Detonation Propagation in Variable Cross Section Channels

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1. Introduction

The detonation phenomenon is maintained by the interaction between front-runnig shock wave and coupled subsequent combustion, generating high pressure and temperature, which is basically uncontrollable in comparison with conventional flames. The direction of research has mostly been prevention or protection of hazard.

Recently, however, there have occurred the trends to control the detonation propagation, and utilize its high-power and high density energy in positive directions like Pulsed Detonation Engine(PDE)[1). There already exist a few "high-cycle" engines running at about 100Hz, where the key issue is whether a true CJ detonation propagates from beginning to end in realistic channels; without achieving the CJ detonation, either high thermal efficiency or estimated high performance is not attainable. Therefore, investigations of detonation propagation in variable cross section channels[2)] become important in theses studies.

In the past, we developed a 2-dimensional code in constant cross section channels taking into account the transport processes by using simple constant-mesh fine grids. By calculating the 2-dimensional detonation propagation in an oxyhydrogen mixture[3)]; we successfully obtained the effect of transport properties to the cell size. Due to the action of wall boundary layer, the calculated cell size getting closer to an experimental value. In this study, the code is extended to allow variable cross section by introducing general coordinate-system. In order to study the basic mechanism of detonation propagation in variable cross section channels, we employ the channel, where the cross section increases with constant rate.

2. Numerical Analysis

The fundamental equations are Navier-Stokes ones containing the mass conservation equations for the two progress variables α(induction reaction) and β(exothermic reaction) [4)] . The utilized numerical scheme is a 2nd-order-accurate explicit Mac-Cormac-TVD one. We calculate the detonation propagating containing Ar-diluted stoichiometric oxyhydrogen mixture ($2H_2 + O_2 + 7Ar$) at the initial pressure 0.5atm and temperature 298.15K. As an initial condition for detonation profile, the CJ detonation obtained from 1-dimensional analysis is utilized. In order to generate a 2-dimensional detonation, the initial CJ detonation is disturbed by placing the properties of unburnt mixture at intervals of 0,2mm in the 1mm x 1mm region near the channel wall immediately behind the shock wave front. The fan-shaped computational domain of 3cm-length moves together with the propagating detonation front (Fig.2).

Since the tube wall boundary layer exists in the calculation domain, the numerical resolution is raised as much as possible, by testing 3 different grids in the 3cm-wide straight channel; the obtained results are compared in Table 1. Grid1(200x200, $\Delta x=\Delta y=$ 0.15mm) gives 4 cells in the channel width(cell size $\lambda=$ 0.75cm). Using finer grids, Grid2(300x300, $\Delta x=\Delta y=$ 0.1mm) and Grid3(450x450, $\Delta x=\Delta y=$ 0.067mm), the cell sizes becomes smaller value. However, Grid2 and Grid3 give the same cell size $\lambda=$ 0.6cm. Based upon these results, the present analyses for different calculation configurations are proceeded by grid systems, where the mesh size doesn't exceed 0.1mm.

3. Results

In the present analysis, in order to investigate the effect of increasing cross section in detonation propagation, 3 different fan-shaped configurations are employed. The calculated soot patterns for 3 different inclinations of the channel wall, $\theta = 0$, 3, 5 deg. are shown in Fig.3(a)-(c). Table 2 shows the grid points used for calculations of 3 different wall inclinations. In the case of no wall slant, $\theta = 0$ deg. (Fig.3(a)), the cell pattern appears at the 6cm position and the cell pattern exists the 6cm position to the downstream end. In this case, the steady cell size is 0.6cm. In the case of wall inclination, $\theta = 3$ deg.(Fig.3(b)), the cell pattern also appears at the 6cm location. However, the cell is gradually stretched out due to the expansion effect and the cell size converges to a certain value, 1.1cm at 25cm. The cell size for $\theta = 3$ deg. is larger than the value of no wall slant. For $\theta = 5$ deg.(Fig.3(c)), the cell size is 1.7cm at 30cm. Thus, we can conclude that a larger wall inclination generates a greater effect of expansion and the cell size becomes larger.

The propagation velocities of shock wave front are also calculated for 3 cases, $\theta = 0$, 3, 5 deg.(Table 2). As shown in Table 2, the velocity becomes slightly lower for a larger wall inclination, θ . The velocity 1544m/sec for $\theta = 5$ deg. is about 98% of the velocity 1571m/sec for $\theta = 0$ deg.. The decrease of velocity for a larger wall inclination, θ is also due to the expansion effect, however, the velocity doesn't strongly depend on the wall inclination, θ in comparison with the cell size.

4. Conclusions

Using a generalized 2-dimensional scheme, the effect of increase of cross section in the channel is investigated for 3 different fan-shaped channel, where wall inclinations are $\theta = 0$, 3, 5 deg.. The obtained results in the present analyses are summarized as follows: (1) A larger wall inclination ,θ generates a greater effect of expansion and a cell size becomes larger.

(2) A propagation velocity of shock wave becomes slightly lower as the wall inclination, θ increases also due to the expansion effect.

References

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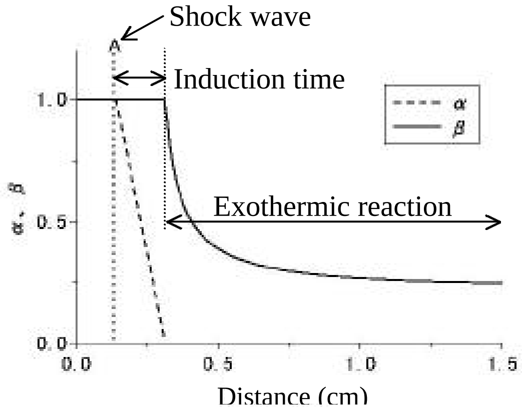


Fig.1 Behavior of the Reaction Progress Parameters α and β

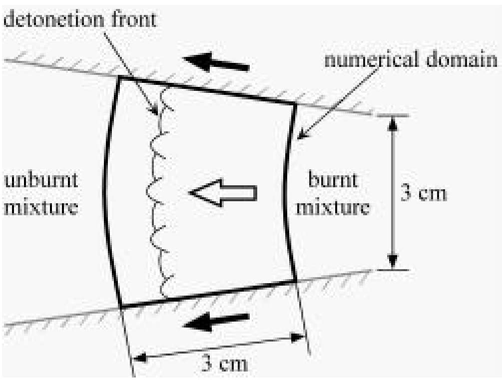


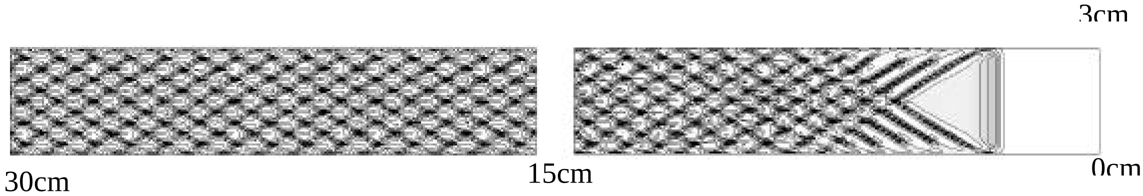
Fig.2 Computational Domain Moving with Wave Front

Table 1 Effect of Grid Resolution on Calculated Cell Size

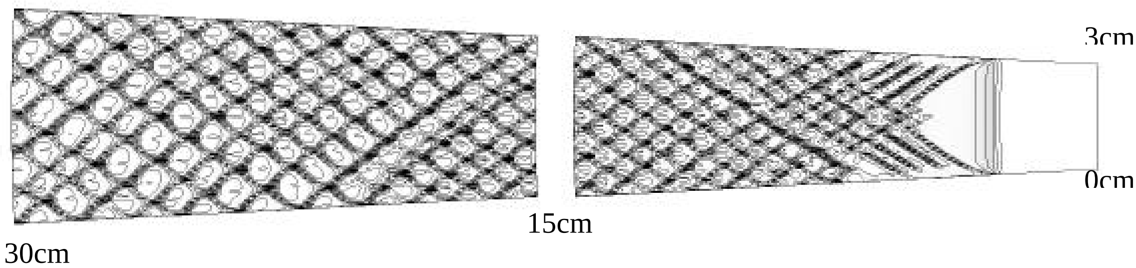
Grids	Mesh size	Cell size
200 x 200	0.15mm	0.75cm
300 x 300	0.1mm	0.6cm
450 x 450	0.067mm	0.6cm

Table 2 Grid Points and Detonation Velocities for Different Wall Inclinations

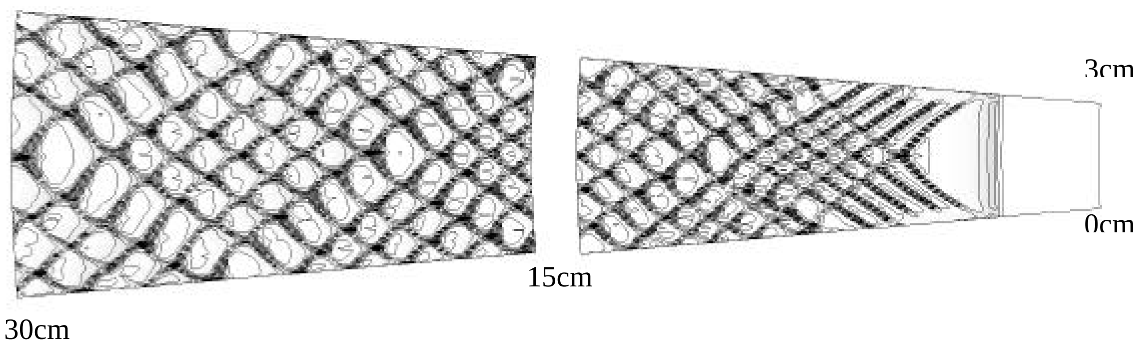
Wall inclination	Grid Points	Detonation velocity
0 deg.	300 x 300	1571m/s
3 deg.	300 x 600	1549m/s
5 deg	300 x 800	1544m/s



(a) 0 degree



(b) 3 degrees



(c) 5 degrees

Fig.3 Soot Patterns for Different Wall Inclinations