Researches in Peking University on RDE

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Center for Combustion and Propulsion

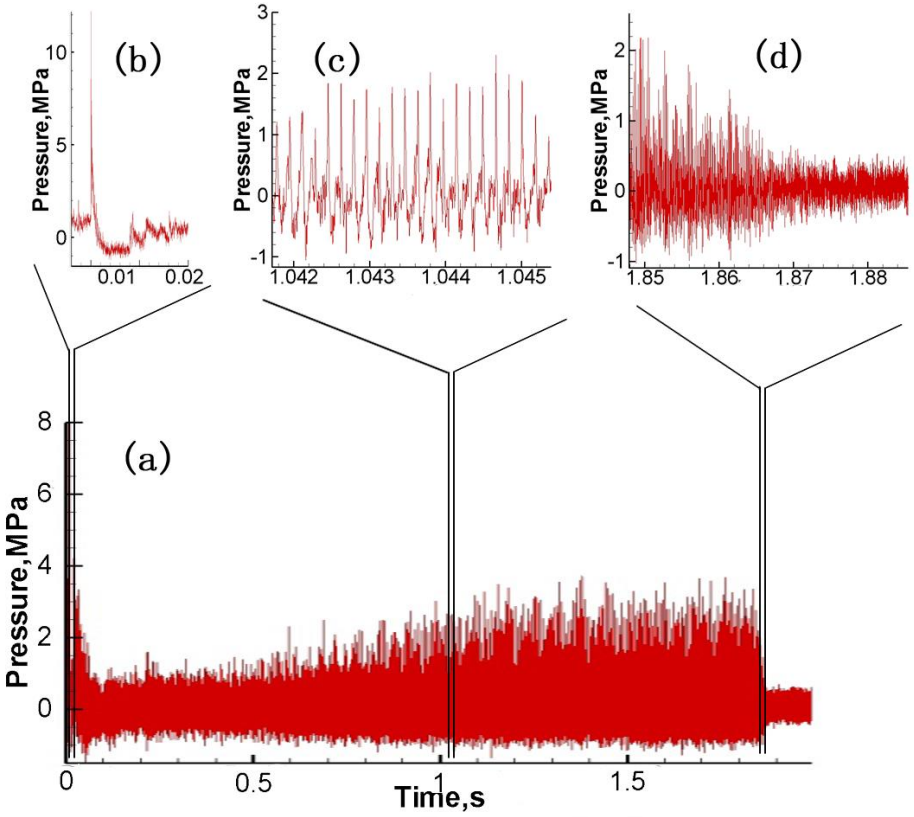
Peking University

Contents

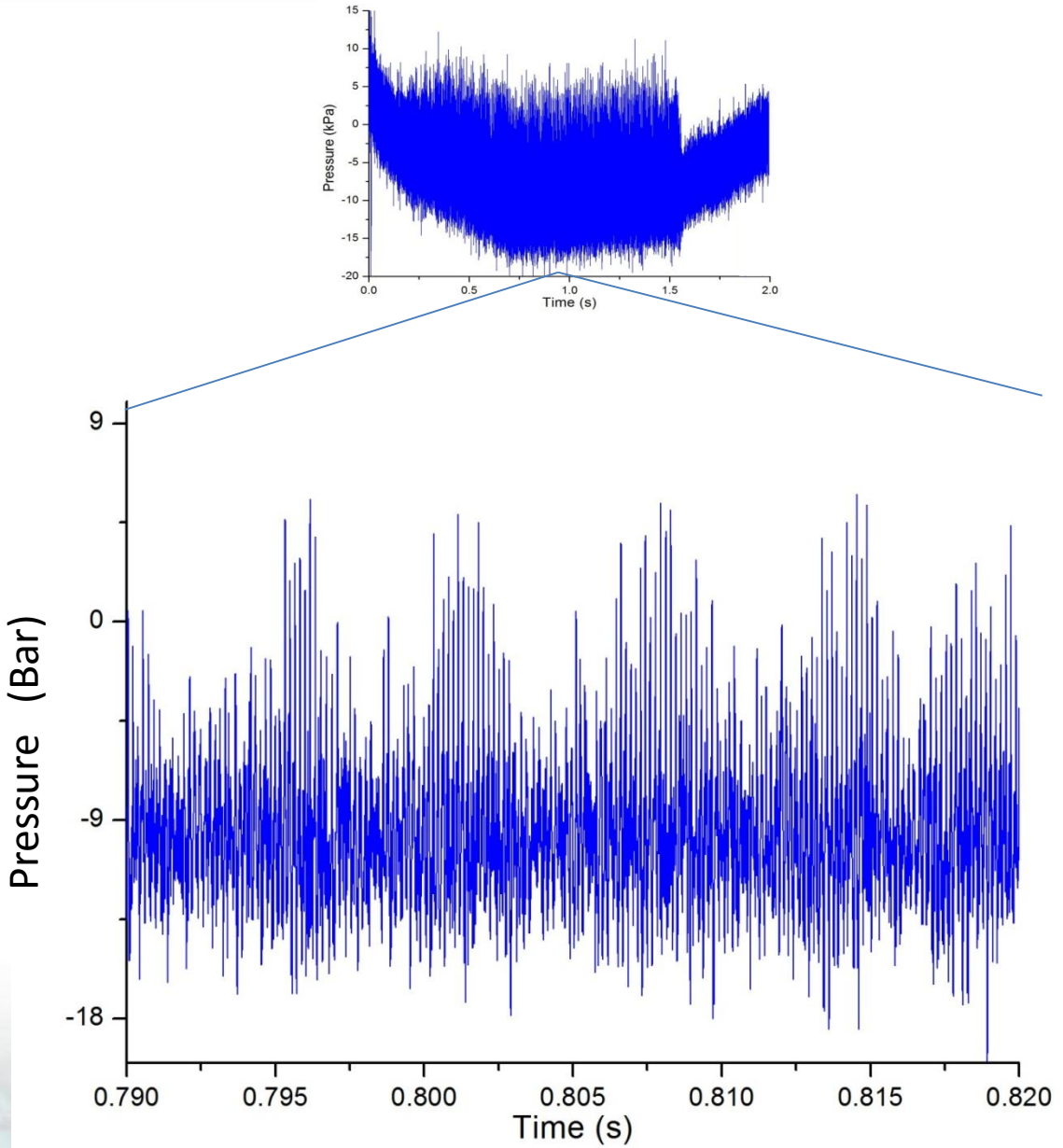
Experiment

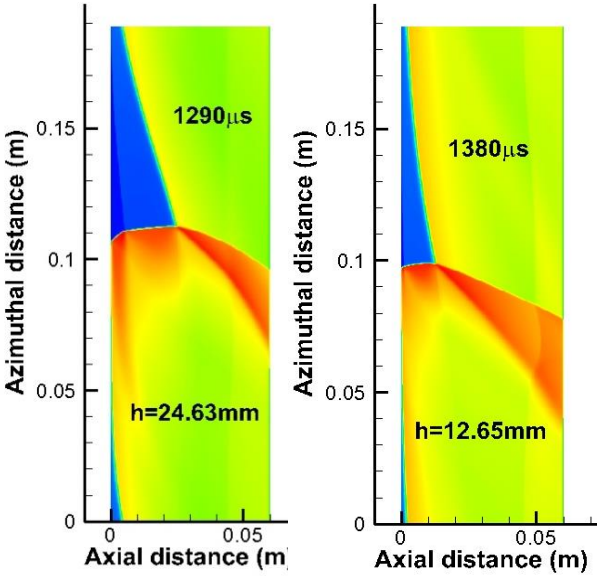
Combustor

Over-view


(a)
(b)
(c)
(d)
Pressure,MPa
Time,s
0
0.5
1
1.5
0.01
0.02
1.042
1.043
1.044
1.045
1.85
1.86
1.87
1.88

Periodic Oscillations





Mechanism of Oscillations

Detonation wave get stronger

Pressure gets higher

More fresh gas

Small DISTURBANCE

Gas feeding gets slower
Non-feeding zone gets larger

Gas feeding gets faster
Non-feeding zone gets smaller

Self-adjusting Mechanism

Less fresh gas

Pressure gets lower

Detonation wave gets weaker

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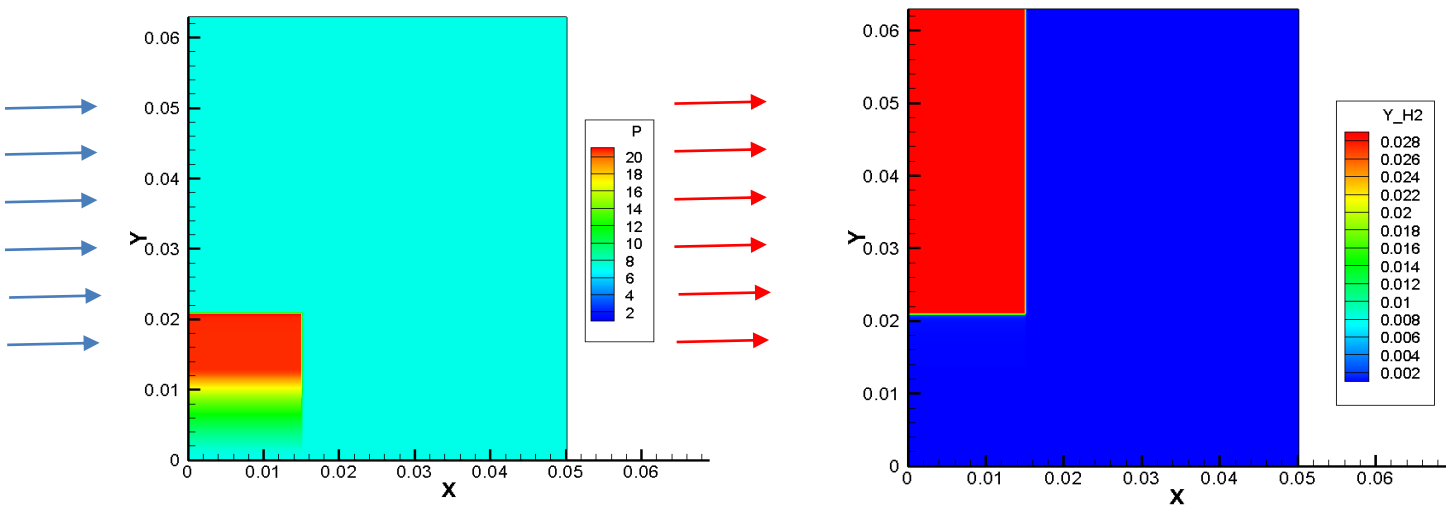
Effects of Equivalence Ratio

- 2-D Euler equations in cylindrical coordinates
- Chemical reaction model [1]

$$\frac{d[H_2]}{dt} = -A(P)P^{-1.15}[\mathrm{H_2}]^2[\mathrm{O_2}]\exp\{-E_a(\varphi)/RT\}$$



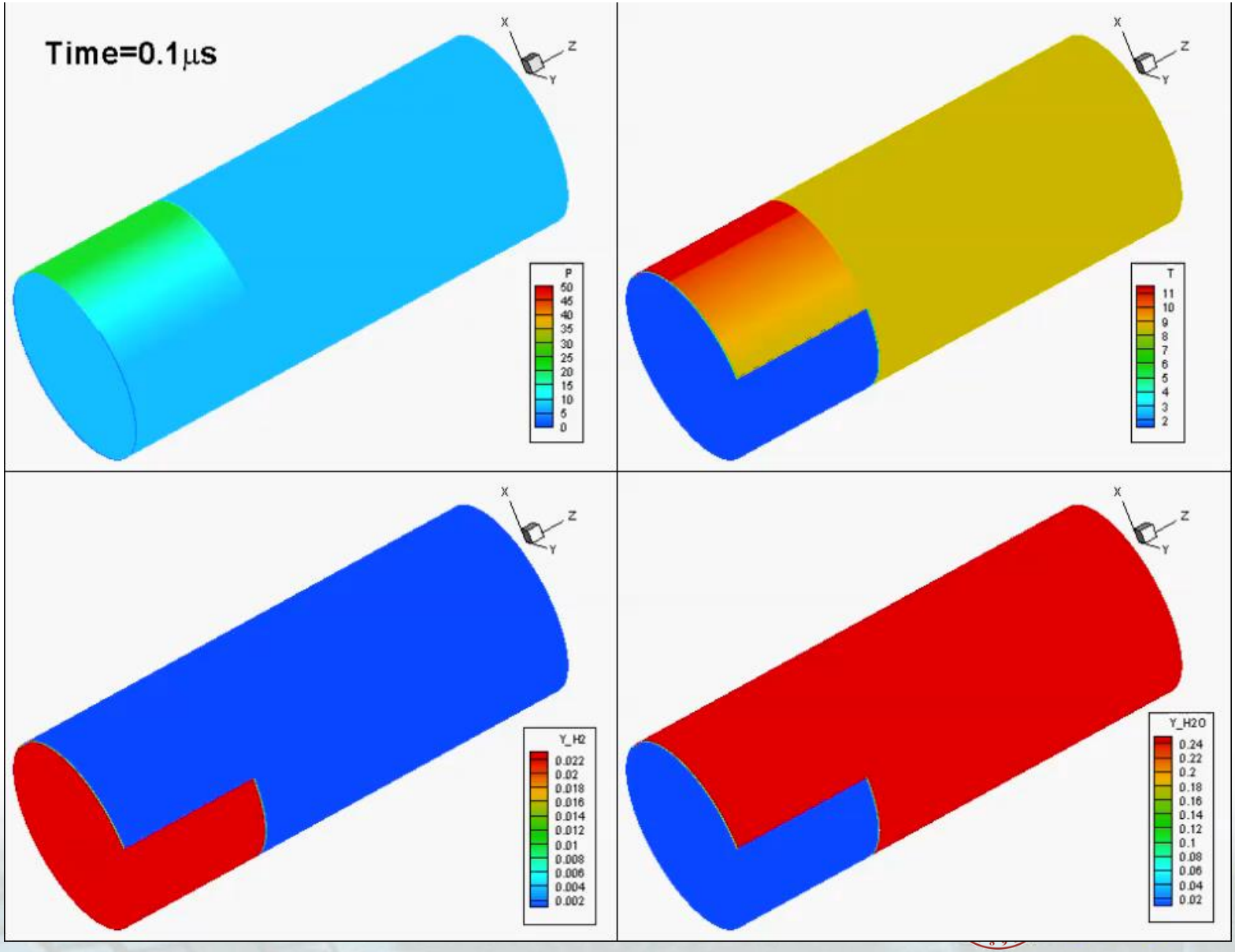
Initial condition

[1] A. V. Dubrovskii, V. S. Ivanov and S. M. Frolov, *Russian Journal of Physical Chemistry B, 2015, Vol. 9, No. 1, pp. 104–119.*

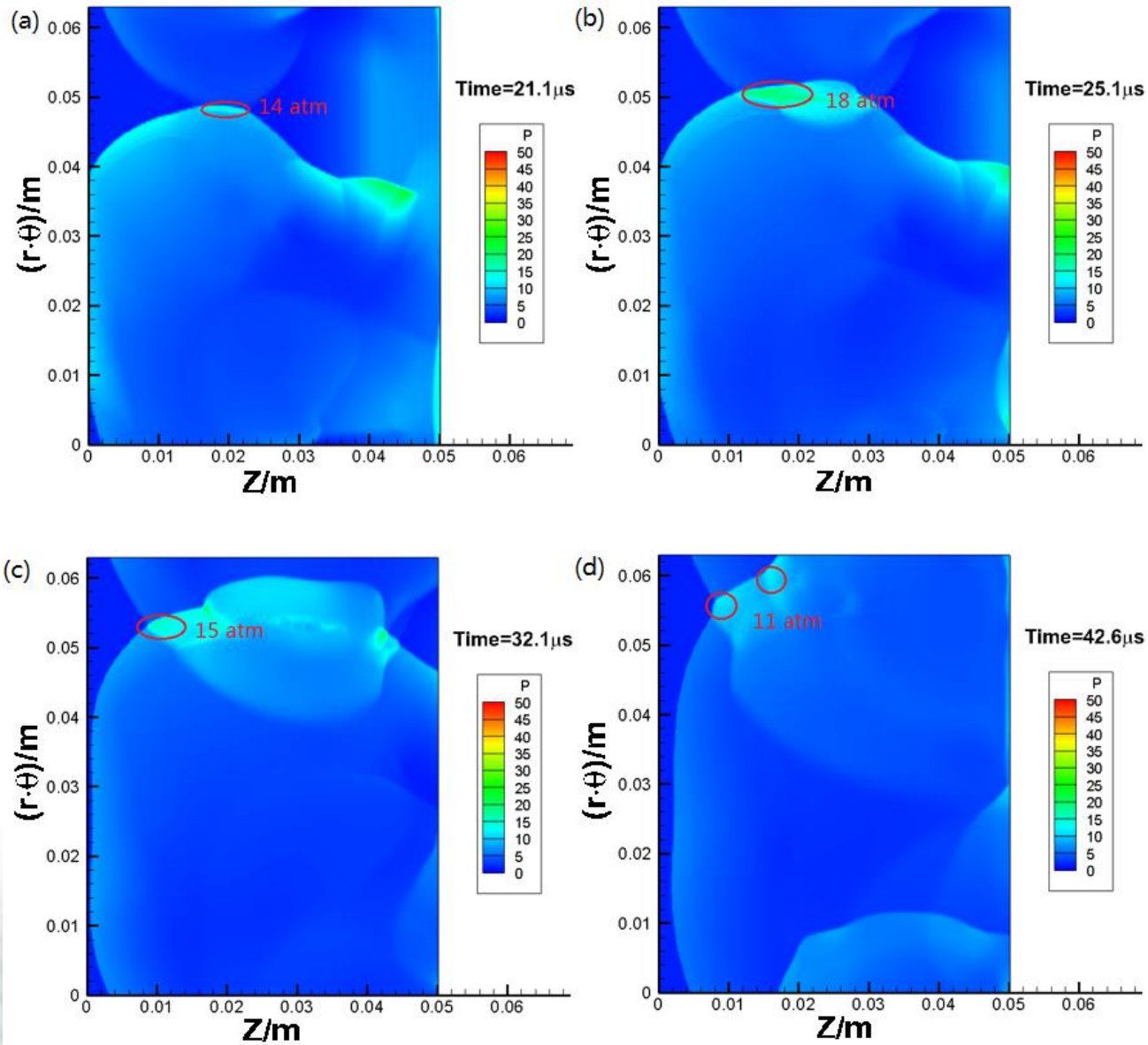
Phenomenons with Equivalence Ratio φ

- $\varphi = 0.4,\ 0.6,\ 0.8$ No detonation
- $\varphi = 1.0,\ 1.2,\ 1.4, 1.6$ Stable detonation
- $\varphi = 1.8,\ 2.0$ No detonation

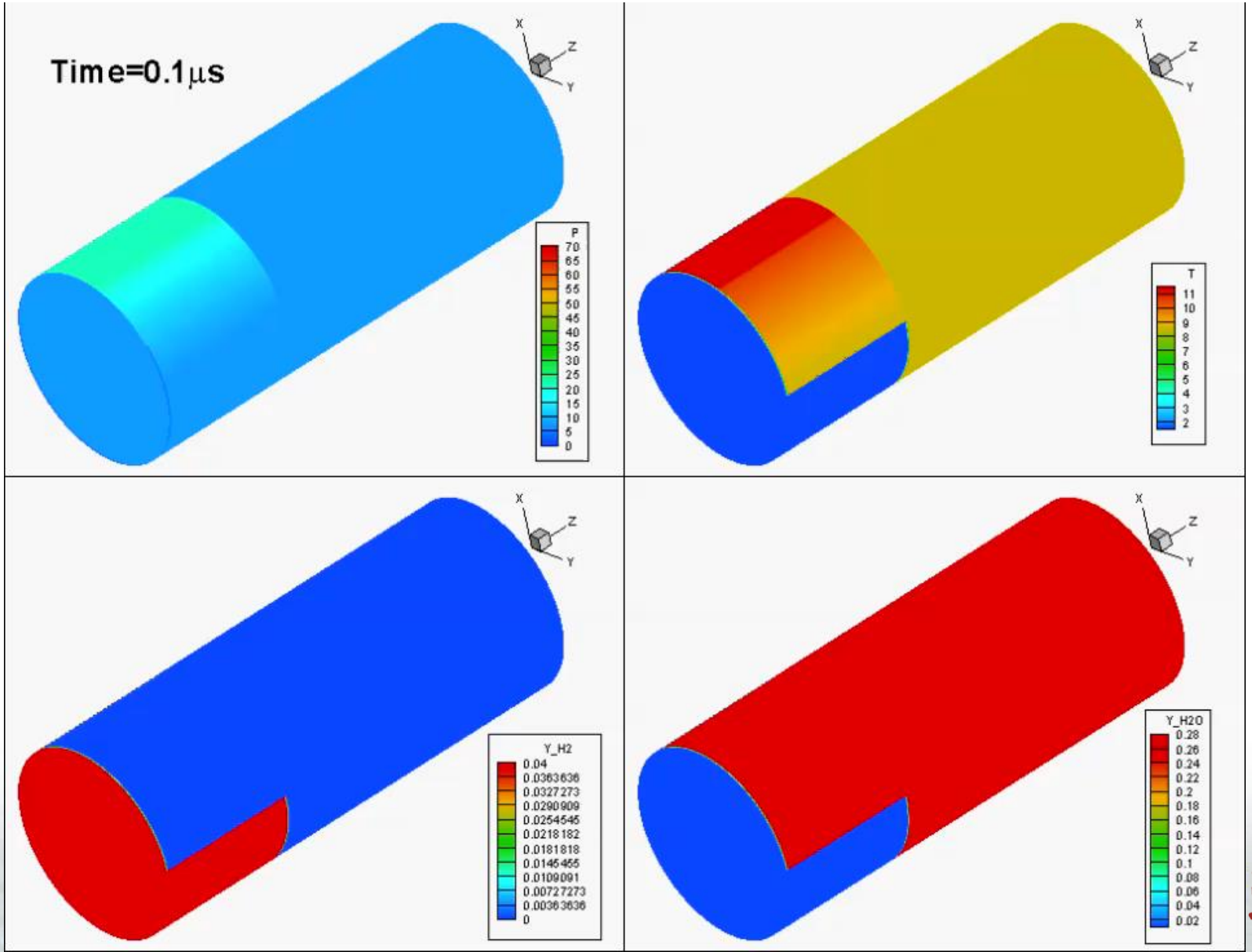
$\varphi = 0.8$ No stable CRDWs



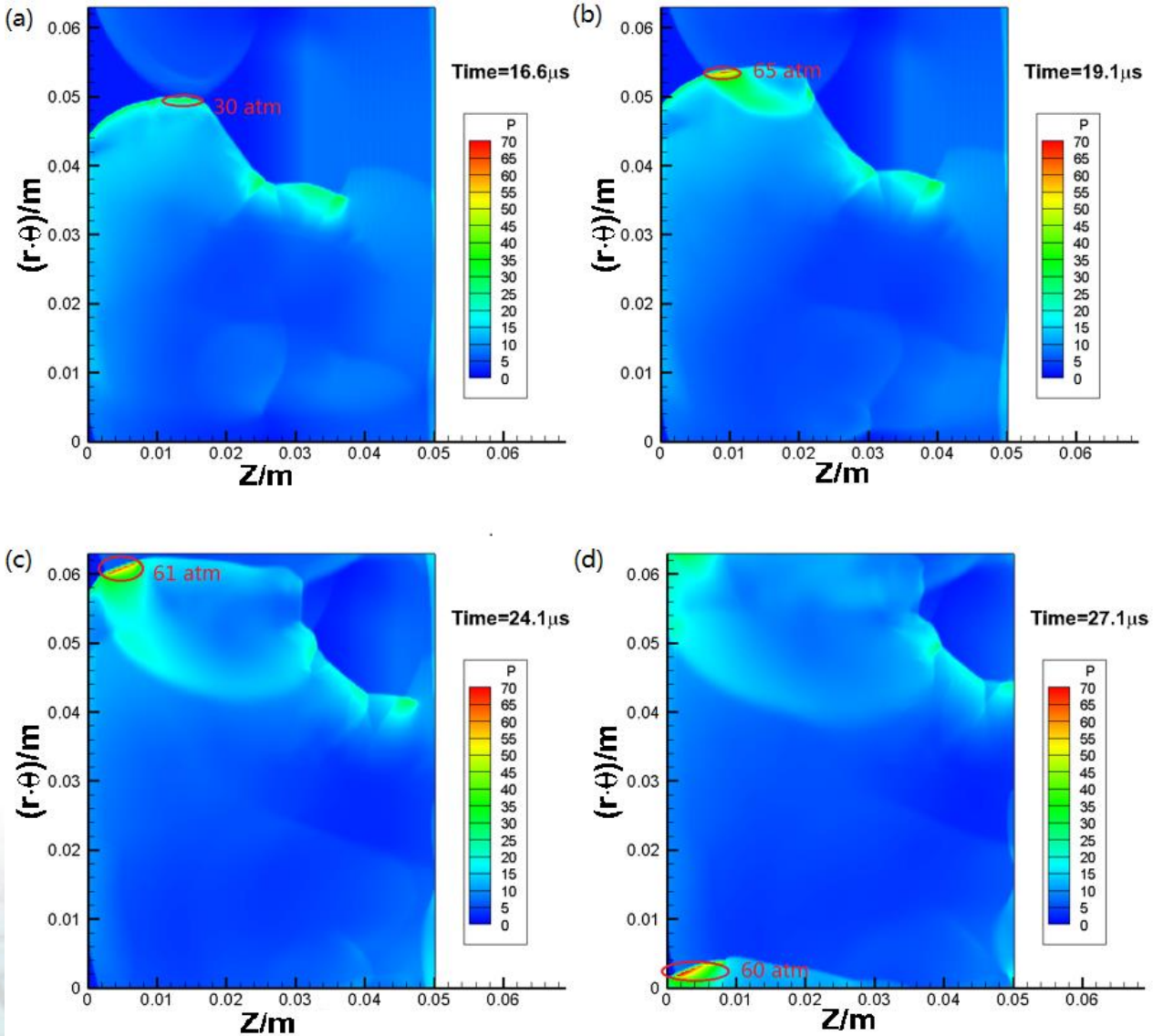
$\varphi = 0.8$ No stable CRDWs

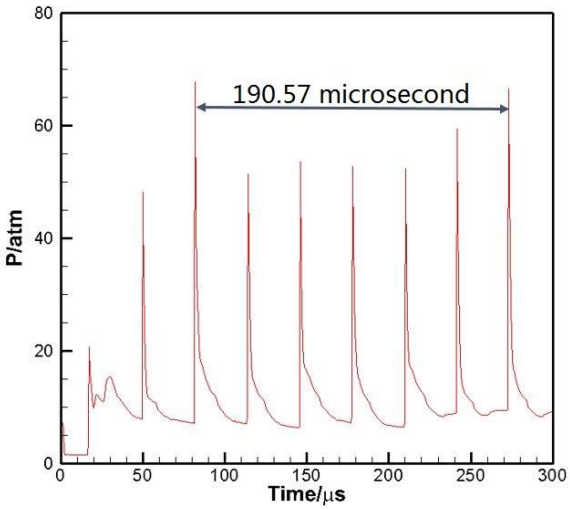


$\varphi = 1.4$ Stable CRDWs



$\varphi = 1.4$ Stable CRDWs

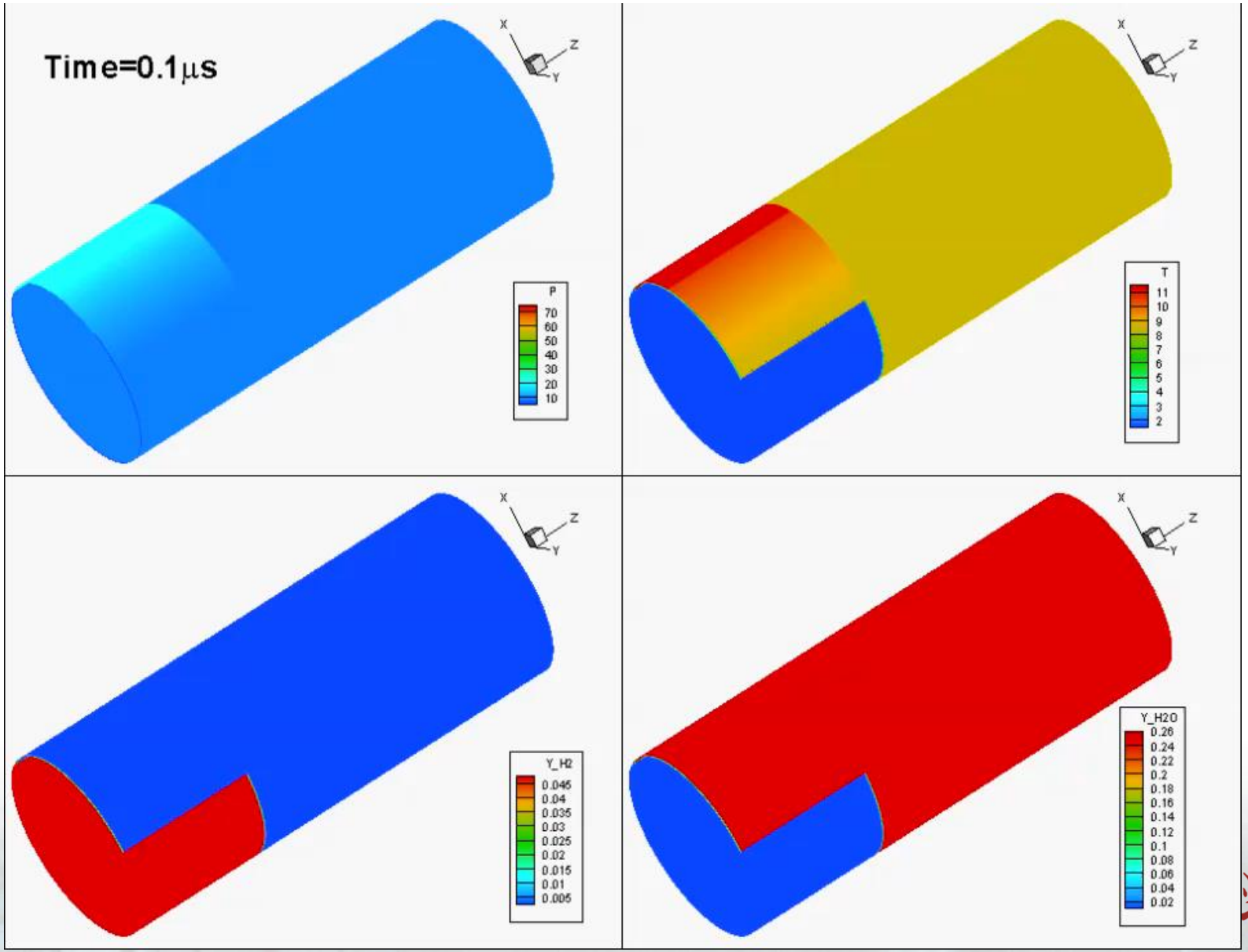




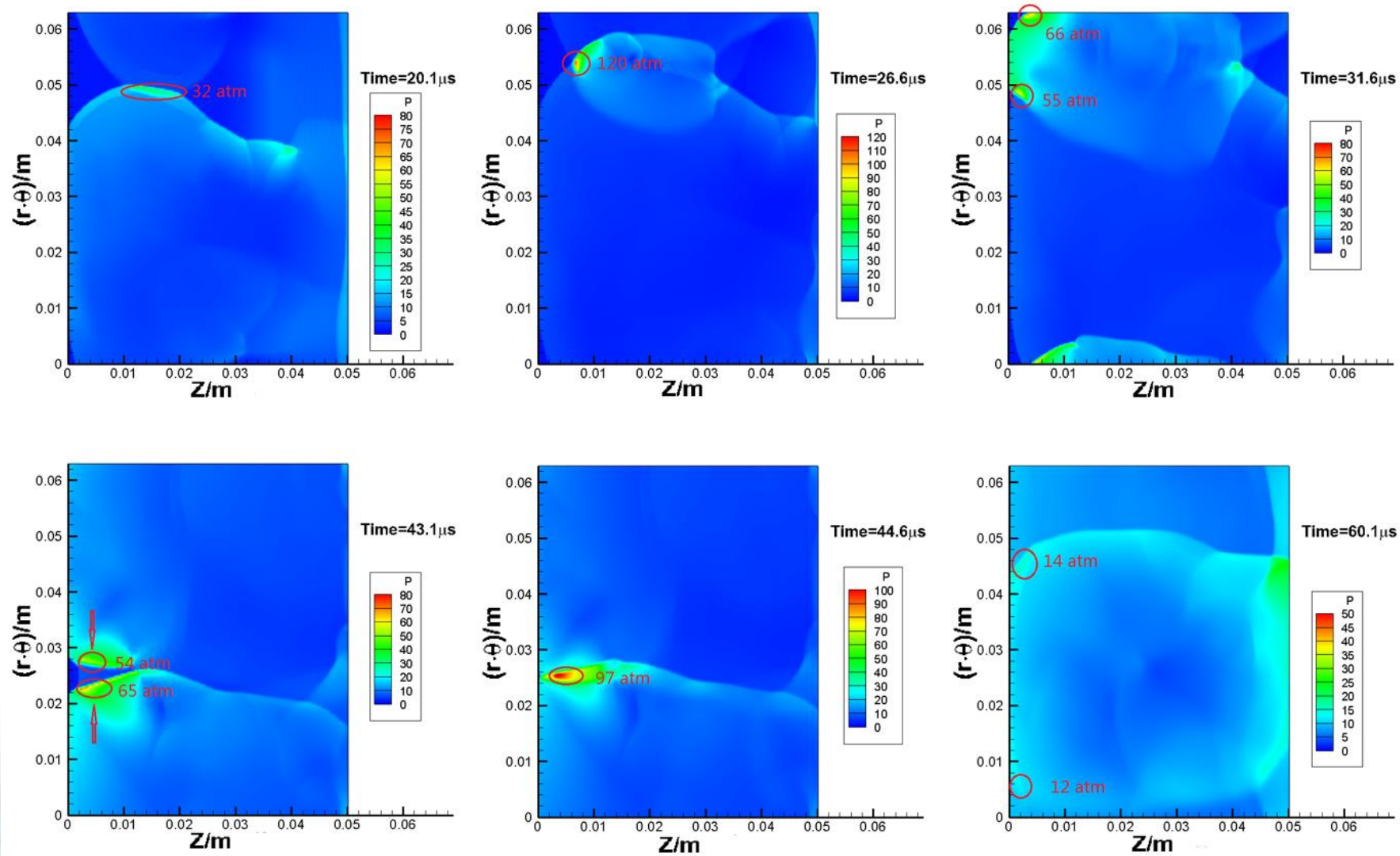
T=31.76 μs
detonation velocity by simulation 1962.1 m/s

(94.5% of theoretical velocity 2076.86 m/s)

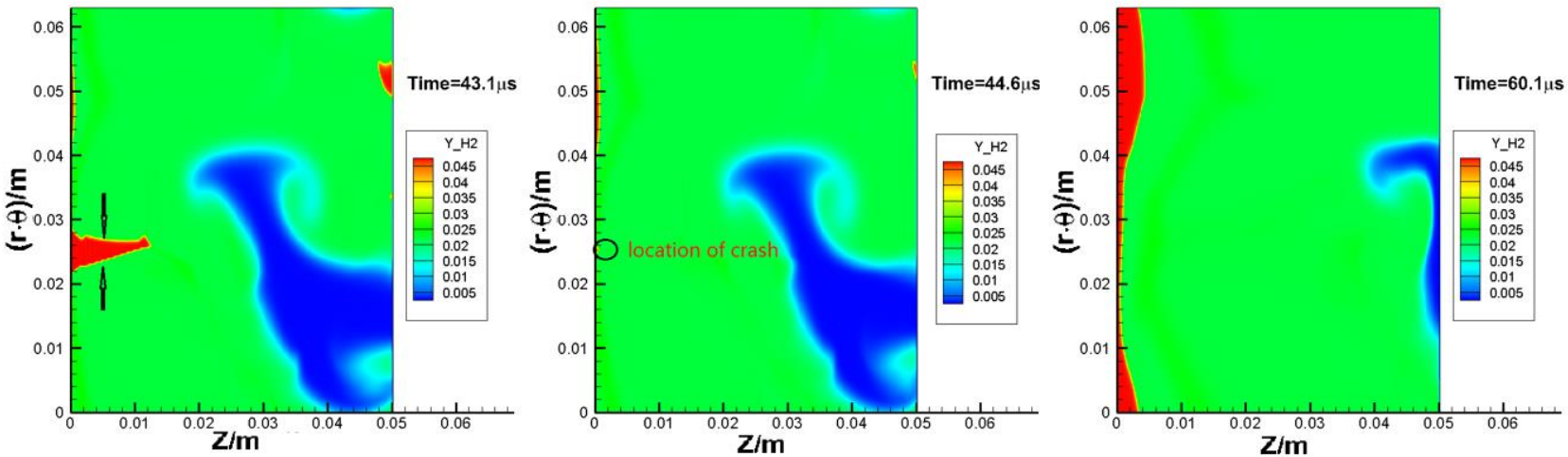
$\varphi = 1.8$ No stable CRDWs

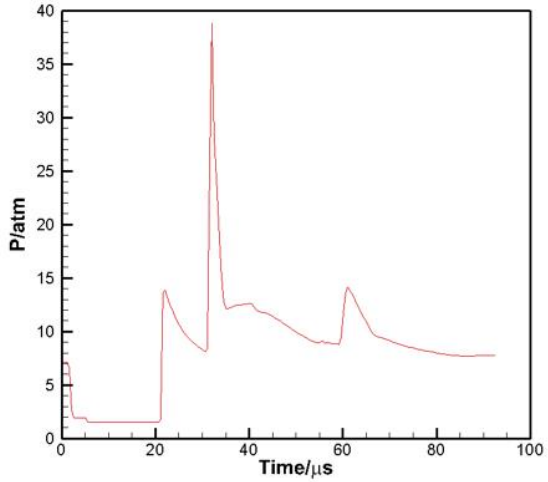


$\varphi = 1.8$ No stable CRDWs

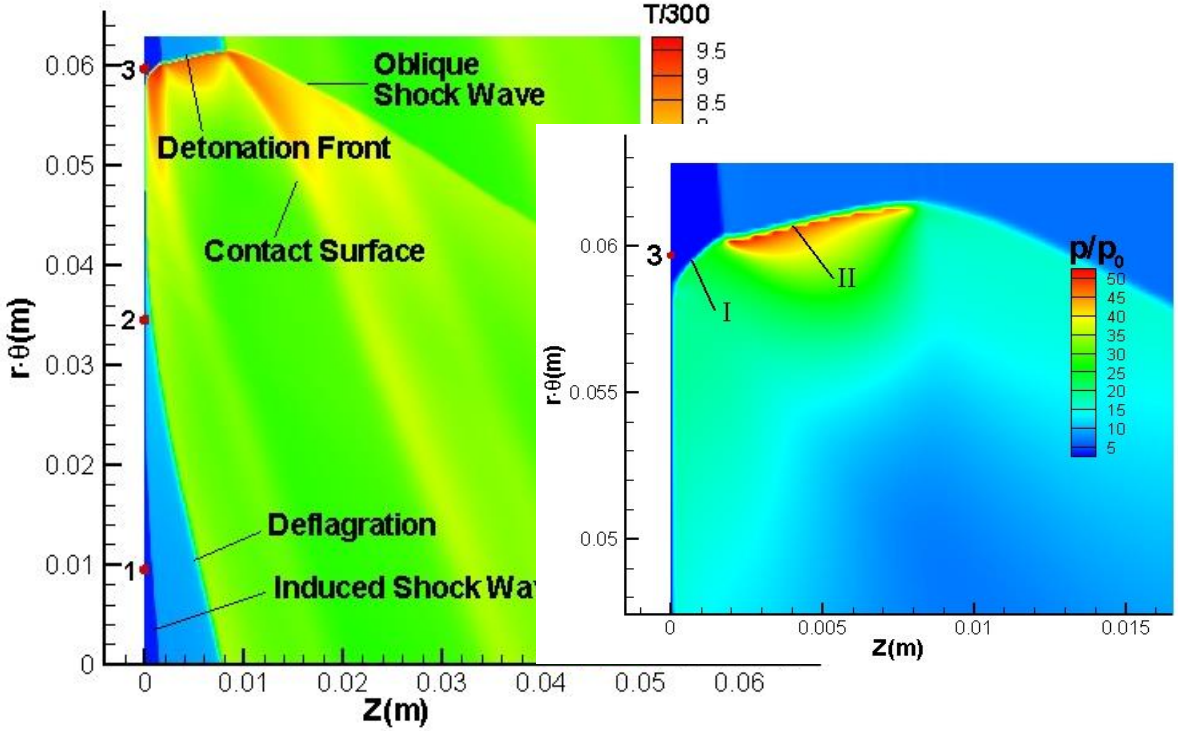


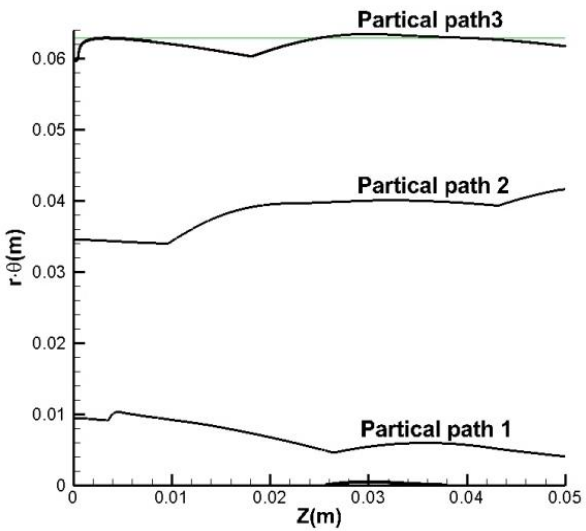
$\varphi = 1.8$ No stable CRDWs





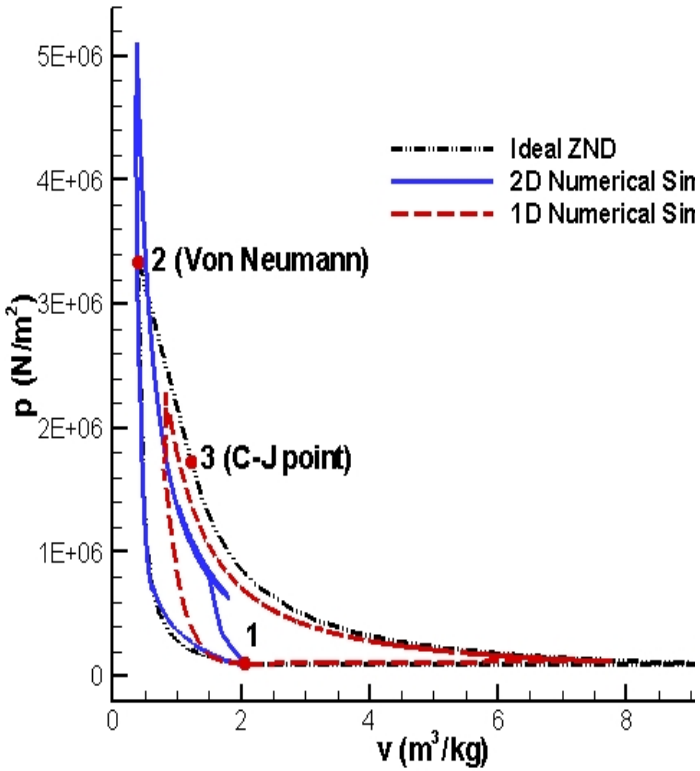
Particles tracing

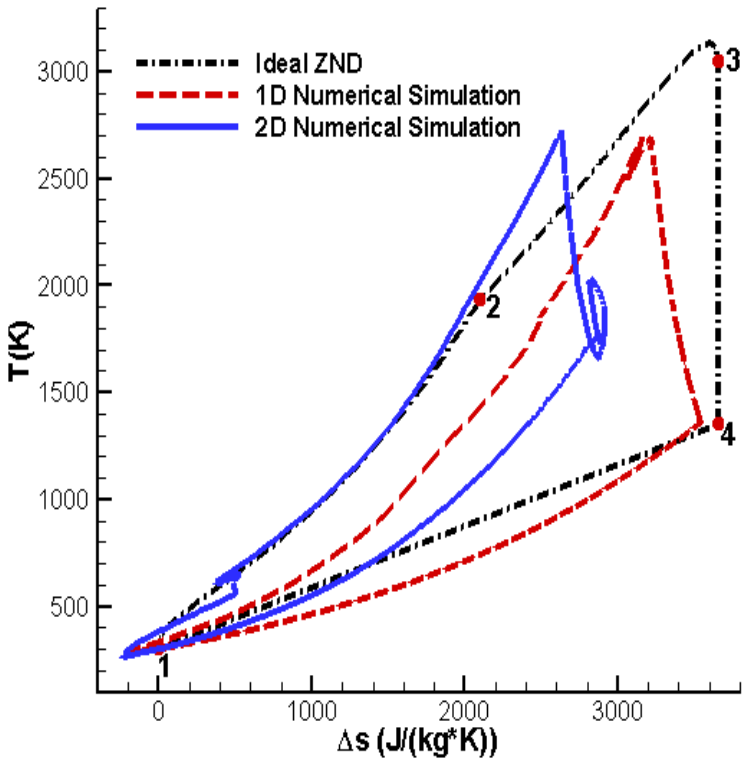




- Particle 1 is burned by detonation wave II
- Particle 2 is burned by the deflagration wave
- Particle 3 is burned by detonation wave I

P-V diagram and T-S diagram

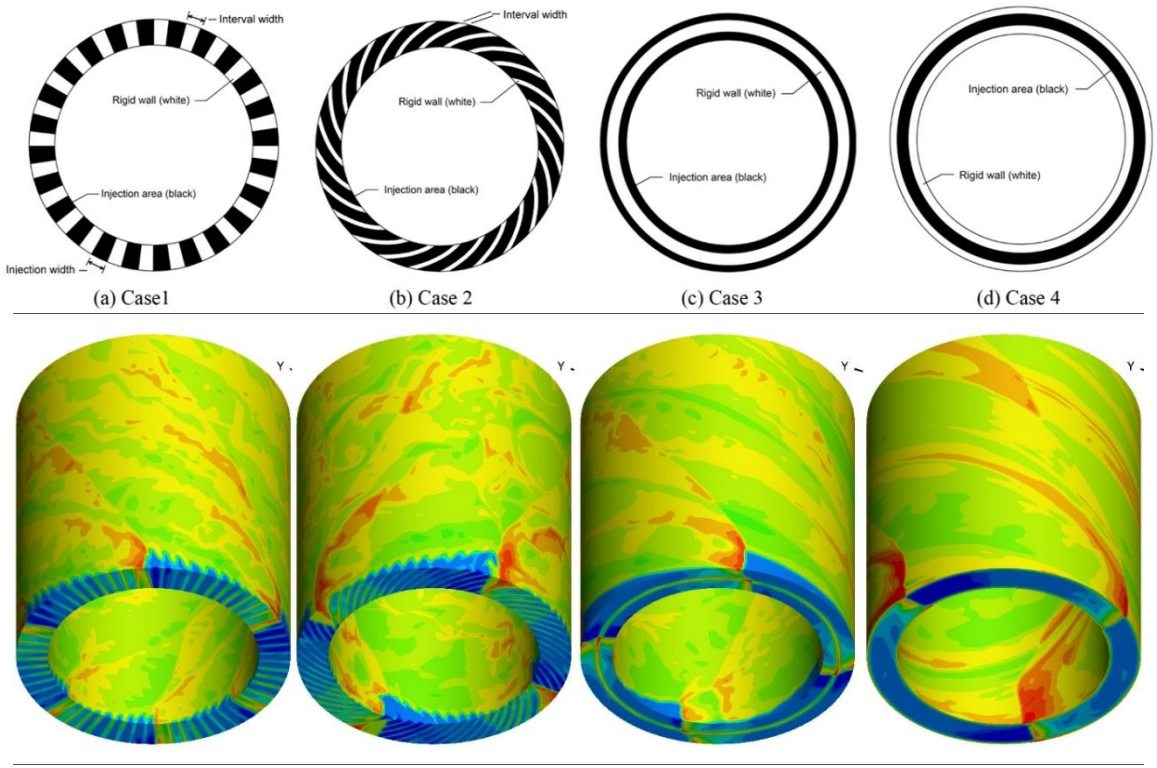




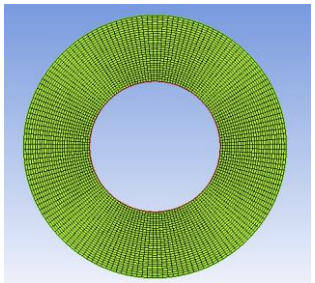
Comparison with ZND model and 1D numerical simulation

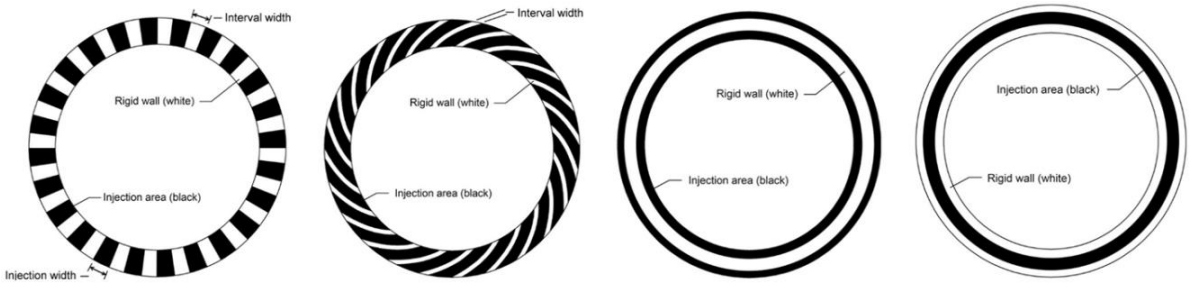
Effect of Injection on Front Number

Effects of injection pattern on number of detonation fronts

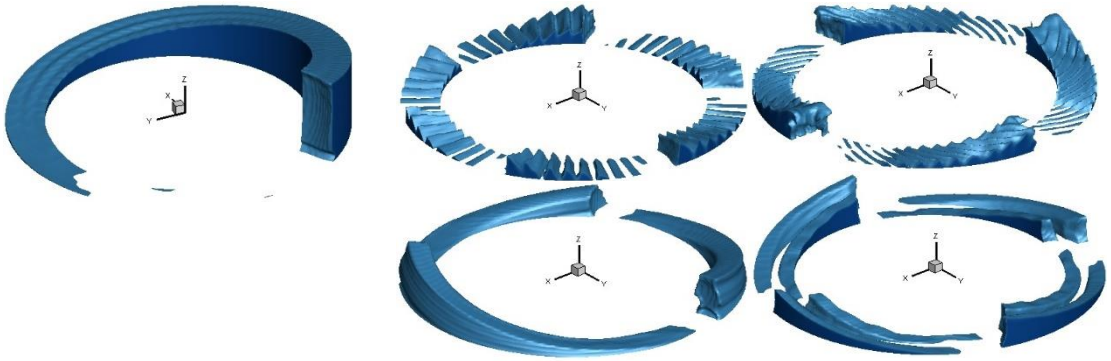


Strip Spiral Two-side slits Central slit





(a) Case1 (b) Case 2 (c) Case 3 (d) Case 4



More injection area>Sufficient fuel>Stronger detonation>Faster>Few fronts

Less injection area>lacking fuel>Weaker detonation>Slower>More fronts

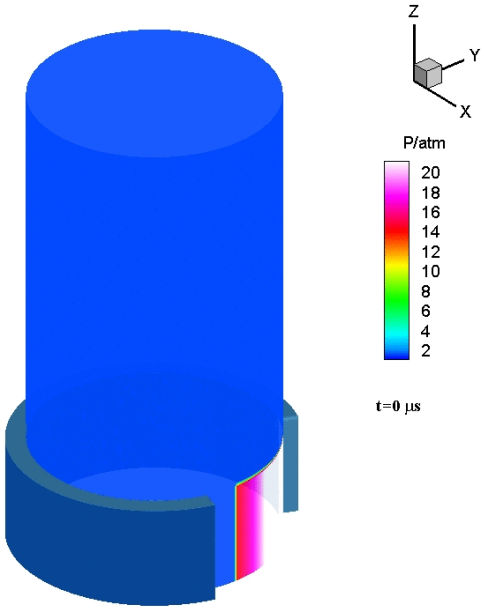
Propulsive Performance

Injection Pattern	Standard case	(a)	(b)	(c)	(d)
I_{sp} (s)	6527	6394	6505	6374	6465

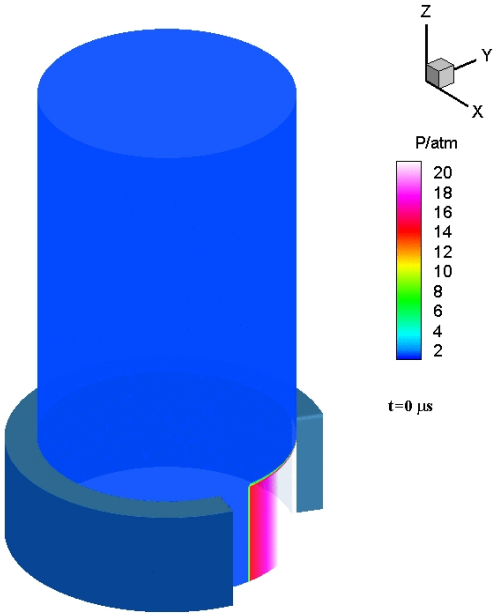
The difference of propulsive performance of the four new injection patterns is small. This is probably because the specific impulse is related to the characteristics of the propellant, which is hydrogen-air mixture in the present model.

Array Hole Injection

Pressure

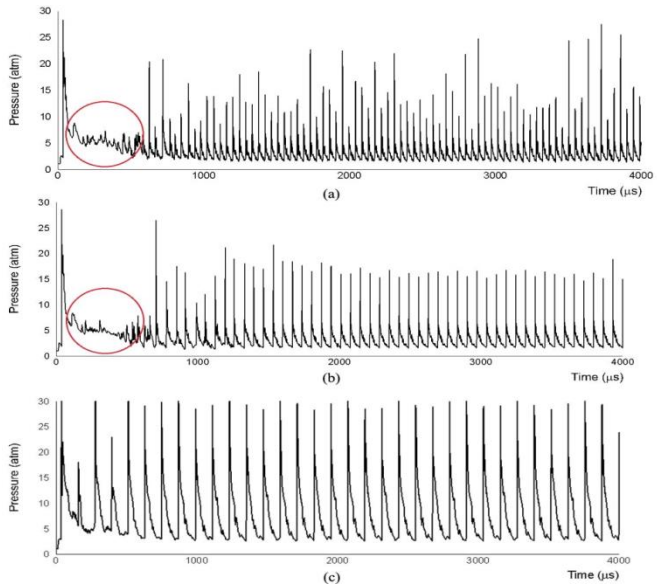


Two-rows

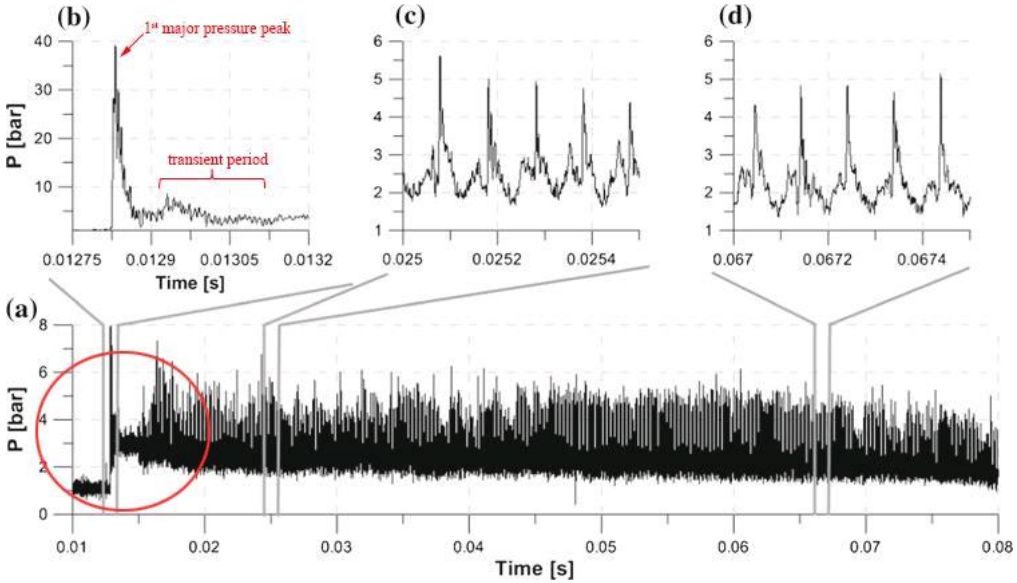


Three-rows

Re-initiation in Experiments

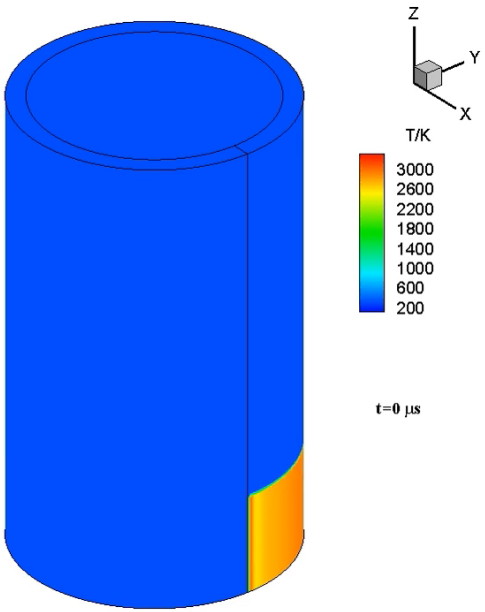


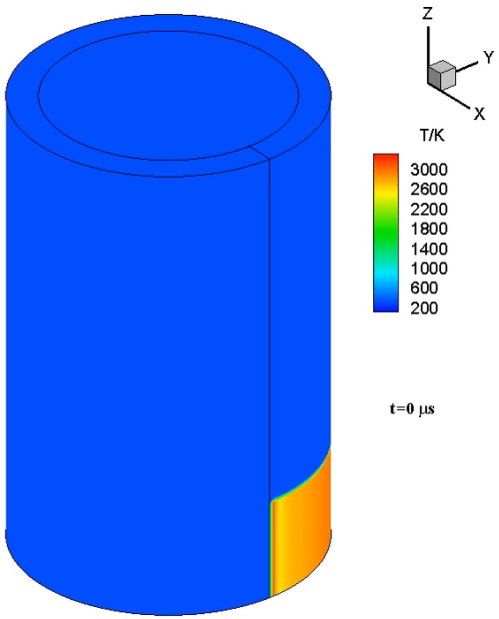
Present



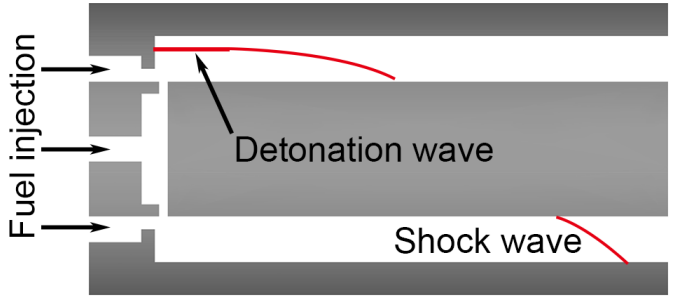
P. Wolanski's experiment

Temperature

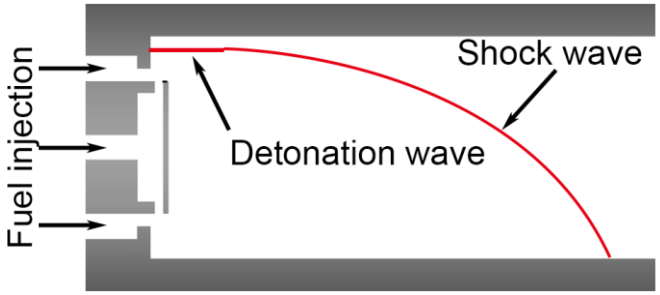




Hollow Combustor



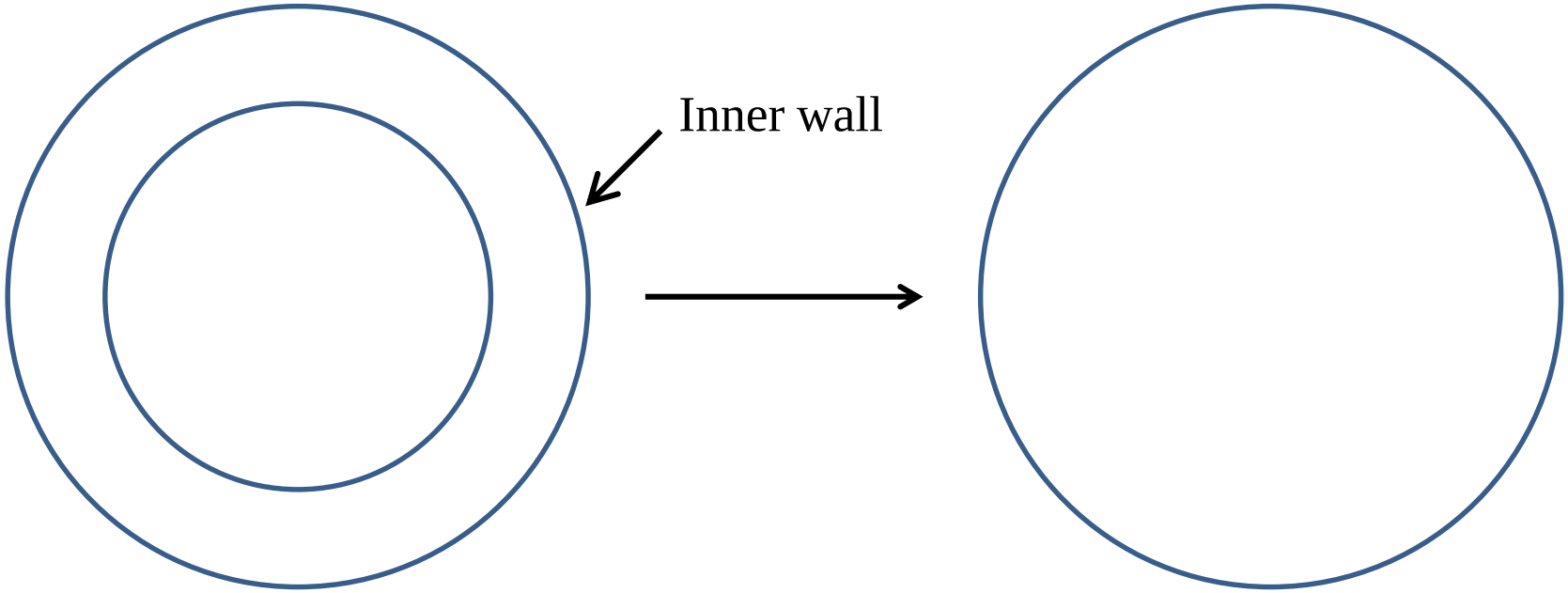
Annular cylindrical chamber



Cylindrical chamber

- Cylindrical chamber is first proposed by Shao and Wang. (23rd ICDERS, 2009)
- Cylindrical chamber is designed for dealing with the overheating problem.

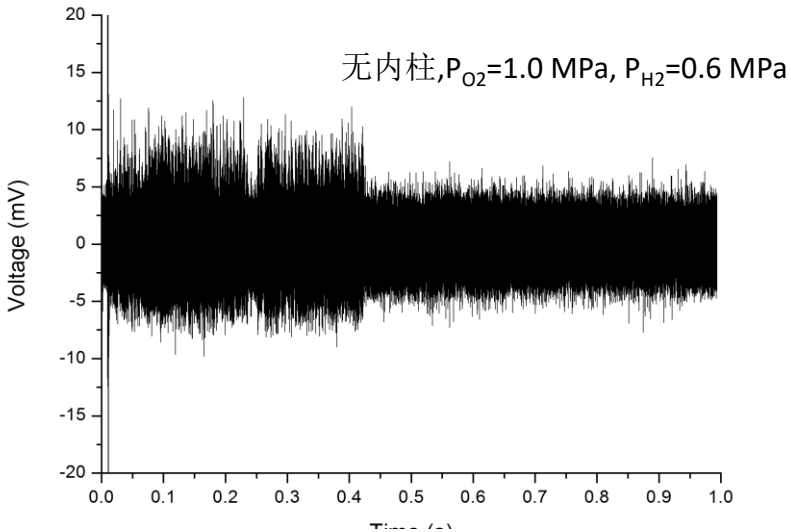
Is it possible to use the whole head end for fuel injection?

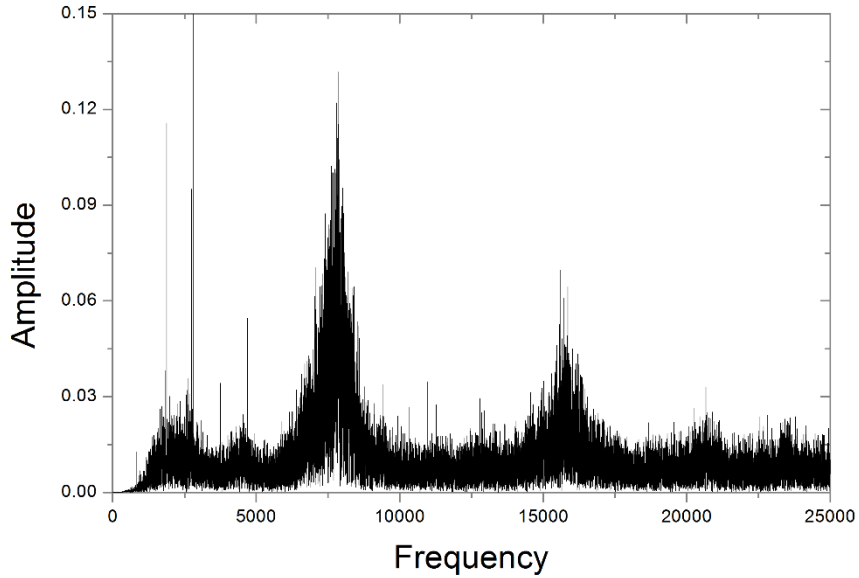


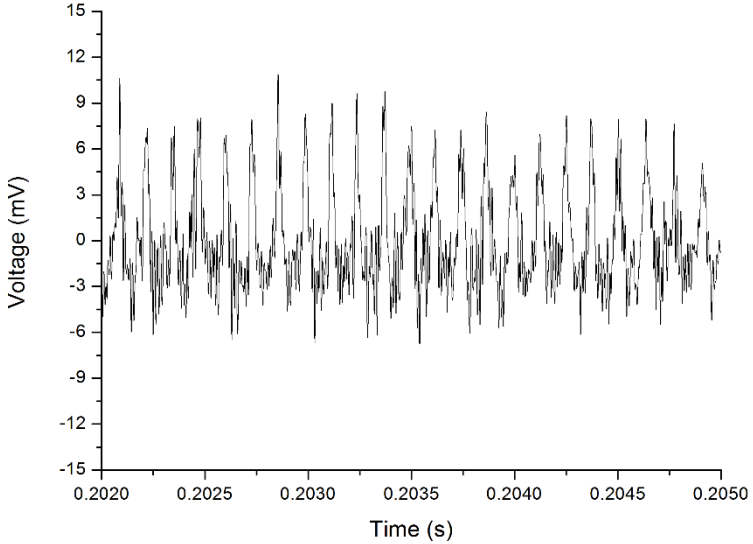
Annular cylindrical combustor

Hollow combustor

Rotating Detonation in Hollow Chamber







H_2 / O_2	0.4	0.5	0.6	0.7	0.8	0.9	1.0
0.4	×	×	×	×	×	×	×
0.5	×	×	×	×	×	△	△
0.6	×	×	×	×	△	△	△
0.7	×	×	×	△	△	○	○
0.8	×	×	×	×	△	△	△
0.9	×	×	×	×	△	△	△
1.0	×	×	×	×	△	△	△

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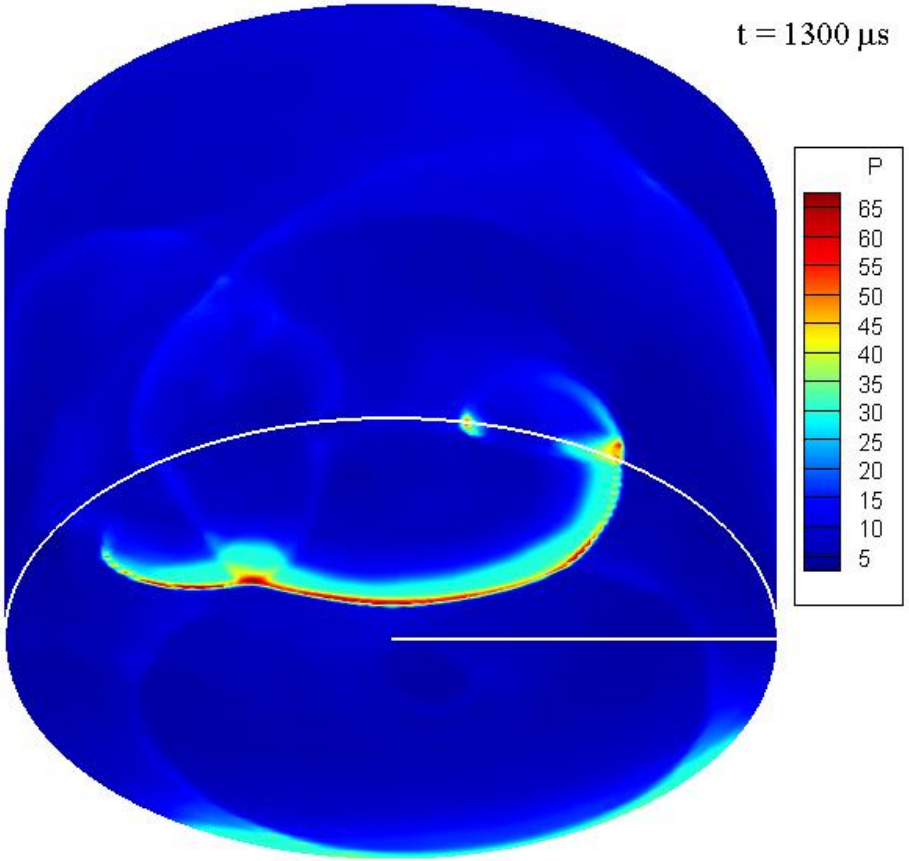
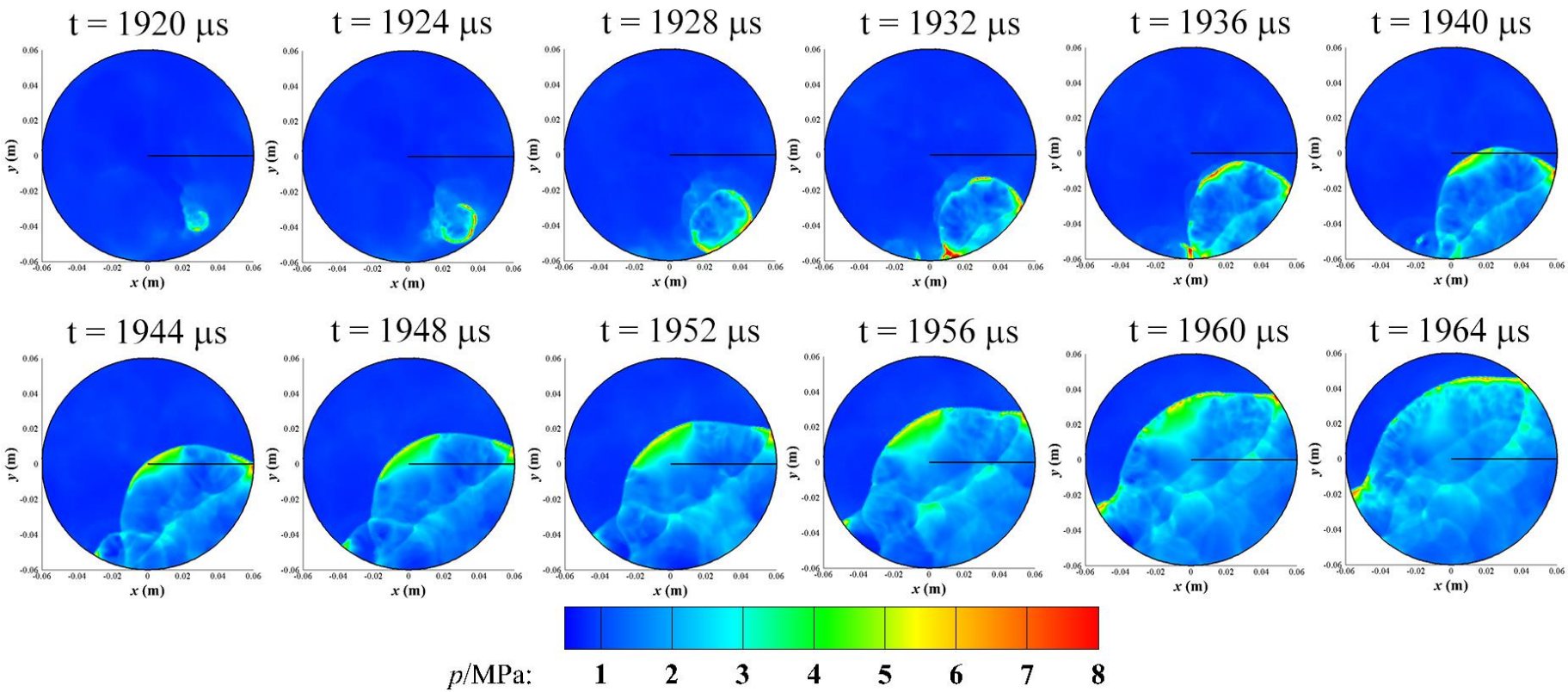
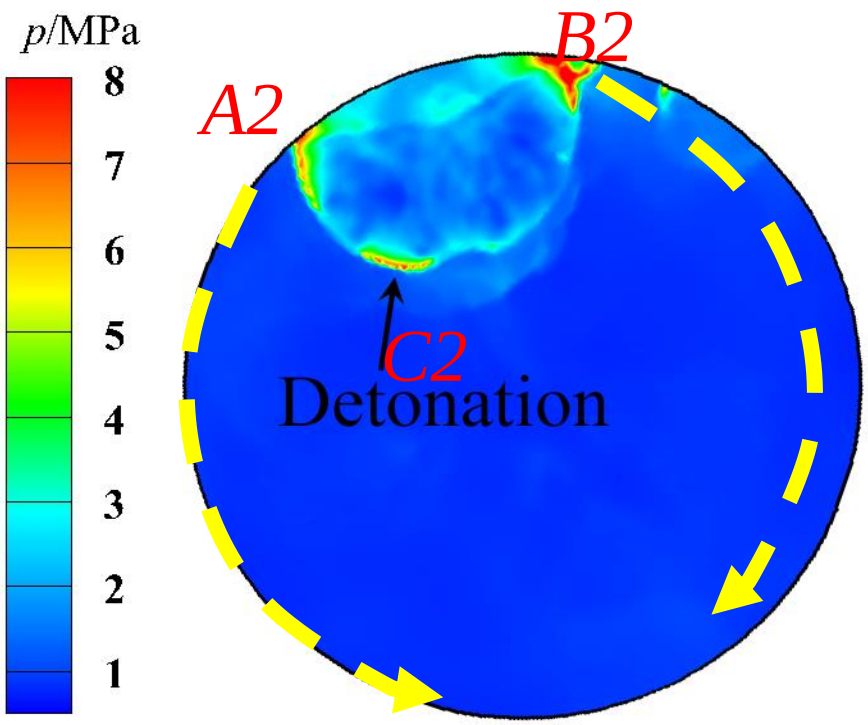

t = 1300 μs
P
65
60
55
50
45
40
35
30
25
20
15
10
5

Re-initiation phenomenon

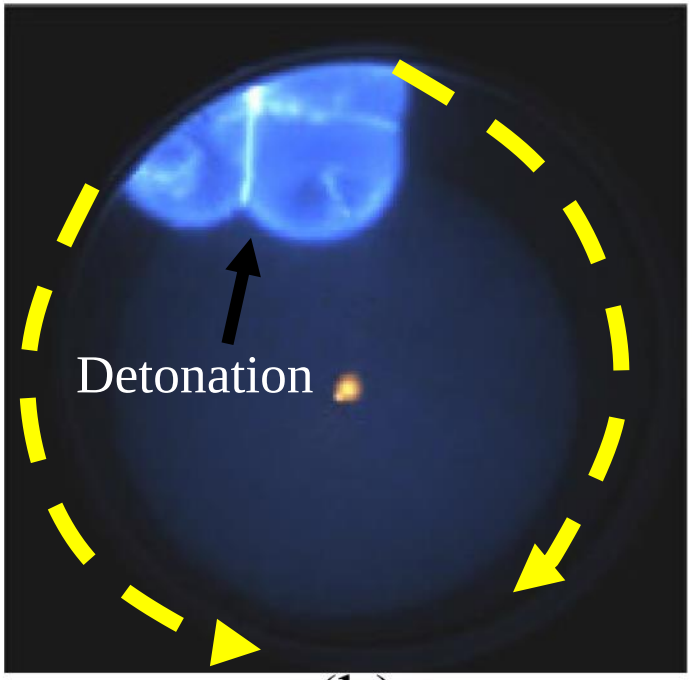
Extinction and re-initiation



Re-initiation phenomenon

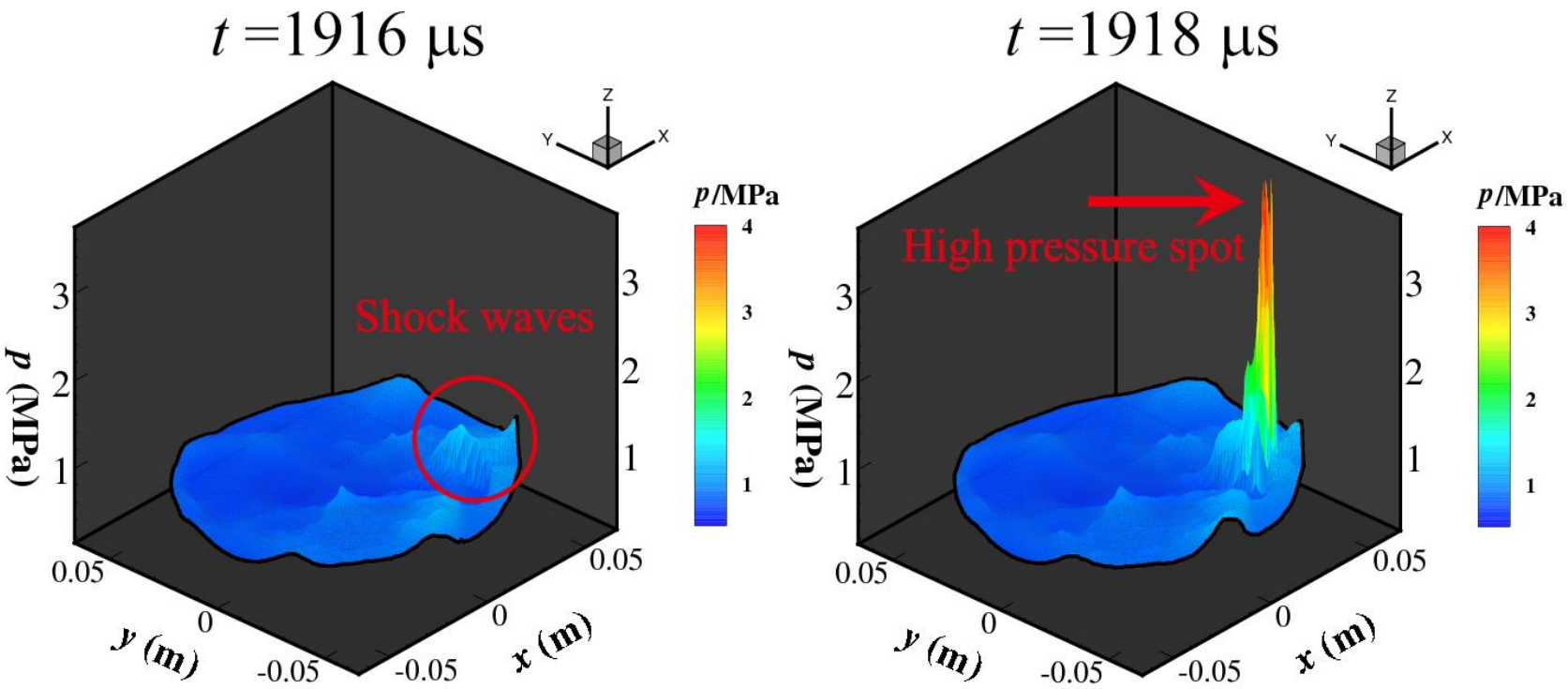


(a)



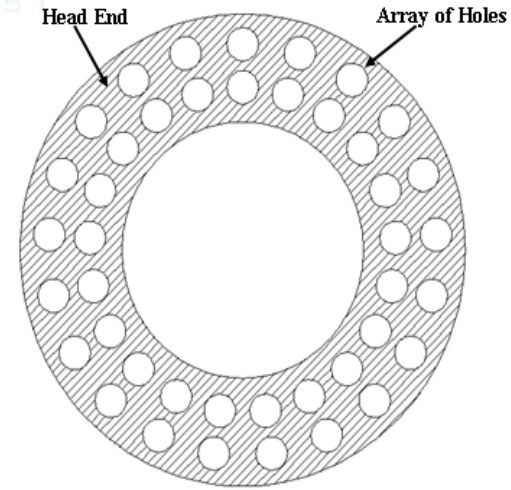
(b)

Expreiment by Y. Qi, Z. Wang

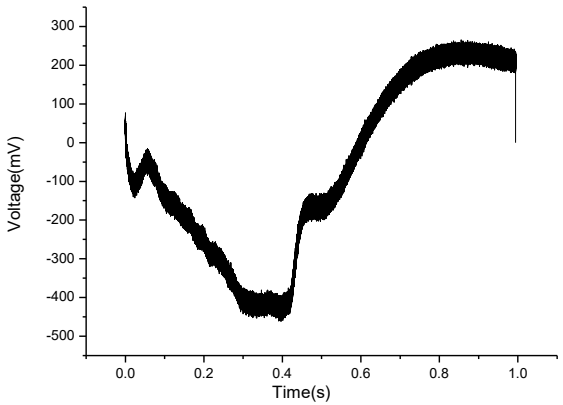


The re-initiation is caused by sharp and sudden increase of pressure.

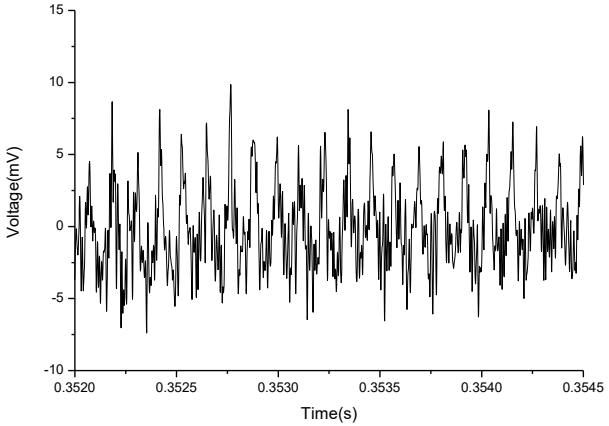
Arrays of orifices Injection Patterns



Front View



Pressure history



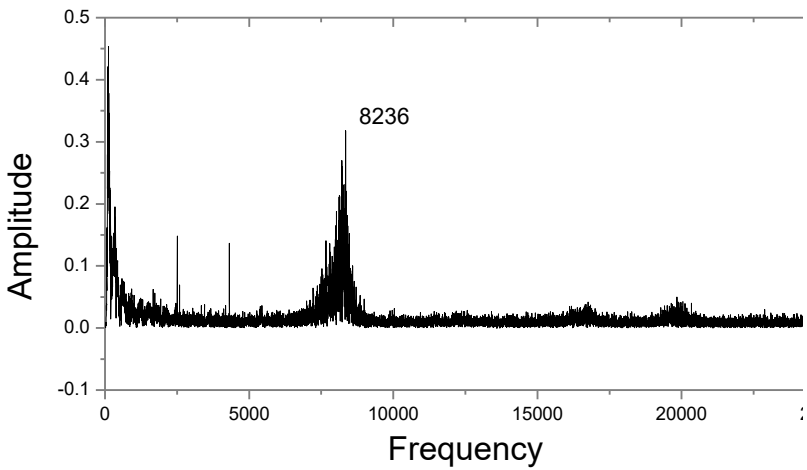
Close-up of pressure history

$$T = 121.4\ \mu s$$

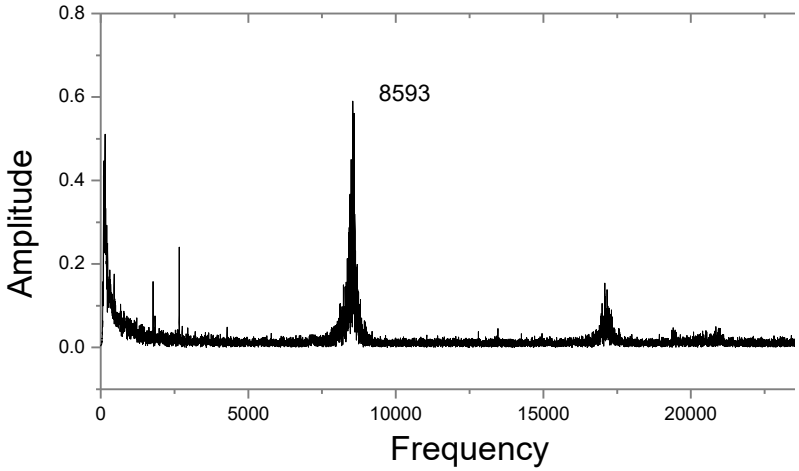
$$V = \frac{\pi d}{T} = 1850\ m/s$$

$$V = 0.85 V_{CJ}$$

Effects of mixing length on traveling frequency and corresponding amplitude



Mixing length L= 5mm



Mixing length L= 5mm

Fourier transforms of pressure transducer data

Domain of stable continuous detonations through a series of tests

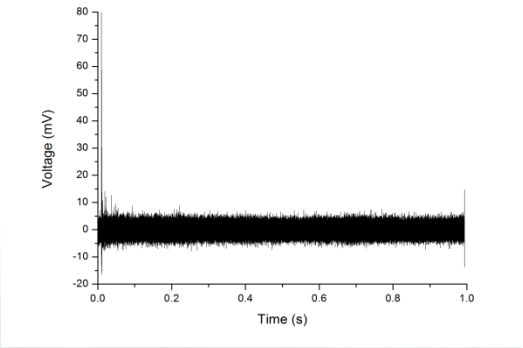
Table 1 H_2-O_2 operating table of RDE with a 5 mm mixing distance

p_{H2} \ p_{O2}	0.6	0.8	1	1.2	1.4	1.6
0.6	×	×	×[a]	×	×	×
0.8	×	×	O[b]	O	×	×
1	×	O	O	O	△[c]	△
1.2	×	×	×	×	O	O
1.4	×	×	×	×	O	O
1.6	×	×	×	×	×	×

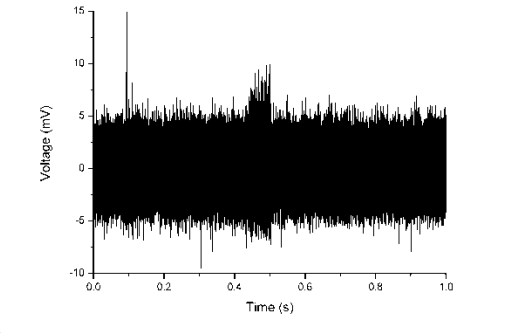
Table 5 H_2-O_2 operating table of RDE with a 10 mm mixing distance

p_{H2} \ p_{O2}	0.6	0.8	1	1.2	1.4	1.6
0.6	×	×	△	O	×	×
0.8	×	O	O	O	△	△
1	×	O	O	O	O	△
1.2	×	×	O	O	O	O
1.4	×	×	×	×	O	O
1.6	×	×	×	×	×	O

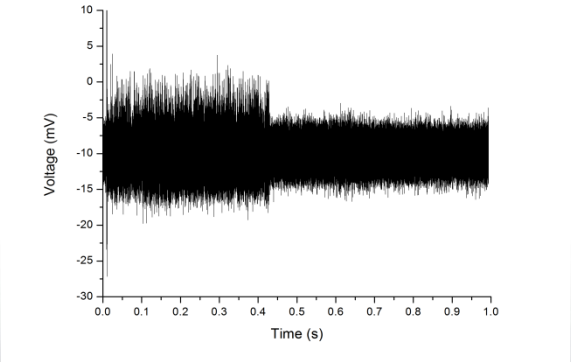
a, ╳ donates failure to attain rotating detonation waves
b, △ donates unstable or transient rotating detonation waves
c, O donates stable detonation waves



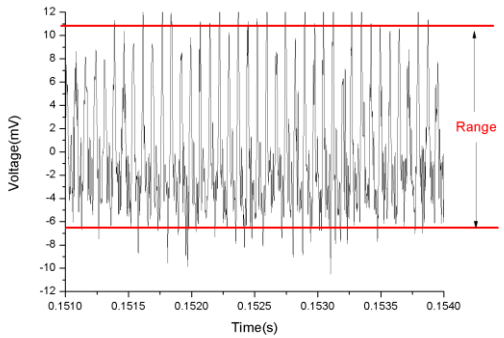
(a)



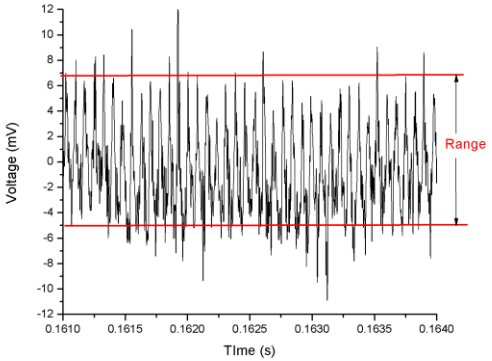
(b)



(c)



(a)



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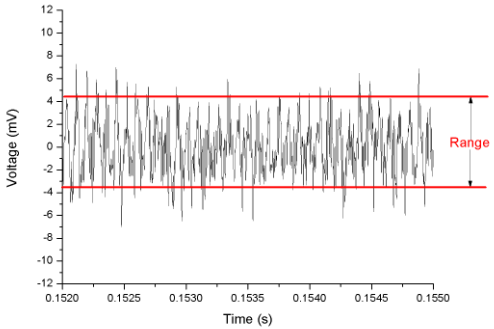
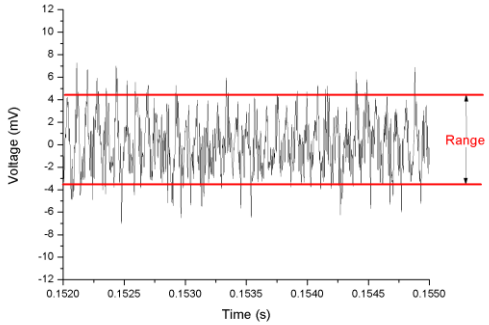


(c)



(d)

(a)P_{O2}=0.5MPa，P_{H2}=0.5MPa，background pressure =0.02MPa
(b) P_{O2}=0.5MPa，P_{H2}=0.5MPa，background pressure =0.03MPa
(c) P_{O2}=0.5MPa，P_{H2}=0.5MPa，background pressure =0.05MPa
(d) P_{O2}=1.2MPa，P_{H2}=0.8MPa，background pressure = 0.1MPa

Conclusions

- Oscillation of detonation strength is due to the fresh gas injection.
- Disparate Equivalence Ratio leads to failure of detonation initiation.
- Less fuel leads to more detonation fronts.
- There is adjusting process between ignition and stable detonation.
- Re-initiation due to enhancement of pressure waves.
- Hollow combustor is successfully realized numerically and experimentally.

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Thank you for your attention!

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