Ideal Ramjet Parametric Cycle Analysis

Introduction

• The steps of parametric cycle analysis to an ideal ramjet
• The output of parametric cycle analysis of an ideal ramjet

© 2015 SIM University. All rights reserved.
Ideal Ramjet

- Brayton Cycle Engine with no rotating part
- Compression of air accomplished by forward motion only

Figure 4.3 T-s Diagram and H-K Diagram of an Ideal Ramjet
(adapted from R-1, page 267)

© 2015 SIM University. All rights reserved.

Adapted: "Elements of Propulsion: Gas Turbines and Rockets" by Jack D. Mattingly
Ideal Ramjet

- **Input**
  
  \[ M_0, T_0, \gamma, c_p, h_{PR}, T_{t4} \]

- **Output**
  
  \[ \frac{F}{m_0}, f, S, \eta_T, \eta_P, \eta_O \]

- **Example:**
  - \( T_0 = 220 \text{ K} \)
  - \( \gamma = 1.4 \)
  - \( c_p = 1.004 \text{ kJ/(kg K)} \)
  - \( h_{PR} = 42,800 \text{ kJ/kg} \)
  - \( T_{t4} = 1600, 1900, \text{ and } 2200 \text{ K} \)

---

Ideal Ramjet

- **Equations:**

  \[ R = \frac{\gamma - 1}{\gamma} c_p \]

  \[ a_0 = \sqrt{\gamma R g_c T_0} \]

  \[ \tau_r = 1 + \frac{\gamma - 1}{2} M_0^2 \]

  \[ \tau_\lambda = \frac{T_{t4}}{T_0} \]

  \[ \frac{V_0}{a_0} = M_0 \sqrt{\frac{\tau_\lambda}{\tau_r}} \]

  \[ \frac{F}{m_0} = \frac{a_0}{g_c} \left( \frac{V_0}{a_0} - M_0 \right) \]

At \( V_0 = 0, \ \tau_r = 1, \) and \( V_0/a_0, F/m_0 = 0 \)
At $V_0 = 0$, $T_r = 1 \
Thus \eta_T, \eta_O = 0$

Ideal Ramjet

- Equations
  \[ f = \frac{c_p T_0}{\eta_{PR}} (\tau_f - \tau_r) \]
  \[ S = \frac{f}{F/m_0} \]
  \[ \eta_T = 1 - \frac{1}{\tau_r} \]
  \[ \eta_P = \frac{2}{\sqrt{\tau_f/\tau_r + 1}} \]
  \[ \eta_O = \eta_T\eta_P = \frac{2(\tau_f - 1)}{\sqrt{\tau_f/\tau_r + 1}} \]

Varying $M_0$ in Ideal Ramjet

$T_0 = 220 \text{ K}; \gamma = 1.4; c_p = 1.004 \text{ kJ/(kg K)}; h_{PR} = 42,800 \text{ kJ/kg}; T_{id} = 1600, 1900, \text{ and } 2200 \text{K}$

Variation of Specific Thrust and TSFC against Mach Number

Source: Soon Kim Tat
Max Specific Thrust in Ideal Ramjet

- Optimum Mach Number (max $F/m_0$)
  \[ M_0 \text{ max } F/m_0 = \frac{2}{\gamma - 1} (\sqrt{\sqrt{\tau_2}} - 1) \]

- Occurring when
  \[ T^*_r \text{ max } F/m_0 = \frac{2}{\sqrt{\tau_2}} \]

Varying $M_0$ in Ideal Ramjet

$T_0 = 220$ K; $\gamma = 1.4$; $c_p = 1.004$ kJ/(kg K); $h_{pg} = 42,800$ kJ/kg; $T_{td} = 1900$K

Variation of Efficiencies against Mach Number

Source: Soon Kim Tat
Mass Flow of Ideal Ramjet

$M_2 = 0.5; \text{ Altitude} = 12 \text{ km}; T_{in} = 1900K; \pi_f = 1.0$

![Figure 4-5 Ideal Ramjet Thrust per Unit Area vs Mach Number](image)

Summary

- Performing parametric cycle analysis to an ideal ramjet
  - Effects on thrust and fuel consumption
- Study of the output of parametric cycle analysis of an ideal ramjet
  - Varying Mach number
  - Varying combustor exit temperature
Reflection Question

• Using relationship for speed of sound, for an ideal ramjet, show that

\[
\left( \frac{V_s}{a_0} \right)^2 = \frac{T_0}{T_0} M_0^2
\]