# Propagation of a Detonation in a Converging Conical Channel

Ivan H. Hung, John H. S. Lee
McGill University
Montreal, Quebec, Canada

## 1 Introduction

The interaction of a shock (or detonation wave front) with a wedge generates a triple-shock configuration consisting of an incident shock, a reflected shock and a Mach stem. The triple point where the three shocks intersect produces a "break" in the shock surface and a discontinuous front. In a recent experimental study of the interaction of a detonation with a wedge by Fortin et al. [1], it was found that for small wedge angles $\lesssim 20^{o}$, the Mach stem becomes curved and intersects smoothly with the incident detonation. The triple point is now a dispersed region and the reflected shock degenerates into a train of compression waves as the incident wave changes continuously to the Mach stem. Thus it appears possible to initiate a smooth converging detonation wave front by a channel consisting of small angle wedges. Furthermore, it is also possible to generate spherical converging detonations by propagating a detonation wave in a small angle conical tube. It should be noted that the curvature of the detonation generated may not correspond to a symmetrical cylindrical (or spherical) detonation with its center at the apex of the converging wedge (or cone). In the present study, we explore the amplification of converging spherical detonations in gaseous mixture generated in a small angle conical tube.

Converging cylindrical detonations were studied by Lee et al. [2] using a diffraction plate to "turn" a diverging cylindrical detonation to form a converging detonation on the other side of the diffraction plate. Similar studies by Fujiwara et al. [3] also exploited the diffraction plate method develop by Lee et al. [2]. The diffraction plate is limited to producing converging cylindrical detonations and cannot be used to generate spherical converging detonations. Amplification of strong shock waves by a converging channel via repeated Mach reflections was studied by Belokon [4] among others. However, converging spherical detonations have not been reported as yet due to difficulties in initiating symmetrical converging spherical detonations.

Correspondence to: ivan.hung@mail.mcgill.ca

## 2 Experimental Details

A schematic of the experimental setup is shown below in Figure 1. The detonation experiments were carried out in a round detonation tube made of steel with two sections: a constant area tube and a conical converging section at the end. The constant area section has an inner diameter of 2.5 inches and a length of 3 meters to ensure a fully developed steady CJ detonation is formed prior to entering the converging section. A spark gap at the front end is used to initiate a detonation wave with a Shchelkin spiral used to promote the formation of a detonation wave. After a stable detonation wave is formed, it enters a smooth, constant area section before entering the converging section. Ion probes are placed periodically throughout the smooth and the converging section to obtain the times of arrival of the detonation wave from which the detonation velocity can be calculated. Smoke foils are also placed in the smooth constant area section and the converging section to observe the cellular structure of the converging detonation.

From previous studies [1] [2], a continuous smooth wave front could be obtained without the presence of Mach stem for wedge angles $\lesssim 20^{o}$. Thus, the present study used cone angles of $6^{o}$ and $10^{o}$. Premixed stoichiometric mixture of acetylene and oxygen $C_2H_2 + 2.5O_2$ was used with initial pressure varying from 3kPa down to 0.5kPa below which no successful initiation of a detonation wave was observed. $C_2H_2 + 2.5O_2 + 70\%\ Ar$ was used and a more stable cell structure was obtained at initial pressure varying from 16kPa down to 4kPa. For the less sensitive Argon diluted mixtures, a sensitive driver gas of $C_2H_2 + O_2$ was used to aid the initiation of a detonation wave in the diluted mixture.

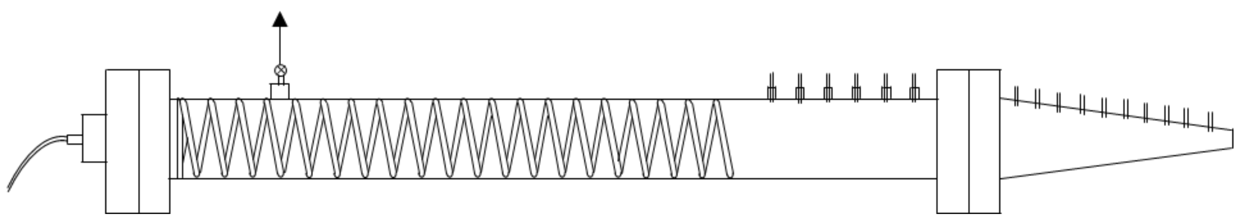


Figure 1: Experimental Apparatus

## 3 Results & Discussions

Unlike a non-reacting shock wave where the flow is subsonic behind it, a detonation is a self-propagating wave sustained by energy release from chemical reactions. A C-J detonation has a sonic plane some distance from the leading shock front, and perturbation downstream of the sonic plane cannot influence the propagation of the detonation front. Thus, for a converging detonation, the area convergence will influence only the reaction zone region. If the reaction zone is very thin, then area convergence will only be effective when the radius is very small, of the order of the reaction zone thickness. Thus for the highly detonable mixture with very thin reaction zone length, the detonation will propagate at C-J speed practically all the way until near the center of convergence.

Real detonations, however, are cellular, with cell size $\lambda$ and cell length of about $1.5\lambda$, which can be considered as a representation of the reaction zone length of a real cellular detonation. In comparison, for a one-dimensional ZND detonation the theoretical reaction zone thickness is typically 50-100 times smaller than the cell size $\lambda$. The cell size was typically about 1cm for the condition of the present experiments and the cell length was thus about 1.5cm. Therefore, the effect of area convergence is expected to be observable at some finite radius of the order of centimeters. If the hydrodynamic thickness is considered as the effective reaction zone thickness, then the effect of the area convergence can be felt at even larger radius since the hydrodynamic thickness is estimated to be about 4-5 $\lambda$.

Figures 2a and 2b show the x-t diagram of an argon diluted acetylene-oxygen mixture at 6º and 10º convergence at an initial pressure of 6kPa. The dotted trajectories using the initial C-J velocities in the constant area section are also presented for comparisons. It is clear that area convergence has an influence on the detonation wave. It was found that the degrees of overdriven at a radius of 0.25 inch from the end are 1.27 and 1.28 respectively for the 6º and 10º converging cone. This is also observed at all other initial pressures for the argon-diluted mixture as well as from 0.5kPa to 1.5kPa for the stoichiometric mixture.

However, the present results show that for the stoichiometric mixture at initial pressure of 2.0kPa or higher, within experimental error, there is no discernible acceleration on the detonation wave until at a close proximity to the center of convergence. The cell sizes are also constant throughout and are of the order of mm or less, meaning the reaction zone thickness is too thin to have any observable influence on the detonation wave, unless at very close proximity to the center of convergence. .

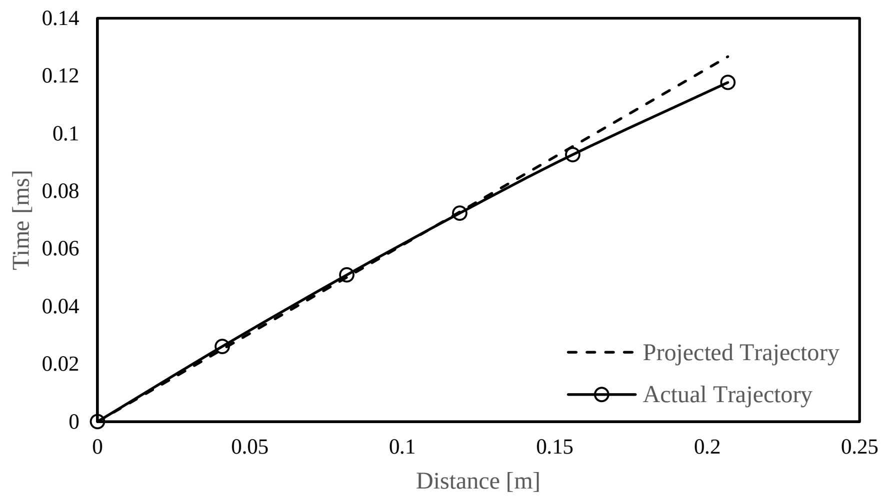



Figure 2a: x-t Diagram for $C_2H_2$+2.5$O_2$+70% Argon of 10º Convergence at 6kPa

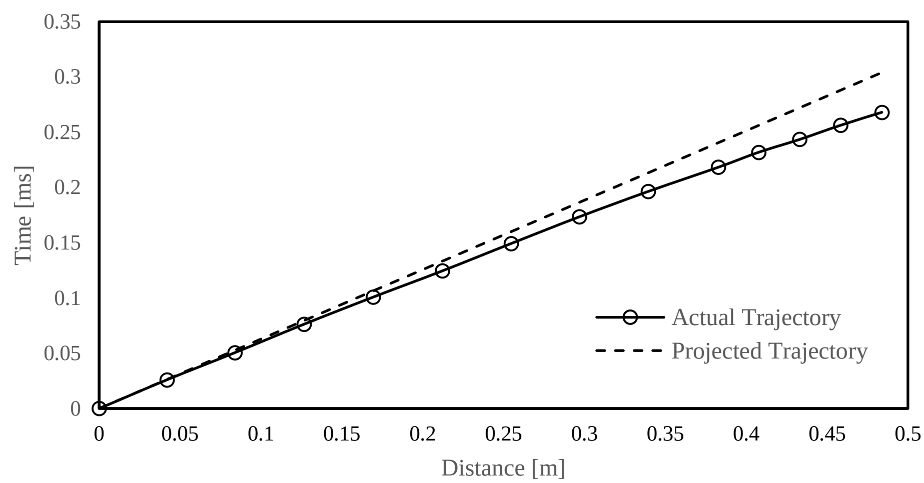
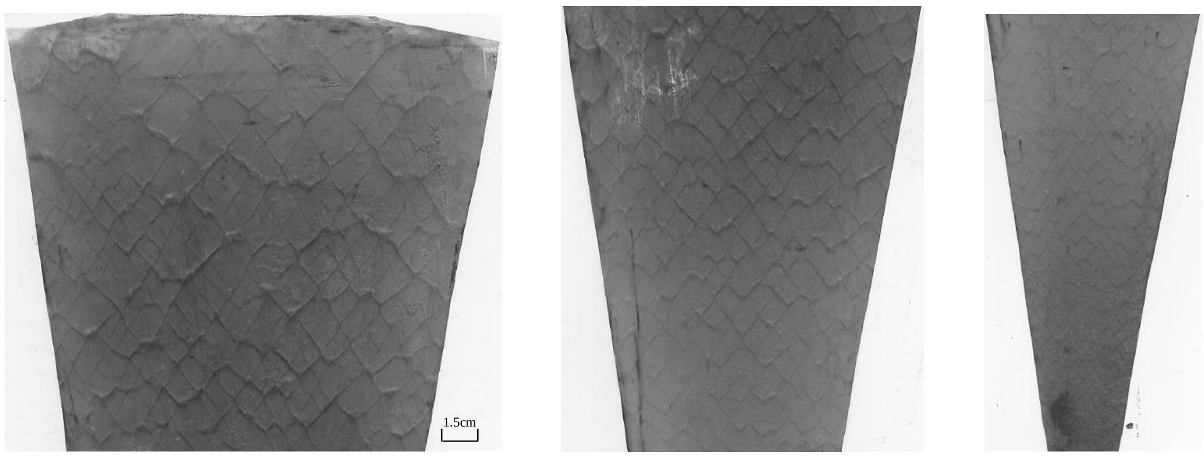



Figure 2b: x-t Diagram for $C_2H_2$+2.5$O_2$+70% Argon of 6º Convergence at 6kPa

The effect of area convergence on the cell structure is presented in the Figures 3a, 3b and 3c which show smoked foils in the converging conical section for the argon diluted mixture at an initial pressure of 6kPa. As the detonation wave progresses into the conical section, the cell size goes down continuously all the way until the end, indicating that the detonation amplifies as it converges.




Figures 3a, 3b and 3c: Smoked Foils for $C_2H_2$+2.5$O_2$+70% Argon at 6$^o$ Convergence and 6kPa

Figure 4 shows the ratio of cell size against the ratio of the position from the apex of the conical section at 6kPa at an angle of convergence of 6$^o$. These ratios are normalized by the initial values at the entrance of the converging section. The result indicates that the cell size decreases linearly with position inside the converging section. This is also observed at other initial pressures for the argon diluted acetylene-oxygen mixtures.

For the stoichiometric mixture, this is observed at initial pressures of 1.5kPa or lower, when the cell size is larger. However, above 2.0kPa the cell size is essentially the same throughout the entire conical section as there is practically no observable change in both the velocities and the cell structure, unless near the end of the converging section. The reaction zone thickness is too thin to have any discernible effect on the detonation wave which means that area convergence has very minimal, or no effect on the detonation wave as chemical energy release dominates above this critical pressure.

It should also be noted that the actual 3-dimensional detonation structure cannot be fully captured with the smoked foils. Therefore, they cannot show whether the curvature of the detonation wave matches the curvature of symmetrical spherical detonation with the center at the apex of the converging wedges.

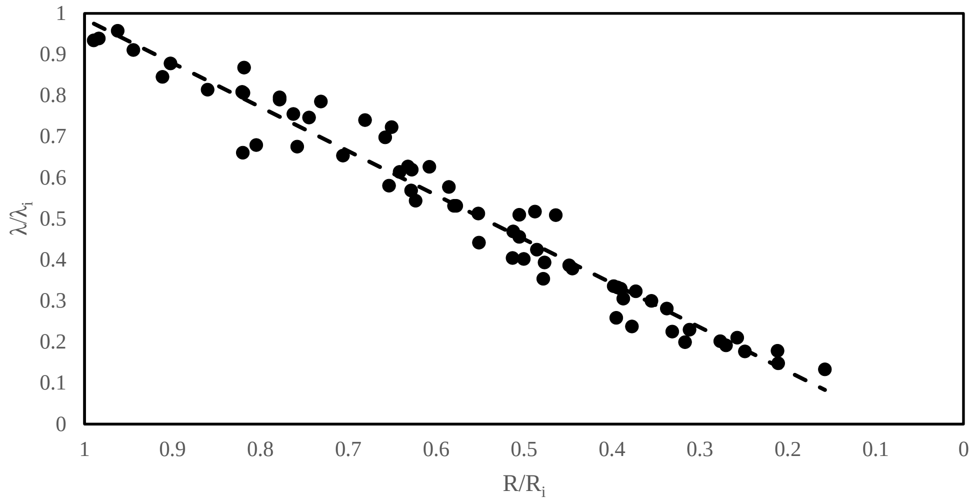



Figure 4: Influence of Area Convergence on the Cell Size at 6kPa

## 4 Conclusion

The presented results indicate that the cell size decreases continuously as the detonation wave propagates into the converging conical tube with an angle of convergence of 10$^o$ or lower, given the initial pressure is sufficiently low that the effective reaction zone thickness is large enough. Thus, it may be concluded that detonation amplification could be obtained in a conical tube with small conical angle of convergence.

## References

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