Physics and Applications of Gaseous Detonation

Toshi FUJIWARA,

FFLab, Nagoya 465-0093

also Department of Aerospace Engineering,

Nagoya University, Nagoya 464-8603, Japan

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Introduction

“Detonation phenomenon” generates high pressure and temperature, and is basically uncontrollable, compared with conventional “flames”. In the past, direction of research has been prevention of and protection from hazard.

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Recently, the trend to control detonation propagation has emerged, utilizing its high-power and high-density energy for “propulsion system of air/space planes”.

- Oblique Detonation Wave Engine：ODWE
- Ram Accelerator：RAMAC
- Pulse Detonation Engine：PDE

Purpose

To improve efficiency of PDE :

- Increase thrust by attaching a diverging nozzle to engine exit.
- Promote early DDT (Deflagration-Detonation Transition) by setting “obstacles” in upstream portion of PDE.

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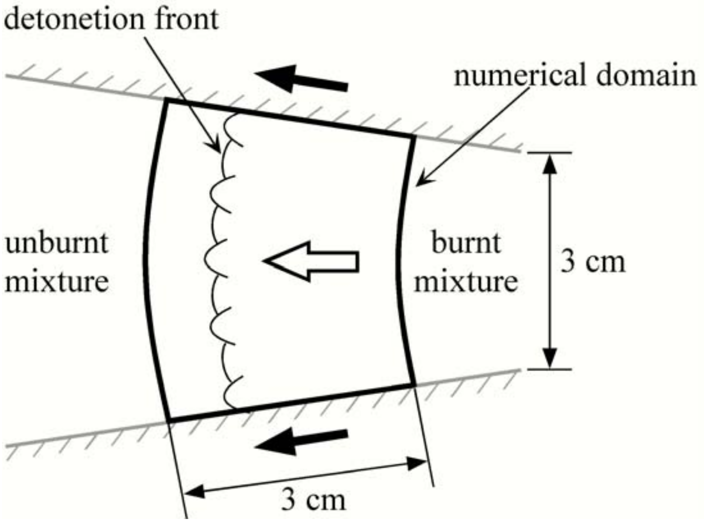
2-Dimensional Numerical Analysis of Detonation Propagation in Variable-Cross-Section Channels

- Establish a 2-dimensional numerical code in a generalized coordinate system.
- Study basic mechanisms of detonation propagation in variable-cross-section channels where the cross sectional area increases at a constant gradient.

Numerical Method

- Governing equations : 2-dimensional "Navier-Stokes equations" based on a generalized coordinate system.
- Chemical reaction model： 2-step chemical model by Korobeinikov-Levin.
- Numerical scheme： 2nd-order-accurate explicit MacCormack-TVD scheme.
- Computational domain： Moves together with propagating detonation front, always within 3cm-length in x-direction.
- Gas mixture： $2H_2 + O_2 + 7Ar$.
- Initial condition： 298.15 K，0.5atm.



Results

Effect of Grid Convergence on Detonation Characteristics

3 different grids have been tested to a 3cm-width straight cannel.

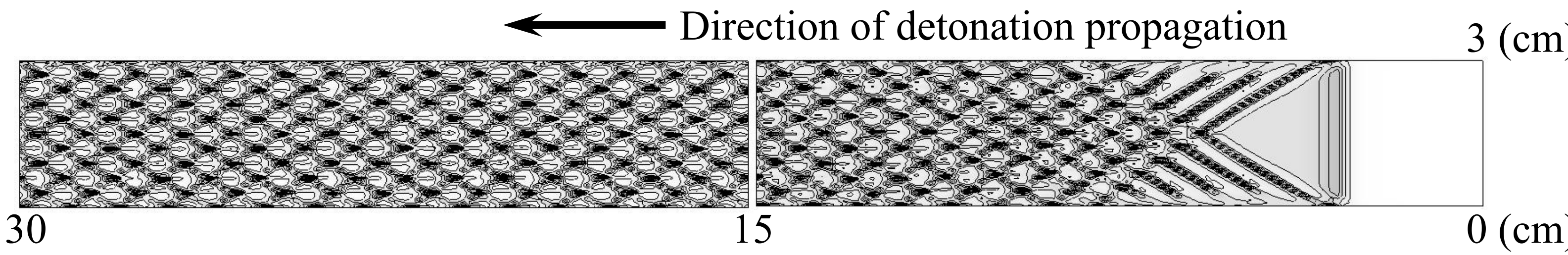
	Grids	Mesh size	Cell size	Ratio of cell size to experimental value
Grid 1	200×200	150μm	0.75cm	1.53
Grid 2	300×300	100μm	0.6cm	1.22
Grid 3	450×450	67μm	0.6cm	1.22

Experimental cell size：0.49cm (Strehlow et al.)

- ●Grid selection affects detonation cell size.
- ●Subsequent analyses are performed using a grid where maximum mesh size ≦100μm.

Results

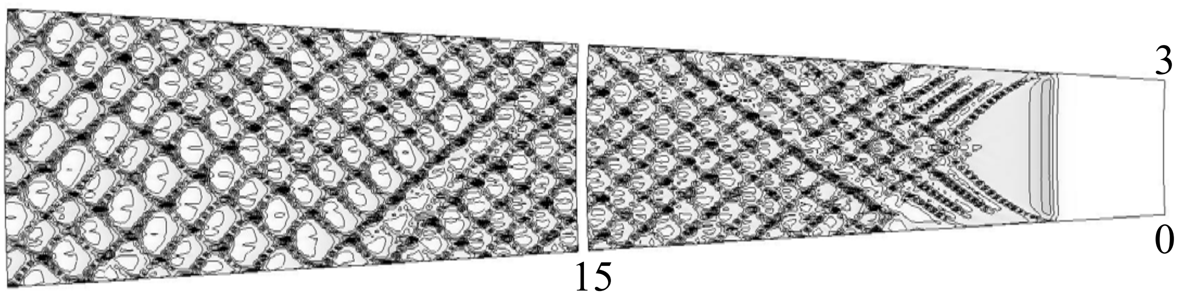
Cell Pattern for No Wall Inclination, θ = 0 deg.



- Grid 2： 300×300 (mesh size 100μm).
- Cell size = 0.6cm, cell number=5, uniform distribution.
- Detonation propagates stably.

Results

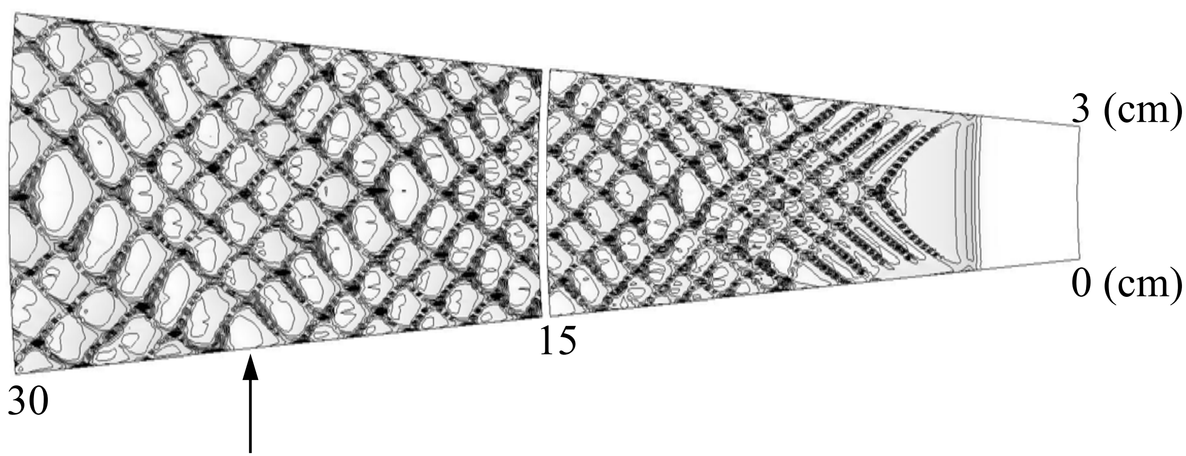
Cell Pattern for Wall Inclination; θ = 3 deg.



- Grid: 300×600
- Detonation propagates stably.
- Cell size gradually increases due to expansion effect, keeping the same cell number (no generation or annihilation).
- Cell size increases from 0.6cm up to 1.1cm at 25cm passage; cell number = 5 (unchanged).

Results

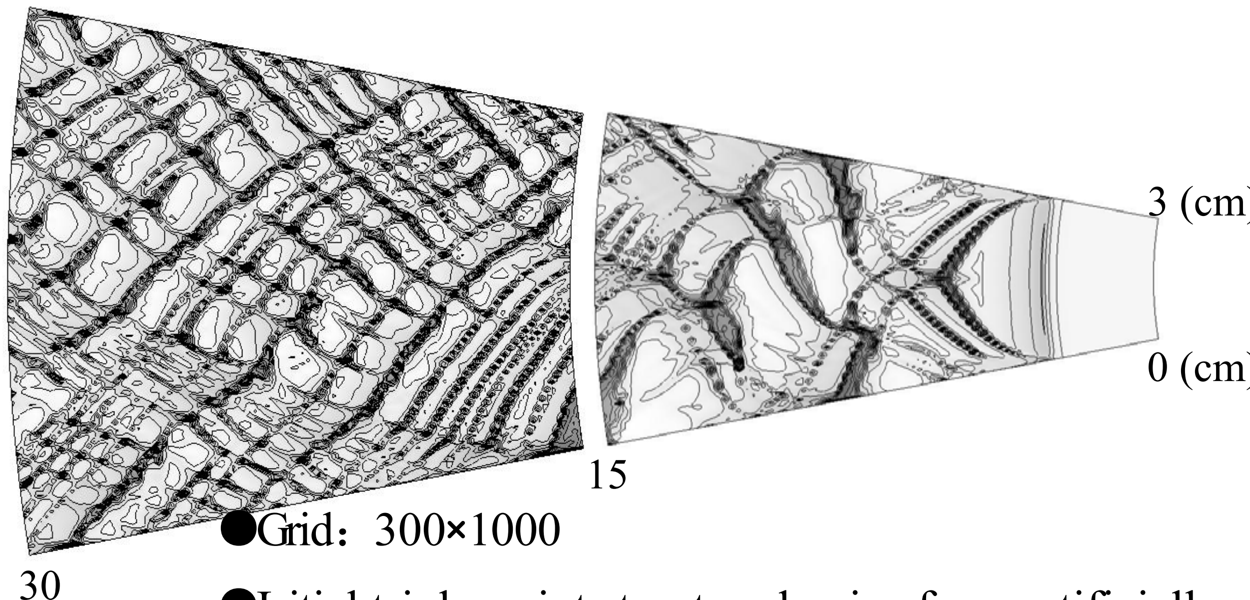
Cell Pattern for Wall Inclination; θ= 5 deg.



- Grid: 300×800.
- Detonation propagates stably.
- Cell size for θ=5 deg. is larger than the one for θ=3 deg., while no generation/annihilation occurs.
- Cell size becomes 1.7cm at 30cm passage; cell number=5 (unchanged).

Results

Cell Pattern for Wall Inclination, θ = 10 deg.



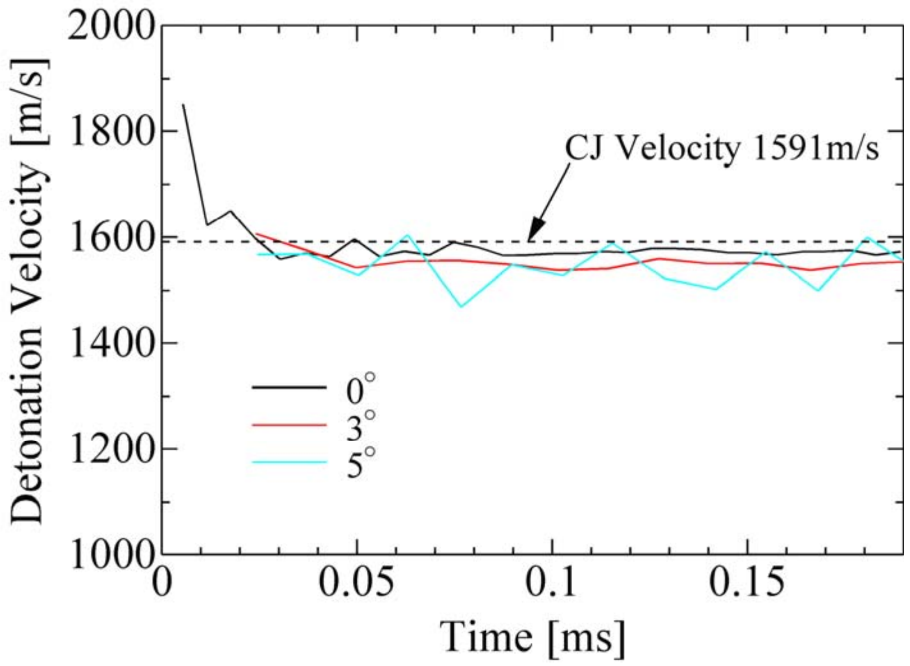
- Grid: 300×1000
- Initial triple-point structure begins from artificially-placed weak disturbances near wall; symmetric.
- Cell number stays at 2; growth is suppressed.
- Symmetrical structure is lost at x < 9 cm.

Cell Pattern for Wall Inclination; θ = 10 deg.

- At 12cm, new triple points are formed, due to (1) mutual collision at center and (2) collision with wall.
- At 20cm, a new cell structure prevails; cell number=12=2 x former cases; the cell structure is still non-uniform.
- At x>20cm, non-uniformity is source of new cells formation→Cell size adjusts to finer, cell number grows up to 15 at x=30cm (cell size = 0.8cm).
- Entire transition process is irregular throughout propagation; it will be interesting to see further development.

Results

Detonation Velocity is Slightly Changed



Angle	Detonation velocity
0°	1571m/s
3°	1549m/s
5°	1544m/s

- Detonation velocity D becomes slightly lower and more fluctuating, for increased wall inclinations θ.

Conclusion

Using a generalized 2-dimensional scheme, the effect of increasing channel cross section is studied, for 4 different fan-shaped channels; θ = 0, 3, 5 and 10 degs.

- A larger wall inclination (θ) generates greater effects of flow expansion, where the cell size simply increases for $\theta \leqq 5$ deg. For $\theta \geqq 10$ deg, detonation propagation becomes irregular, but still does not extinguish; cell size adjustment is observed.

- Propagation velocity of detonation (1) is only slightly "lowered" and (2) "fluctuates" more, for increased wall inclinations, due to flow expansion effects.