical simulation of a lobed fuel injector. *Physics of Fluids* **10**(11):2950-2964, 1998.

[4] Tomioka S., Murakami A., Kudo K., Mitani T.: Combustion Tests of a Staged Supersonic Combustor with a Strut. *Journal of Propulsion and Power* **17**(2):293-300, 2001.

[5] Guerra R., Waidmann W., Laible C.: An Experimental Investigation of the Combustion of a Hydrogen Jet Injected Parallel in a Supersonic Air Stream. AIAA 3rd International Aerospace Planes Conference, Orlando, AIAA 91-5102, December 1991.