Detonation Resonator as an Air-Breathing Thruster

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High-Frequency Levin-Tarasov Detonation Resonator (by V. A. Levin et al, 2001): 25kHz Operation

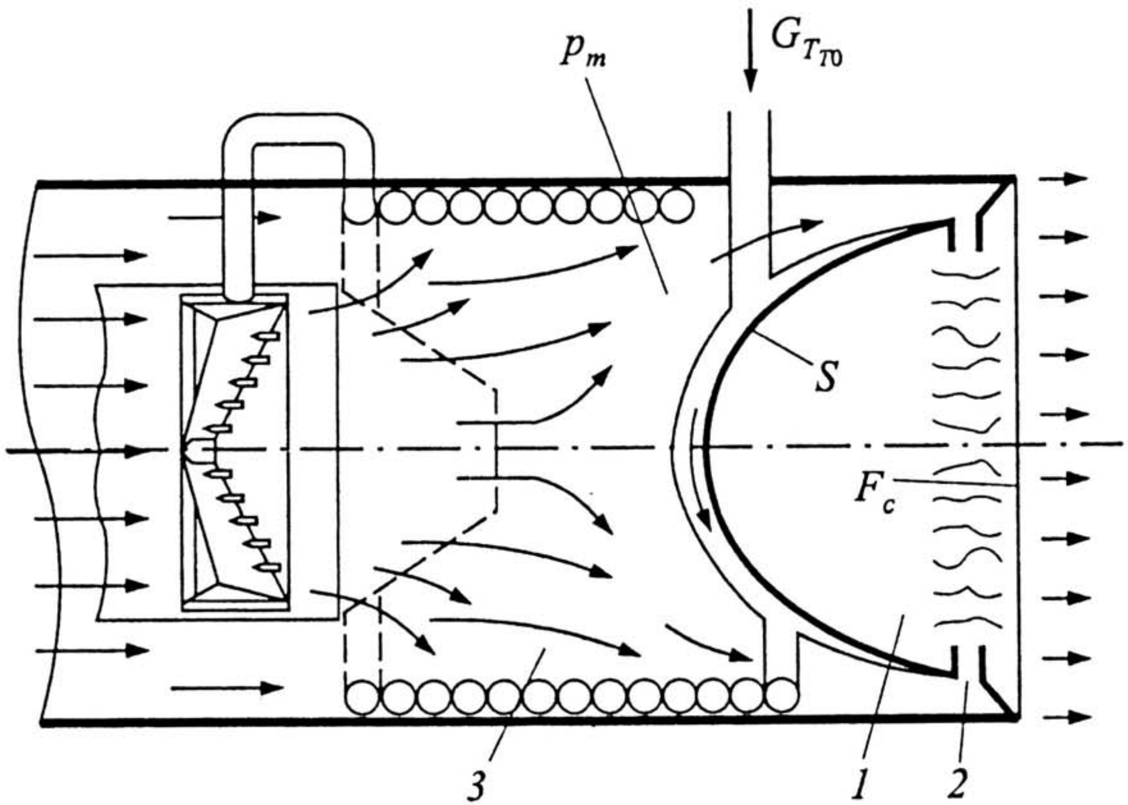


Figure 3 General schematic of the PDE TD: *1* — resonator cavity; *2* — annular nozzle; *3* — reactor

Applicability of Detonation Resonator to Pulse Detonation Engine

Advantages:

- High Frequency > kHz
  → Close to Continuous Operation and Continuous Fuel Supply
- Valve-less for Main Combustor/Cavity
- High-Speed Jet Exhaust without Nozzle

Parameters changed in Numerical Simulations

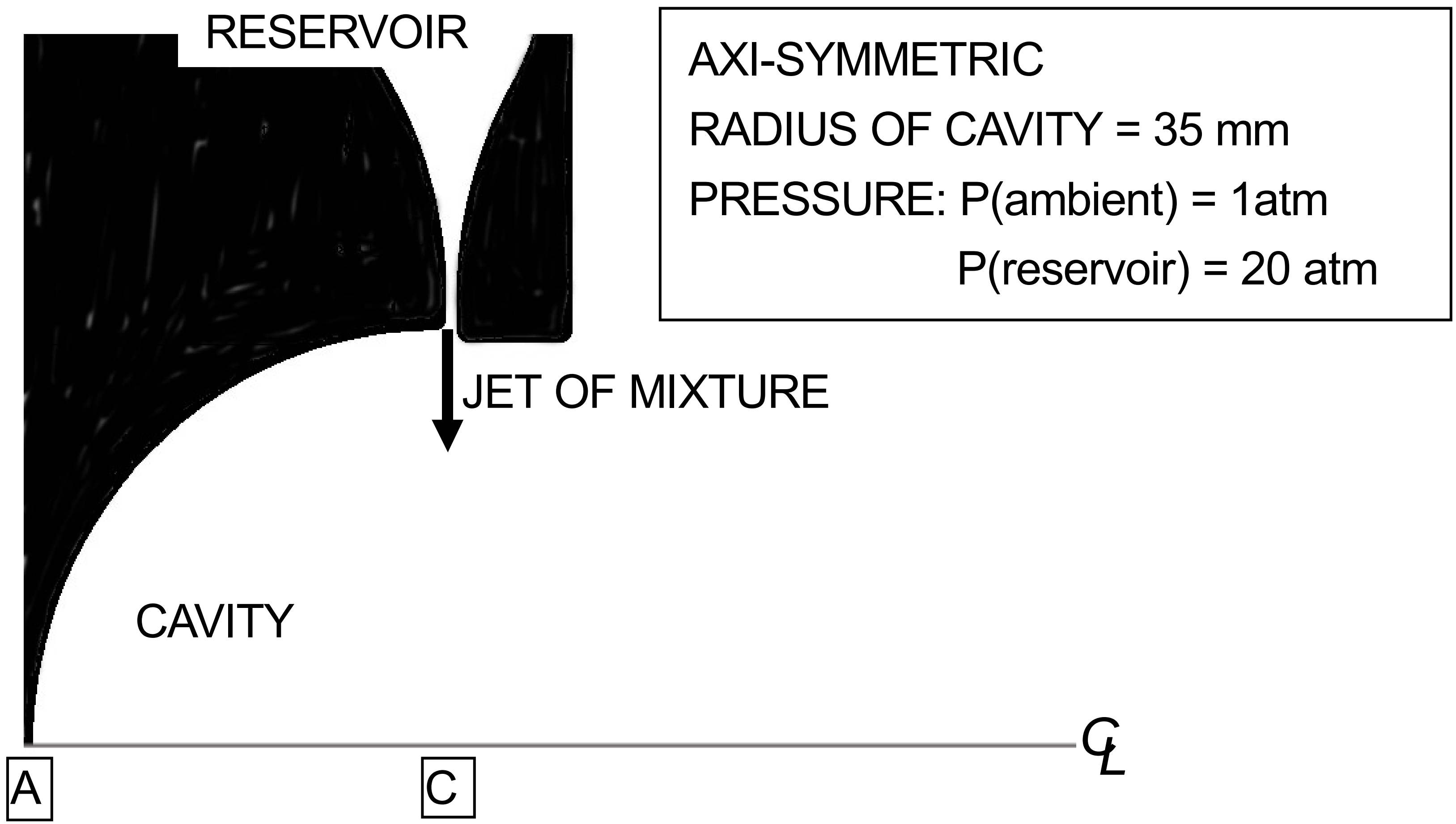
(1) Cavity Diameter: D = 7, 14, 28cm

(2) Reaction Rate of Gas Mixture:
Activation Energy T_a, Frequency Factor k_a,
Heat of Reaction Q

(3) Length of Cylindrical Nozzle/Ejector:
L = 1, 2, 3, 4cm

Numerical Simulations for Fictitious Gas Mixtures:

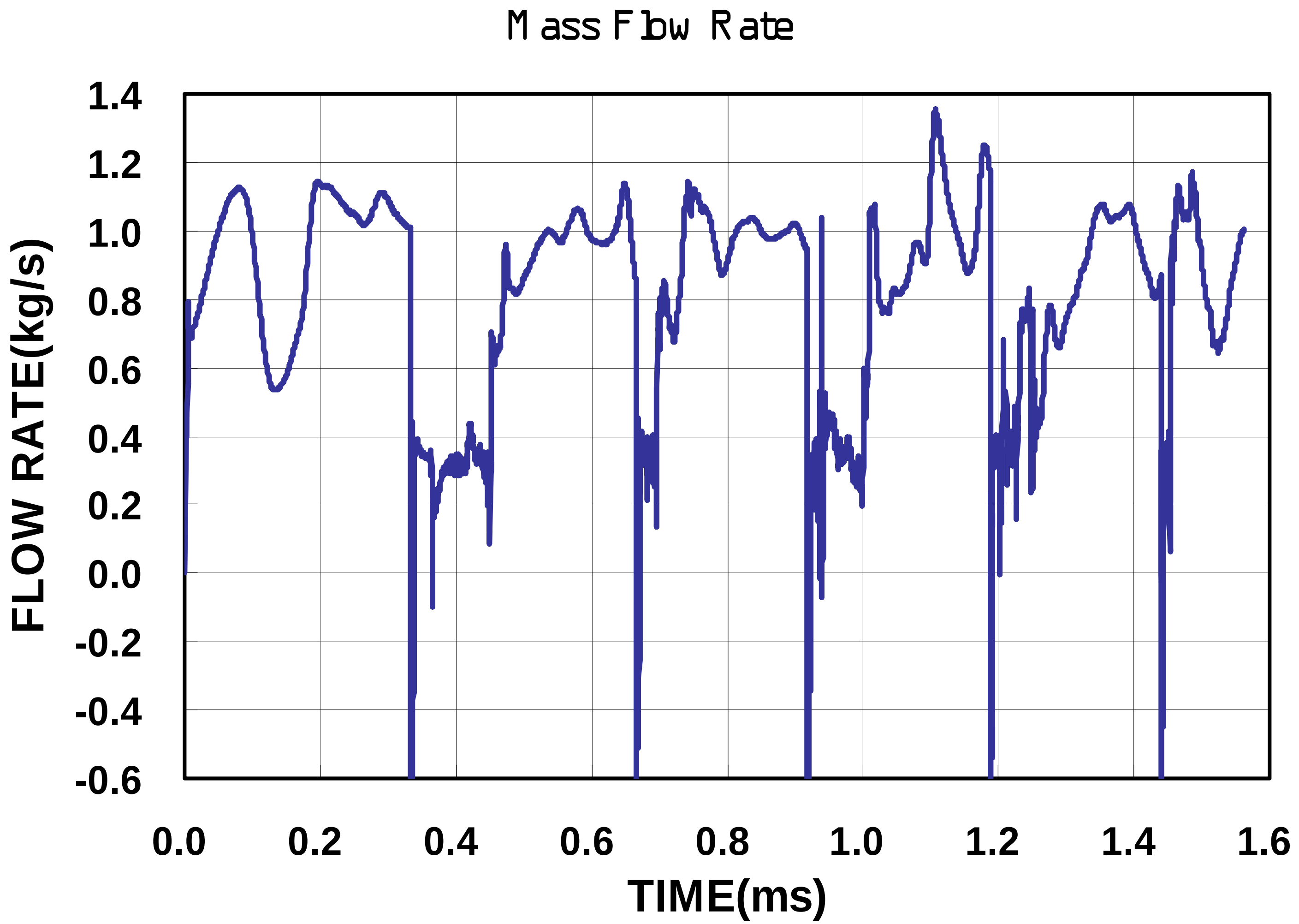
(1) High-temperature gas mixture or
(2) Low-temperature HC + high-temperature air mixed at supply throat
(3) Not unrealistic chemical parameters



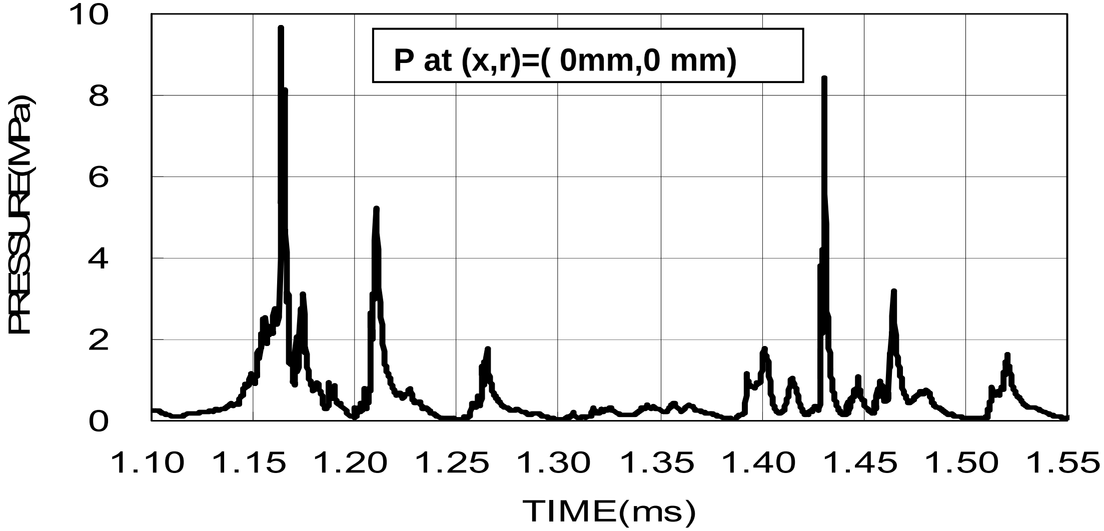
Geometry of detonation resonator: Oscillations of physical quantities are monitored at two axial Locations A (wall center) and C (hemisphere center). A cylindrical nozzle/ejector of length L = 1cm – 4cm is attached.

Table 1 Parameters and Calculated Results for B-Series (D = 7cm, L = 1cm)

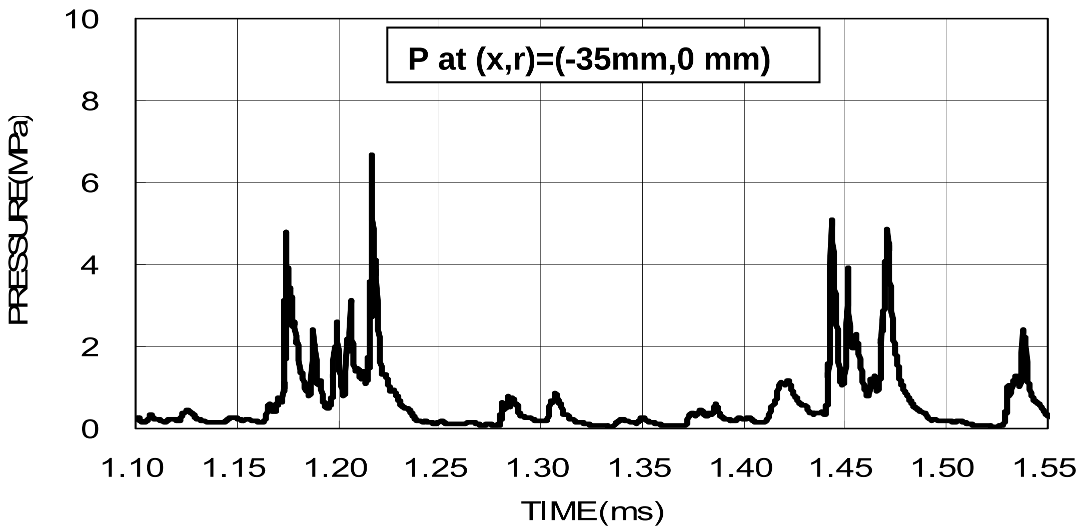
Case	Heat of reaction; Q (MJ/kg)	Rate Constant; $k_a(m^3/kg.s)$	Injected Gas Temperature ; $T_{00}(K)$	Resonance Frequency ; f (kHz)	Specific Impulse; $I_{sp}(sec)$
B-0	2.10	0.50e+9	293.15	3.96	1,450
B-1	2.10	0.50e+9	350.00	4.70	
B-2	2.80	0.50e+9	293,15	4.43	1,310
B-3	2.10	0.25e+9	293.15	4.11	1,560



History of Mass flow Rate of Injected Gas Mixture for Case B-0:
D = 7cm, L = 1cm, 1 Cycle = 0.25msec.



Pressure History at Center of Cavity for Case B-0.



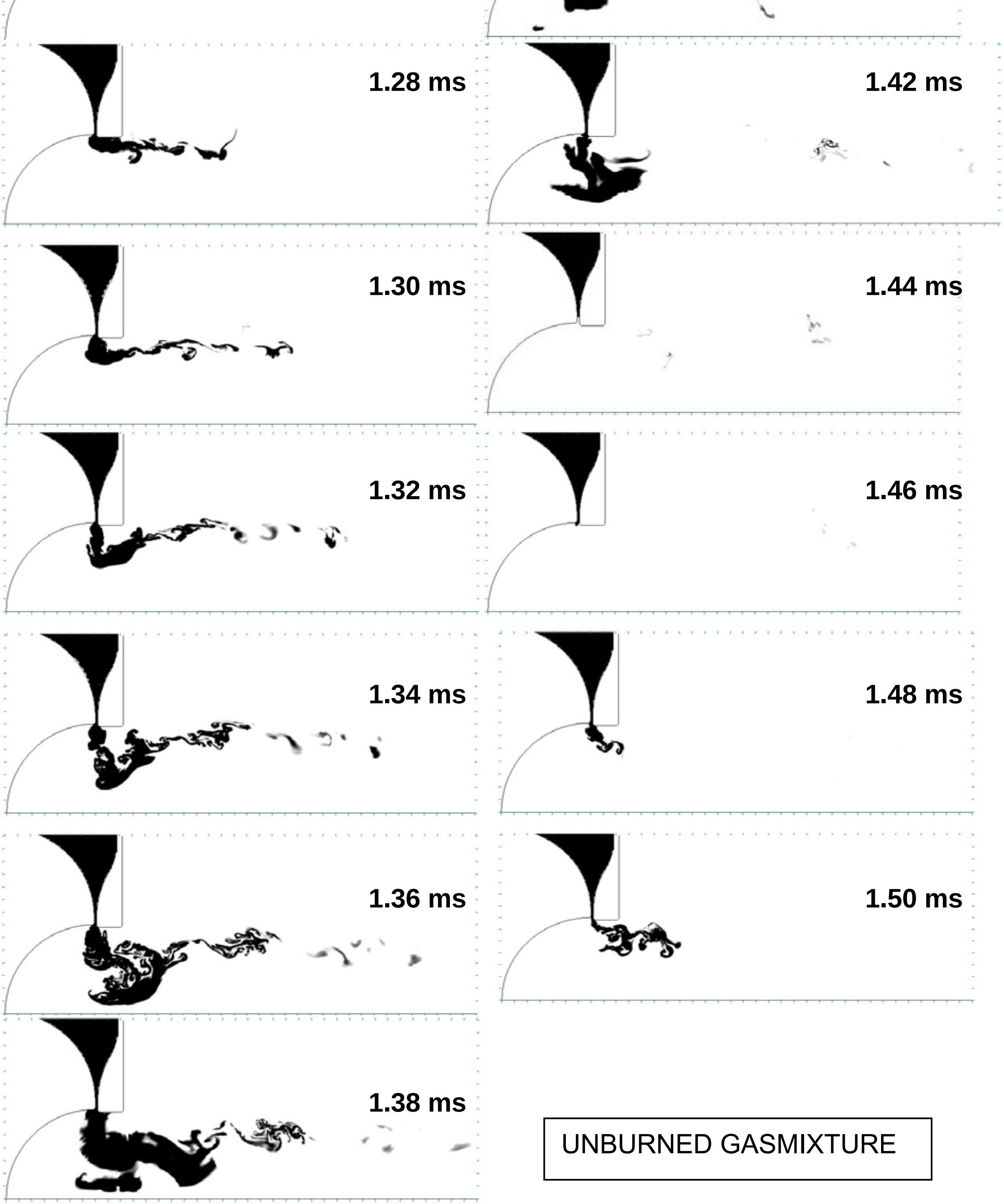
Pressure History at Wall Center of Cavity for Case B-0.

Comparison between Pressure Histories at Cavity Center and Wall Center

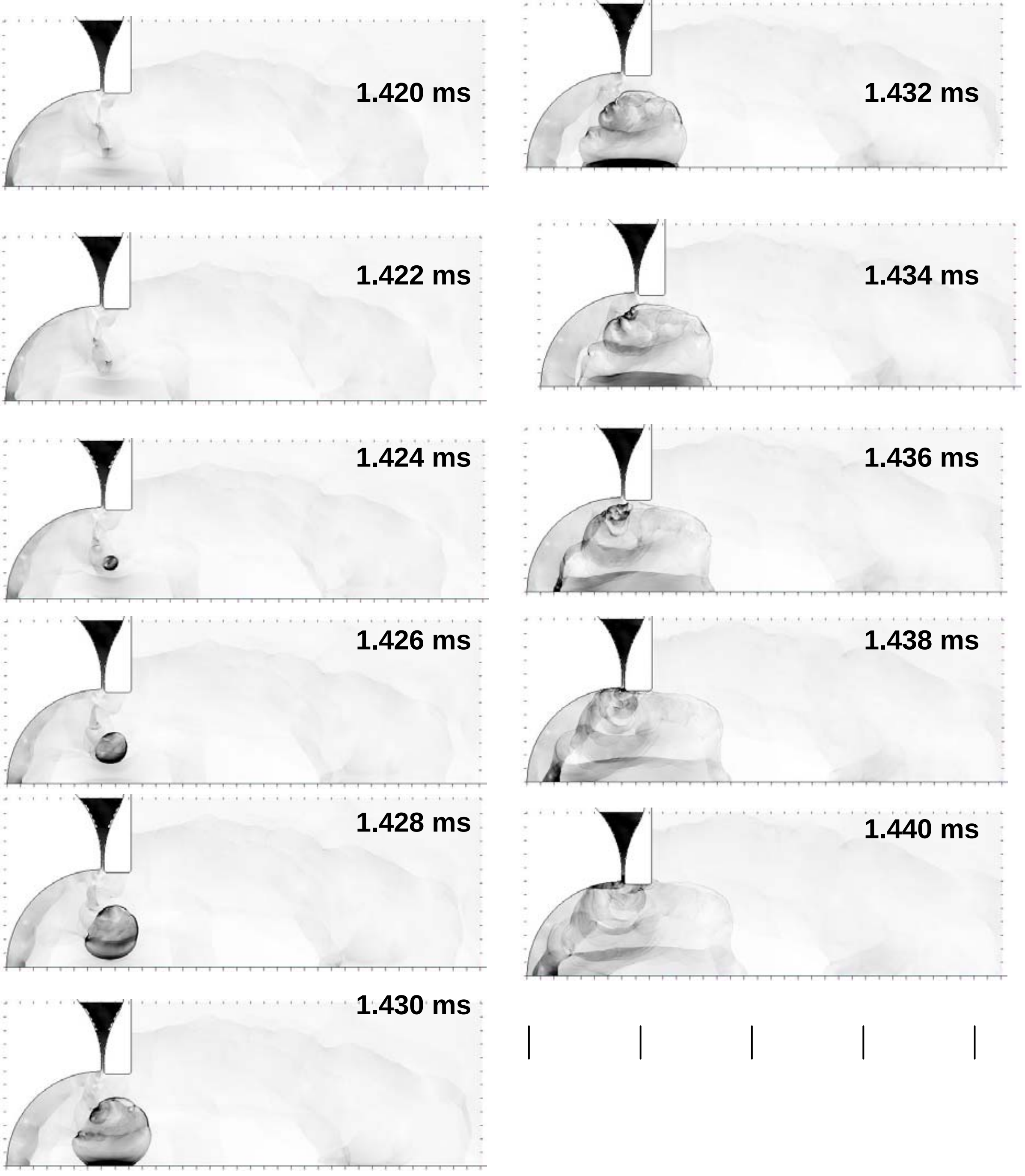
Explosion or detonation initiation starts at cavity center:

(1) Peaks are earlier by 100-200microsec

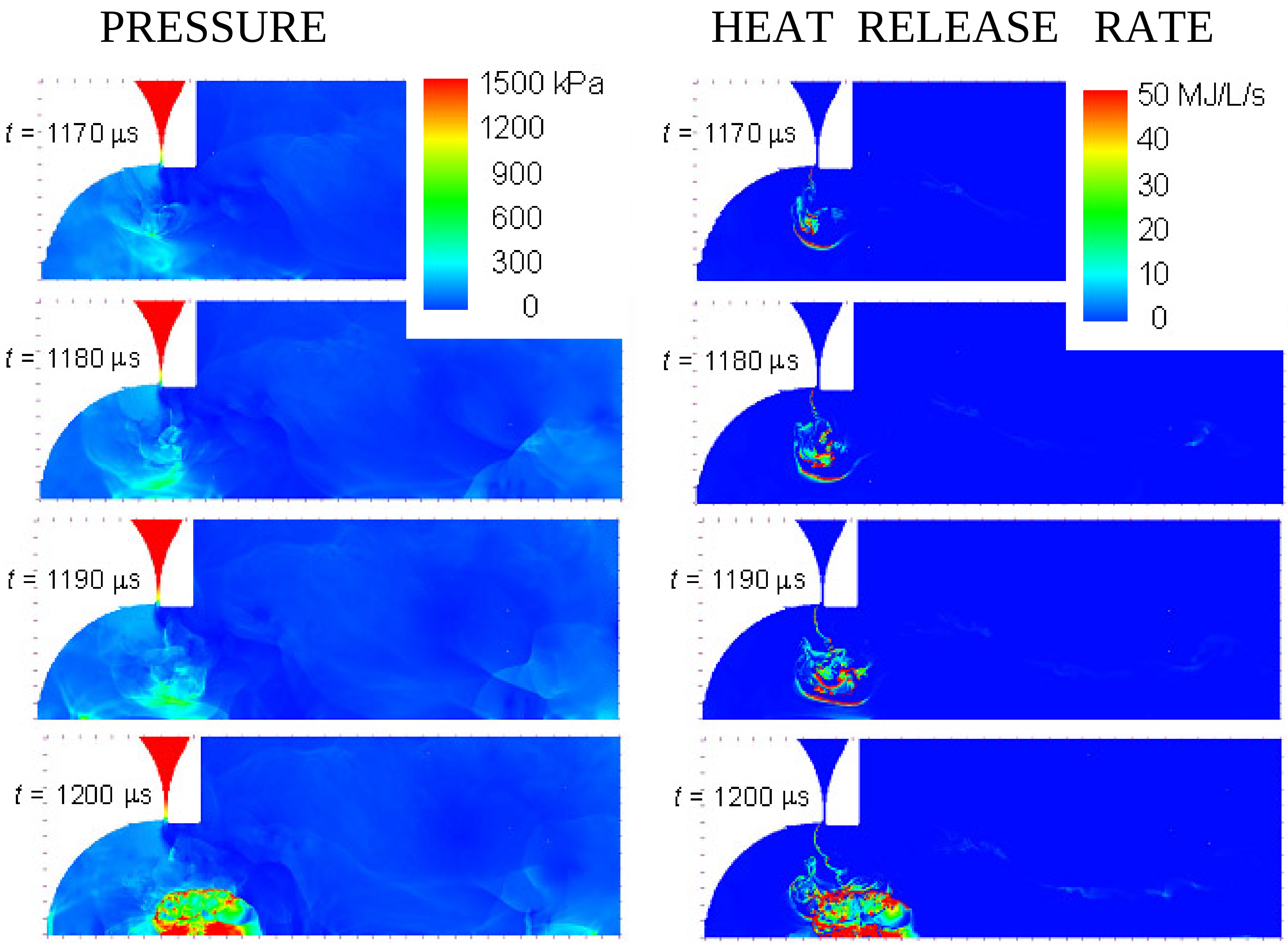
(2) Peaks are higher



Detonation occurs between t = 1.42 – 1.48msec for Case B-0 (within 60microsec), after slow reaction.



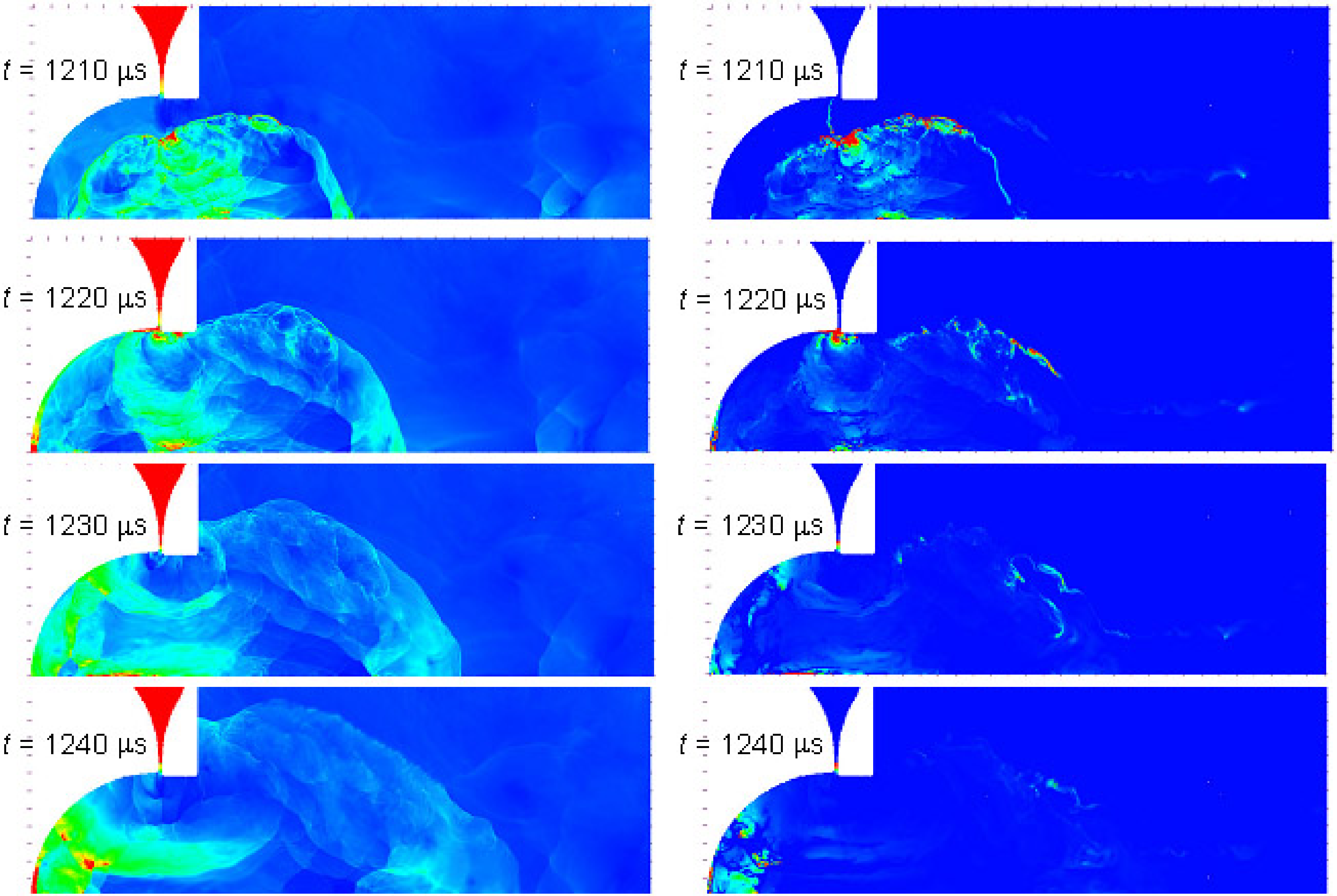
Detonation occurrence for Case B-0 during t = 1.420 – 1.440msec (total 20microsec): Pressure distribution



PRESSURE
HEAT RELEASE RATE
1500 kPa
1200
900
600
300
0
50 MJ/L/s
40
30
20
10
0
t = 1170 µs
t = 1180 µs
t = 1190 µs
t = 1200 µs

Pressure Distribution

Heat Release Rate



Observation during t = 1.170 –1.240 msec

Propagation of detonation: t = 1190 – 1220microsec = about 20microsec, giving the detonation velocity = 1750m/sec.

Values Utilized for Calculation C-Series of Cavity Size D = 14cm, L = 1cm

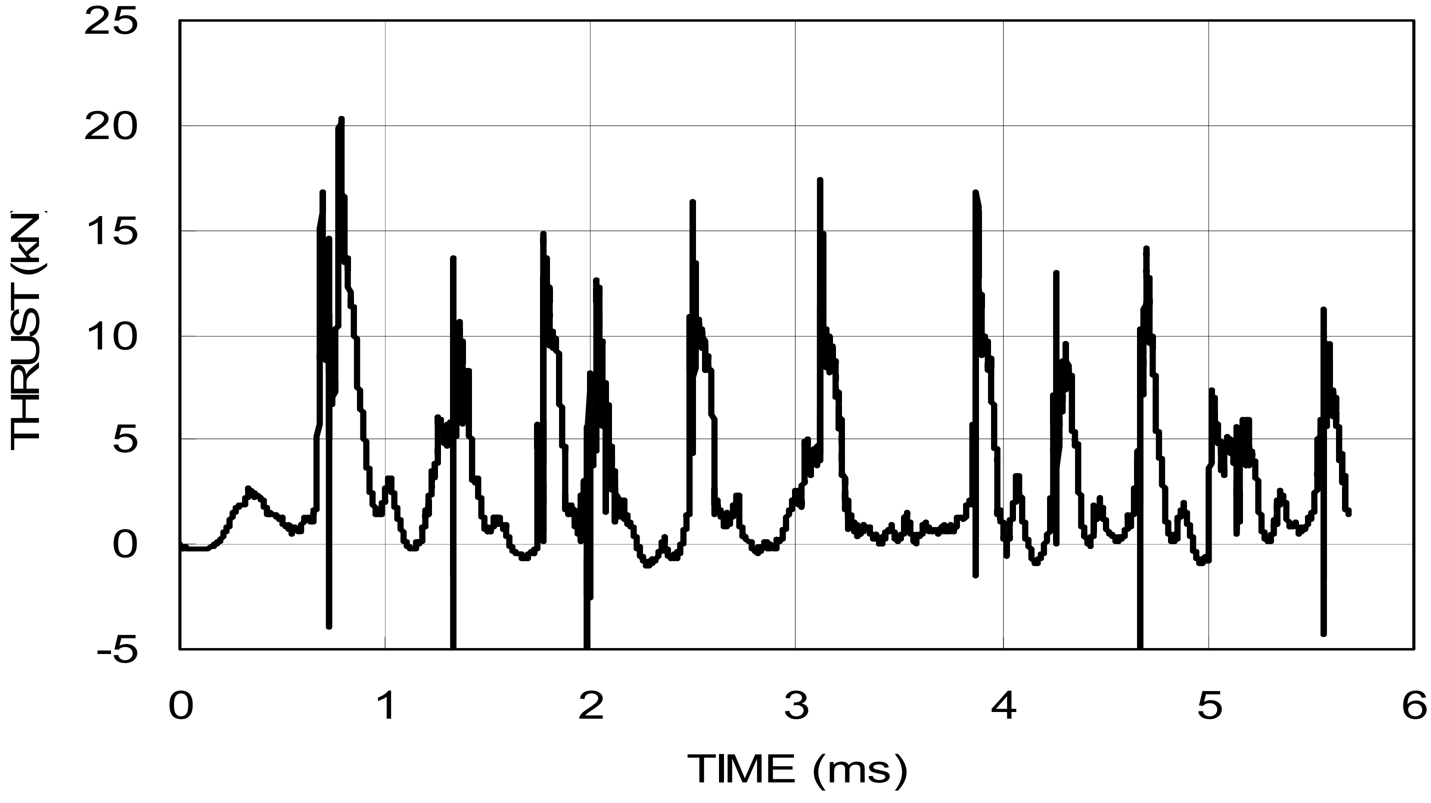
(1) Activation Energy: 8000K (Case C-2), 9000K (Case C-3)

(2) Injected Gas: T_{00} = 293.15K

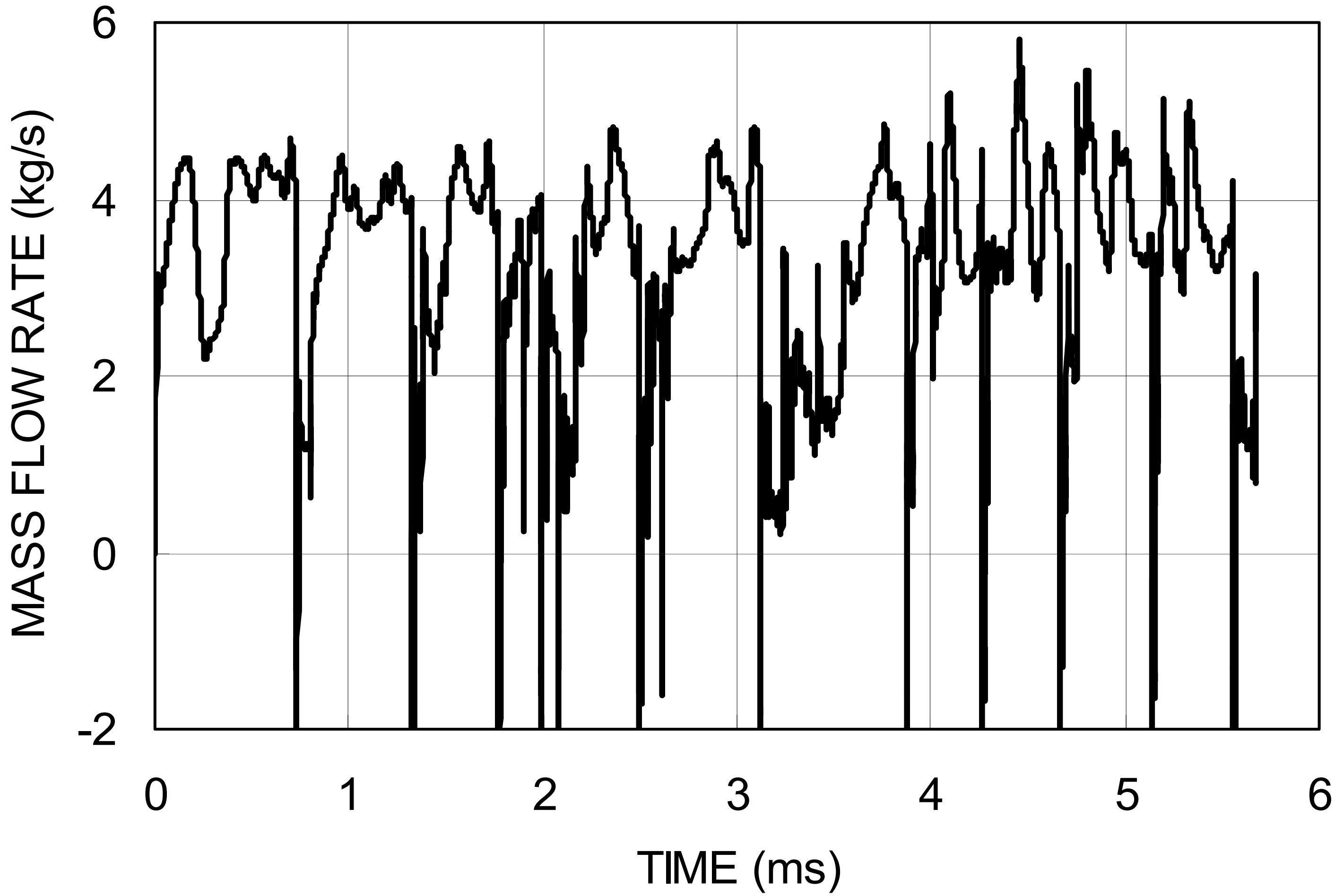
(3) Calculated Ignition Temperature = 571.33 K, defined by Ignition Delay Time 0.1 ms

(4) C-J detonation:
C-J detonation velocity = 1724.74 m/s
Mach number of C-J velocity = 5.1203

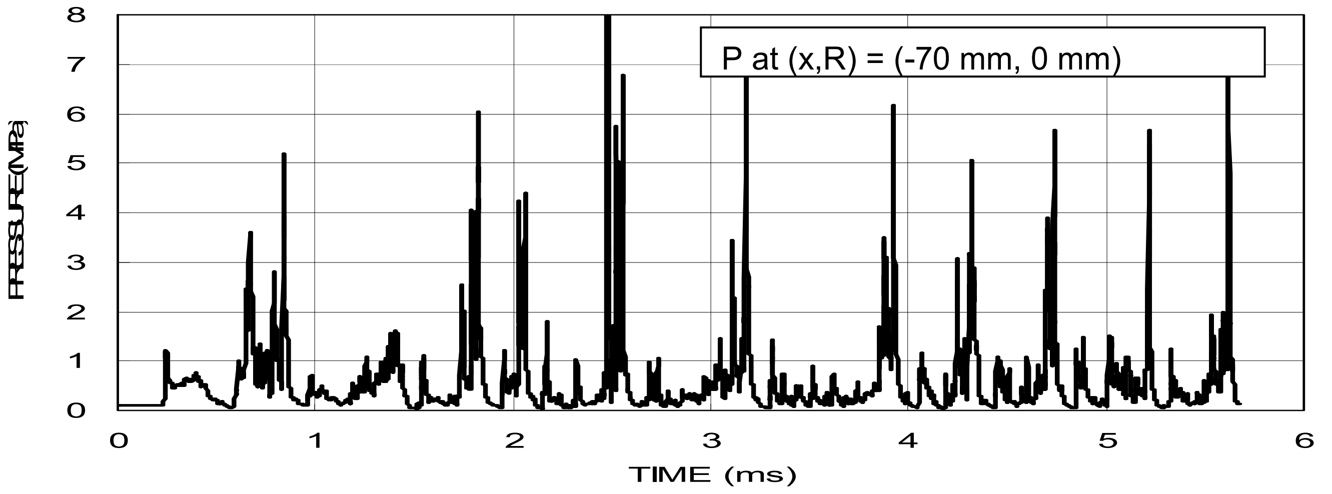
(5) Induction length = 14.245μm



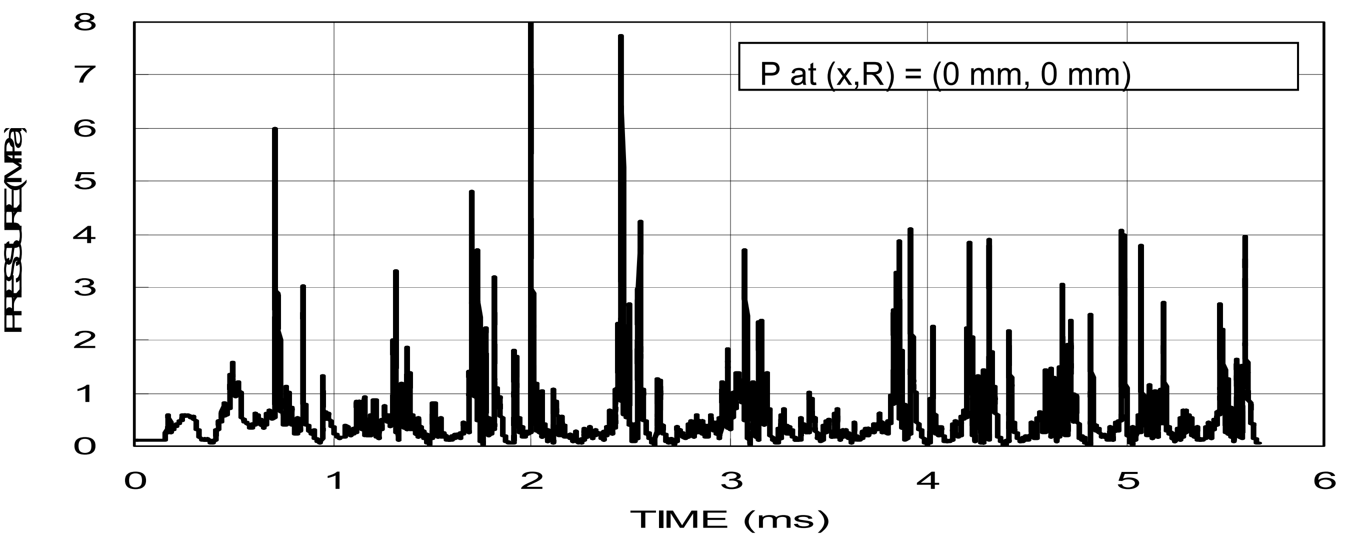
History of Thrust for Case C-2: D = 14cm, L = 1cm, T_a = 8000K. Resonant Cycle Time τ= (5.5－0.8)/10 = 0.47msec→Frequency f = 2kHz



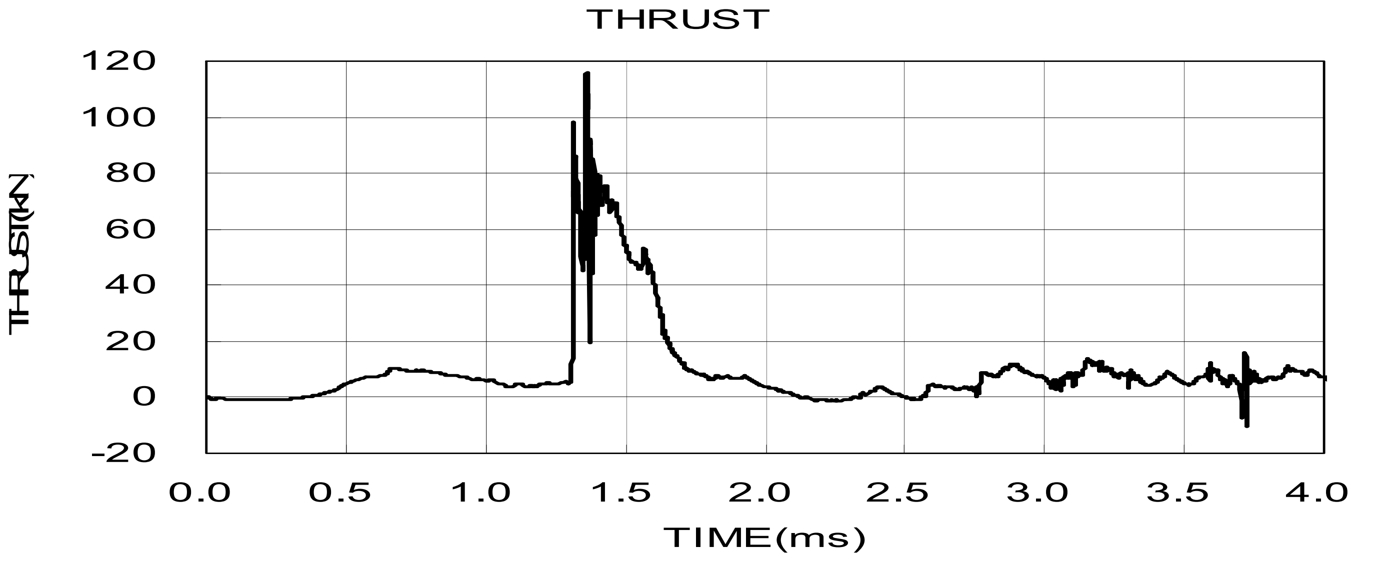
Mass Flow Rate of Gas Mixture Injected into Resonator for Case C-2. D = 14cm, L = 1cm. Intermittency is caused by breakdown of choking condition in supply throat.



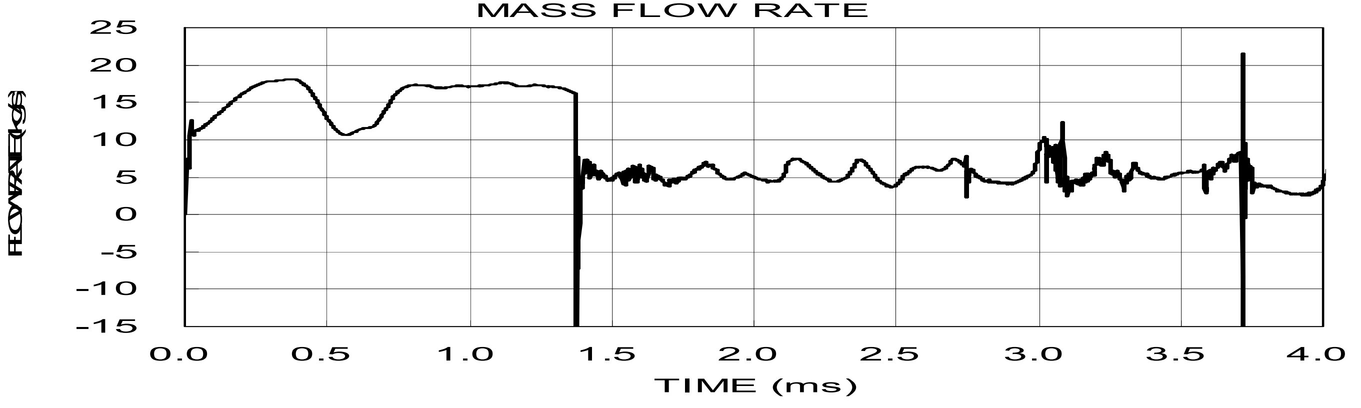
Pressure History at Wall Center for Case C-2



Pressure History at Cavity Center for Case C-2



History of Thrust for Case C-3 (Ta = 9000K): No Resonance



Mass Flow Rate of Gas Mixture Injected into Resonator for Case C-3: Weak Oscillation

Series-D Calculations

(1) D = 7cm

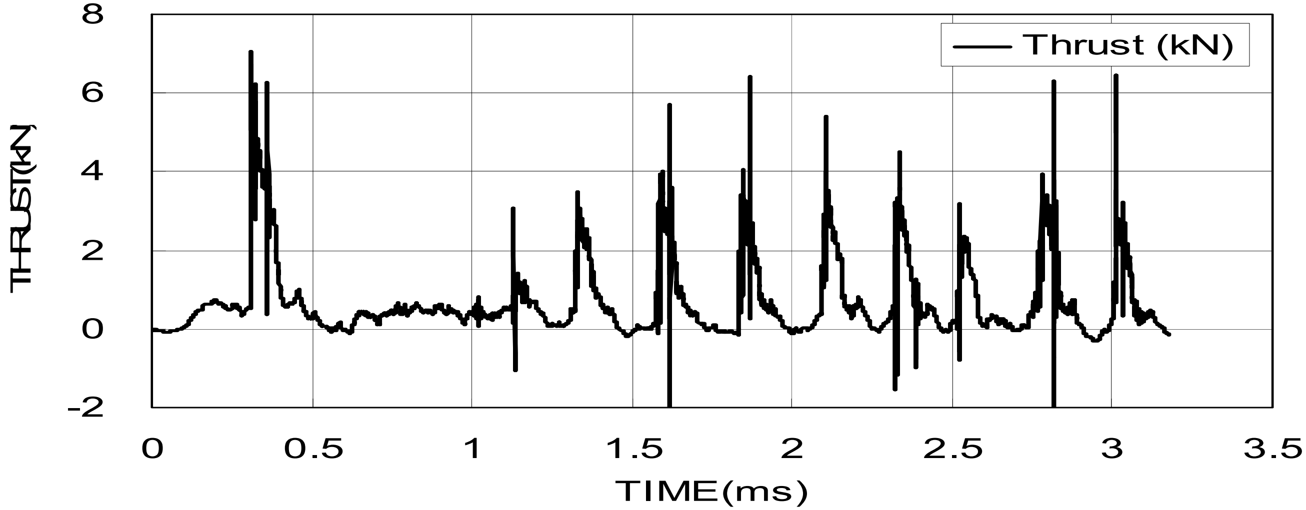
(2) Nozzle/ejector length:

L = 2cm → steady resonant detonation,

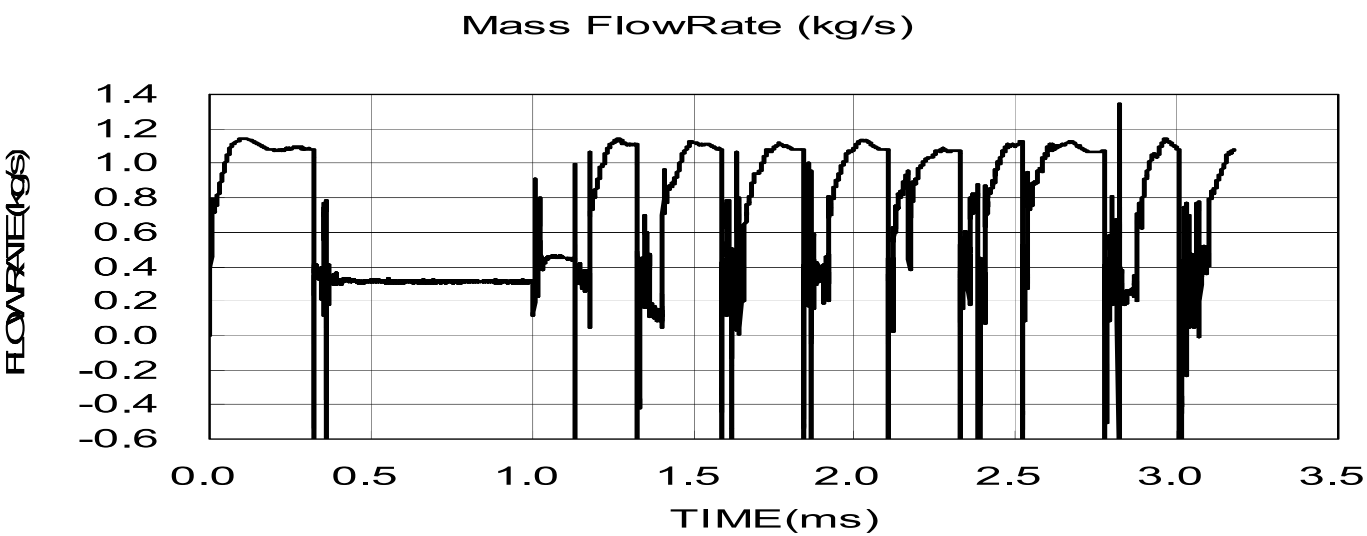
L = 3cm → intermittent galloping detonation,

L = 4cm → initial detonation followed by no continuation

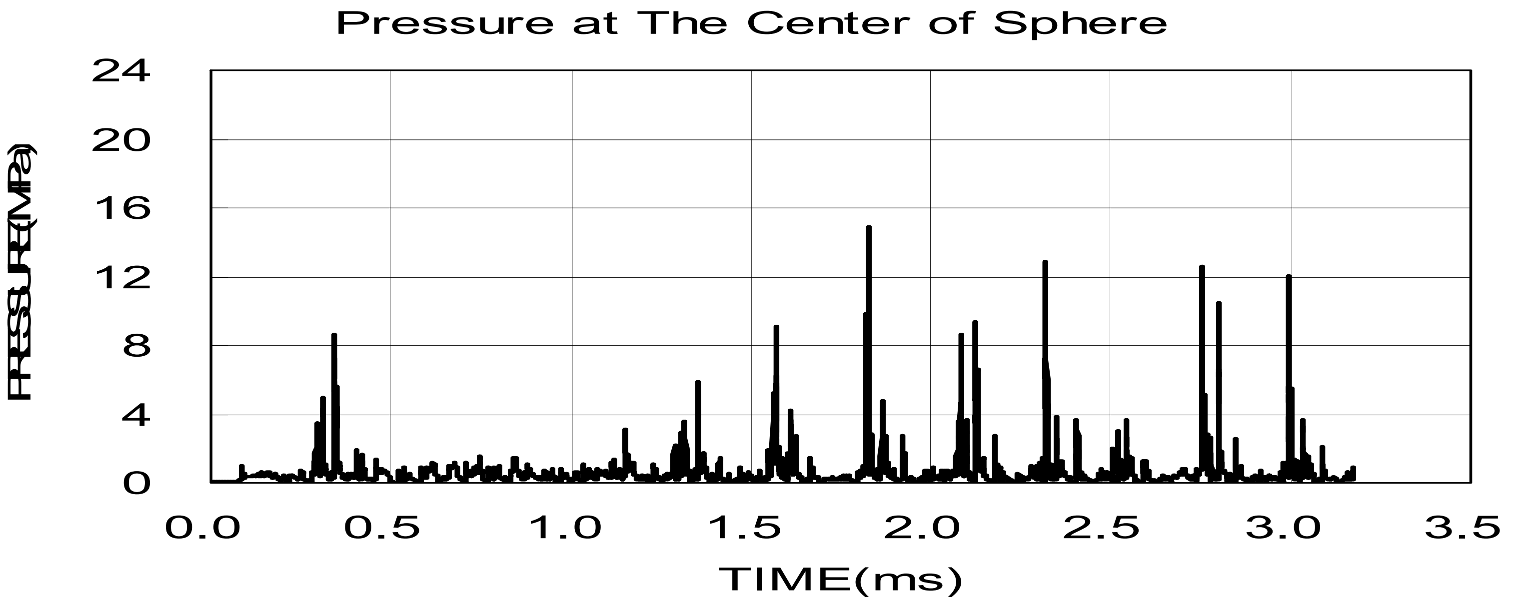
(3) Other parameters: standard conditions



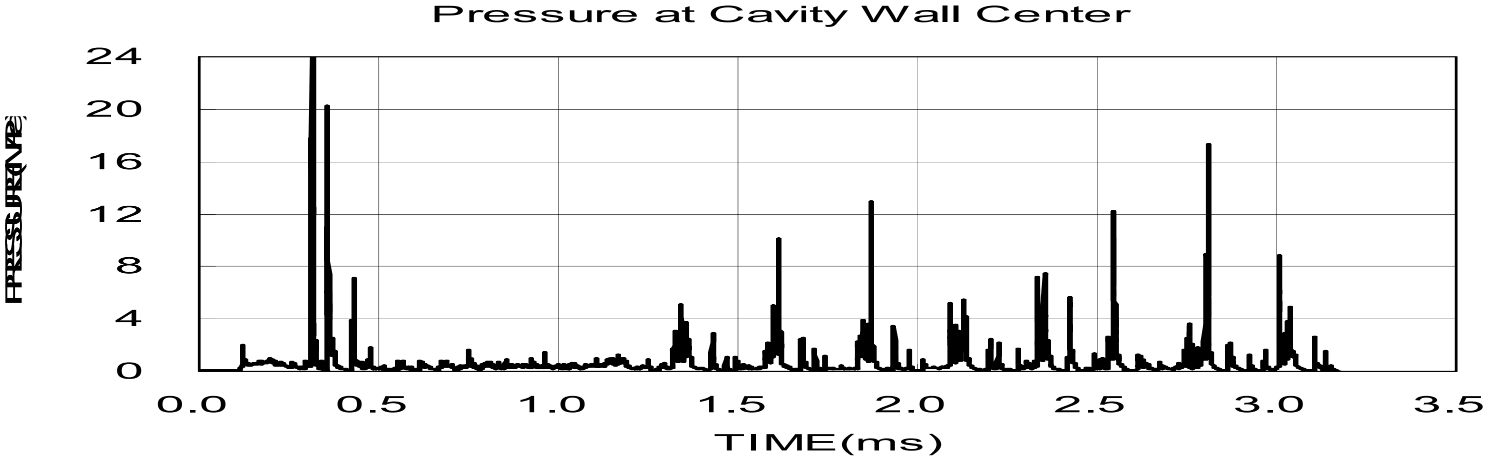
History of Thrust for Case D-1 (Nozzle Length L=2cm).



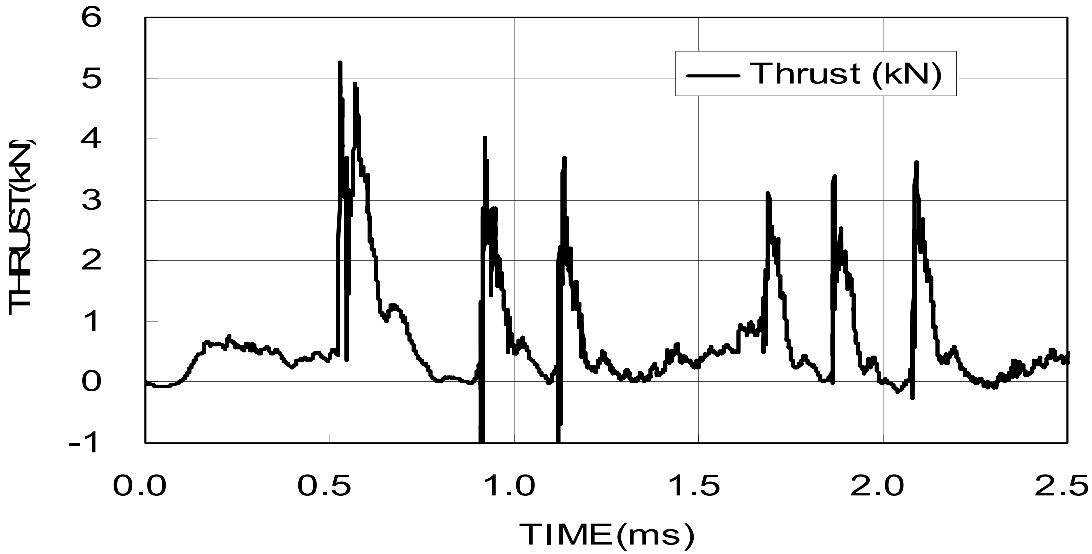
Mass Flow Rate of Gas Mixture Injected into Resonator for Case D-1 (Nozzle Length L=2cm).



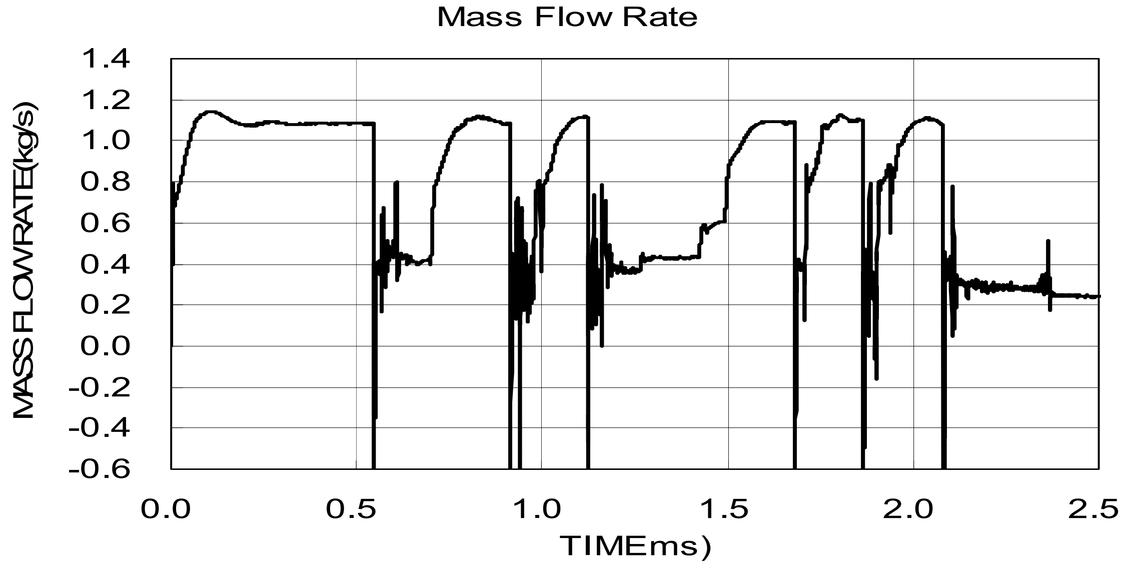
Pressure History at Center of Cavity for Case D-1 (Nozzle Length L=2cm)



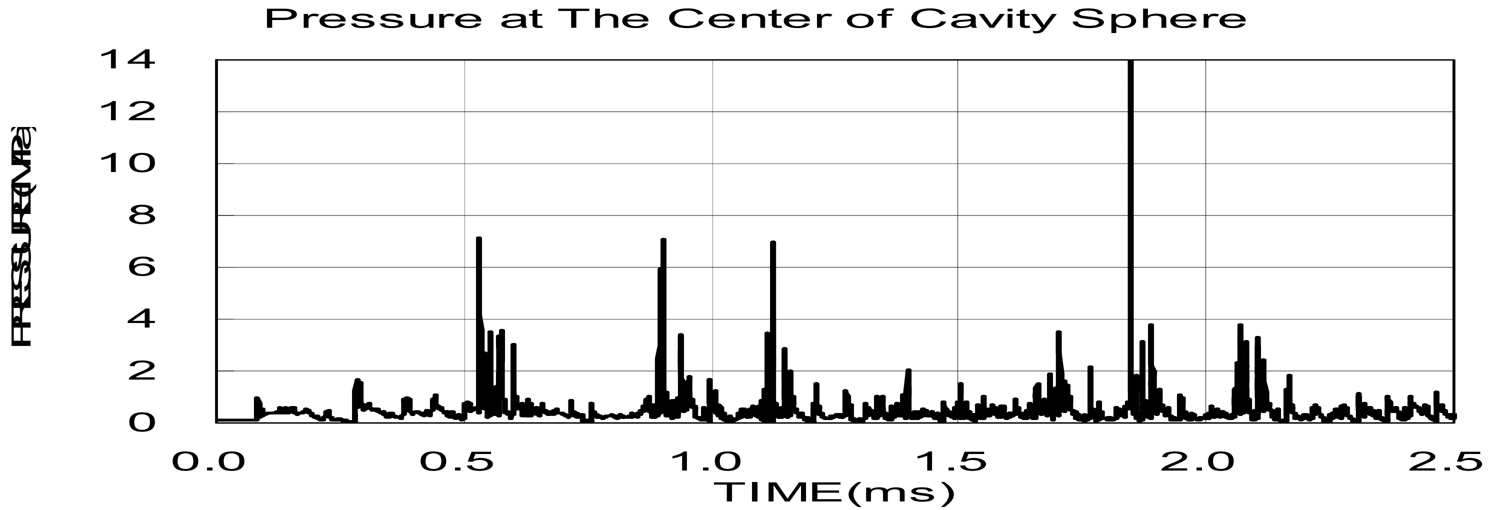
Pressure History at Wall Center of Cavity for Case D-1 (Nozzle Length L=2cm)



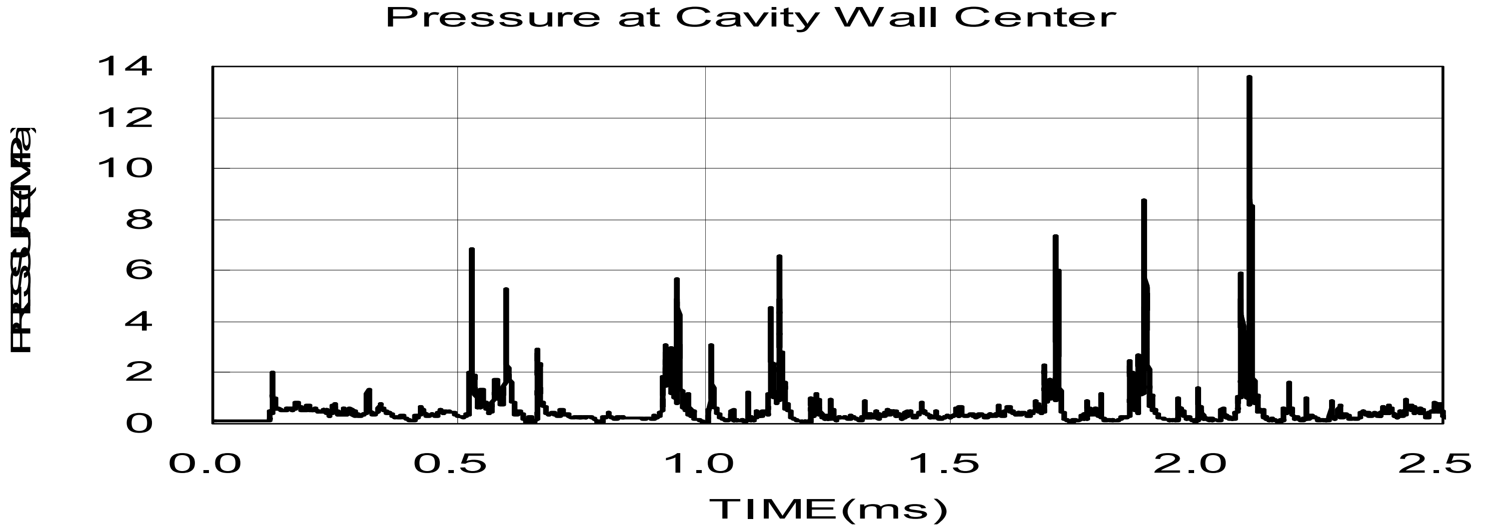
History of Thrust for Case D-2 (Nozzle Length L = 3cm).



Mass Flow Rate of Gas Mixture Injected into Resonator for Case D-2 (Nozzle length L = 3cm).



Pressure History at Center of Cavity for Case D-2
(Nozzle Length L = 3cm)



Pressure History at Wall Center of Cavity for Case D-2
(Nozzle Length L = 3cm)

Series-E Calculations

Numerical Analysis for D = 28cm Cavity:

(1) Using the standard conditions

(2) Initial ignition generated only a flame having slow burning velocity; no detonation

(3) There were always small-amplitude pressure oscillations, probably due to acoustics

Conditions to Widen Resonance Range: Conjecture

(1) **A large cavity D = 28cm failed to generate the resonant detonation.**

(2) **Caused by inability of injected gas mixture to reach the cavity center due to insufficient purging of burnt gas from the previous cycle.**

(3) **The present method of supplying combustible gas mixture only from periphery may have a limit.**

(4) **Gas mixture can also be supplied from wall surface or from cavity center, in order to overcome the above difficulty and also to have easier ignition.**

Conclusion

(1) Physics of detonation resonator is well revealed, for complicated gasdynamics

(2) Resonant range is widened

(3) Effects of parameters are found out

(4) A wider resonant range of parameters may be acquired

(5) Realistic gas mixture must be tested as next goal