Numerical Simulations of the Supersonic Jet Impingement in a Confined Plenum of Vertical Launching System

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Key Words: Supersonic Jet Impingement, Vertical Launching System, Stationary Fire, Moving Fire, Heat Flux

ABSTRACT

The Vertical Launching System design is especially complicated by complex flow structure in a plenum 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.

1. INTRODUCTION

The study of the jet and its structure has been conducted for many years both experimentally [1]-[12] and numerically [13]-[22]. Recently, Hong and Lee [19] presented the numerical simulations of jet plume impingement onto a duct using the Navier-Stokes equations. Lee et al. [20]-[22] also gave the numerical solutions of supersonic jet impingement in a Vertical Launching System (VLS) type internal missile launcher.

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 structures, 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.

2. NEMERICAL METHOD

The flow solver used is CFD-FASTRAN, which solves the compressible time dependent Navier-Stokes equations in three dimensions. In our computations, the flow and geometry condition is axi-symmetric. Turbulence is modeled by the Baldwin-Lomax model.

3. RESULTS AND DISSCUSIONS

The computational geometry used for flow simulation is shown in Fig. 1. It consists of a supersonic nozzle mounted at the butt of the launched missile perpendicular to the launcher's bottom, launching tube, uptake, missile and plenum. The complex 3-dimentional VLS geometries are simplified by the axi-symmetric ones which maintain the wetted area ratio between the plenum upper surface and the exit area of the launching tube and the uptake. The main parameters are Mach number at the nozzle exit, the pressure ratio between the jet exit and the ambient, and the distance between the nozzle and the bottom wall. In our simulations, the pressure ratio, the exit Mach number and the initial height (z/D) are 2.51, 2.88 and 5.4, respectively. The computation starts from the rocket motor chamber with a chamber condition. The boundary condition of the chamber is the inlet condition with the total pressure and the total temperature.

Figure 2 presents the contours of Mach number and temperature and the curves of heat flux and pressure on the bottom wall. The elapsed time is 0.44 seconds. At this time, the contours of solution are unchanged. Therefore the heat flux and pressure levels are reached as a steady state value. High level of heat flux and high pressure zone are limited at the center of the wall as shown in Fig.2.

Figure 3 is an instantaneous state during the missile launching. The elapsed time is 0.62 sec. Heat flux histories in time are plotted in Fig. 4. Stationary fire reaches a steady state level of heat flux. On the other hand, moving fire represents severe fluctuations. But the average value of moving fire is below that of stationary fire. Heat flux is the one of main causes of ablation of materials. Temperature contours as shown in Fig. 5 reveal similar patterns with Fig.4.

Pressure histories at the center and off the center are plotted in Fig. 6 and Fig. 7, respectively. Pressure levels of the moving fire are higher than those of stationary fire at the center. The pressure value at the impinging wall is determined by the distance between the nozzle exit and the impinging wall.

4. CONCULSIONS

Numerical study of VLS flow is carried out using CFD-FASTRAN. Two different launching cases are investigated numerically to achieve flow structures and heat flux at the bottom wall. The stationary case is more severe than the moving fire considering the heat flux histories.

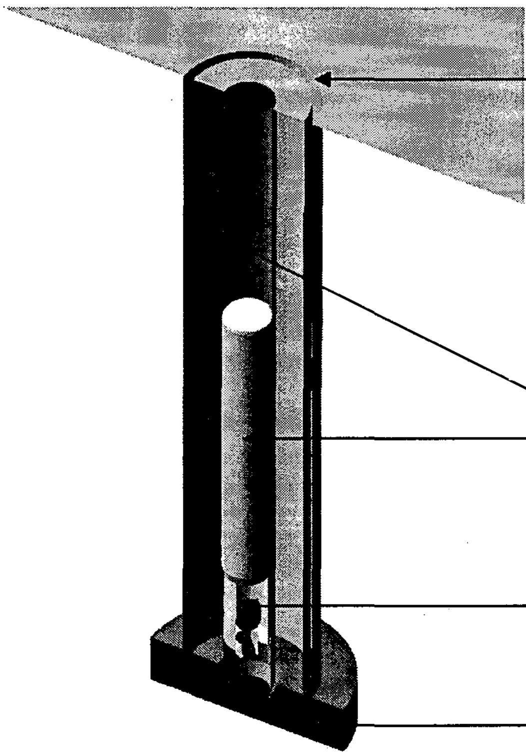

Fig. 1 Definitions of the computational geometries

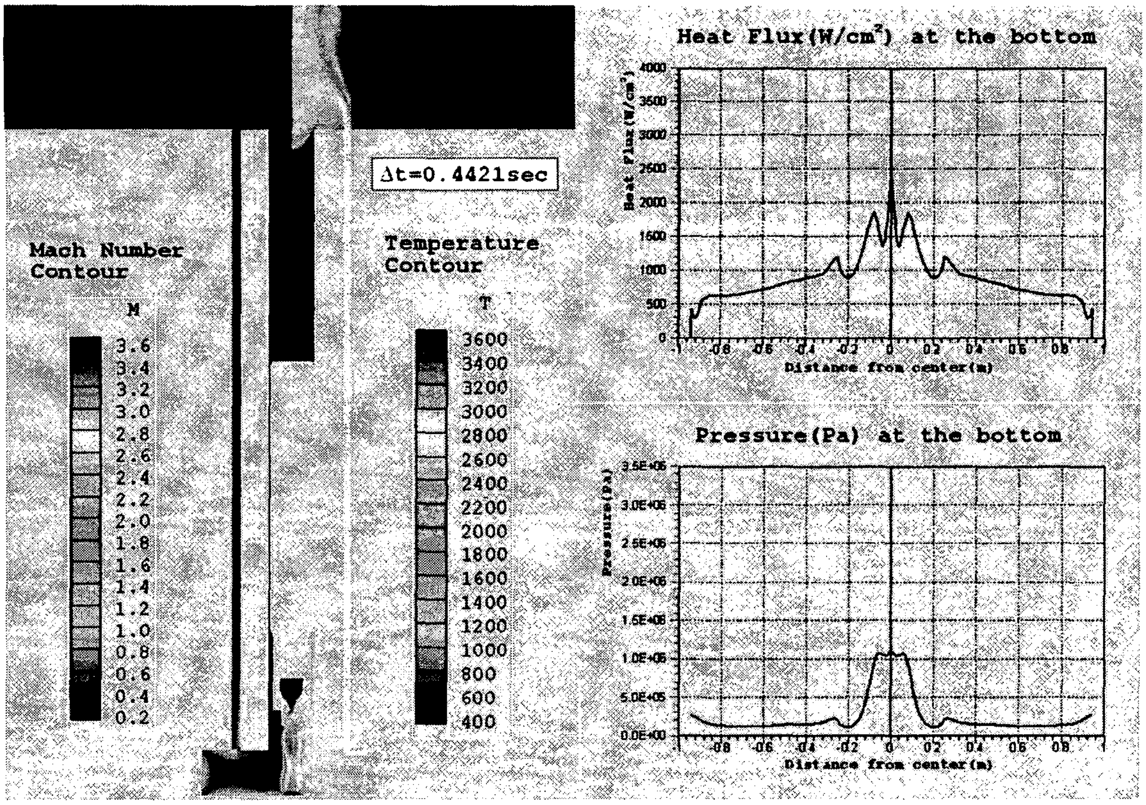

Fig. 2 Mach number and temperature contours with stationary fire(unsteady simulation)

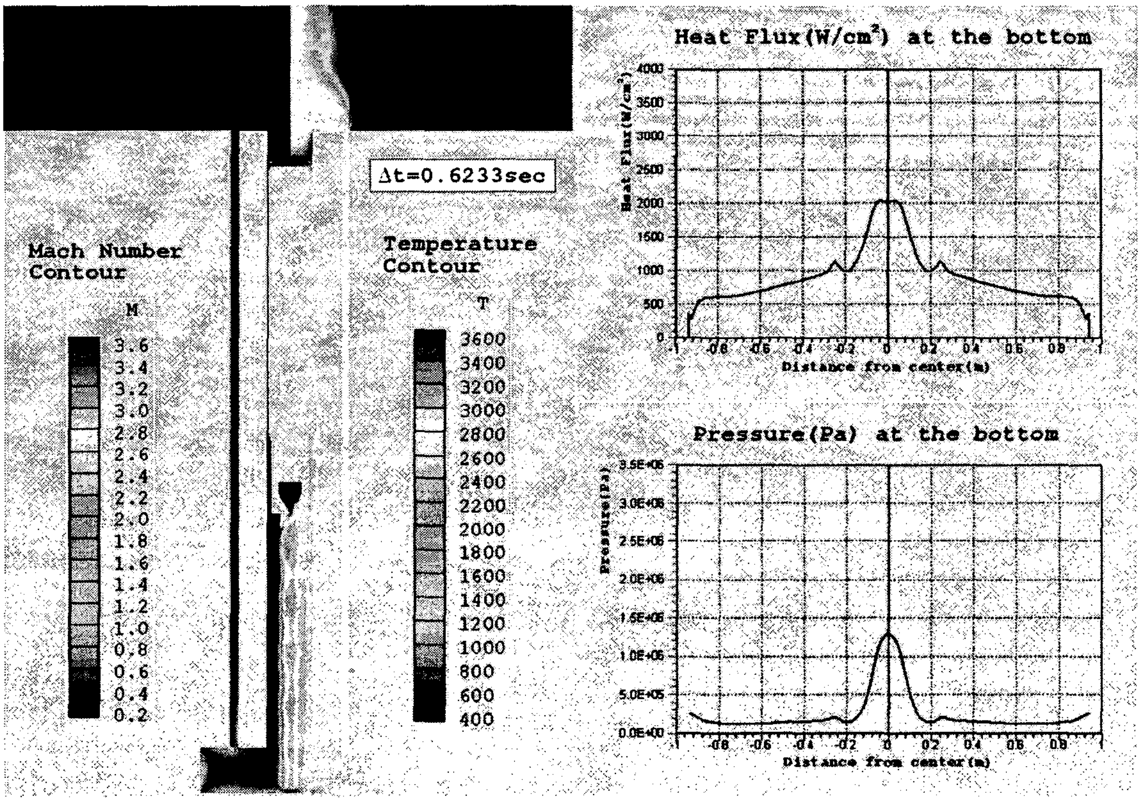

Fig. 3 Mach number and temperature contours with moving fire(unsteady simulaion)

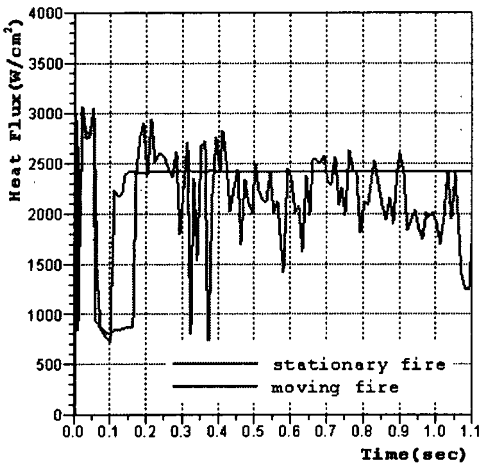

Fig. 4 Heat flux histories at center

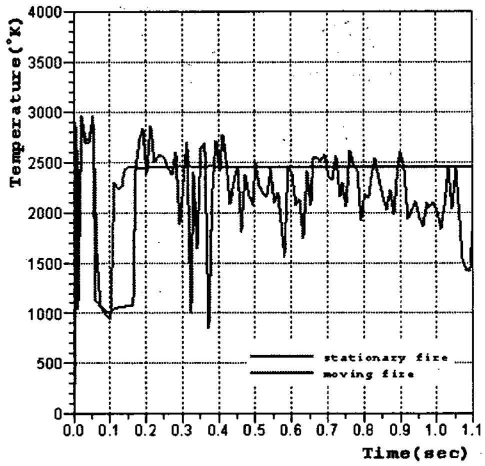

Fig. 5 Temperature histories at center

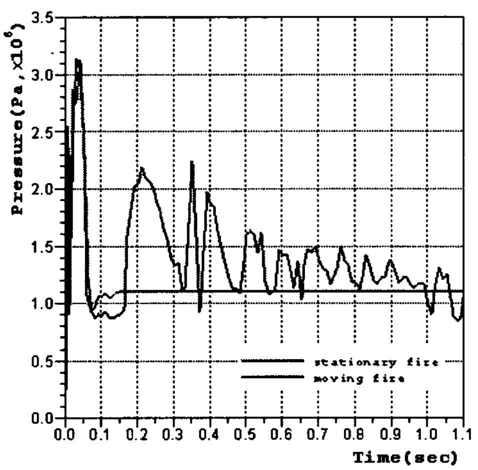

Fig. 6 Pressure histories at center

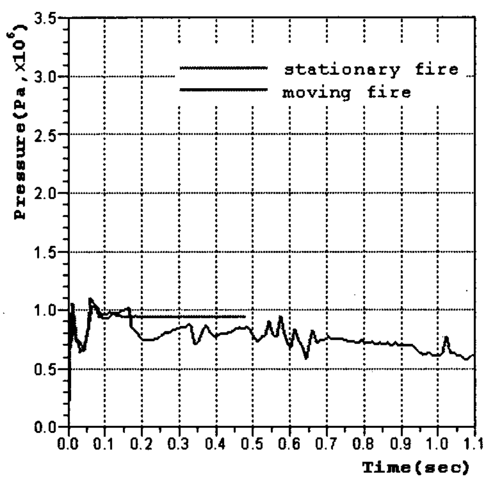

Fig. 7 Preaasure histories off the center

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