Visualization Experimental and Numerical Investigation on the Muzzle Flow

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Summary Both visualization experiment and numerical simulation of the muzzle flow of 7.62mm-caliber gun are carried out. Direct shadowgraph technique was used in the experiment, and both flow dynamics and chemical kinetics were taken into account in the computation. The computational results are in good agreement with the experimental, and the chemical reaction process of the muzzle flow was also demonstrated in detail.

INTRODUCTION

Gun muzzle blast and flash, as the primary muzzle signatures, are of great importance not only for their influence on firing accuracy, but also for harms on the gun crew and surrounding instruments[1]. Researchers most focused on the theoretical and experimental study in the early years [1]. Recently a series of works has looked into the numerical investigation of muzzle flow [2,3], and the physical phenomena has been understood well. Although some works were also carried out on the chemical kinetics in firing process [4,5], the detail chemical dynamics process is still of worth to be studied in detail.

In this paper, as a fundamental study on the fluid dynamics and chemical kinetics of muzzle flow, both visualization experiment and numerical simulation of the muzzle flow of 7.62mm-caliber gun are implemented. Initially, the high-resolution sequential pictures were obtained by using direct shadowgraph technique in visualization experiment. Later, numerical simulation with ALE Navier-Stokes equation was performed to reveal the muzzle flow wave dynamics, and the computational shadowgraphs are compared to the experimental ones. Finally, the chemical reaction is considered in the computation.

METHODS

Fig.1 is the schematic diagram of the experiment system with direct shadowgraph technique to identifying the density field. When the pressure detected by the gauge exceeds the threshold value, a signal will be generated to trigger the light source to spark within the time interval preset in the time generator. The light traverses the interested flow field and the shadowgraph forms on the photographic film.

In the present computation, multi-component N-S equation considering dynamic meshes dispersed by finite-volume method and second-order AUSM+ scheme with MUSCL interpolation was used to calculate the flux. Runge-Kutta method is adopted to advance the solution in time. Schematic of computational domain was showed in fig.2. For the consideration of the moving projectile, chimera grids method was employed. The background grids (subdomain 1-6) are laboratory- fixed, and attached grids (subdomain 7-8) moves with the projectile. In the practical computation, the computational domain was divided into 29 subdomains for MPI parallel computing.

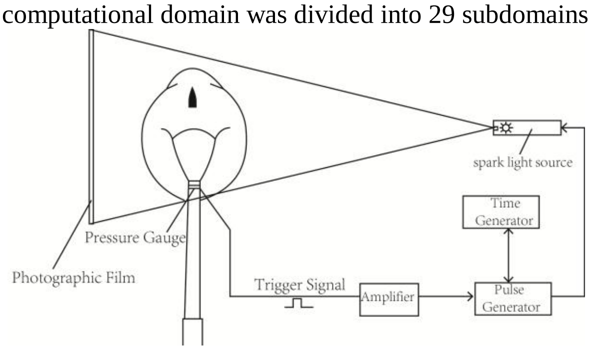

Fig. 1. Schematic diagram of the experiment system

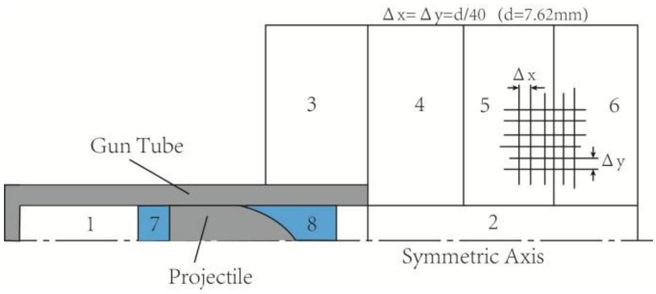

Fig. 2 Schematic of computational domain

RESULTS AND DISCUSSION

The gun selected in the visualization experiment is a 7.62mm-caliber rifle with a 733mm tube length. The exit velocity, mass of the projectile and the maximum pressure of propellant gas are 798m/s, 7.9g and 32.4MPa respectively. Two cases coupled with the classical internal ballistic program were simulated numerically. The first one is computed based on ALE N-S equation and the second take the chemical kinetics into account by using 9-species, 19-step elementary reacting mechanics of H_2-air mixture. Projectile speed and in-bore gas property are specified according to interior ballistics code before the projectile exit the muzzle.

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In fig.3 the computational and experimental shadowgraphs are presented in the upper and lower half respectively. Compression waves produced by the projectile accelerating inside the gun tube rapidly coalesce into a steep precursor shock wave(i.e. precursor shock wave), which expand into the ambient atmosphere, as showed in fig.3a. A Mach disk(MD) and barrel shock wave(BS) with a following contact discontinuity(C1) appeared and the reflected shock wave(RS) was produced. In fig.3b, the vortex (VR) induced by the instability of the jet boundary and another contact discontinuity (C2) originated from the triple point (TP) were observed. After the projectile exited from the muzzle, the high-pressure propellant gas expanded intensively, and the main propellant blast wave(MS) quickly overtaken the projectile, showed as fig3.c. A shock wave behind the projectile (PB) was observed because the gas velocity is supersonic relative to the projectile. In fig3.d, the main propellant blast wave continued to expand and in front of projectile the protruding bow shock was formed. From the comparisons, it can be seen that the experimental shadowgraph is clear enough to distinct most structures of the muzzle flow and the computational results are in good agreement with the experimental ones.

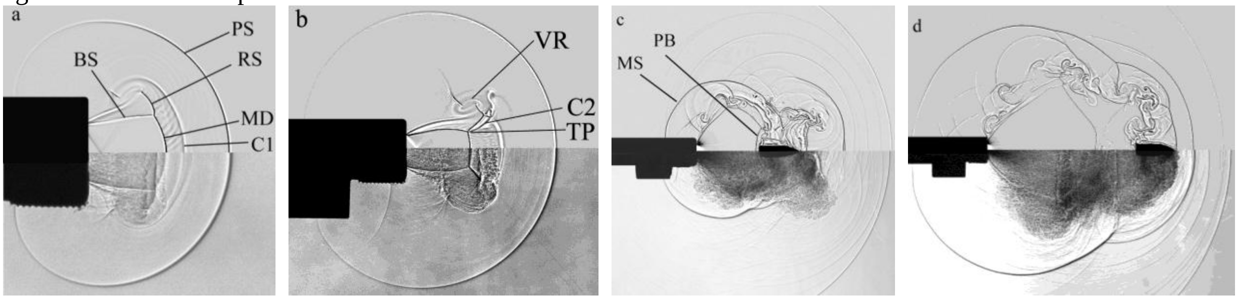

Fig.3 Numerical (upper half) and experimental (lower half) shadowgraph at the same time

The computational results of second case are presented in Fig.4, in which the contours of temperature and mass fraction of OH are in the upper and lower half respectively. As above, in the initial time the projectile launched from the breech of barrel. When the projectile exited from the muzzle, it was assumed that the fuel in-bore with H_2-O_2 mixture was consumed and the H_2-H_2O mixture with mass ratio of 1:9 was remained with temperature of 2300K. In fig.4.a, the precursor flow field has formed before the projectile exited from the muzzle (similar to fig3.b), and there is not the species OH outside for the air only in the precursor flow. After the projectile launched out of muzzle, the combustible propellant gas spurted out, and chemical reaction happened on the contact surface (i.e. flame front) between gas and air, due to the high temperature of propellant gas, showed in Fig4.b. In Fig.4c, the flame front was wrinkled because of the instability effect. And the reaction was still restrained on the gas-air interface owing to the lack of oxygen in the inner zone. In Fig.4d, the ambient air was involved into the inner propellant by the entrainment of vortex, which will cause the crush of the reacting surface and speeding up of the chemical reaction.

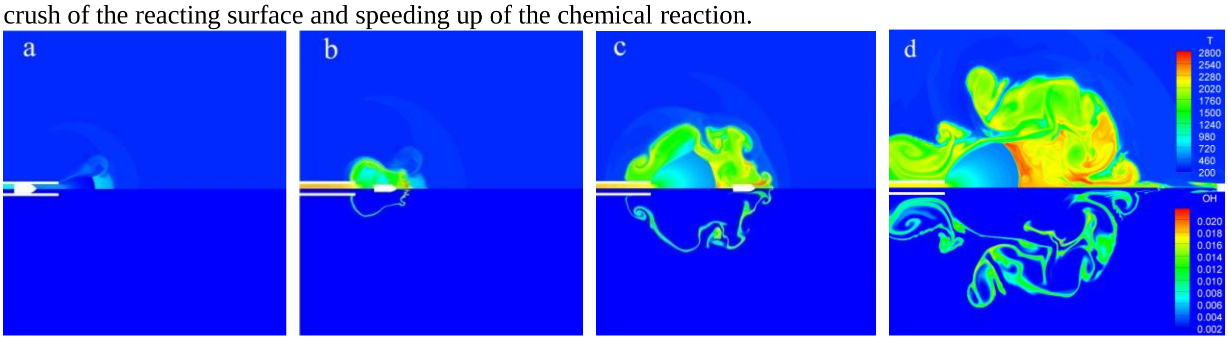

Fig.4 Contours of temperature (upper half) and mass fraction of OH (lower half)

CONCLUSION

By using direct shadowgraph method, the pictures of muzzle flow were obtained which clearly show the structure both of precursor and propellant flow in detail. The numerical results are in good agreement with the experimental pictures. And the chemical reaction process of the muzzle flow was also demonstrated in detail according to the numerical results.

Acknowledgements This work was funded by NSFC(10902052) and NUST Research（2011ZDJH30）.

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