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 $L = 1\text{cm} - 4\text{cm}$ is attached.
### Table 1 Parameters and Calculated Results for B-Series (D = 7cm, L = 1cm)

<table>
<thead>
<tr>
<th>Case</th>
<th>Heat reaction; Q (MJ/kg)</th>
<th>Rate Constant; $k_a$ (m³/kg.s)</th>
<th>Injected Gas Temperature; $T_{00}$ (K)</th>
<th>Resonance Frequency; $f$ (kHz)</th>
<th>Specific Impulse; $I_{sp}$ (sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>B-0</td>
<td>2.10</td>
<td>0.50e+9</td>
<td>293.15</td>
<td>3.96</td>
<td>1,450</td>
</tr>
<tr>
<td>B-1</td>
<td>2.10</td>
<td>0.50e+9</td>
<td>350.00</td>
<td>4.70</td>
<td></td>
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<tr>
<td>B-2</td>
<td>2.80</td>
<td>0.50e+9</td>
<td>293.15</td>
<td>4.43</td>
<td>1,310</td>
</tr>
<tr>
<td>B-3</td>
<td>2.10</td>
<td>0.25e+9</td>
<td>293.15</td>
<td>4.11</td>
<td>1,560</td>
</tr>
</tbody>
</table>
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 100-200 microsec
(2) Peaks are higher
Detonation occurs between $t = 1.42 - 1.48\text{msec}$ for Case B-0 (within 60 microsec), after slow reaction.
Detonation occurrence for Case B-0 during $t = 1.420 - 1.440\text{msec}$ (total 20microsec): Pressure distribution
Observation during $t = 1.170 - 1.240$ msec

Propagation of detonation: $t = 1190 - 1220 \text{microsec} = \text{about } 20 \text{microsec}$, giving the detonation velocity $= 1750 \text{m/sec}$. 
Values Utilized for Calculation C-Series of Cavity Size $D = 14\text{cm}$, $L = 1\text{cm}$

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

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

(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 = 14.245$\mu\text{m}$
History of Thrust for Case C-2: \( D = 14\text{cm}, \ L = 1\text{cm}, \ T_a = 8000\text{K}. \) Resonant Cycle Time \( \tau = (5.5 - 0.8)/10 = 0.47\text{msec} \rightarrow \text{Frequency} \ f = 2\text{kHz} \)
Mass Flow Rate of Gas Mixture Injected into Resonator for Case C-2. $D = 14\text{cm}$, $L = 1\text{cm}$. 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) $D = 7\text{cm}$

(2) Nozzle/ejector length:
   - $L = 2\text{cm}$ – steady resonant detonation,
   - $L = 3\text{cm}$ – intermittent galloping detonation,
   - $L = 4\text{cm}$ – 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 $D = 28\, \text{cm}$ 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 $D = 28\text{cm}$ 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