Aerodynamic Heating Research of Induction System under Different Attack Angle Condition

Zhaowei Wang*, Ran Yao and Pengju Hu
China Academy of Launch Vehicle, Beijing, China.

*Corresponding author e-mail: wangzhaowei-01@163.com

Abstract. Series aerodynamic heating problems often occurs in induction system of high mach number vehicle. Especially when accompanied by shock-shock interaction and shock-boundary layer interaction. Simulation is carried out on the strong interaction between impinging shock wave and specified induction model at Mach 5~6 under different attack angle ranging from -10° -10°. Results indicated that the attack angle largely affect the aerodynamic heating values.

1. Introduction
At high Mach number flight conditions, particularly for a long time and long range fly, the serious aerodynamic heating problems become an unavoidable key issue in the design of a induction system. This needs to take into account both aerodynamic performance and aerodynamic heating, which are actually dependent on local flow characteristics. Consequently, it is of great importance to study flow characteristics on typical parts of an induction system subjected to severe aerodynamic heating for the engineering application and development of basic subject.

The flow about the airbreathing high mach number vehicle is generally characterized by the occurrence of intense shock that form around the nose leading edge and induction leading edge, of which shock-shock wave interaction can form the complex types of interferences with large increase in pressure and temperature levels, while the shock wave-boundary layer interaction can form and separation with moderate increase in pressure and temperature levels.

In this paper, flow characteristics of the shock-shock wave interaction and shock wave-boundary interaction for two dimensional typical induction were simulated under different attack angle at Mach 6. Ten cases depending attack angle relative to incoming flow were investigated to study the aerodynamic heating rules of the specified induction system.
2. Problems and Modelling
It is well recognized that attack angle can largely affect the interference between the external waves and a bow shock in front of a cowl lip[1-2], thus resulting totally different heating rates distributions in high Mach number induction. However the effect of incoming flow condition on aerodynamic heating of cowl lip and induction were not thoroughly studied and a clear conclusion was never drawn for engineering application[3]. It is may be due to the fact that the complicated flow conditions are difficult to simulate and results at given induction design may not easy to explain. However engineers still want to get a rule between incoming flow conditions and heating rates of high Mach number induction.

In this study, research and CFD method are based on commercial software FLUNT and Navier-Stokes equations. It is a convenience tool and has better precision for complicate flow. The results were validated with experiments in reference[4-6]. The results had good agreement with the experiment results obtained at NASA scramjet investigation, indicating the CFD model and simulation methods were suitable for the induction aerodynamic heating modeling.

3. Results and Discussion

3.1. Flow characteristics of 2D high Mach number induction
Flow conditions of nine different attack angles ranging from -10° to 10° have been calculated. Mach contours and static pressure of computation results (Fig.2-Fig.6) showed that the bow shock wave and compression waves converged at the cowl lip and the scramjet induction at attack angle of 0°, 6° and 10°, however the compression wave and oblique waves were out of induction with negative attack angles. With the negative angles studied, the shock wave convergence effect tend to became weaker. The static pressure of scramjet induction increased with the attack angle. The flow characteristic results indicated strong aerodynamic heating effect occurred at positive angle conditions.
Key parameters at the exit of the isolator and the rules of variation have been given at different conditions (Tab.1). The static pressure and static temperature of high mach number induction were
increased with the attack angle due to the compression effect. The total pressure recovery and mass flow coefficient showed different tendency compared with the pressure and temperature, due to the varied boundary layer thickness.

Table 1 Key induction exit parameter under different attack angles

| attack angle(α) | total pressure recovery coefficient | Mach number | static pressure rise | static temperature rise | flow per unit width(kg/s) |
|-----------------|----------------------------------|-------------|----------------------|------------------------|--------------------------|
| -10°            | 0.43                             | 3.59        | 6.14                 | 2.31                   | 14.96                    |
| -6°             | 0.48                             | 3.43        | 9.72                 | 2.44                   | 23.48                    |
| -4°             | 0.52                             | 3.34        | 12.00                | 2.52                   | 29.07                    |
| -2°             | 0.54                             | 3.24        | 15.03                | 2.64                   | 35.29                    |
| 0°              | 0.55                             | 3.10        | 19.13                | 2.81                   | 41.84                    |
| 2°              | 0.58                             | 2.97        | 23.90                | 2.95                   | 48.61                    |
| 4°              | 0.57                             | 2.82        | 29.57                | 3.16                   | 54.28                    |
| 6°              | 0.50                             | 2.58        | 37.56                | 3.49                   | 58.78                    |
| 10°             | 0.37                             | 2.18        | 52.17                | 4.14                   | 65.34                    |

Total pressure distribution for induction exit under negative attack angles were shown in Fig. 7, indicating total pressure decreased with the attack angle. Low pressure area increased and the flow rate had great loss at negative attack angle conditions.

![Fig.7 Total pressure distribution for induction exit under negative attack angles](image-url)

3.2. Aerodynamic heating characteristics of 2D high mach number induction

Figure 8 showed heat flux distribution of induction forebody at given attack angle of -6°, 0°, 6° and 10°. In general, the heat flux increased with the attack angle, which had good agreement with the static pressure variation tendency, indicating pressure and heat flux had similar variation rules for high mach number scramjet induction. At the same time, separation flow field may increase under strong shock/shock interaction condition, which introduced severe influence for thermal protection system.
Fig. 8 Aerodynamic heating results of induction under attack angle of -6°, 0°, 6° and 10°.

Cowl lip static pressure distribution did not simply increase or decrease with the attack angle due to the complicated interaction between shock waves and different angle of free stream. Of all the condition studied, the static pressure of cowl lip was the largest at 10°.

4. Conclusion
The high mach number induction performance and aerodynamic heating characteristics are the main concern in engineering applications, both theoretical and experimental guidance are in great need in induction aerodynamic heating evaluation. This paper tried to obtain the rules and connections between aerodynamic heating and incoming flow conditions, such as attack angles.

(1). The static pressure of scramjet induction increased with the attack angle. The flow characteristic results indicated strong heating occurred at positive angle conditions;

(2). The negative angle is not good for forebody compression, the bow shock from leading edge and oblique shock can not be converged with the angle of less than -2°;

(3). Cowl lip static pressure distribution did not simply increase or decrease with the attack angle due to the complicated interaction between shock waves and different angle of free stream. Of all the cases studied, heat flux of cowl lip at 6° and 10° are the largest, which are almost two times larger than the 0° condition.

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