

Numerical Simulation and Analysis of Free-jet

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Abstract. In this paper, the operating conditions of Free-jet experimental is simulated based on axial symmetry N-S (Navier-Stokes) equations and finite differential method. Then it further analyzes the flow field characteristics of the nozzle exit. It shows that the results from numerical simulation capture mach number diamond structures and complicated wave structures.

Keywords: Free-jet; axial symmetry N-S equations; numerical simulation

1. Introduction

Based on research and practice, we can find many researchers study free-jet problem by numerical simulation methods at home and abroad. He Feng^[1] simulated under expanded supersonic impinging jet by S-A(Spalart-Allmaras) turbulence model and analyzed the pressure distribution on Impact Plate. Chen Qing-guang^[2] gave a numerical study of turbulence impinging jet flow by applying of improved RNG mode, and analyzed the effect of turbulence model on numerical simulation. Li Jun^[3] studied the formation and development of the SRM(Solid Rocket Motor) gas jet flow near field, and analyzed the formation and movement of initial shock-wave. I-Shih Chang^[4] presented numerical simulations of unsteady under expanded free-jet by CE/SE(Conservative Element/Solver Element) method. Literature^[5, 6, 7] presented the relevant test studies of impinging jet.

In this paper, we simulated experimental conditions of free-jet by applying of finite element discrete method based on axial symmetry N-S equations, and analyzed the flow characteristic in the exit of Laval nozzle.

2. Control Equations and Computational Method

The control equation is the conservative axial symmetry N-S equation, in Cartesian coordinates O-xy, the equation can be written as:

$$\frac{\partial U}{\partial t} + \frac{\partial (E + E_v)}{\partial x} + \frac{\partial (F + F_v)}{\partial y} = S \quad (1)$$

where, $U = (\rho, \rho u, \rho v, e)^T$; E, F are advection term fluxes, E_v, F_v are diffusion term fluxes, S is control equation source term in axial symmetry coordinates. $e = 0.5\rho(u^2 + v^2) + p/(\gamma - 1)$, ρ and e are total density and total energy of fluid particles per unit volume, u, v are the coordinate direction gaseous phase velocity components in Cartesian coordinate, p is pressure, γ is ratio of gaseous phase specific heats. Viscidity coefficient of gaseous phase laminar flows μ can be calculated by Sutherland equation. State equation

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$p = \rho RT$ based on Dalton's law of partial pressures and perfect gas conditions are assumed is utilized for the closure of the equations. R is gas constant, T is gas temperature.

For describing geometric shape of the boundary accurately, the body-fitted coordinate system was used. We transformed equation (1) from the Cartesian coordinates (t, x, y) into the arbitrary coordinates (τ, ξ, η) . Spatial Discrete used Academician Zhang Han-xin's NND(Non-oscillatory Non-free-parameter Diminishing)modification, time discrete used Runge-Kutta method of three order TVD(Total Variation Diminishing).

3. Physics Models and Related Parameters

Taking the practical experiments into consideration, the problem in this paper is supersonic free-jet flow field from hyperbaric chamber and nozzle into atmospheric flight environment. As shown in Figure 1, OD is axis, AE is a plate (thickness is 3mm, length is 800mm), spout radius OA is 400mm, the bottom jet flow under given conditions is simulated. To make it easier for us to get boundary conditions, the calculation region is quite wide, AB is 60m, BC is 80m.

Related parameter choosing is presented: (1) the medium is air, the total pressure is 1.2MPa, the jet total temperature is 700K, the Mach number is 3, flow parameters such as u_{jet} , p_{jet} and ρ_{jet} at the exit of nozzle zone can be obtained according to the relevance of one dimensional isentropic flow; (2) in accordance with environment parameter at sea level, $P_{\infty}=101325.0\text{Pa}$, $T_{\infty}=288.15\text{K}$.

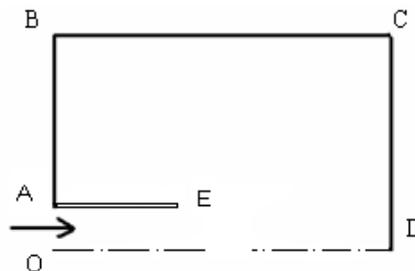


Fig. 1. Schematic diagram of model

4. Grid Computing and Boundary Conditions

Fig. 2 is schematic diagram of grid near the plate zone. The domain is subdivided into three sub-domains. Grid-distributed of Zone1 is 20×20 , grid-distributed of Zone2 is 20×60 , grid-distributed of Zone3 is 200×81 . In reality, the figures of grid come out at 17800.

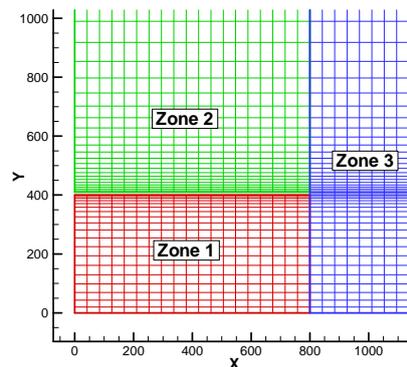


Fig. 2. Schematic diagram of grid (plate zone)

In these calculations, the boundary conditions involved are the reflecting boundary conditions, the jet boundary conditions, the outlet boundary conditions, and the body Solid Boundary Conditions. The processing methods for them are:

the reflecting boundary conditions: obtained from the neighboring zone of the exit of nozzle and axis, normal velocity=0, and others were obtained by extrapolating.

the jet boundary conditions : obtained from the the entrance of combustion chamber, and others were obtained by referring to the above.

the outlet boundary conditions : because downstream has no effect on upstream in supersonic flow, parameters can be extrapolated.

the body boundary conditions: processed according to the no-slip adiabatic wall boundary conditions, the result that the grid density of the body is big supported the hypothesis of boundary layer, so $u = 0, v = 0, w = 0, \partial T / \partial n = 0, \partial p / \partial n = 0$.

5. Calculations and Discussion

Fig. 3 and Fig. 4 are Mach number cloud pictures at the exit of nozzle zone. The pictures showed that the free-jet flow field are complicated, including typical structures of expansion wave ejected at high speed from the exit of nozzle zone, barrel shaped shock wave, jet boundary, Mach number diamond zone. Because of the whirlpool, there are complicated banded structure in jet boundary from Fig. 4.

Fig. 5 is pressure distribution curves on the axis. The characteristic of Space Distribution is ridden up and down caused by Mach number diamond zone.

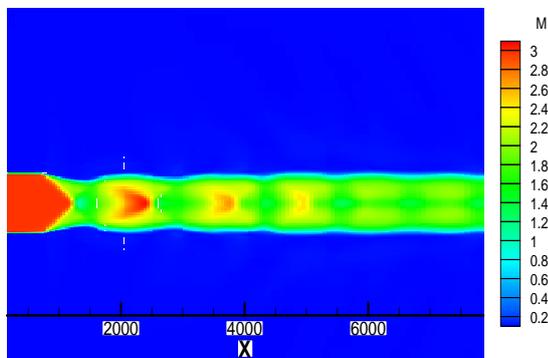


Fig. 3. Mach number cloud picture at the exit of nozzle zone

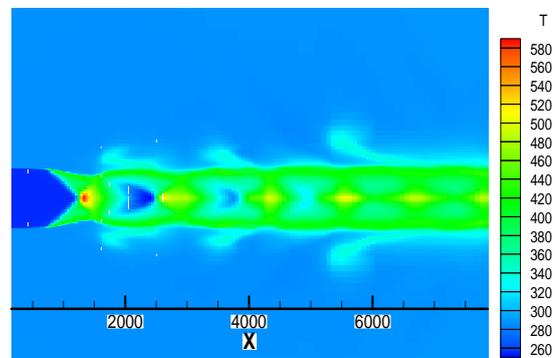


Fig. 4. Temperature cloud picture at the exit of nozzle zone

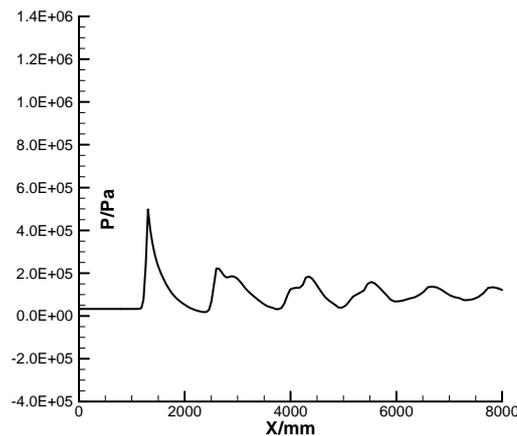


Fig. 5. Pressure distribution curves on the axis

6. Conclusion

- we obtained supersonic free-jet flow field from hyperbaric chamber and nozzle into atmospheric flight environment, including typical structures of expansion wave ejected at high speed from the exit of nozzle zone, barrel shaped shock wave, jet boundary, Mach number diamond zone. The characteristic is highly non-linear.
- we obtained pressure distribution curves on the axis, the characteristic is ridden up and down.

7. References

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