EFFECTS OF BURNING SURFACE MOVING BACK ON STEADY-STATE COMBUSTION OF HIGH-METAL WATER RAMJET ENGINES

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Summary A numerical model was built to study the combustion characteristic of high-metal water ramjet engines as the burning surface moving back. Coupling combustion between the burning surface and the primary water injection has been considered. Changing rules of combustor pressure, water fuel ratio, burning surface temperature and burning rate were obtained. Methods to reduce the effect of burning surface moving back were also presented.

INTRODUCTION

As the water ramjet engine works, the distance which determines heat feedback from the combustion zone between the burning surface and the primary water injection keeps increasing with the burning surface moving back. It is significant to acquire rules of the inner flow field for performance improving of the engine. In this paper, a numerical model describes flow and combustion in the high-metal water ramjet engine has been built. Effects of burning surface moving back on the steady combustion of water ramjet engines were analyzed. Suitable working manners were also suggested for achieving steady-continuous working of high-metal water ramjet engines.

The combustion characteristic of magnesium-based hydro-reactive fuels with a metal content of more than 70% in steam atmosphere has been studied in former work[1]. It was tested that the burning surface temperature is higher than magnesium melting point. Conclusions that magnesium particles melt on the burning surface and do not go into gas phase were obtained. This paper is based on the upper result.

NUMERICAL MODEL

The working process, including surface moving, droplets evaporating, coupling combustion and multi-phase turbulent flow in water ramjet engines is complex. The inner flow field of the engine is simplified before simulation. 1) The combustion process is supposed to be standard steady state, and the moving back of burning surface will be carried out by changing the distance between the surface and the primary water injection. 2) The water injection is equipollence to a uniform injection round the circumference, and the combustor can be calculated as an axis-symmetry structure. 3) Only the reaction $Mg + H_2O = MgO + H_2$ is considered, and the coagulation of MgO is ignored.

The structure used for numerical simulation is showed in Fig 1. User define functions are taken to give gas boundary conditions. Temperature of grid cells near the surface is considered to be the surface temperature and be calculated through the heat balance equation on the combustion surface. The mass flow of gas is defined as the function of surface temperature. Water injection is described by the discrete particle model, and the combustion of gas is described using the EDM model. The numerical simulation is carried out by Fluent6.3.

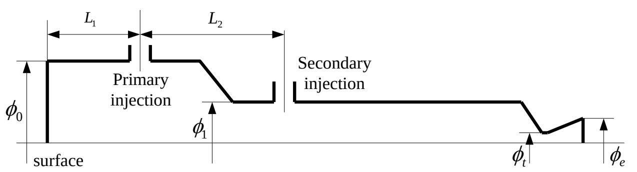

Fig.1. Structure of the water ramjet engine

RESULTS

The distance between the surface and the primary water injection of 20mm、50mm、80mm、110mm are simulated. Results and the simulating cases are showed in Table 1. As the surface moving, the primary and total water/fuel ratio

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increase, the combustor pressure, the average surface temperature and burning rate decrease. Finally, all the parameters become stable as the primary water injection distance over 80mm.

Table.1. Cases and results

Case	Case 1	Case 2	Case 3	Case 4
Primary water injection distance（mm）	20	50	80	110
Primary water/fuel ratio	0.887	1.096	1.097	1.097
Total water/fuel ratio	2.367	2.926	2.929	2.929
Pressure(MPa)	2.88	2.36	2.37	2.37
Average surface temperature(K)	983.0	958.3	958.2	958.2
Average burning rate(mm/s)	28.2	23.5	23.3	23.3

Fig.2 shows the pathway of water droplets and the gas temperature distribution as the surface moving back. It can be seen that the quantity of droplets is decreasing near the surface and the combustion zone moving to the nozzle, which indicates less heat feedback to the surface and results in low gas temperature. Fig 3 shows the radial distribution of burning rate and temperature on the burning surface changing with the surface moving back. There is a hump between the axis and wall of the combustor in case 1, which corresponding to a high concentration of steam and temperature. The hump moving to axis as the distance over 50mm, and the peak value also decreased. The “double hump” changes to “single hump” and more becomes uniform. Fig.4 shows curves of pressure and mass flow rate in a water ramjet engine test. The metal content of the fuel is 73 percent. There are slightly decreasing caused by the surface moving back in the steady segment, which accords with the simulation results.

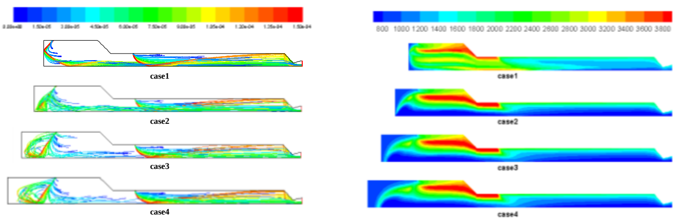

Fig.2. Distribution of droplets and gas temperature

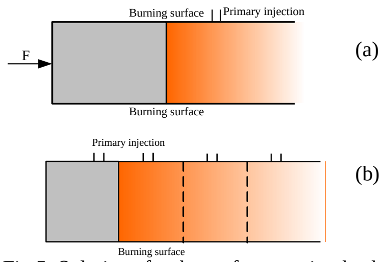

Fig.5. Solutions for the surface moving back

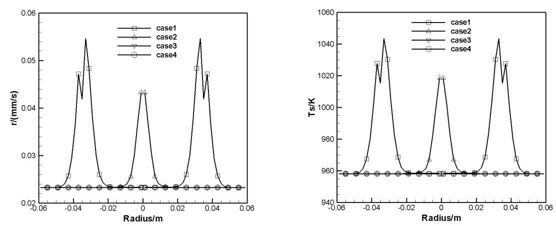

Fig.3. Radial distribution of burning rate and surface temperature

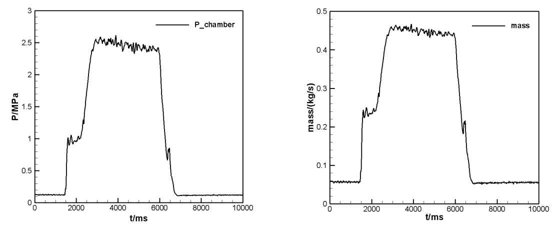

Fig.4. Curves of pressure and mass flow rate in a water ramjet engine test

For the fuel pole used in test is short, the effect of the surface moving back on combustion can be ignored. In model of weapons, the length of fuel is bigger, the pressure and mass flow would decrease in high extent which would result in a big decrease of thrust and affect the velocity of torpedoes. Fig.5 gives two kinds of solution in order to reduce the effect of surface moving. (1) Changing the way of fuel supply. As in Fig.5(a), driving the fuel by outside force and keeping the distance between the surface and the primary water injection. (2) Changing the primary water injection position. As in Fig.5(b), setting several injections in the moving direction of the surface, and controlling them by time scheduling according to the combustion condition.

References

[1] Chao Han, Zhixun Xia, Jianxin Hu, Likun Ma. Steady-state combustion characteristic of hydro-reactive metal fuel in steam atmosphere(in Chinese). Journal of Solid Rocket Technology,2005, 34(1):75-78.