Mode Switching in 2-Dimensional Continuous Detonation Chambers with Discrete Injectors

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1 Abstract

In this paper, numerical simulations for Continuous Detonation Chambers (CDCs) with separate injectors are carried out and mode switching is realized by raising the inlet total temperature. It is found that there is a series of reversed compression waves. They play an important part in mode switching in CDCs. A reversed compression wave can develop into a detonation wave after passing through a distance where unburnt gas and burnt gas distribute alternatively or bumping against another compression wave. When the inlet total temperature increases, a compression wave is easier to develop into a detonation wave and result in mode switching.

2 Introduction

Continuous Detonation Engine (CDE) is one of future engine concepts. It has many advantages, like high thermal efficiency, adjustable quantity of flow, simple structure and so on. Thus it has attracted the attention of many researchers. The structure of Continuous Rotating Chamber (CDC) is always an annular cylinder or a hollow cylinder. Gas flow into the chamber by micro-nozzles. Rotating detonation waves propagate in circumference direction, burning gas and generating thrust.

Mode switching is change in the number of detonation waves existing in the CDC responding to sudden change in working condition, such like switch from one wave mode to two wave mode [1]. Mode switching in CDCs has already been discovered in experiments [1, 2]. However, because of the limit of measurement means, the mechanism and process of mode switching have not been discussed in detail. In this paper, mode switching is realized in numerical simulation for CDCs with separate injectors and the effect of reversed compression waves on mode switching are discussed.

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3 Physical Model and Numerical Method

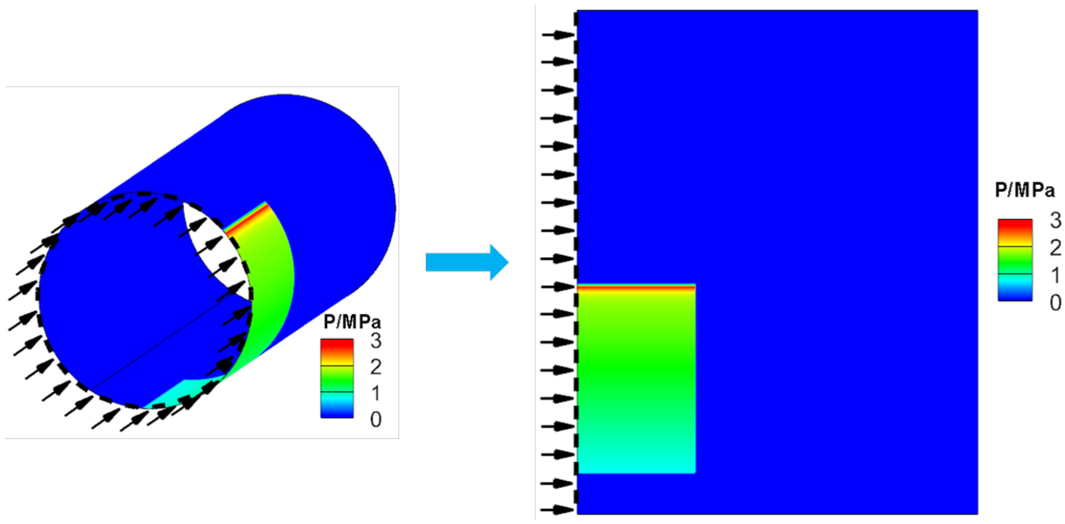


Figure 1. Sketch for the simulation region

In 2-dimensional simulation, the chamber is regarded as an infinite thin cylinder, ignoring the variety in radial direction. The chamber is 2cm in diameter and 5cm in length, as shown in Figure 1. The pre-mixed fuel is injected into the chamber through the micro-nozzles on the head-end wall. As shown in Figure 2, micro-nozzles and solid walls are distributed alternatively on the injection wall. Solid lines represent solid walls. Dashed lines represent micro-nozzles. The ratio of total area of all micro-nozzles to the area of injection wall is called injection ratio.

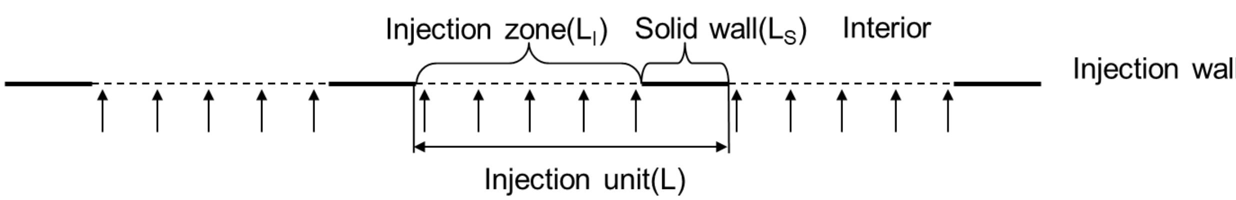


Figure 2. Sketch for the simulation region [4]

2-dimensional *Euler* equations with source term in cylindrical coordinate is used as governing equations. Two-step chemistry model [3] is used for the stoichiometric hydro-oxygen reaction. The flux terms are treated by the fifth-order WENO scheme. Third-order Runge-Kutta method is used for time integration.

4 Results and Discussion

Figure 3 shows one typical results of CDCs with separate injectors. In the flow field, unburnt gas is separate by several segments of burnt gas. There is a series of reversed compression waves. They are caused by discontinuity before detonation wave. The detail about their formation is discussed in [4].

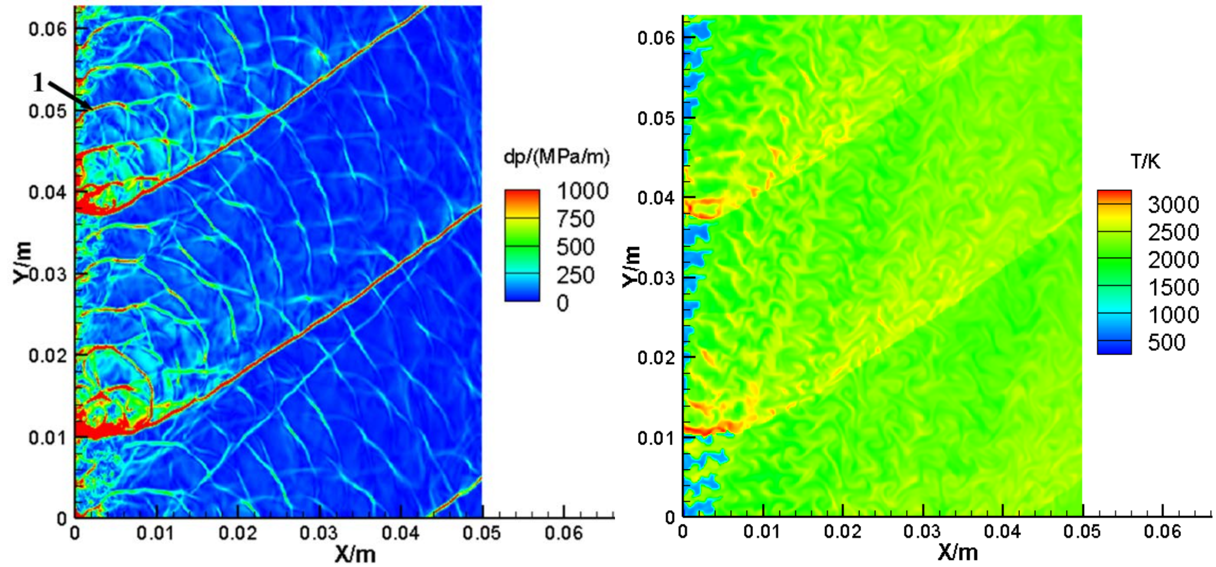


Figure 3. Left: pressure gradient contour; right: temperature contour. 1: Reversed compression waves [4]

There are two features of compression waves that can influence mode switching in CDCs. Firstly, when a compression wave passes through a distance where unburnt gas and burnt gas distribute alternatively, it may develop into a detonation wave. In Figure 4, P denotes local pressure and beta denotes reaction progress parameter. At first, low-temperature unburnt gas and high-temperature burnt gas distribute alternatively before a compression wave. After the compression wave passes through a distance, a detonation wave appears near interface of burnt gas and unburnt gas and catch up with the original compression wave soon. It is because that at the interface of burnt gas and unburnt gas, temperature is higher than unburnt gas so that gas here can be ignited. As the temperature rises, the reaction rate also increases, a compression wave is easier to develop into a detonation wave. Secondly, a reversed compression wave will be strengthened after bumping against a detonation wave [4].

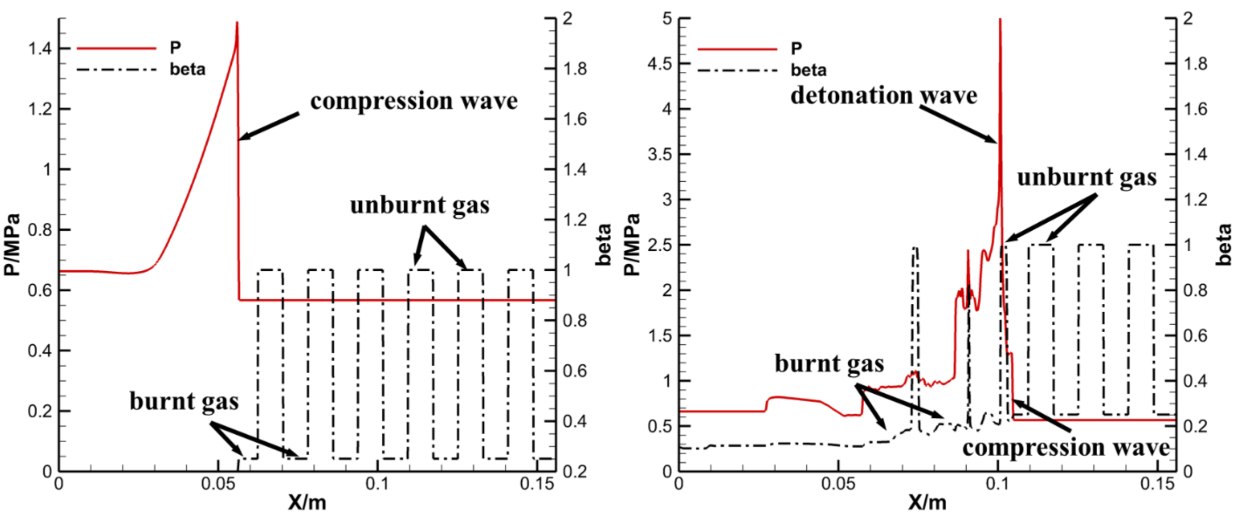
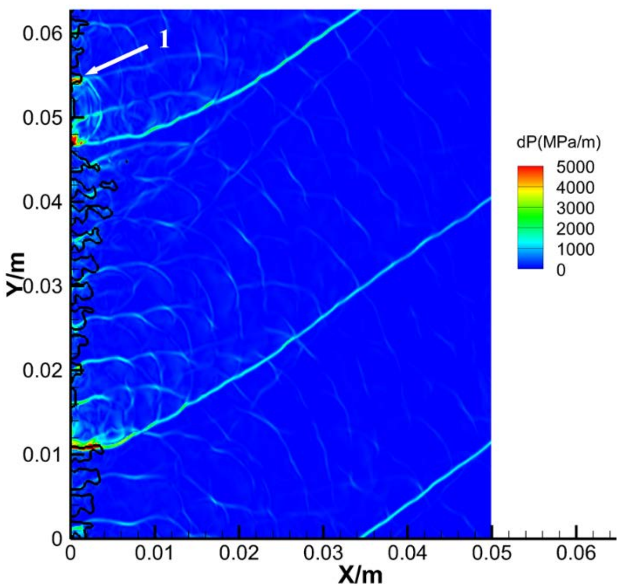
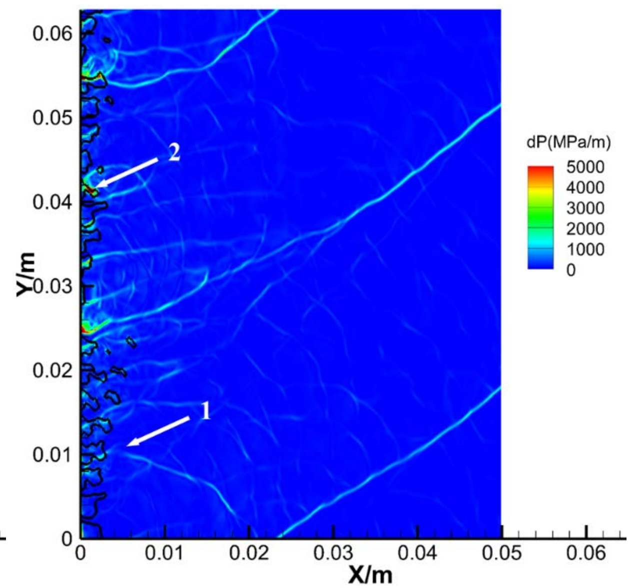


Figure 4. Pressure and reaction progress parameter in 1-dimensional detonation tube Left: before; right: after

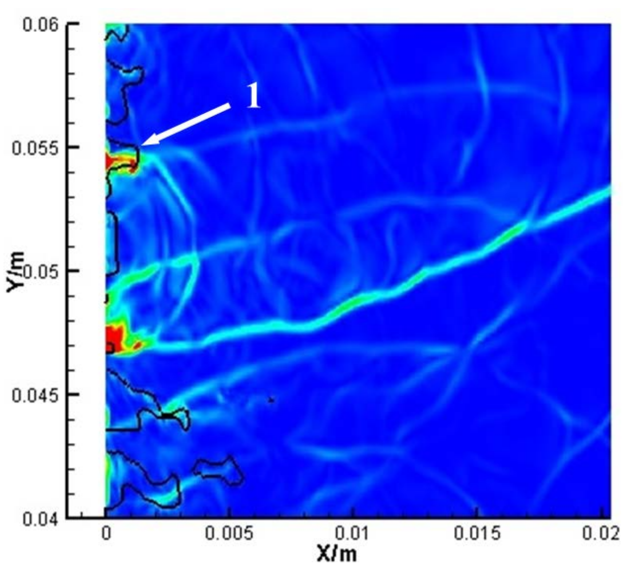
Then the effect of reversed compression waves on mode switching is discussed in a specific case in CDC. At initial time, the flow field is that in Figure 3. Then raise the inlet total temperature to 1.3 times. We can observe mode switching in the CDC flow field. From Figure 5, we can see at 13 μs, after bumping against a detonation wave, the compression wave is strengthened. It ignites the unburnt gas and develops into a detonation wave whose propagation direction is opposite to other detonation waves. Denote it by wave 1 in Figure 5. At 22 μs, compression waves propagating in different direction bump against each other, causing another new detonation wave, denoted by wave 2. Reversed compression wave 1 extinct after bumping against another detonation wave. At 121 μs, there are 3 detonation waves in the CDC while the flow field is still unstable at this moment. Transitions between compression waves and detonation waves still happen. Finally, 4 detonation waves propagate in the CDC stably.



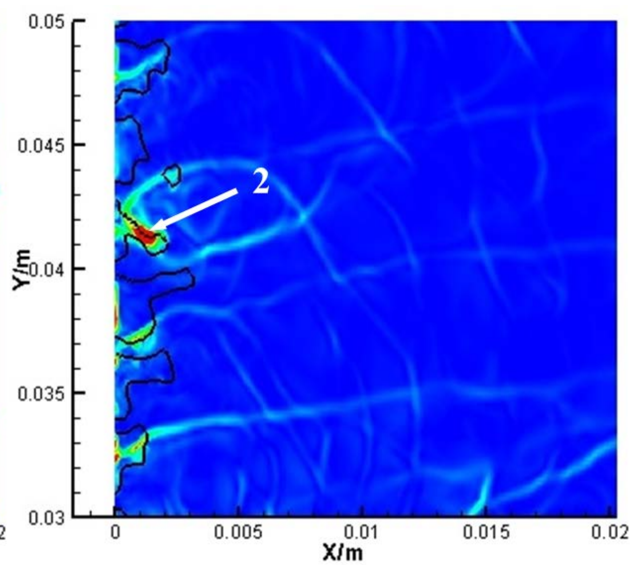
(a)



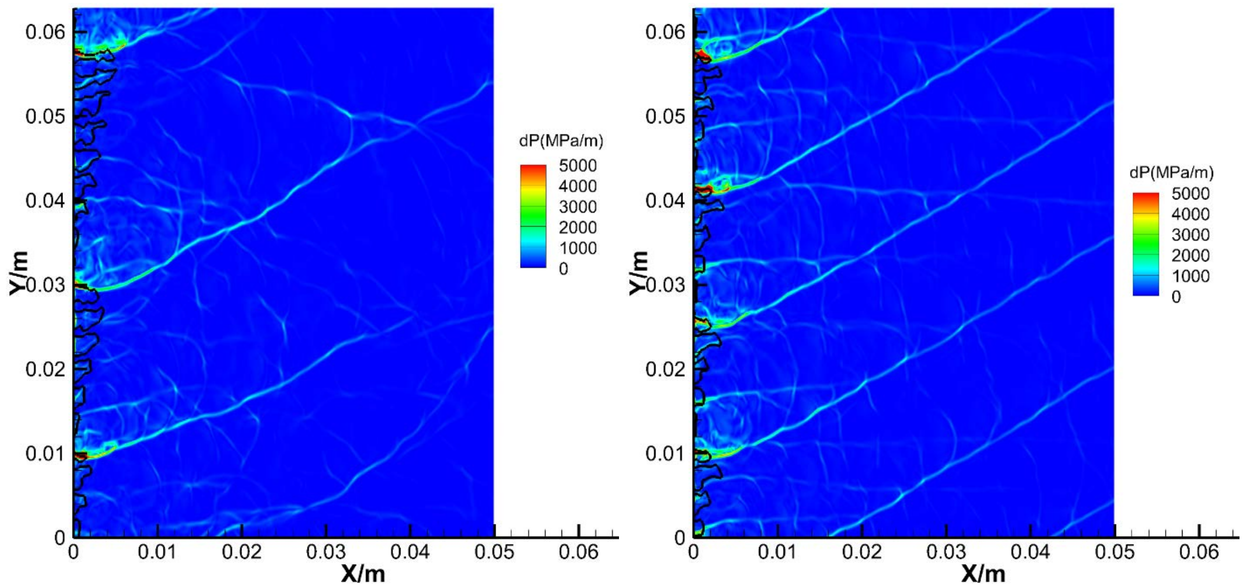
(b)



(c)



(d)



(e) (f)

Figure 5. Pressure gradient magnitude contour. (a): 13 μs; (b): 22 μs; (c): local contour at 13 μs; (d): local contour at 22 μs; (e): 121 μs; (f): 504 μs

However, in the case in which the inlet total temperature only rises to 1.25 times, the number of detonation waves in the CDC remains at 2. Comparing the pressure gradient magnitude contours for the two cases at 13 μs in Figure 6, we can see that reversed compression wave 1 in the right side cannot develop into detonation wave. As a result, the mode does not switch in the right case. This shows that whether the compression wave develop into a detonation wave is a key factor in mode switching.

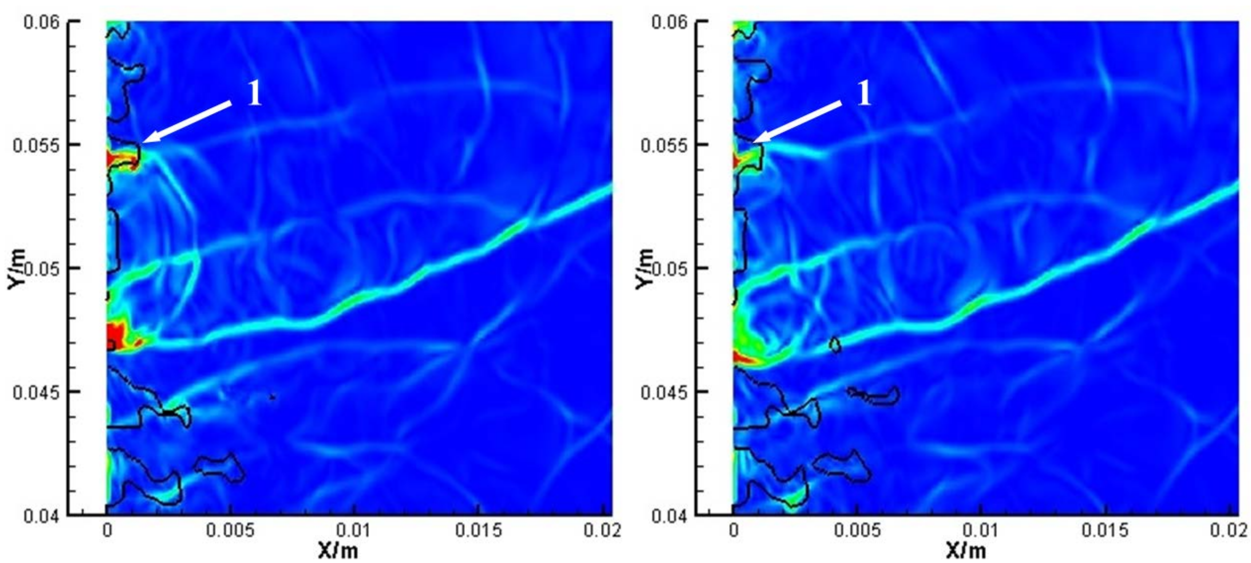


Figure 6. Local pressure gradient magnitude contour at 13 μs. Left: 1.3 times in the inlet total temperature; Right: 1.25 times in the inlet total temperature

5 Conclusion

2-dimensional numerical simulation for CDCs with separate injectors have been carried out. It is found that reversed compression waves play an important role in mode switching in CDCs with separate injectors. A reversed compression wave can develop into a detonation wave after passing through a distance where unburnt gas and burnt gas distribute alternatively. When the inlet total temperature increases, a compression wave is easier to develop into a detonation wave and result in mode switching. The transition from compression wave to detonation wave is one of the immediate causes of mode switching.

Acknowledgements

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References

[1] Anand V, George A S, Driscoll R, Gutmark E. (2015). Characterization of instabilities in a rotating detonation combustor. International Journal of Hydrogen Energy, 2015, 40(46): 16649-16659.

[2] Suchocki J, Yu ST, Hoke J, Naples A, Schauer F, Russo R. (2012). Rotating detonation engine operation. 50th AIAA aerospace sciences meeting including the new horizons forum and aerospace exposition. 119.

[3] Korobeinikov VP, Levin VA, Markov VV, Chernyi GG. (1972). Propagation of blast wave in a combustion gas. Astronautica Acta, 17(4-5): 529-537.

[4] Chen YL, Liu XY, Wang JP. (2018). Influences of separate injectors on rotating detonation engines. 2018 Joint Propulsion Conference. 2018, 10.2514/6.2018-4785.