Studies on Evolutions of Exhaust Flowfield of Pulse Detonation Engines

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1 Intruduction

Pulse detonation engine (PDE) has been expected as a new engine of a future aerospace vehicle and received considerable interest in recent years due to the advantage of its inherent simplicity and high operating efficiency (Kailasansth,K. 2002 [1], Roy,G.D.2004 [2]). Because gas blow-down process occupy a lot of time in each firing cycle of PDE, a complete understanding of the dynamic process and insight into how the dynamic process affects the thrust production are of interest to optimization of PDE systems.

Preliminary investigations of evolutions of the exhaust flow field of PDE have been performed experimentally and computationally (Zhang,Z.C.2001 [3],Allgood,D.2003 [4]), Further studies still are needed to understand it in more detail. In this paper, A high-speed shadowgraph imaging system is used to visualize the exhaust flowfield and Navier-Stokes equations in conjunction with 9 species and 18 elementary reactions are solved numerically, and the measured and calculated results also shown good agreement.

2 Experimental

The setup used in the experiments is sketch in Fig.1. The configuration of PDE tested here is 30mm diameter straight tube of 1000mm length. The tube is filled with a detonable mixture of H_2 and air, and mounted vertically, where the top end is fully open. Three pressure transducers are used to record sample pressure traces.

A high-speed shadowgraph imaging system is used to visualize the exhaust flowfield after the blowout of the detonation, which is consisted of a light source, a concave mirror and a high speed multi-lens camera. The light source including 16 high voltage generators flashes according to the time sequence predefined by the time control unit. The light, coming from the light source, is reflected by the concave mirror and penetrated into the tested flow field area and then reaches the camera.

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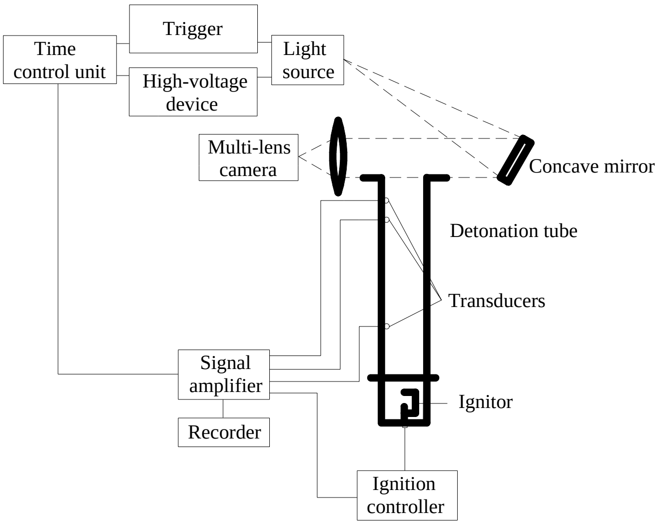


Fig.1 Schematics of experimental set-up and shadowgraph system

Only single shot detonations are run in these experiments. The typical shadow photographs of the exhaust flowfield after the blowout of the detonation are shown in Fig2.

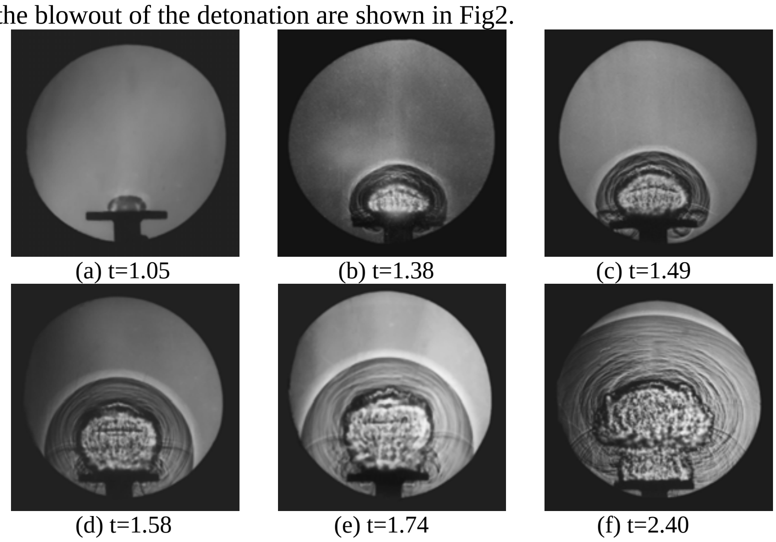
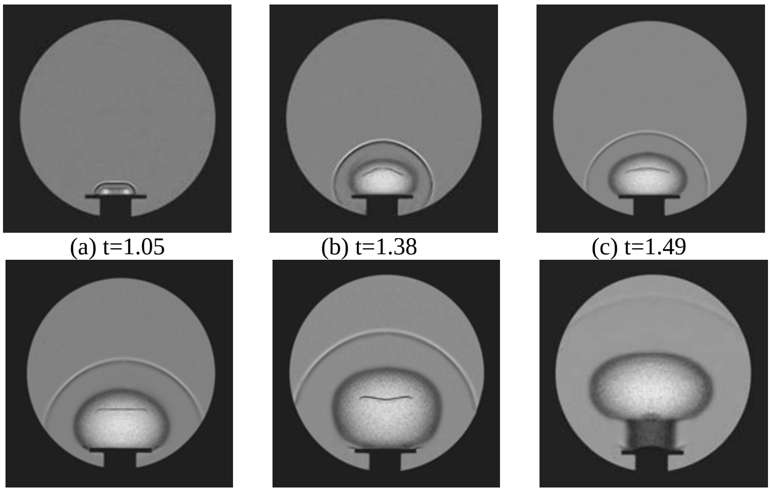


Fig.2 Experimental shadow photographs of exhaust flow field

3 Computational Simulation

Compressible flow with H_2 /air reaction considered here is governed by the two-dimensional and axisymmetric Navier-Stokes equations in conjunction with 9 species and 18 elementary reactions. The equations are integrated by the fractional step method. The wave propagation algorithm is used for the numerical flux and viscous fluxes are computed from the second order in space central differences. The implicit Gear algorithm is used for the stiff chemical reaction source term in the species equation. The calculated shadow photographs of the flowfield in the vicinity of the exit of PDE tube are shown in Fig3.



(a) t=1.05 (b) t=1.38 (c) t=1.49

(d) t=1.58 (e) t=1.74 (f) t=2.40

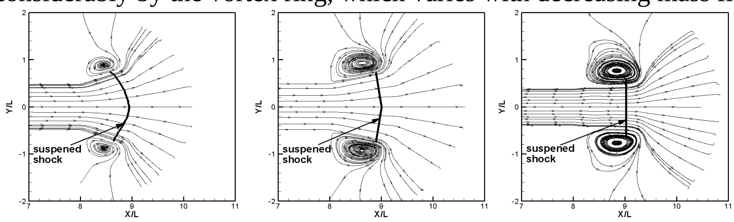
Fig.3 Calculated shadow photographs of exhaust flow field

4 Results and Discussions

After the detonation on set, a stabilized propagation of detonation wave at 1582m/s is obtained from the calculations, meanwhile the CJ velocities got from Gordon-Mcbride code and the current experiments are 1619m/s and 1638m/s respectively. Hence, the agreement among them is excellent.

In comparison between Fig.2 and Fig.3, both the experimental and computational shadowgraph images show qualitatively the same structure of the PDE exhaust flow fields. After the detonation wave has exited the PDE tube, it quenches and becomes a non-reactive shock wave followed by hot combustion products. Then, the pressurized burned gases expand out of the PDE tube, a vortex ring forms as shown in Fig.2a) and Fig.3a). The secondary backward propagating upward-facing shock wave occurs in the second image of Fig.2 and 3, which is connected with a low-pressure core of the vortex ring. The shape and standing location of the upward-facing shock vary with the development of the PDE exhaust flow fields as shown in c-e of Fig.2 and 3. Meanwhile, The leading shock increases its detachment distance from the trailing combustion gases and the burned gases overturn toward the back finally, like a mushroom.

As shown in Fig4, a vortex ring functions as a convergent/divergent nozzle, which pressurized burned gases pass through. A standing shock wave occurs in the nozzle to adjust the pressure difference with the surrounding air, and is influenced considerably by the vortex ring, which varies with decreasing mass flow rate.



(a) t=1.35 (b) t=1.49 (c) t=1.58

Fig.4 Calculated instantaneous streamlines

A typical flow pattern of the exhaust flow field is shown in Fig5. The pressure distributions are shown in the bottom-half of the picture, and in the top-half of the picture, the pressure contours are described, meanwhile curve 1 and 2 represent profiles of pressure and mass fraction of H_2O at the axis respectively. It can be seen that there exist a leading shock wave (S1), a upward-facing shock wave (S2) and an expansion wave traveling upstream into the PDE tube from the curve 1 and the front of the contact surface between the two shock waves separating the compressed air and combustion products is also displaced in the curve 2.

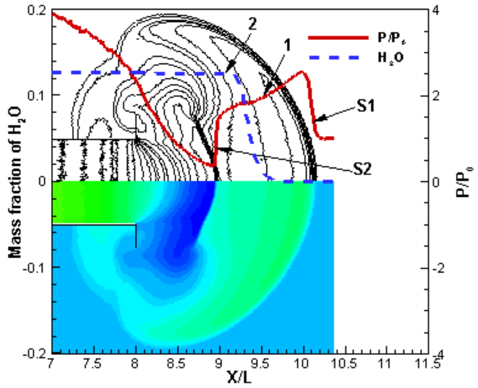


Fig.5 Flow pattern in exhaust flow field

The time history of at the closed end of the PDE tube is shown in Fig 6. After ignition, there is a big thrust jump up related with an overdriven detonation. Then the thrust quickly reduces to a constant level which is maintained until the expansion waves reaches the closed end. The thrust declines steeply after. Finally, the thrust fluctuations are observed due to vortex/shock interactions.

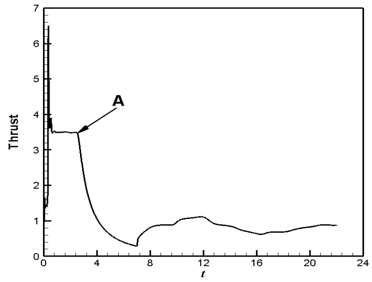


Fig.6 Thrust history on closed end wall

Acknowledgements

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