6th International Symposium on Air Breathing Engines

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FOREWORD

The International Society on Air Breathing Engines (ISABE) is a scientific not-for-profit association of individuals and/or organizations, open to all nations of the world that are interested in the field of airbreathing propulsion for flight vehicles. The Society was formed for the purpose of furthering the free exchange on an international level of knowledge on flight propulsion systems. The governing body of the Society is the Executive Committee, which presently is comprised of members from 22 nations.

The Sixth International Symposium on Air Breathing Engines - XVI International Aeronautical Congress will be held in Paris, France, June 6-10, 1983. The Symposium is organized jointly by the Association Aéronautique et Astronautique de France, the International Society on Air Breathing Engines, the International Council of the Aeronautical Sciences, and the American Institute of Aeronautics and Astronautics.

This volume is comprised of the manuscripts that were submitted for publication in time for distribution at the symposium. The Table of Contents lists the titles and authors of the entire program of 6 keynote lectures complemented with 98 technical papers. Copies of this publication and the remaining papers can be ordered from the American Institute of Aeronautics and Astronautics, 1633 Broadway, New York, N.Y. 10019.

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RAMJETS/ROCKETS

83-7000

AN EXPERIMENTAL STUDY ON CONFIGURATION OF SECONDARY COMBUSTION CHAMBER FOR RAM-ROCKET

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Abstract

Solid propellant fuel for ram-rocket, that has been highly metalized with aluminum, magnesium and boron and reduced oxidizer, has been experimentary investigated with a chimny type strand test burner as well as ram-rocket simulation test motor. The fuels can sustain stable combustion in the primary rocket motor (primary combustion chamber, fuel gas generator, etc.) without any extra device if the metallic fuel concentration is below 50%. However, the amount of combustion residue left in the primary rocket motor and wasted increases as metallic fuel concentration increases. The practical upper limit of aluminum or boron concentration recommended to minimize the residue is about 40%. The blending of magnesium or magnesium alloy in the metallic fuel and potassium salt such as KN (potssium -nitrate), KC (potassium-chlorate) and KP (potassium-perchlorate) in AP (ammonium perchlorate) oxidizer not only efficiently decreases the combustion residue but also improves re-ignition and -combustion characteristics in the ram-combustor (secondary combustion chamber) due to the production of high temperature magnesium- /or potassium-oxide solid particles. The ram-rocket simulation tests were carried out with several selcted fuels and a test motor with various secondary combustion chambers. Secondary combustion characteristics were also observed in the pyrex glass transparent secondary combustion chamber. The chambers with characteristic lengths from 0.21 to 1.54 m were examined. For metalized fuel, even the shortest characteristic length was enough to complete the secondary combustion. About 7 kN-s/kg Isp (specific impulse) for 40% aluminum of magnalium (50% magnesium/50% aluminum alloy) loaded fuel and 10.5 kN-s/kg Isp for 40.5% boron/4.5% magnalium loaded fuel was obtained by simulated tests at 600 m/s sea level flight.

1. Introduction

The ram-rocket, often called the rocket-ramjet, air breathing rocket, air augmented rocket, or ducted rocket, is a combined propulsion system of rocket and ramjet engine. Since the rocket propellants are usually designed fuel rich to obtain high Isp (specific impulse), the rocket exhaust is mixed with ambient air and forms a large flame plume righ after the thrust nozzle. By enclosing the flame in a restricted chamber, called a ram-combustor, the ram-rocket canmultiply the thrust to several times that of original rocket. Since the thrust augmentation is done only by the introduction of ram-air into the ram-combustor, the ram-rocket has significantly increased fuel economy in comparison with the pure rocket mode operation.

The most significant advantage of the ram-rocket is its very simple configuration, which is fully demonstrated when solid propellant is utilized in the original rocket motor (in the case, the motor called primary rocket motor, primary combustion chamber or fuel (gas) generator). Considerablly high Isp is obtained if high energy metallic fuel such as aluminum, magnesium /or boron loaded and reduced oxidizer solid propellant are used in the primary rocket motor as ram-rocket fuel.

The combustion products of the fuel in the primary rocket motor usually include solid particles of metal oxide and imperfectly burnt or decomposed hydrocarbon. They are exhausted into the ram-combustor. Here secondary combustion of a mixture of the exhaust and introduced ram-air spontaneously takes place with the aid of high temperature metal oxide particles. These particles are kept at a much higher temperature than ambient gaseous exhaust even when they expanded through the primary rocket nozzle.

The metallic fuel contained in the fuel plays several important roles as mentioned above. However, with the exception of magnesium (the least energetic among the three metallic fuels) the combustion in the primary rocket motor mainly sustains the reaction between fuel binder and oxidizer. The metallic fuel acts only as heat sink. Therefore, over concentration of metallic fuel in the fuel causes harmful results on the combustion characteristics in the primary rocket. There include a increase of combustion residue, quenching of fuel combustion, etc. The optimum concentration of the metallic fuel has to be designed taking into consideration combustion characteristics and the amount of combustion residue left in the primary rocket motor.

Magnesium or magnesium alloys burn actively, even in the primary rocket motor which is considerably deficient in oxidizer. As mentioned previously, the main combustion products, magnesium oxide, plays an important role in the ram combustor. Potassium oxide, a combustion product of potassium salt, such as KN (potassium-nitrate), KC (potassium chlorate) and KP (potassium-perchlorate) is blended in the AP (ammonium perchlorate) oxidizer and plays a similar role in the primary rocket motor and ram-combustor.

In order to increase volumetric effciency, the ram-combustor usually utilizes the rocket motor in advance as a booster (integral rocket ramjet; IRR). Therefore, the configuration and volume of the ram-combustor have to be enough for both secondary combustion and booster rocket use. For the fuel contain magnesium, magnesium alloys and/or potassium salt appropriate for primary and secondary combustion, the configuration and volume of the booster

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rocket motor is usually sufficient for secondary combustion.

2. Experimental Fuels

2.1 Formulation of the fuels

The formulation of the experimental fuels has been designed taking into account fuel performance both calculated and exzmined, and the amount of the combustion residue left in the primary rocket motor. Figure 1 shows the outline of combustion limits of the fuel based on metallic fuel, HTPB (hydroxy terminated poly-butadiene) fuel binder and AP oxidizer[1].

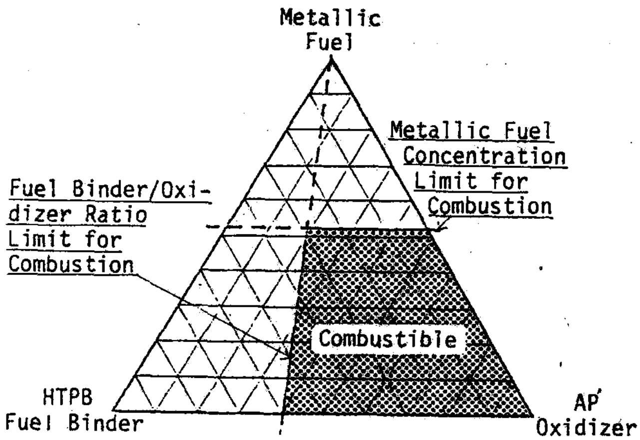

Fig. 1 Combustion limits of fuel based on metallic fuel, HTPB fuel binder and AP oxidizer.

In the primary rocket motor, the combustion of composing fuels slightly inside the combustion limits are sustained mainly by the reaction between fuel binder and oxidizer, while the metallic fuel acts only as the heat sink. Magnesium is an exception. It burns slightly next inside the limits (which is extremely lacking oxidizer) and produces magnesium oxide particles.

Metallic fuels of high melting points, for example, boron; MP=2,450±20 °K show higher concentration limit than that of fuels with lower melting point, such as aluminum; MP=932 °K . This is because the average flame temperature is usually 1,000 1,300 °K and heat of melt added to the effect of heat sink. However, the difference is not so significant and the limit of metallic fuel concentration is almost the same for both high and low melting point metallic fuel, about 50%.

Higher fuel binder/oxidizer ratios also quench the flames in the primary rocket motor. Thogh, the combustion in the primary rocket motor is sustained until the ratio of 65/35 if the fuel is not metallized, usual highly metalized fuel for ram-rocket sustains self combustion until 60/40. Of eause, calculations shows that the high adopted the ratio, the higher the performance obtained. However, the characteristics needed to sustainstable combustion even when highly metalized and minimize the combustion residue are the most important requirement for the ram-rocket fuel. Therefore, the ratio, in the present research, is much lower than limit, around 33/67. Most of heating energy is sustained by the combustion of metallic fuel and ram-air.

As mentioned previously, the blending of magnesium and/or magnesium alloys (in the present research, 50% magnesium/50% aluminum magnalium were utilized through the test) in the metallic fuel is very effective in stabilizing the primary combustion and re-igniting secondary combustion. The experimental fuel also contains at least 4% magnalium as a metallic fuel ingredient.

The blending of potassium salt in the AP is also efficient for re-ignition in the secondary combustion. The experimental fuel replaced one third of AP with KN, KC and KP.

2.2 Performance calculation

In order to estimate the performance of the ram-rocket, Isp (specific impulse), Tc (ram-combustor flame temperature) and C* (characteristic velocity) were calculated with wide ranging fuel composition and ram-air excess ratios for the hypothetical rocket which is propelled by fuel and ram-air[2]. The calculated Isp for the rocket was corrected for the ram-rocket by following:

$$Isp(e) = Isp(c) \times (R+1) - \frac{V}{g} R \quad \text{-------(1)}$$

where Isp(e) is corrected to Isp for the ram-rocket at flight speed V, Isp(c) is the Isp calculated for the hypothetical rocket, R is the ram-air/fuel ratio and V is the flight speed. The combustion pressure of the hypothetical rocket was selected same as ram-combustor pressure of ram-rocket, which depend on flight speed (Mach No.) and altitude. In the present calculation, 600m/s at sea level flight (M = 1.76) is assumed. Based on results of ram-air intakes pressure recovery factor experiments[3], ram-combustor pressure was calculated as 0.573 MPa (5.66 ATM).

Figure 2 shows the calculated performances of fuel that is 40% metallic fuel, 20% HTPB fuel binder and 40% AP oxidizer. At a ram-air excess ratio below 5, aluminum and magnalium loaded fuel show high ram-combustor temperature and consequentially, C* and Isp both higher than boron loaded fuel. However, in practice, high ram-air excess ratios such as 10 or higher are applied and boron loaded fuel shows a much higher Tc, C* and Isp than aluminum or magnalium loaded fuel. Obviously, for ram-rocket fuel with high Isp (higher than 10 kN-s/kg), boron is the preferable metallic fuel.

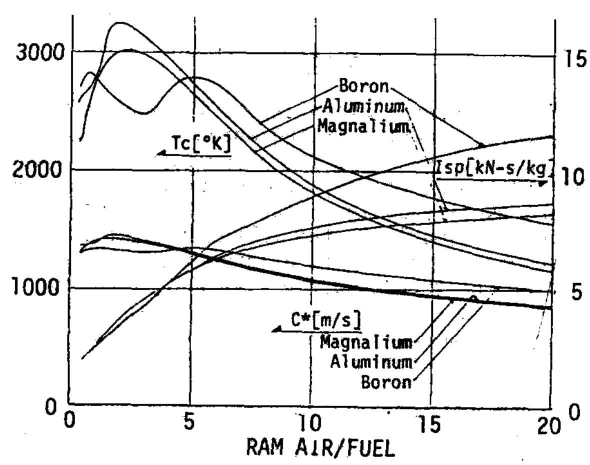

Fig. 2. Calculated performances for 40% metal/20% HTPB/40% AP fuel @600m/s sealevel flight.