

Numerical Study on The Jet Impinging and Structure Responses

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Abstract—In order to study the loads and responses for structures impacted by exhausted gas jets, a jet impinging plate is investigated numerically, As well as the computational fluid dynamic method are utilized to simulate the jet flow, the finite element method are imposed to calculate structure responses. Simulation results show that: 1) the distribution of the jet impinging pressure was the annular along radial of the plate when the impacting distance is in the specific conditions. The maximum pressure on the plate is about 20%~30% of the total pressure in the rocket motor combustor. 2) For near field jet impinging, the pressure on the plate vibrates with the variation of impingement distance. For far field jet impinging, the load on the plate decreased gradually with the increase of impact distance. 3) The maximum displacement and maximum stress in the steady-state average load analysis were respectively put out by 9.9% and -26.1% with the unsteady analysis's . And the maximum displacement and maximum stress in maximum load analysis were respectively put out by 96% and 94% with the unsteady analysis .

Keyword—*Jet impinging; Impact load; Stationary response; Transient response; Calculation method*

1. INTRODUCTION

Rocket, missile will produce a large amount of high temperature and high speed gas jet in launch process, which have a marked impact on the transmitting device and the surrounding environment. In general, as the change of impact range, impact load can present a significant transient characteristics, which have a marked impact on the transmitting device. We study the impact load characteristics of gas jet and the response of the structure, which have important theoretical meaning

and engineering value on the design of transmitters and protection¹.

Based on the gas jet impact plate structure as the research object, the mechanical load characteristics of jet impact conditions and slab structure under the average load, maximum load under the action of the steady-state response and the dynamic response of a detailed study, to obtain the difference of structural response under different load and analysis model, at the same time of provide scientific basis for the engineering application, and provide reference for further theoretical analysis².

II. THE JET IMPACT LOAD

A. The control equation of gas flow

In this paper, we study the gas jet with high temperature and high speed characteristics, the flow in the process of compressibility and viscosity should not be neglected. Three-dimensional compressible, viscous gas flow control equations can be expressed as³

$$\frac{\partial Q}{\partial t} + \frac{\partial(F_c - F_v)}{\partial x} + \frac{\partial(G_c - G_v)}{\partial y} + \frac{\partial(H_c - H_v)}{\partial z} = 0 \quad (1)$$

On the type, Q for the conservation of variable vector; F_c , G_c , H_c for three coordinate directions for circulation respectively, F_v , G_v , H_v the sticky flux of the three coordinate directions respectively^[3]. They can be represented as:

$$Q = \begin{bmatrix} \rho \\ \rho\mu \\ \rho v \\ \rho\omega \\ \rho e \end{bmatrix}, \quad F_c = \begin{bmatrix} \rho\mu \\ \rho\mu^2 + p \\ \rho\mu v \\ \rho\mu\omega \\ (\rho e + p)\mu \end{bmatrix}, \quad G_c = \begin{bmatrix} \rho v \\ \rho\mu v \\ \rho v^2 + p \\ \rho v\omega \\ (\rho e + p)v \end{bmatrix}, \quad H_c = \begin{bmatrix} \rho\omega \\ \rho\mu\omega \\ \rho v\omega \\ \rho\omega^2 + p \\ (\rho e + p)\omega \end{bmatrix},$$

$$F_v = \begin{bmatrix} 0 \\ \tau_{xx} \\ \tau_{xy} \\ \tau_{xz} \\ Q_x \end{bmatrix}, \quad G_v = \begin{bmatrix} 0 \\ \tau_{xy} \\ \tau_{yy} \\ \tau_{yz} \\ Q_y \end{bmatrix}, \quad H_v = \begin{bmatrix} 0 \\ \tau_{xz} \\ \tau_{yz} \\ \tau_{zz} \\ Q_z \end{bmatrix} \quad (2)$$

In order to solve the control equations, we refer to the research of others, based on the eddy viscosity turbulence model RNG k - ε to simulate the assumption of the Reynolds stress and turbulent scalar transport items to make the equation of the closed. The model

$$\rho \frac{dk}{dt} = \frac{\partial}{\partial x_i} \left[(\alpha_k \mu_{eff}) \frac{\partial k}{\partial x_i} \right] + G_k + G_b - \rho \varepsilon - Y_M \quad (3)$$

On the type. G_k for the average velocity gradient caused by the turbulent kinetic energy generated; G_b for the buoyancy caused by the turbulent kinetic

considering the influence of fluid compressibility on the turbulent flow, the transport equation of turbulent kinetic energy k and turbulence dissipation rate ε as^{4,5}:

$$\rho \frac{d\varepsilon}{dt} = \frac{\partial}{\partial x_i} \left[(\alpha_\varepsilon \mu_{eff}) \frac{\partial \varepsilon}{\partial x_i} \right] + C_{1\varepsilon} \frac{\varepsilon}{k} (G_k + C_{3\varepsilon} G_b) - C_{2\varepsilon} \rho \frac{\varepsilon^2}{k} - R \quad (4)$$

energy generated; Y_m for compressible flow pulsation in diffusion caused by the dissipation rate; And S_k , S_ε for the source term^{6,7}.

B. Calculation model

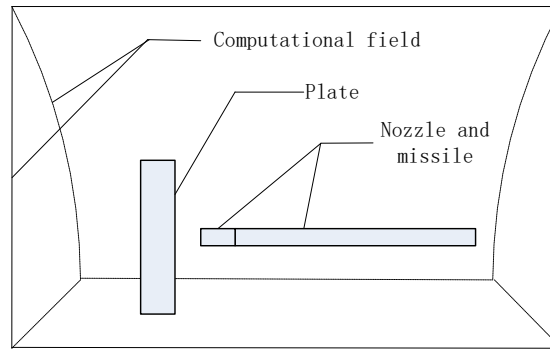


Figure 1 Schematic of computational field

As the calculating process of unsteady gas effect on the impact of the tablet, in this paper, the impact on flow field is solved by using the commercial software Fluent, and USES the field containing dynamic and static domain dynamic grid technology to simulate the movement of the projectile. In the process of calculation, the engine nozzle, projectile surface area with the projectile motion, such as computing grid corresponding change. Calculation

model is shown in Fig . 1. Calculation model of nozzle exit $D = 0.0243$ m diameter, nozzle throat diameter of $D_s = 0.4 D$, missile diameter of $3 D$, missile long $30 D$. In initial position, the gas from the nozzle mouth spews from the projectile impact the bottom slab of 4 times the diameter of nozzle, tablet 6 diameter D , the thickness of $0.4 D$. Choose the size of the computational domain along the length direction of missile body is $132 D$, radial for $103 D$ ^[8].

To facilitate comparison with the existing research results, calculated with some parameters from the literature, typical calculation conditions and parameters including: field boundary conditions using homogenization pressure, the pressure of 101325 Pa, temperature of 300 K; Entry nozzle USES the pressure inlet conditions, the total pressure of 4 MPa, total temperature of 3117 K; Between solid and fluid coupled wall conditions; In other areas such as nozzle and wall surface, no slip adiabatic wall. Gas using compressible ideal gas, the specific heat at constant pressure is set to 1946 J / kg, K, the molecular weight of 28 kg/mol, viscous coefficient is obtained by using the formula of Sutherland⁹.

C. The load characteristics of jet impact tablet

Fig .2 shows the calculation time of 0.2 s and 0.5 s tablet pressure distribution on the surface of the cloud,

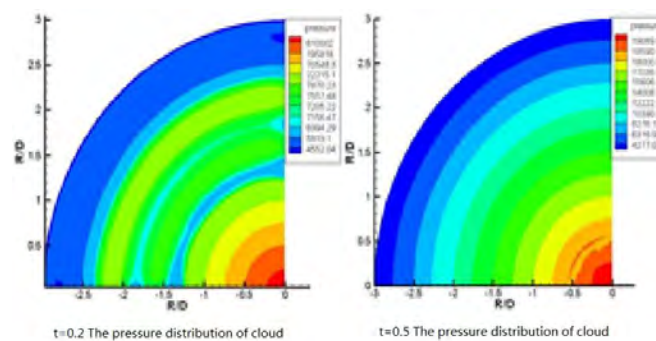


Figure 2 Contours of pressure at $t=0.2s$ and $t=0.5s$

In order to more fully describe the impact load of gas on the tablet, tablet on several typical position of pressure changing with time curve is shown in Fig .3. Can be seen from the diagram, in the initial stage, the impact pressure oscillation on tablet, this is due to gas after impact on the tablet, near field impact shock wave is formed by blocking the development of gas jet and total pressure have a significant attenuation, by standing before a Mach wave Mach number in the free jet section within the change trend of present from small to large, makes the pressure after the wave attenuation and from small to large changes in the process. Reflect on the impact pressure, the pressure on the tablet is from big to small changes in the process. In addition, because the free jet core

at this time the distance between nozzle exit and tablet were 12.3 D and 12.3 D. Can be seen from the diagram, along the radial direction, the stagnation point to 0.5 D for jet impact the stagnation of the area, has the very high pressure; In 0.5 D outside, assumes the circular flat surface pressure distribution. Shocks in the near field ($H = 12.3 D$), the distribution of the annular pressure oscillation in change, namely around the stagnation zone, creates a low pressure distribution area; Outside the region, there is a circle of high pressure loop area, and repeatedly changes, consistent with literature described. At the far field impact ($H = 54.8 D$), although assumes the circular flat surface pressure distribution, but the pressure along the radial oscillation phenomenon has not obvious change.

often contain multiple Mach wave section, so the variation of pressure oscillation present in near field impact¹⁰. Between 0.1 s to 0.2 s, the length of jet core area has more than shock distance, but the impact to the gas jet velocity on the surface of the plate is still supersonic state, the impact pressure oscillation phenomenon is not obvious, instead, the impact pressure gradually increase. To 0.2 s later, gas jet arrived at near the surface of the tablet for subsonic flow, the formation of the far field, the pressure on the surface of the tablet with the change of impact distance gradually reduced. To 0.5 s moment, projectile range tablet to 54 times the nozzle diameter, nozzle at the gas force to the whole tablet almost to zero.

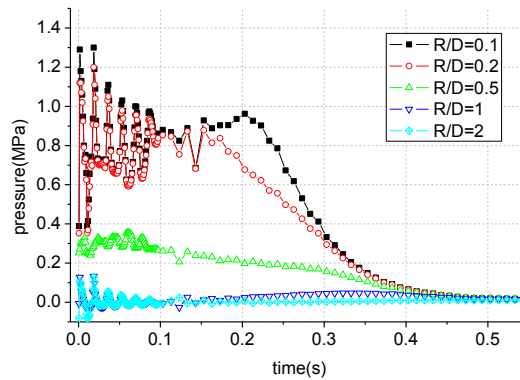


Figure 3. Pressure on typical position against time

III. ANALYSIS AND CONCLUSION

Based on the rocket launch in the process of gas jet impact to launcher effect as the background, respectively by using the computational fluid dynamics method and finite element method (fem) of gas jet impact load and response of the plate structure, numerical study to obtain the following conclusions:

1) in the jet near field shock stage, the impact pressure load on the surface of the structure changes in oscillation; For subsonic flow in jet near the tablet of far-field shock stage, the impact pressure decreases with the increase of the impact of distance. Under the effect of jet impact, mainly in the jet impact pressure load of stagnation zone, along with the increase of the impact from stagnation zone widened, the highest pressure decreases.

2) for the structure of the gas jet impact response, the maximum pressure distribution is greater than the response of the load calculation results and time-varying load calculation, with larger error; Average pressure under the load of the steady state, the time-varying load transient response and distribution of the maximum response of the error is relatively small.

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