Simulation of Blast Waves Inside a Nozzle Tube

Shing-Ian Huang [1], Yang-Yao Niu [2]
[1]skyshing@hotmail.com.tw
No.151, Yingzhuan Rd., Tamsui Dist., New Taipei City 25137, Taiwan (R.O.C.)

ABSTRACT

The performance study of the engine has always been a hot research top in aerodynamics, like the earliest piston-cylinder engine, jet engine, rocket engine and the scramjet engine for the hypersonic vehicle. Recently, the pulse detonation engines(PDE) has been recognized as the promising propulsion technology that offers potential advantages in thermodynamic cycle efficiency, hardware simplicity, and operation scalability. In this study, the single-tube nozzle is chosen as the benchmark test. The thrust efficiency is estimated based on the simulation of flows through the PDE nozzle and the chosen valve opening frequency. In numerical methodology, the Roe's flux splitting is used to evaluate the spatial differencing and Van Albada limiter to avoid the numerical spurious oscillations. Also, a second-order type Runge-Kutta time marching method is adapted to perform the time evolution. The assumption of the flows considered here is inviscid and unsteady. In the numerical results, detonation waves and shock waves and expansion fans in the cycle are simulated against the related computed data by the other group.

1. Introduction

Detonation is a phenomenon which including the supersonic flows compressing front edge containing the combustion air, and it push the shock wave propagating directly. According to Fuhua ma's result about pulse detonation engine(PDE) [1], he compared the single-tube-combustor with the triple-tube-combustor, and he gets the result of the triple-tube-combustor has the better thrust efficiency.

The nozzle's full body length is 80 cm and the valve wide is 16 cm, with a 45 convergent angle and a 15 divergent angle. The length of the single-tube-combustor is 60 cm. The system contour is shown in Fig, 1.

Ideally, the process about the valve operation is initially filled up with a stoichiometric hydrogen/air mixture at the 0.2 pressure and temperature 228 K. Initiation is set by a small driver region behind the valve. The temperature and pressure of the driver region are 2,000K and 30 atm respectively. In our preliminary simulation, we start on the case of cold flow. We set the inlet speed is 2 Mach, and a region which is 2000k and 30 atm from the valve about 1 cm.

About the valve opening frequency, we considered the Operation cycle time (τ_cycle), and that is $\tau\_cycle = \tau\_close + \tau\_refill$. τ_close is the valve close-up period, during which the valve is closed and the tube undergoes detonation initiation and propagation processes. τ_refill is refilling period, during which the combustible mixture is delivered to the tube.

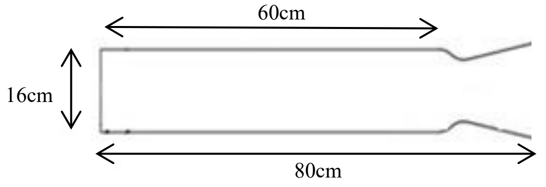

Fig. 1 Single-tube-combustor counter.

2. Method

About the first model, we adopt Roe's flux method to evaluate the spatial differencing and Van Albada limiter to avoid the oscillation that occurs with high order spatial discretization schemes due to shocks discontinuities or sharp changes in the solution domain. And a 2-order type Runge-Kutta scheme to perform the time evolution. The mesh numbers of the first model are 303688 unstructured quadrilateral type grid cells.

About the second model, the AUSMD scheme was based on Niu et. al (2008). [2][3]. We use multi-block for meshing. The computational domain is discretized into 360000 structured grid cells. We selected third order MUSCL and explicit Runge-Kutta for flux separation, MUSCL and AUSMD method for spatial discretization and fourth Runge-Kutta for time discretization.

The pulse period both models are τ_close =2.1ms, and τ_refill =0.1ms respectively, and the CFL numbers are both 0.1.

3. Results and Discussion

The second method, AUSMD scheme can actually capture more clearly shock waves, Taylor waves, expansion waves, and reflection waves than the first model during the period of valve close-up.

Time evolution of density-gradient field by the AUSMD scheme is shown from Fig, 2 to Fig, 5. The Taylor waves immediately generated and followed when the flows pass through the region of the high-temperature region. The central region of the Taylor waves has a uniform region with constant flow properties. Both the Taylor waves and the uniform region are shown in the Fig, 2.

At the time is 1.46ms, the expansion waves are generated from the curved wall, and the two reflected shock waves from the curved wall have crossed with each other. Shown in Fig, 3.

When the primary shock waves reached x= 0.97 m, the upper vortex sheets are formed and roll up at x= 0.81 m, y= 0.12 m, and the property of the center is stationary and low pressure. The Prandtl-Meyer expansion fan is also generated when the shock waves over a sharp corner. Due to expansion waves emanated from the edge, the flow near the wall is accelerated

Corresponding author: Shing-Ian Huang
E-mail address: skyshing@hotmail.com.tw

from subsonic to sonic. Both the expansion fan and the vortex sheets are shown in the Fig. 7.

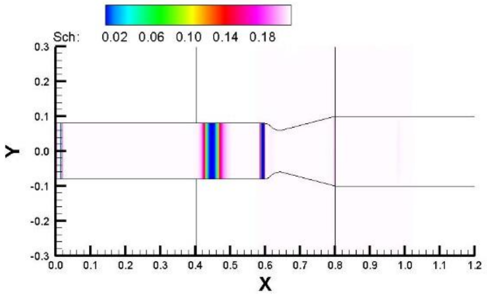

Fig. 2 the contour plot of density gradients at t= 1.1ms.

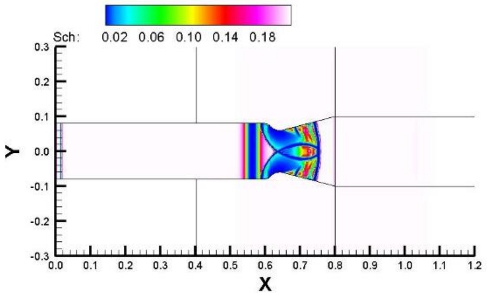

Fig. 3 the contour plot of density gradients at t= 1.46ms.

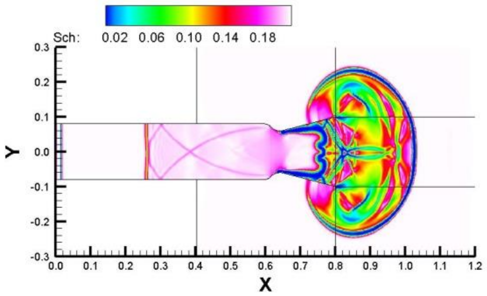

Fig. 4 the contour plot of density gradients at t= 2.06ms.

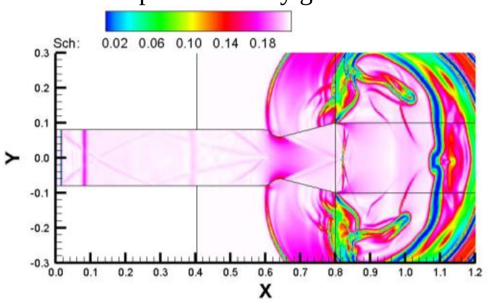

Fig. 5 the contour plot of density gradients at t= 2.761ms.

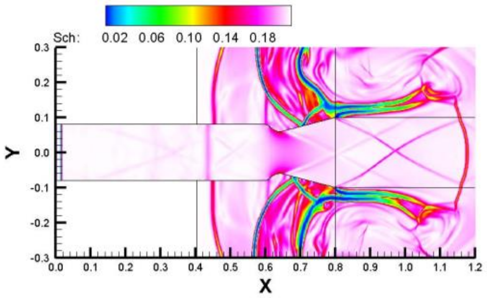

Fig. 6 the contour plot of density gradients at t= 3.001ms.

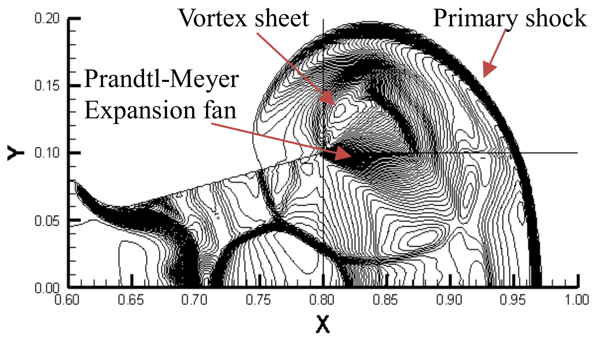

Fig. 7 Enlarged views of cold flow pressure contour by AUSMD at time= 1.92ms.

4. Concluding Remarks

The final goal is to get the thrust efficiency of the nozzle and find the best model type about the valve opening frequency. According to our preliminary simulation result, we will choose the second model which is AUSMD scheme to simulate the chemical reaction.

References

[1] Fuhua ma, *Thrust Chamber Dynamics and Propulsive Performance of Airbreathing Pulse Detonation Engines*, (2003)

[2] Y.Y . Niu, Y.C. Lin, C.H. Chang, *A further work on multi-phase two-fluid approach for compressible multi-phase flows*, *International Journal for Numerical Methods in Fluids*., Vol.58, Issue 8(2008), 879-896.

[3] Y.Y. Niu, *Computations of two-fluid models based on a simple and robust hybrid primitive variable riemann solver with AUSMD*, *Journal of Computational Physics*, Vol.308 (2016), 389-410.