Numerical Simulation of Detonation Propagation in the Branch Tubes of the Detonation Wave Ignition System

Guo Hongjie, Liang Guozhu
School of Astronautics, Beihang University
Beijing, China

Key Laboratory of Spacecraft Design Optimization and Dynamic Simulation Technologies,
Ministry of Education
Beijing, China

1 Introduction

For the reliable characteristics of simultaneous ignition, the Detonation Wave Ignition (DWI) system appears to be the most practical one among various ignition techniques for those large liquid rocket engines which have multiple chambers or a large chamber with multiple combustion regions.

In former papers, experiment ignition system was set up and a series of experiments were carried out to make detail investigation on the DWI technique, such as how initial conditions influenced the detonation wave ignition, multiple-tube ignition and vacuum ignition characteristics, and the feasibility of detonation wave ignition for a practical rocket engine.

In this paper, numerical simulation was carried out according to the same dimension of the experiment system. Results show the process of the detonation wave propagation in the tubes of the system.

2 Calculation setting-up

Simulation was conducted according to the same dimension of the experiment system and the same condition with experiment by the pressure, temperature and O2/H2 mixture ratio. The calculation zones and the computational mesh were show as Fig.1. The whole zone was divided into 13 zones listed in Table 1.

Zone 1 was the premix chamber zone of 50 X Φ20mm, zone 2 was the connection tube of 50 X Φ10mm, zone 3 was the main tube of 2020mmX Φ10mm, zone 4-6 were to act as the four-way connection which was about 50mmX Φ10mm at each way, zone 7-10 were the 3 branch tubes of Φ6mm, zone 11-13 were the 3 ignition tubes of Φ2mm.

Correspondence to: guohongjie@buaa.edu.cn

Eight record points (as shown in Fig. 1) were set on the tubes to monitor the pressure, temperature, mass fraction of species, and to evaluate the detonation wave propagation and simultaneous properties. The distances of these points are shown in Table 2.

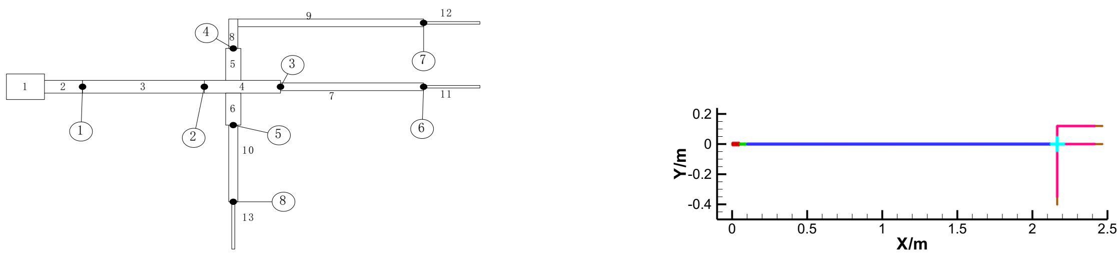

Fig.1 Calculation zones and mesh

Table 1: Calculation zones

Zone	Length (mm)	Diameter (mm)	Remark
1	50	20	Premix chamber
2	50	10	First connection tube
3	2020	10	Main tube
4	100	10	Four-way connection
5	50	10	Four-way connection
6	50	10	Four-way connection
7	200	6	Branch tube
8	60	6	Branch tube
9	260	6	Branch tube
10	300	6	Branch tube
11	50	2	Ignition tube
12	50	2	Ignition tube
13	50	2	Ignition tube

Table 2: Record points

Record point	Distance from the left wall(mm)
1	100
2	2120
3	2220
4	2220
5	2220
6	2420
7	2540
8	2520

The two dimension Navier-Stokes equations were used and SST k-w model was used as the turbulent model. The finite rate chemical mechanic of 6 species and 8 steps for gaseous H2 and O2 was adopted.

In the tubes there were full of mixture of initial pressure 0.1MPa, the initial temperature 300K and the mixture ratio 3. The detonation initial zone was 8mm long from the left wall of the premix chamber with high temperature and high pressure.

3 Results and analysis

The simulation results shows the working process of the detonation wave ignition system. The detonation wave is initiated in the premix chamber and propagated along the main conduction tube. At the four-way connection, the detonation wave goes three ways following the branch tubes and stably propagates to the ignition tubes. If there were H2/O2 mixture, it would be ignited immediately by the detonation wave.

The pressure distribution and temperature contour in the initial stage are shown in Fig.2 . The moments in the figure are 10 μ s, 19.6 μ s, 29.6 μ s, 40.5 μ s, 52.9 μ s, 66.3 μ s.

The detonation propagation in the four-way connection is shown in Fig.3 and the moments are 0.74ms, 0.75ms, 0.754ms, 0.759ms, 0.769ms.

The wave propagation in the three branch tubes is shown in Fig.4. The moments are 0.769ms, 0.789ms, 0.810ms, 0.820ms, 0.851ms, 0.871ms.

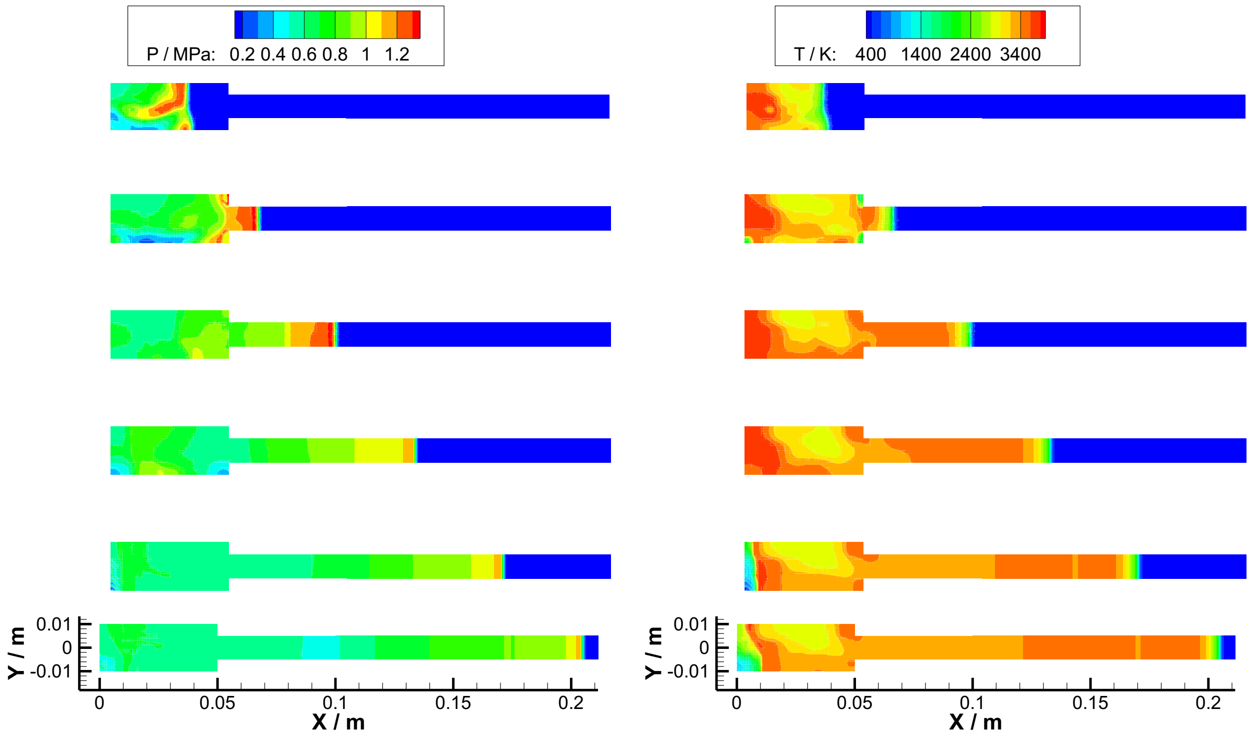

Fig.2 Contour in the initial stage Left: Pressure contour Right: Temperature contour

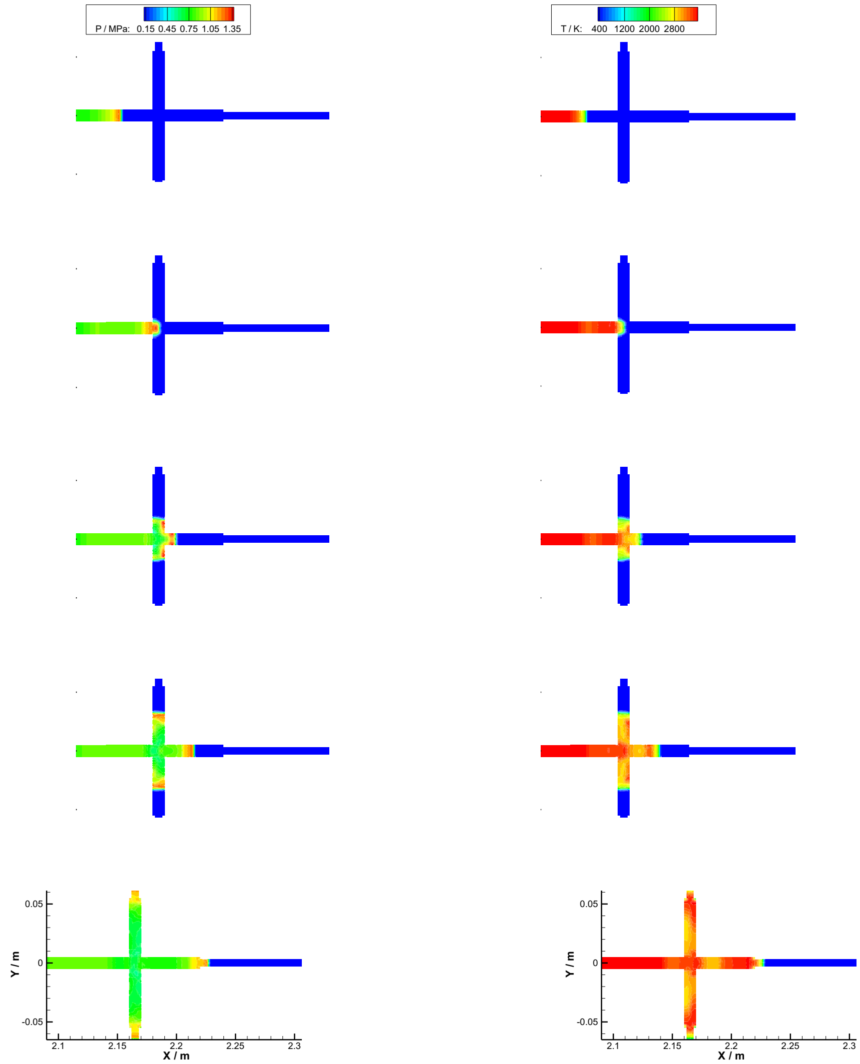

Fig.3 contour at the four-way connection Left :Pressure contour Right: Temperature contour

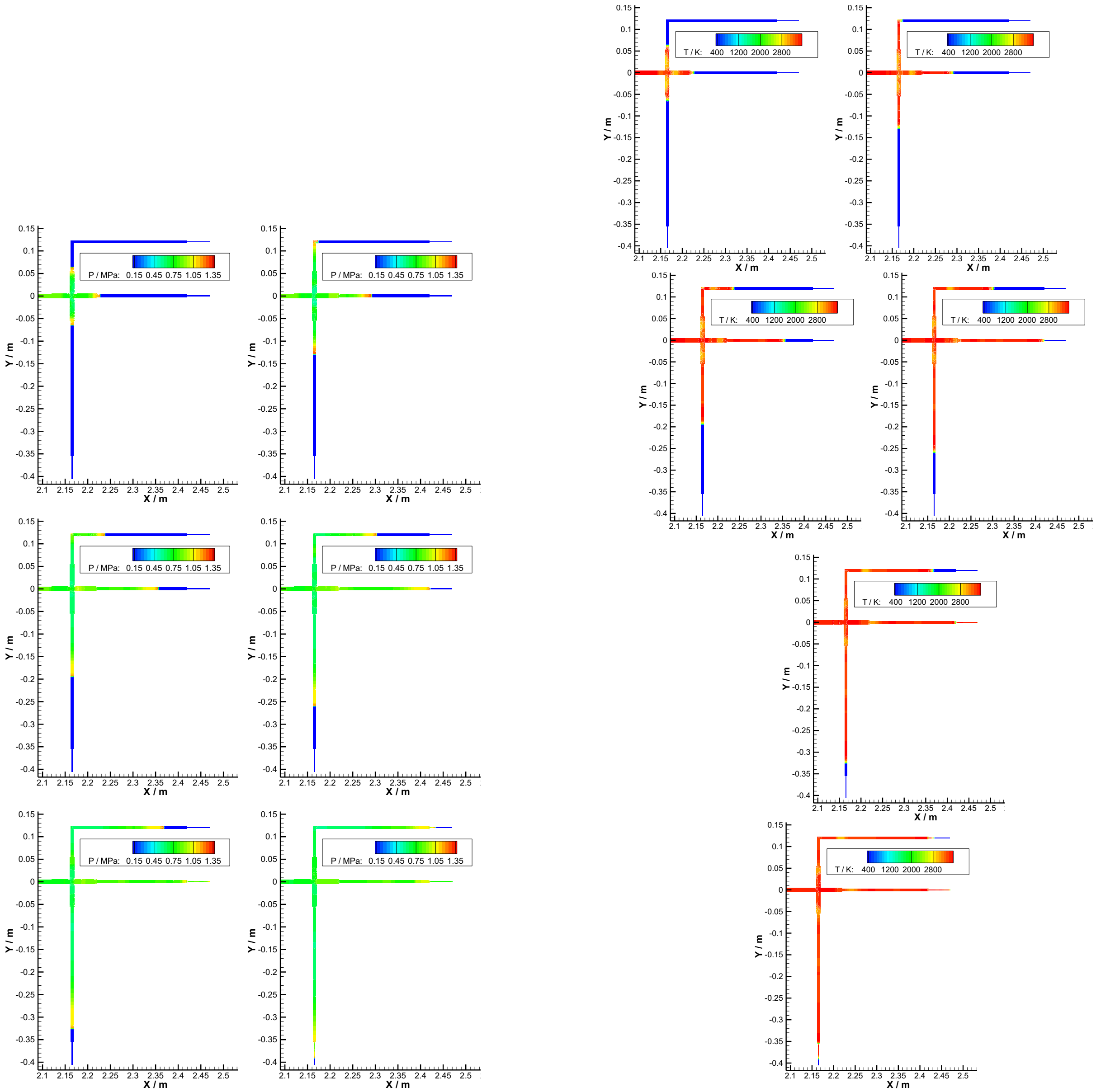

Fig.4 contour of the detonation wave propagation in branch tubes Left: Pressure Right: Temperature

The above results show that the detonation wave propagates 2.5 meters long, from the premix chamber to the ignition unit, in less than 1ms .

From the results, quantitative analysis has been made on the detonation parameters at the eight record points, shown as Fig.5. The suffix x=2.22(1)(2)(3) represent the rightward branch tube, the upward branch tube and the downward branch tube. These three lines almost overlap like one. The time difference of the three lines is about 1 μ s. Comparison of the results of the point 6-7-8 show that the largest time difference is about 0.04ms while the longest distance difference is 120mm.

The results also show that the propagation speed of the detonation wave is about 3000m/s , the temperature is about 2500K and the pressure is about 1.2~1.3MPa.

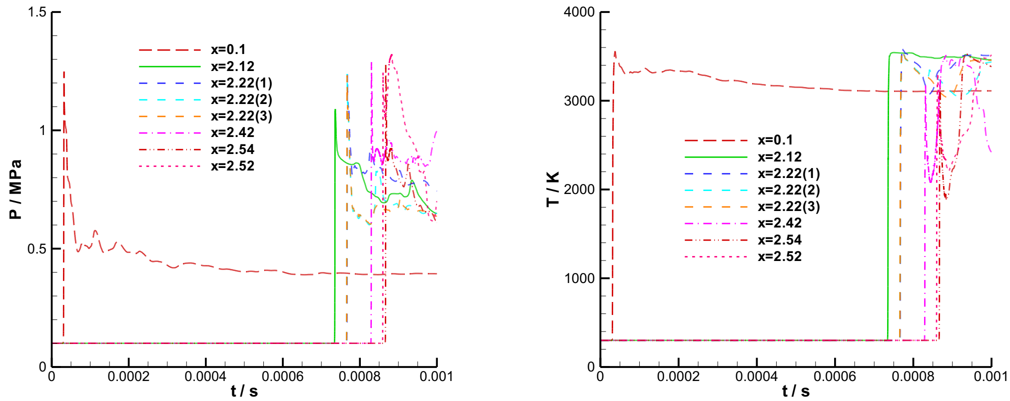

Fig.5 History recorded by the record points Left: Pressure Right: Temperature

4 Conclusion

The numerical simulation results show that the detonation wave propagate stably along the ignition system with high speed about 3000m/s, high temperature about 2500K, high pressure(about 10 times initial pressure), and the detonation wave ignition system has excellent simultaneous time difference about 0.04ms between different ignition units by distance difference of 120mm. Same conclusion could be drawn from the experiments data.

References

[1] Liou L C. Combustion-wave ignition for rocket engines. NASA 92-20043

[2] Lockheed Martin, Allied Signal Aerospace, Rocketdyne X-33 Phase II Annual Performance Report. NASA-CR-205695.

[3] Walter S Kim. 1998 Research & Technology[R]. NASA TM-1999-208815, April 1999

[4] Guo H., Liang G., Ma B., et al. (2005)Preliminary investigation on detonation wave ignition technique, Journal of BUAA, 2005(04):375

[5] Guo H., Liang G., (2006)Numerical simulation of detonation propagation in tube of detonation wave igniter. Journal of propulsion and power,(27):83