Jet Flow Interactions in the Practical Airframe Design

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Abstract: Three kinds of jet flows encountered in the practical airframe design phase are discussed in this paper. Firstly, the side jet effect on the cavity flow over the flat plate was investigated. Secondly, the aerodynamic modeling of side jet influence on body-tail configuration was presented. Computational study of the similarity parameters was done to minimize the wind tunnel test. Lastly, supersonic jet impingement on a flat plate surrounded by solid walls was simulated numerically for both axi-symmetric and three-dimensional calculations with moving body method.

Keywords: Side jet, jet effect on the cavity, supersonic jet impingement, nozzle flow, jet interaction

1. INTRODUCTION

The interactive phenomena that occur in lateral jet and the plume flowfield generated by an supersonic jet with its surrounding environment involve complex nature such as bow shock, plate shock and Mach disk depending on the flow parameters. Supersonic jet occurs in the exhaust from rocket motors and from V/STOL aircraft engines and in various other situations such as multistage rocket separation, deep-space docking, lunar and planetary landing and take-off, shock-impingement heating, among others. A flexible adjustment of range of a missile can be done by adopting TCO (Thrust Cut-Off) mechanism. For rapid and abrupt maneuver, side jet thrust generators have been adopted to recent tactical missile development programs in several conditions. It is known that a highly maneuverable missile with side jet contains the separation caused by the jet-boundary layer interaction and the complex phenomena of shock-shock interactions. Efforts have been made to quantify these effects both numerically and experimentally. The objective is to characterize these complex flows of shock-shock, shock-boundary, shock-freestream interactions at the missile design phase.

2. RESULTS AND DISCUSSIONS

2.1 The side jet effect on the cavity flow over the flat plate

The side jet effect on the cavity flow over the flat plate was investigated. The W/T test and the numerical computations were performed for the vertical and the forward jet cases. For vertical jet, the cavity pressure was not affected much even when PR(pressure ratio) was increased. But for the forward jet cases, the cavity pressure was increased because the jet crept into the cavity directly arising from the boundary layer separation. To validate this complex flow field, an independent wind tunnel tests were carried out by USAF (Ref. 3). The wind tunnel geometry is shown as Fig. 1. The results of the calculations show good agreement with the wind tunnel tests.

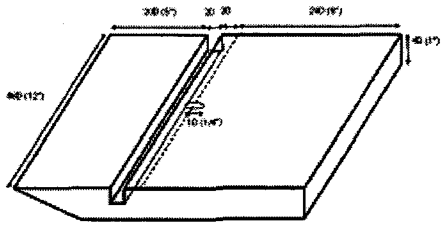

Fig. 1 geometry of wind tunnel model.

Fig.2 and Fig.3 show typical results of calculation and test.

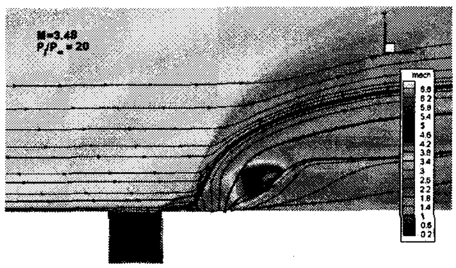

Fig. 2 Mach contours .

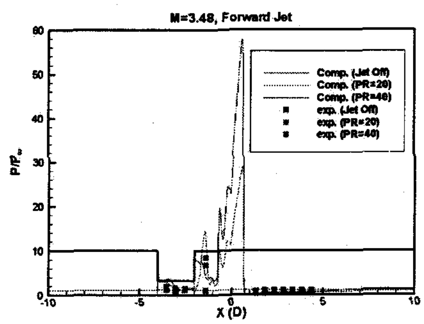

Fig. 3 Longitudinal pressure distribution.
(M=3.48, Forward Jet)

2.2 Side jet influence on body-tail configuration

Computational and experimental studies have been undertaken to determine the influence of side jet on aerodynamic coefficients in supersonic flow region. The goal of the whole studies and activities is to formulate a methodology and to quantify the magnitude of interaction between the side jet and missile body. The mutual interference of the side jet with the supersonic free-stream leads to change in force and moment. The expectation of the side jet effect is very important to aerodynamic modeling for the 6 DOF data. It is found out that the important parameters are the jet pressure ratio, jet orientation, flight Mach number and angle of attack. The influence was quantified through a parameter termed as the jet effectiveness factor. Computational study helped to prioritize the parameters; for example, the effectiveness factor is more affected in the low jet pressure range, thereby planning more low pressure runs than high pressure runs. Experimental data yielded a phantom yaw in the case of jet injected longitudinally into the wake region at high angles of attack, which is not otherwise discovered computationally. Fig.4 presents a typical calculation results.

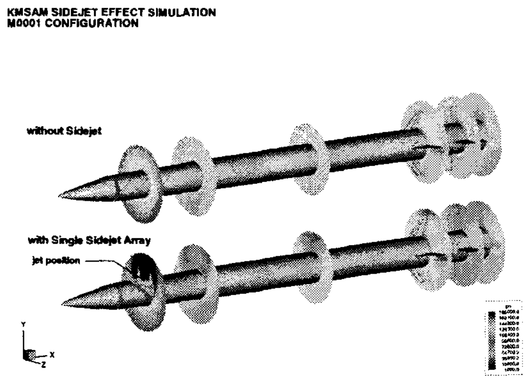

Fig. 4 Total pressure variation.

2.3 Supersonic jet impingement on a flat plate in a confined walls

The Jet impingement onto a flat plate is especially complicated by complex flow structure with the severe thermal state and high pressure load from the hot exhaust plume. The flow structures are numerically simulated by using the commercial code, CFD-FASTRAN with the axi-symmetrical Navier-Stokes equations. Two different cases are considered; that is, the stationary fire and the moving fire. Vertically launched missile has many advantages in steering the initial direction of missiles regardless of launch platforms. Turbulent convective heat transfer from hot exhaust plume provides the largest thermal input to the launching system and requires the design of protective material for the interior surfaces of the canister and launchers. Complicated and ill-understood chemical reactions occur in the exhaust plume as it passes through the system. Objectives of this numerical simulation are to understand the difference between stationary fire and moving fire. Firstly, the unsteady analysis of the stationary missile is to investigate the flow structure, heat flux, pressure and temperature at the launcher's bottom and the plenum. Secondly, the unsteady simulation of the moving missile is conducted by using the overlapping grid. The differences between the stationary and the moving fire are obvious considering the heat flux at the launcher's bottom.

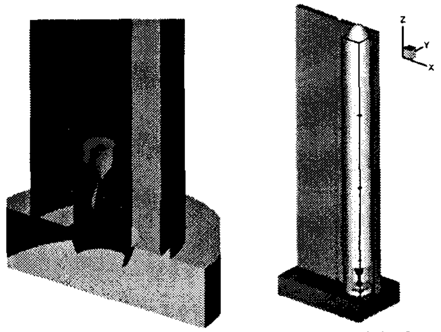

Fig.5 Axi-symmetric and full scaled model of VLS.

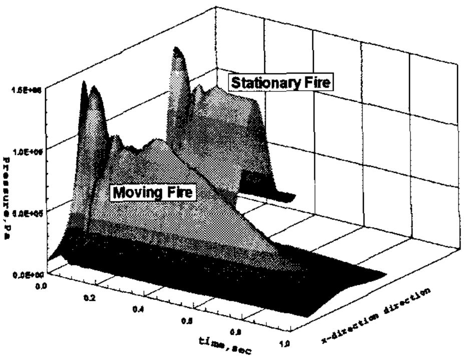

Fig. 6 Heat flux at the center of the plate.

3. CONCULSIONS

Three kinds of studies about the jet interactions in the practical design phase were presented and discussed. Present day CFD capability not only uncovers the flow structure but also predicts key design parameters. But as the flow becomes more complex, there is obviously still room to improve in terms of accuracy as well as turn-around time.

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