한국추진공학회 2007년도 추계학술대회 논문집 pp.271~274 2007 KSPE Fall Conference

램제트 성능에 미치는 흡입 공기 온도에 대한 고찰

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Review of the Inlet Air Temperature Effect on the Ramjet Performance Efficiency

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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 main factors to affect the inlet air temperature is the free stream temperature and the flight Mach number. Also the flow velocity in the combustor does an important role, therefore entire range of the air flow; from the stagnation to the sonic velocity in the ramjet combustor is considered.

초 록

고체 램제트 추진기관에서도 일반 로켓 추진기관에서와 같이 Isp 즉 추력을 증대시키기 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 램제트 성능에 미치는 영향을 조사하였다. 연소실 흡입공기 온도에 영향을 미치는 인자는 자유 유동장 즉 대기 온도와 비행 마하수이다. 램제트 연소실에서의 유속 또한 중요한 역할을 함으로 유속 전 영역 즉 정체상태부터 음속까지에 대하여 조사하였다.

Key Words: Performance (성능), Combustion Efficiency(연소 효율), Brayton Cycle(브레이튼 사이클)

1. INTRODUCTION

The use of metals such as boron[1,2] or boron- carbide[3] introduced to the polymeric fuel of a solid ramjet may theoretically provide a better energetic performance of the motor together with increased fuel loading itself[4] and fuel properties[5]. However, extracting the energetic potential from boron or boron-carbide is difficult task due to the

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complicated ignition and combustion process of the boron and boron-carbide particles. Even though the combustion behavior of the solid fuel ramjet is reasonably well understood[6,7,8]. Recently the effect of the inlet air temperature on the combustion was investigated using the boron carbide fuel[9].

The objective of the present study was to investigate the effect of the inlet air temperature on the performance efficiency limit 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.

$$\eta_B = 1.1 \times 10^{-7} \phi^{0.5} G^{-0.61} T_2^{\ 2.17} \tag{1}$$

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, ($m_f = 0.03 m_a$) we can assume the following heat balance equation

$$m_a q = \eta_B m_f H_f, \quad (m_f = m_a) \tag{2}$$

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).

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

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

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).

$$\frac{q}{c_pT_0} = \phi\left(\frac{m_f}{m_a}\right)_{st}\frac{\eta_B H_f}{c_pT_0} \tag{5}$$

In generally the performance efficiency is considered with the fixed heat input parameter in order to investigate the effect of the Mach number. For the given value of the heat input parameter, for example $q/c_pT_0 = 6$, the performance efficiency can be expressed by using the equation (4) and is shown in the Figure 2. Also in the Figure 2 the heat input parameter effect is shown for the given Mach number with the fixed M_2/M_0.

In the Figure 1, the two lines with the symbol of square and circle are represented the performance efficiencies of the cases when the combustor gas Mach number is zero and one respectively.

Between these two lines there will be a ramjet performance efficiency because of subsonic combustor gas velocity. The figure shows that the performance efficiency increases monotonously with Mach number. Even though we assumed the fixed Mach number ratio of the combustor gas to the free stream, it will be a subsonic or supersonic, other words ramjet or scramjet depending on the free stream Mach number. If we choose $M_2 / M_0 = 0.1$ the performance efficiency is located between these two lines till Mach number 7, but $M_2 / M_0 = 0.4$ the performance efficiency is deviated at the Mach number 2.5.

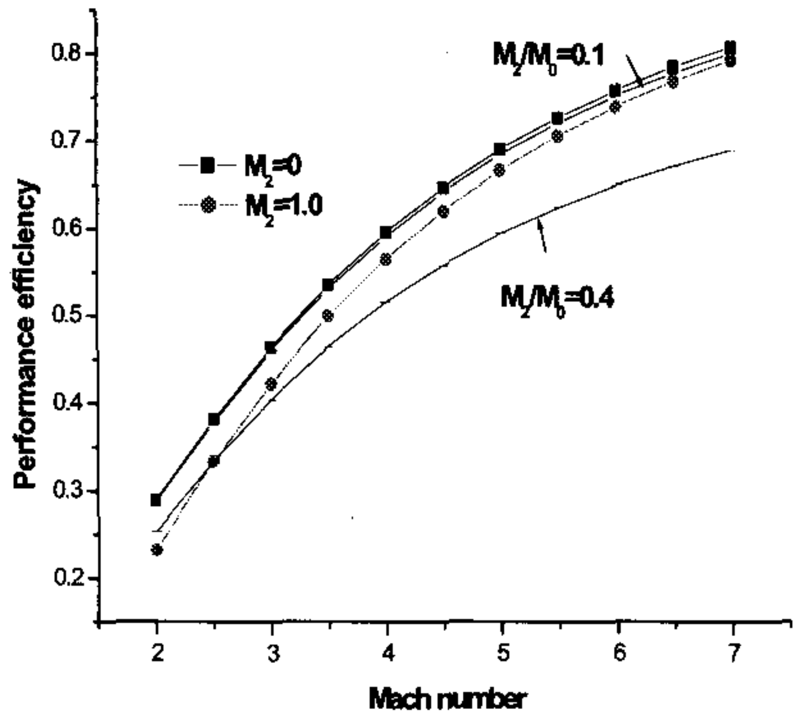

Fig. 1 Ideal Brayton cycle performance

Figure 2 shows the performance efficiency variations for the free stream Mach number 3 and given value of M_2 / M_0 or M_2 with the heat input parameter. It decreases monotonously with the heat input parameter.

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

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

For the conventional ramjet combustor inflow the Mach number M_2 is very low, therefore $T_2 \simeq T_{t2} = T_{t0}$

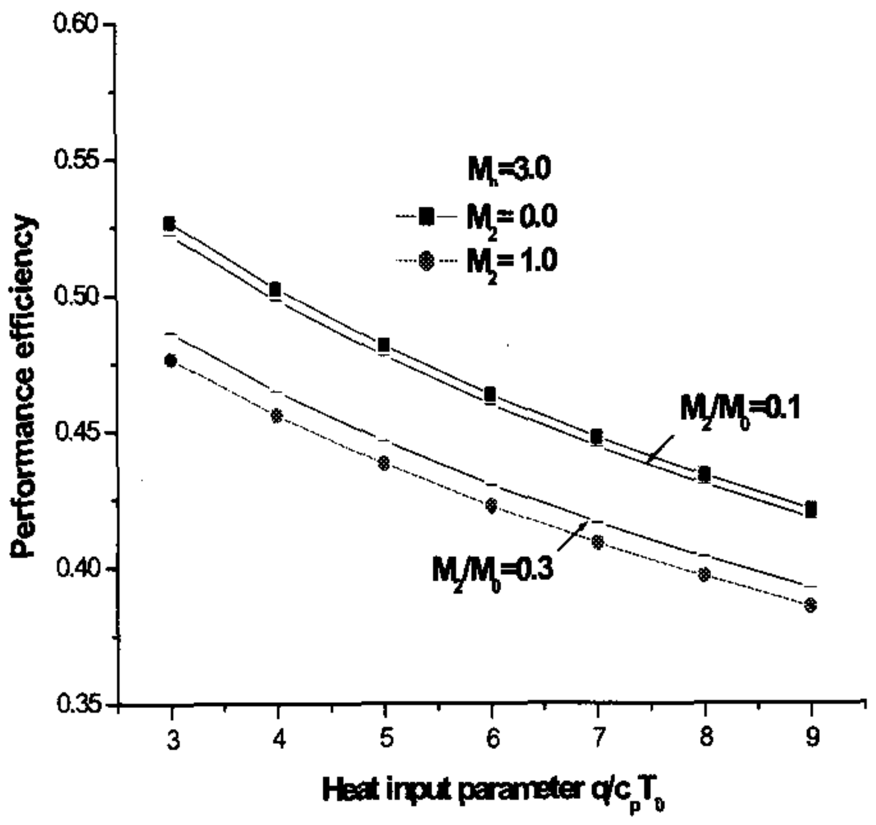

Fig. 2 Effect of Heat input parameter

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

$$\frac{q}{c_p T_0} = \phi \left(\frac{m_f}{m_a} \right)_{st} \frac{\eta_B H_f}{c_p T_0} = \alpha \frac{1}{T_0} T_2^{2.17}$$
$$= \alpha \frac{1}{T_0} [T_0 \left(1 + \frac{\gamma - 1}{2} M_0^2 \right)]^{2.17} \tag{7}$$

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.

Here one reference point is considered;

$T_0 = 250k$, $q / c_p T_0 = 6$, $M_2 / M_0 = 0.1$

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

For the given Mach number the performance efficiency decreases monotonously with the free stream temperature ratio, but the decreasing ratio is slightly different. The normalized performance efficiency ratio is lower with the high Mach number for the given free stream temperature ratio.

For the given free stream temperature, the different Mach number also gives the different combustor inlet air temperature like as the equation (6).

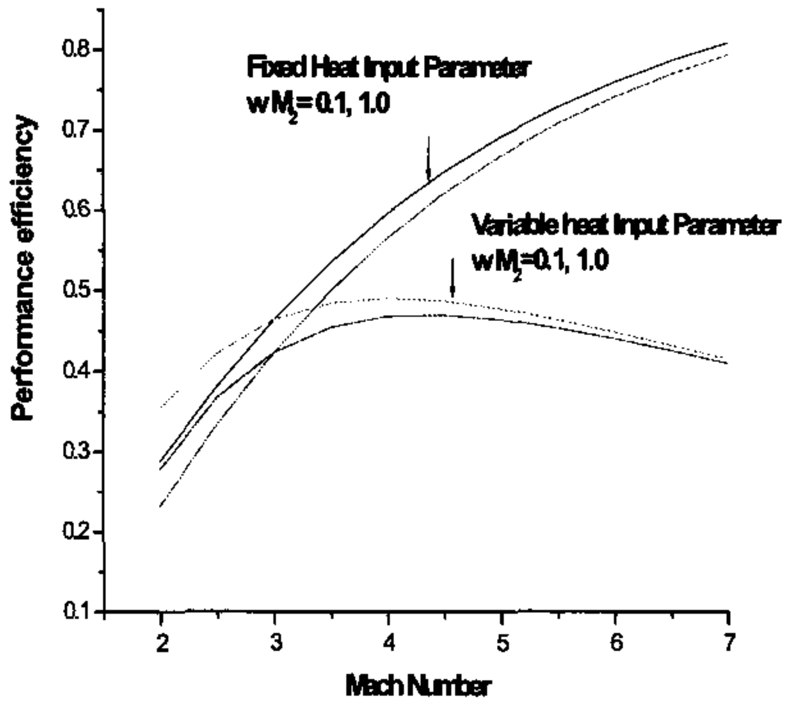

Fig. 3 Comparison of the Heat Input Parameter

And we have very interesting results, comparing the fixed heat input parameter to the variable parameter which is considered the combustion efficiency, the performance efficiency shows curve including the maximum value around Mach number 4. For the fixed heat input parameter, the Brayton cycle performance is increasing monotonously with Mach number referring the Figure 1. The Figure 3 shows the differences between the fixed heat input parameter and variable heat input parameter model.

3. CONCLUDING REMARKS

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

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

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

The maximum performance efficiency occurs around the Mach number 4 comparing the monotonous increasing for the ideal Brayton cycle.

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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