# Modelling Analysis of Wave Interactions during the Ignition Process of Rotating Detonation Engines

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## 1 Extended Abstracts

The rotating detonation engines (RDEs) create continuously propagating detonation wave in the annular combustor to achieve the sustained and stable detonation combustion. Compared to the pulse detonation engines (PDEs), the ignition of RDEs is much simpler and only needed once. The main approaches of ignition in the RDEs constist of igniting a pre-detonation tube [1-2], a spark plug [3], and an exploding wire [4]. In the ignition process, the flow field structure is very complex. The interactions among wave structures occur frequently until stalbe detonation waves form inside the chamber. The possible interactions could lie between detonation wave and shock wave, or combustion wave, or even detonation wave.

In this paper the wave interactions are analyzed in one-dimension model and then numerically studied. The multi-species reactive Euler equations are solved,

$$\frac{\partial \rho}{\partial t} + \frac{\partial \rho u}{\partial x} = 0 \tag{1}$$

$$\frac{\partial \rho u}{\partial t} + \frac{\partial (\rho u u + p)}{\partial x} = 0 \tag{2}$$

$$\frac{\partial \rho E}{\partial t} + \frac{\partial (\rho E u + p u)}{\partial x} = 0 \tag{3}$$

$$\frac{\partial \rho Y_k}{\partial t} + \frac{\partial \rho Y_k u}{\partial x} = \dot{\omega}_k \tag{4}$$

where $\rho$, $u$, $p$, $E$, and $Y_k$ are the density, the velocity, the pressure, the total energy and the mass fraction of the $k^{\text{th}}$ species respectively. $\dot{\omega}_k$ is the reaction rate of production of species $k$, and a chemical reaction system containing of 9 species and 19 steps is adopted [5].

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The fifth-order WENO scheme [6] is used to compute the convection terms, and a point implicit method is used for the source term.

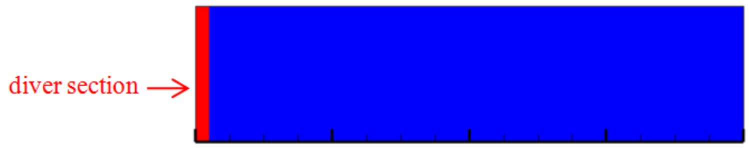


Figure 1. The schematic of the detonation tube.

The propagation of a detonation wave is studied firstly and the schematic is as shown in figure 1. The initial pressure, temperature and species in the detonation tube is set as 1atm, 300K and stoichiometric $H_2$/air, respectively. A 2mm long part at the left side of the tube with 50atm and 3000K to initiate a detonation wave directively. The left side boundary is set as the reflective boundary, while the right side boundary is set as the outflow boundary. The grid size is set uniformly as 5μm.

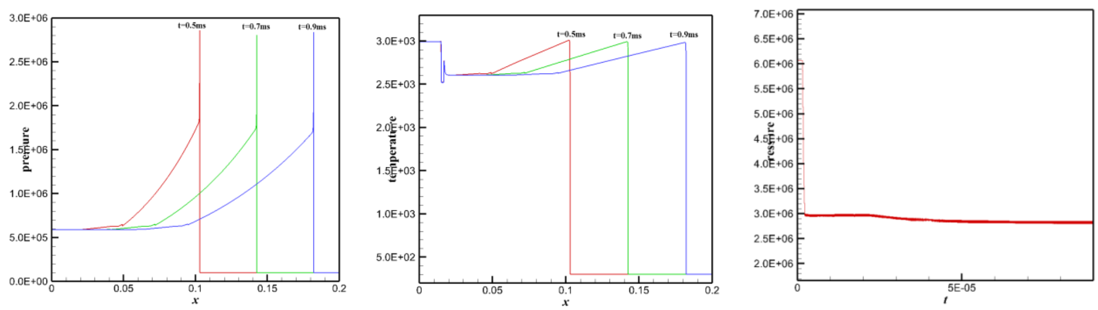

Figure 2. The propagation of a detonation wave in a detonation tube. Left: pressure pofile; middle: temperature profile; right: history of the maxium pressure in the tube

Figure 2 shows the propagation of a detonation wave. The left and middle figures present the pressure and temperature profile at $t$ is 0.5, 0.7, 0.9ms. When $t$ is 0.07ms, the detonation wave propagates to about 0.14m, and the C-J detonation is basically formed. This also can be seen from the history of the maxium pressure. At the initial moment, the maxium pressure is distributed in the driven section. Then as the propagating of the detonation wave, the maxium pressure is exactly the preshock pressure of the detonation wave. From the right figure, the preshock pressure decreases slowly, which implies that the inital driven detonation is tranformed to the C-J detonation.

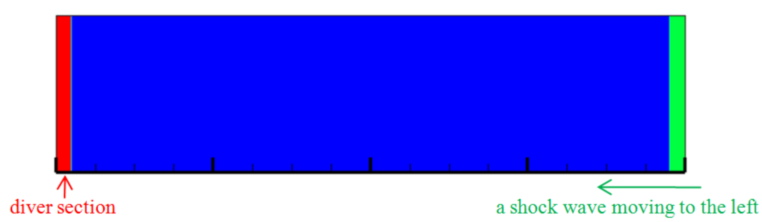


Figure 3. The schematic of the interation between a detonation wave and a shock wave.

Then the interation between a detonation wave and a shock wave is studied. The schematic is shown in figure 3. The driver section is set at the left side, while a shock wave is set at the right side. The Mach number of the shock wave is taken as 1.2, 1.5 and 2.0 respectively.

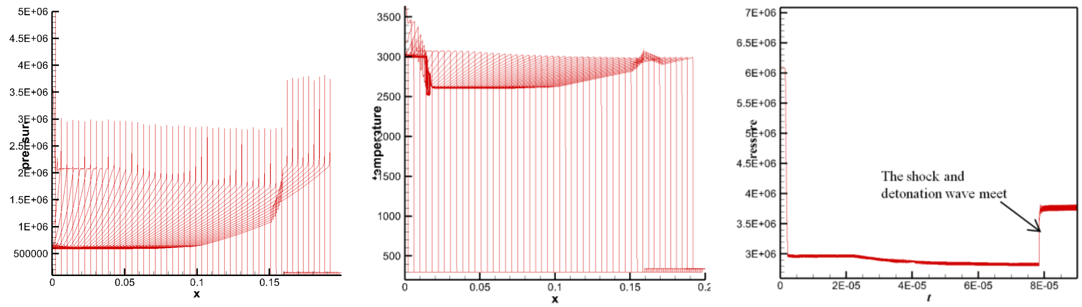


Figure 4. The interation between a detonation wave and a shock (Ma = 1.2). Left: pressure pofile; middle: temperature profile; right: history of the maxium pressure in the tube

Table 1: Results of interaction between a detonation wave and a shock. $P_b$: pressure afer the shock; $P_d$: pressure afer the detonation wave; $T_b$: temperature afer the shock; $T_d$: temperature afer the detonation wave.

| Ma | $P_b$ (bar) | $P_d$ (bar) | $T_b$ (K) | $\mathbf{T_d}$ (K) |
|---|---|---|---|---|
| Ref. | 1.0 | 27.8 | 300 | 2995 |
| 1.2 | 1.52 | 37.5 | 340 | 3030 |
| 1.5 | 2.46 | 54.5 | 396 | 3051 |
| 2.0 | 4.52 | 80.4 | 507 | 3111 |

Figure 4 shows the pressure and temperature profile during the process of the interaction between a detonation wave and a shock wave. When $t$ is about 0.07ms, the shock and detonation wave meet. After the interaction, the pressure of preshock rises sharply while the temperature increases slightly. Table 1 shows the summary of results with different Mach numbers of shockwave. Here the reference result corresponds to the result of C-J detonation without shock. It can be seen that, as the intensity of shock wave increases, the pressure after the detonation wave increases greatly. This high pressure would cause the decrease of the inlet mass flow of fresh unburnt gas in the RDE, which may cause the quench of the detonation wave.

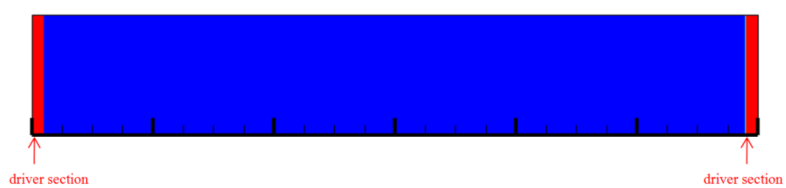


Figure 5. The schematic of the interation between two detonation waves.

The interation between two detonation waves is also studied. The schematic is shown in figure 5. Two driver sections are set at the left and right sides respectively. After the detonation waves are initiated, they propagates with the opposite directions and meet at the middle.

Figure 6 shows the pressure profile and the history of the maxium pressure during the process of the interaction between two detonation waves. After the interaction of detonation waves, initially the pressure of the wave front increases sharply, which reaches more than 100atm. Since there is no existence of reactants, both detonation waves extinguish; and then two pressure waves form and decay gradually.

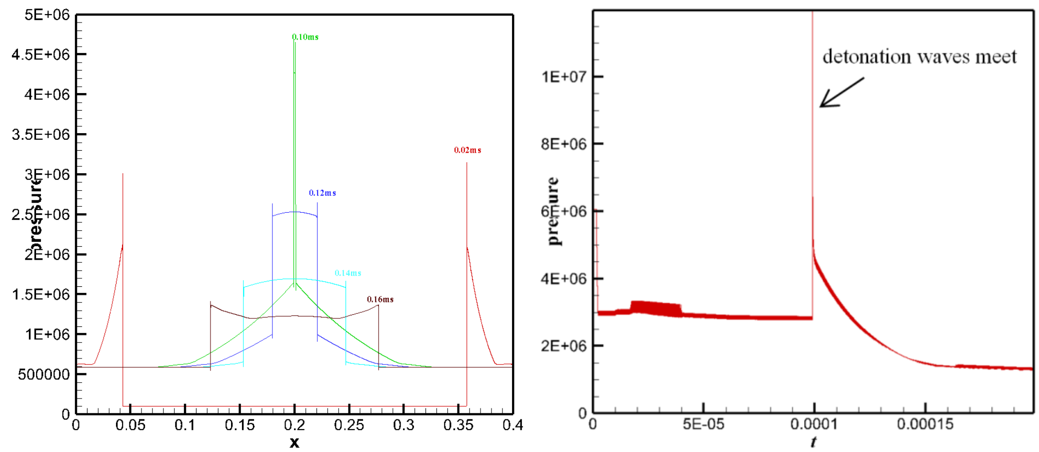


Figure 6. The interation between two detonation waves. Left: pressure pofile; right: history of the maxium pressure in the tube

## References

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