

Three Dimensional Simulation of Rotating Detonation Engine without Inner Wall

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1 Introduction

Rotating detonation engine (RDE) is currently a new research hot spot. Compared to the pulse detonation engine, it can maintain the high efficiency of combustion but more likely to be realized [1]. Cooling for supersonic combustion is one of the major problem in engine design. The temperature of detonation products is about 2000K to 3000K. The best way to solve this problem is to get rid of the unnecessary part of the engine which take on heat load. The present experiment and numerical simulation use the RDE concept which has both inner wall and outer all coaxially [2-5]. There is a lack of study for a RDE concept without the inner wall. The inner wall reflects the shock wave, which sustains the strength of detonation wave. But the high temperature and the limited space of the inner wall make it difficult for cooling. If the RDE can work without the inner wall, cooling for the outer wall is the only concern. It will simplify the design of RDE, and improve its reliability. This paper uses 3D simulation to investigate the feasibility of this new concept by utilizing one-step chemical kinetic model and overset grid. The result will be a basic reference for further study.

2 Numerical methods

2.1 Governing Equations

A one-step chemical kinetic model was used in this simulation, and the combustible mixture is air and hydrogen. The governing equations are the three-dimensional Euler equations. Flux terms are solved by using the so-called monotonicity-preserving weighted essentially non-oscillatory scheme (WENO),

and time integration is performed by using the third-order total variation diminishing Runge-Kutta method.

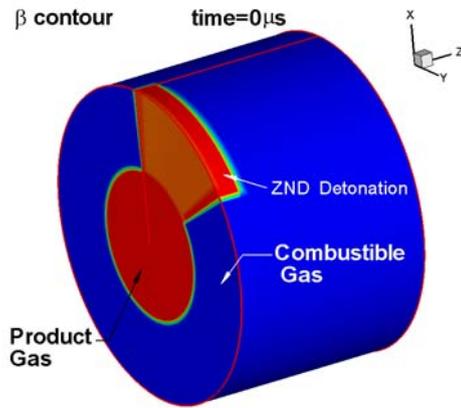


Figure 1. Initiation of the RDE chamber

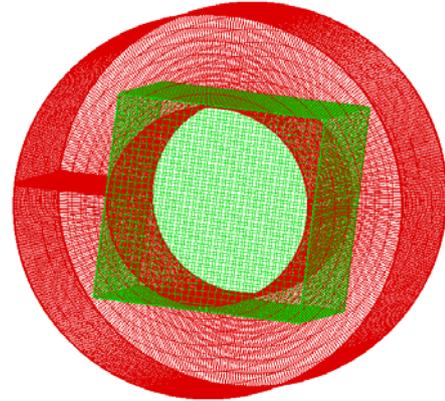


Figure 2. Overset grids

2.2 Initiation and boundary conditions

The Detonation wave is initially set by the one dimensional simulation result, as showed in Figure 1. The whole cylinder is the combustion chamber, and the radius is 6cm. The combustible mixture is injected into the cylinder from the head wall. It then gets into the outer space of the cylinder, which is in the space between 3cm to 6cm in radius. In the picture, the blue part is combustible mixture, and the red part is combustion products. The inlet boundary condition was set in accordance with the local wall pressure following the Laval theory. The inlet stagnation pressure is $p_0=20\text{atm}$, and the ambient pressure is 1atm. The injection hole area normalized by the area of Laval tube throat is $A_w/A_{throat}=10$. The central round part of the head wall is solid, which is within 3cm in radius. All the space behind this part is filled with combustion products. The velocity of all the air in the cylinder is zero.

2.3 Overset grid

To avoid singularity around the axis of the cylinder, the normal square grid is used in the center part of the cylinder. We use interpolation to exchange the information between the cylindrical grid and the square grid, as showed in Figure 2. The crossing area is at the radius of 3cm. The points of grid in the crossing area are interpolated by the adjacent points of the other grid. The cylinder grid is $41(\text{radius}) \times 481(\text{circumference}) \times 161(\text{axis})$. The square grid is $81 \times 81 \times 161$. The average size of a grid unit is 0.4mm.

3 Results and discussion

Figure 4 shows the pressure contour of the detonation at the time of $1360 \mu s$. There are two central symmetric detonation waves in the chamber.

Figure 5 shows the velocity vector in the chamber at the time of $1360 \mu s$. The combustion products are emitted from the chamber at the similar speed, and almost in the same direction.

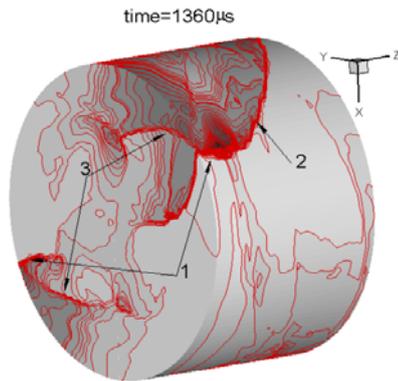


Figure 4. The pressure contour at the time of $1360 \mu s$

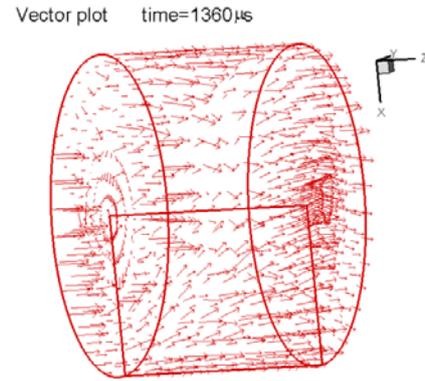
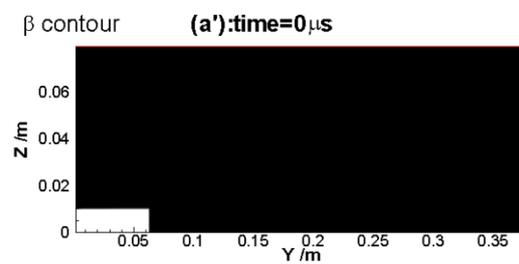
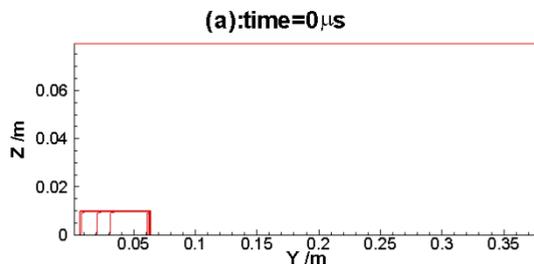
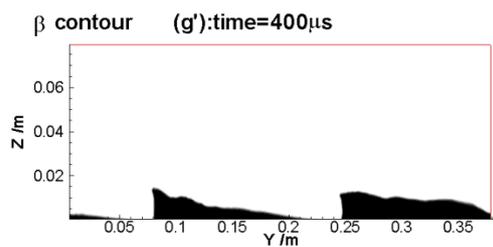
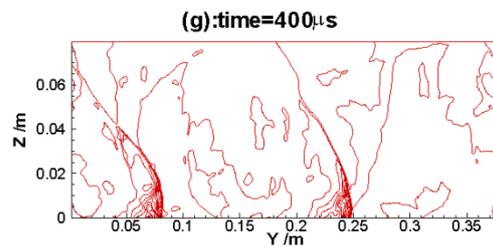
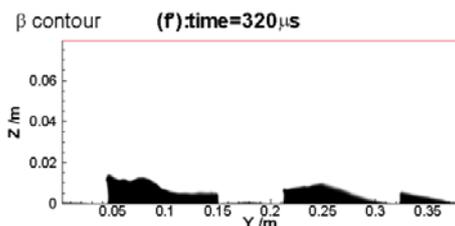
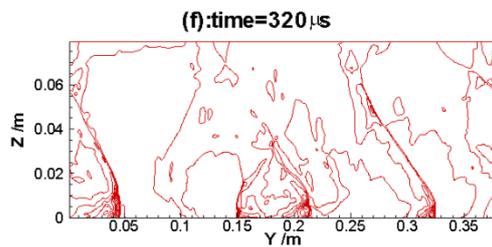
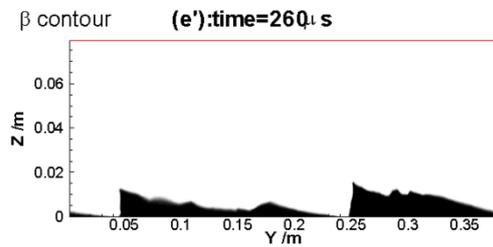
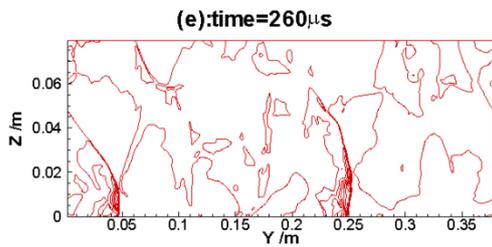
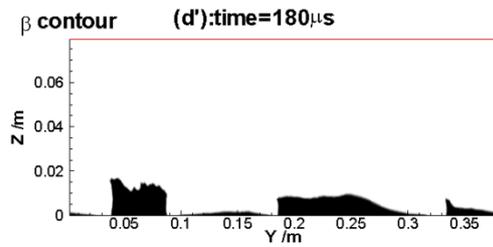
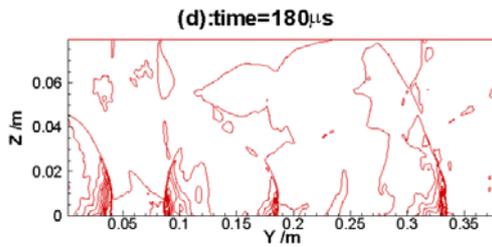
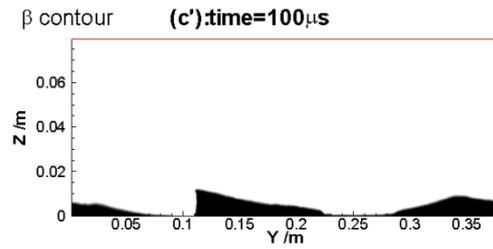
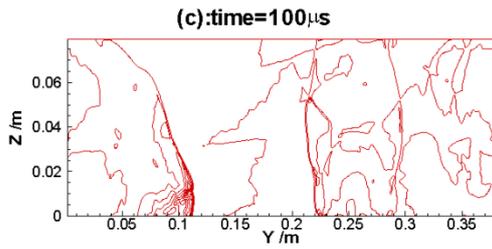
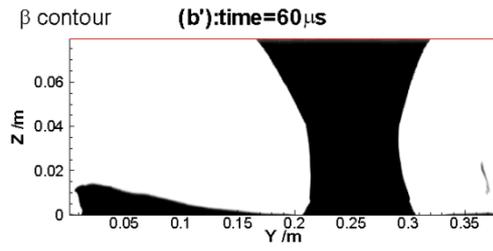
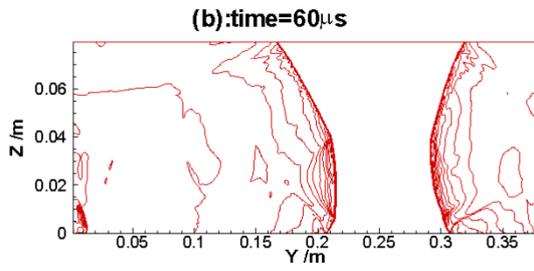


Figure 5. The velocity vectors of the flow field at the time of $1360 \mu s$

Figure 6 shows the detonation wave development at the cylinder sidewall. It is unfolded into a flat plot. The figures in the left column show the pressure contour. And the ones on the right show the reaction progress, which the black part means the combustible air, and the white part means the combustion products. Figure 7 shows the pressure contour of an axial cross section ($z=0.2\text{cm}$) at time of $20\text{-}1360 \mu s$, the numbers in the plot point out the different detonation waves. The big size of the chamber and reflection of shock waves generate detonation waves in two opposite directions. The collision of detonation waves may turn to generate new detonation waves, or make the detonation waves decline. Finally, the flow field are stabled, and two detonation waves remain.





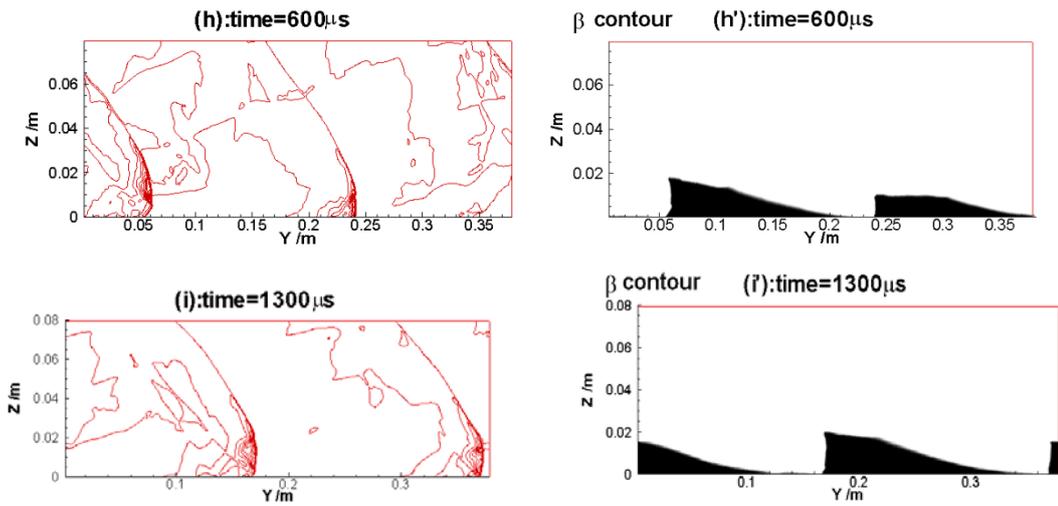


Figure 6. Pressure contour and reaction progress from 0 to $1330 \mu s$

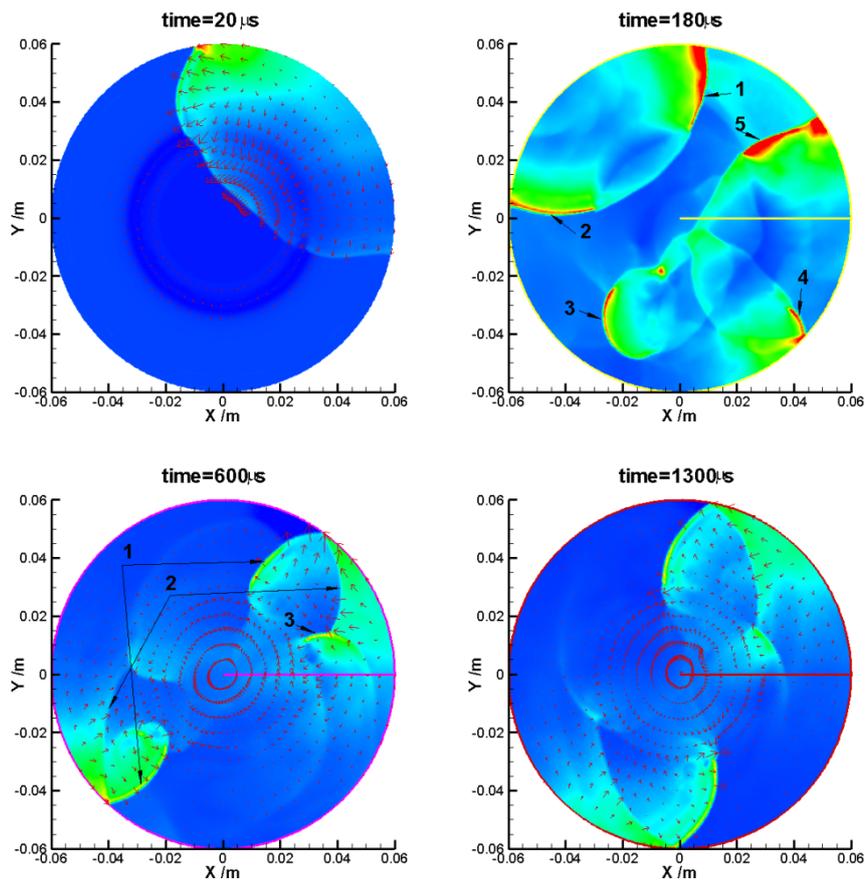


Figure 7. The flow field and pressure contour of the cross section at the time between 20-1300 μs

3 Conclusions

This three dimensional simulation has analyzed the flow field, and finds out the influence from the ignition process and curvature of the chamber wall. The work proves that the overset grid is fine enough to depict the detonation waves movement without non-physical oscillation.

The development of the detonation waves shows that detonation waves may ignited and extinguished repeatedly during the collisions of the initiation period. A two-head steady central symmetric detonation flow field is finally converged.

References

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