반 실험적 방법을 통한 고체 램 제트 성능에 대한 흡입 공기 온도의 영향

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Inlet Air Temperature Effect on the Performance Efficiency of the Solid Fuel Ramjet through Semi-empirical Method

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ABSTRACT

In the fuel of the solid fuel ramjet there are metal particles in order to improve the Isp like as solid rocket propellants. Because of the short combustion residence time these metallized fuels have low combustion efficiencies. Therefore it is necessary to increase the combustion efficiency and the inlet air temperature does an important role to this. The effect of the inlet air temperature to the performance is investigated through the semi-empirical method by adopting the experimental combustion efficiency. There are two factors to affect the inlet temperature, free stream temperature and the flight Mach number.

초 록

고체 램 제트 추진기관에서도 일반 로켓 추진기관에서와 같이 Isp 즉 추력을 증대 시키기 위하여 고체 입자들을 연료에 함유시킨다. 이러한 고체입자가 포함된 연료들은 매우 짧은 연소실 체류시간 때문에 연소 효율의 증대가 필수적이며 흡입공기 온도가 중요한 역할을 한다. 이 흡입공기 온도가 램 제트 성능에 미치는 영향을 조사하였다. 성능조사는 실험적 방법에 한계가 있어 연소실험을 통한 연소효율을 이용하여 반-실험적으로 조사하였다.

연소실 흡입공기 온도에 영향을 미치는 인자는 자유 유동장 즉 대기 온도와 비행 마하 수이며 이들에 대한 효과를 조사하였다.

NOMENCLATURE

c	specific heat at constant pressure
G	air mass flux
H	heating value of the fuel
$\dot{m}$	mass flow rate
M	Mach number
NPS	naval post graduate school
p	pressure
q	heat input rate per unit of air mass flow rate
T	temperature

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TR	temperature ratio
V	velocity
η	efficiency
ϕ	equivalence ratio

Subscripts

a	air
f	fuel
B	burning
P	constant pressure
t	total, stagnation
th	thermal
tot	total, performance
0	free stream
2	combustor inlet

1. INTRODUCTION

The use of metals such as boron or boron-carbide introduced to the polymeric fuel of a solid ramjet for abetter energetic performance[1–6].

Previously the effect of the inlet air temperature on the combustion was investigated using the boron carbide fuel[6].

The objective of the present study was to investigate the effect of the inlet air temperature on the performance efficiency using the experimental combustion data. The experimental apparatus, test procedures, test conditions are described well in the reference paper 7. And in this paper simply the result of the combustion efficiency is adopted. The regression analysis was employed for the combustion efficiency and following correlation expression is represented all the data in the reference 7.

$$\eta_B = 1.1\times10^{-7}\phi^{0.5}G^{-0.61}T_2^{\ 2.17} \qquad (1)$$

Now the performance efficiency will be considered with this equation representing the experimental data.

2. ANALYSIS

If the fuel flow rate is much less than the air mass flow rate, ($m_f = 0.03m_a$) we can assume the following heat balance equation

$$m_a q = \eta_B m_f H_f,\quad (m_f \ll m_a) \qquad (2)$$

This equation shows that the combustion efficiency 'η_B' will affect the heat input rate'q'.

In general it is well known in thermodynamic analysis that the cycle engine performance efficiency decreases with increasing inlet air temperature. But in the experimental tests, the combustion efficiency increases with increasing inlet air temperature like as equation (1).

If combustion efficiency increases, does total (performance) efficiency increase also or not? In the Brayton cycle (which is simplified ramjet cycle) thermal efficiency is increased but total efficiency of the ramjet is decreased respectively with the heat input parameter q/c_pT_0 through equation (3) and (4).

$$\eta_{th} = \frac{V_e^2 - V_0^2}{2q} = 1 - \frac{1}{q/c_pT_0}\left(\frac{T_e}{T_0} - 1\right) \qquad (3)$$

$$\eta_{tot} = \frac{(\gamma-1)M_0^2}{q/c_pT_0}\left[\sqrt{1+\frac{q}{c_pT_0}\frac{1-\left(\frac{M_2}{M_0}\right)^2}{1+\frac{\gamma-1}{2}M_0^2}} - 1\right] \qquad (4)$$

Above equations are the thermal and the total efficiency one of the ideal Brayton cycle through the thermodynamic analysis[8,9]. Seeing the equation (3), we can see that the thermal efficiency will increase with the heat input parameter q/c_pT_0 which is represented by equation (5). And the heat input parameter q/c_pT_0 is linearly depending on the heat input rate 'q' for the fixed T_0. Also it is noted that 'q' itself depends on the combustion efficiency η_B, which increases with the inlet air temperature strongly more than power 2 from the experimental results like as the equation (1).

$$\frac{q}{c_pT_0}=\phi\left(\frac{m_f}{m_a}\right)_{st}\frac{\eta_BH_f}{c_pT_0} \qquad (5)$$

Between the stagnation and static temperature, there is the following relation.

$$T_{t0}=T_0(1+\frac{\gamma-1}{2}M_0^2) \qquad (6)$$

For the conventional ramjet combustor inflow the Mach number M_2 is very low, therefore

$$T_2\simeq T_{t2}=T_{t0}$$

Now combining the equations (1), (6) then the equation (5) is following

$$\frac{q}{c_pT_0}=\phi\left(\frac{m_f}{m_a}\right)_{st}\frac{\eta_BH_f}{c_pT_0}=\alpha\frac{1}{T_0}T_2^{2.17}$$

$$=\alpha\frac{1}{T_0}[T_0\left(1+\frac{\gamma-1}{2}M_0^2\right)]^{2.17} \qquad (7)$$

Where η_B, ϕ, c_p, G are assumed constant. We know that the combustion efficiency is affected by the heat input parameter, which depends on the free stream temperature itself and flight Mach number

3. RESULTS AND DISCUSSION

Here one reference point is considered $T_0=250k$, $q/c_pT_0=6$, $M_2/M_0=0.1$

These will give the η_{tot} from equation (4)for the given specific heat ratio γ.

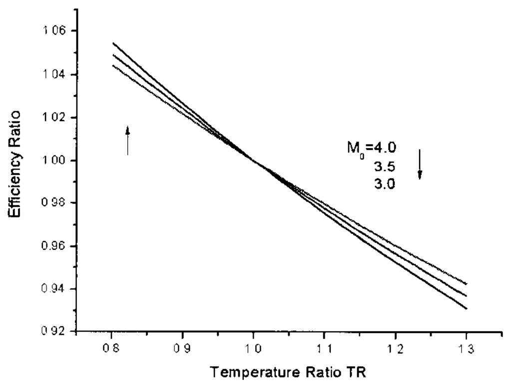

Fig. 1 Normalized Performance Efficiency

For the given Mach number the performance efficiency decreases monotonously with the free stream temperature ratio, but the decreasing ratio is slightly different shown in the Figure 1. In this figure the performance efficiencies are normalized by the value of the reference point at the given Mach number.The normalized performance efficiency ratio is lower with higher Mach number for the given temperature ratio.

For the given free stream temperature, the different Mach number also gives the different combustor inlet air temperature like as equation (6) and the effects of the Mach number of the given free stream temperature ratio are shown in the Figure 2. The performance efficiency shows the maximum value around Mach 4. And the performance efficiency is decreased with the increasing the free stream temperature ratio.

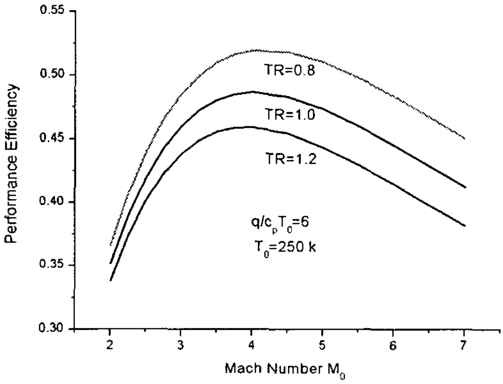

Fig. 2 Performance Efficiency vs TR

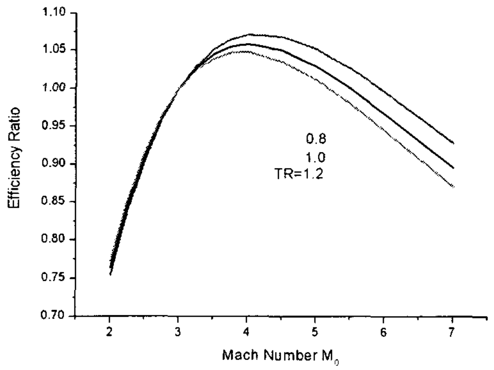

Fig. 3 Normalized Performance Efficiency

Finally if the temperature ratio and Mach number vary simultaneously, then the performance efficiency will vary like as the curves in Figure3. In this, the efficiencies were normalized by the value of Mach number 3 of the given temperature ratio respectively.

The results show that the difference of the normalized performance efficienciesat the low Mach number among the different temperature ratios is closer than that at the high Mach number.

4. CONCLUDING REMARKS

Higher inlet air temperature produced higher combustion efficiency, but lower performance efficiency.

The normalized performance efficiency ratio is lower with higher Mach number for the given temperature ratio.

The performance efficiency shows the maximum value around Mach 4.

The performance efficiency is decreased with the increasing the free stream temperature ratio.

The difference of the normalized performance efficiencies at the low Mach number among the different temperature ratios is closer than that at the high Mach number.

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