Shock Wave Induced Mixing and Reaction

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Introduction

Experiments are being performed on the interaction of a shock wave and an interface between air or oxygen and partially oxidized detonation products. The goals of these experiments are to study the mixing and subsequent chemical reactions that result from the creation of a turbulent mixing zone (TMZ) from the interface. Pintgen and Shepherd (2003) carried out experiments that examined the production of blast waves from the combustion of rich propane-oxygen mixtures inside balloons surrounded by air. In those tests, a secondary blast wave was observed for a range of rich mixtures ($2 < \phi < 3$) in the balloon. This was interpreted as being due to combustion resulting from the mixing of the partially oxidized products and surrounding air. Although repeatable results were obtained from these experiments, the geometry of the TMZ was very non-ideal due to the directionality of combustion initiation and the balloon rupture.

The experiments in the current study will greatly simplify the geometry, using a thin membrane or sliding valve to separate the interface between reactants and oxidizer. A planar detonation will be used to combust the reactants. The detonation will pass through the interface between the combustion products and oxidizer, setting the interface into motion and creating a transmitted shock wave. The interfacial acceleration caused by the incident detonation and reflected shock wave create a TMZ by the Richtmyer-Meshkov (RM) instability. The initial instability of the interface is determined by the perturbations on the interface, the velocity jump across the shock, and the Atwood number. There has been extensive prior work on the non-reactive RM instability (see review by M. Brouillette 2002) that indicates that the reflected shock can greatly enhance mixing.

Experimental Setup

The experiments are carried out in the GALCIT Detonation Tube (GDT) shown in Fig. 1. The GDT is separated into two sections by a diaphragm or valve. A fuel-rich ethylene-oxygen combustible mixture is placed on one side of the diaphragm (driver section), and oxidizer (air or oxygen) is placed on the other side (driven section). A detonation is initiated in the fuel-rich combustible mixture and propagates through the diaphragm or valve location. A shock wave will propagate into the oxidizer and an expansion wave will propagate into the partially oxidized products. The contact surface between products and oxidizer will be unstable, developing into the TMZ. The transmitted shock will reflect off the end-wall and interact with the TMZ. Figure 2 is an ideal position versus time diagram illustrating this process for a detonation in a $\Phi = 2.5$ ethylene-oxygen mixture propagating into oxygen. The initial pressure for this example experiment is 15 kPa. Simple gas dynamic calculations allow us to predict where the interaction of the reflected shock and TMZ should ideally occur. The linear RM stability theory can be used to estimate the size of the interface at the time when the reflected shock and contact surface meet. The shape of the diaphragm characterizes the initial contact surface. The diaphragm is considered to have a half sine wave mode initial profile and has maximum displacement at the center of 1 cm. The interface is predicted to be between 10 and 16 cm thick by the time the reflected shock brings it to rest near the end of the test section (Fig. 2).

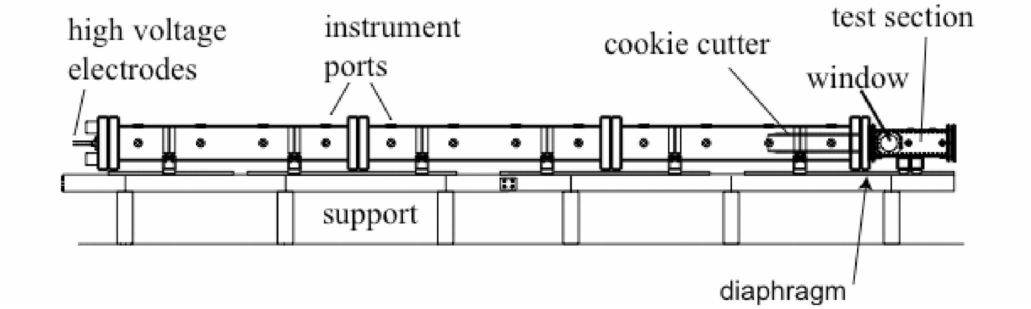


Figure 1: Schematic of the GDT facility with a diaphragm located between the cookie cutter and test section flanges. In most experiments, the test section is reversed so that the window is located near the far right end of the test section.

Results and Discussion

Initial experiments were carried out to determine the detonation cell size of the ethylene-oxygen mixtures of interest. The cell size was determined prior to the mixing experiments so that cell width could be held constant, between 2-5 cm in the shock-TMZ interaction study. Cell size was measured using the soot foil technique (Figure 3).

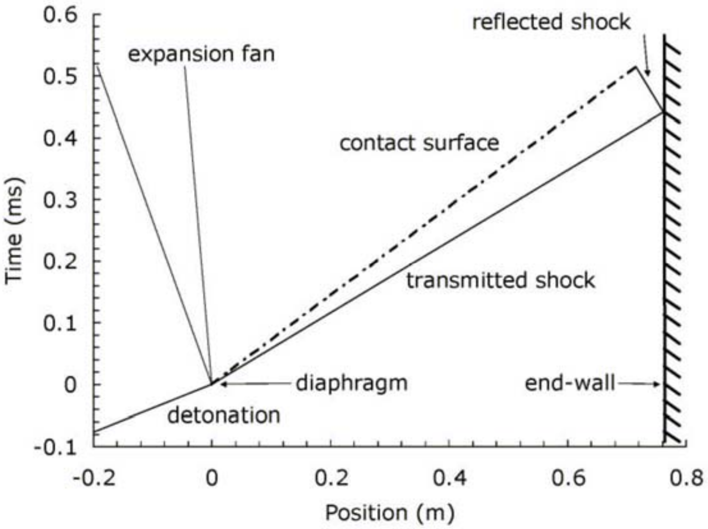


Figure 2: An ideal position vs. time wave diagram computed for an ethylene-oxygen detonation of a $\Phi = 2.5$ propagating into a quiescent mixture of oxygen. The initial pressure is 15 kPa and the initial temperature is 297 K.

A schlieren image of an ethylene-oxygen detonation at an equivalence ratio of 2.5 and an initial pressure of 15 kPa is shown in Fig. 4a. The detonation propagation is from left to right at a speed of 2622 m/s. The detonation velocity is within 5% of the CJ value. The transverse wave structure is almost invisible at this magnification but close examination shows that it is present behind the slightly curved detonation front. Figure 4b is an incident shock, moving from left to right at a speed of 1570 m/s, followed by a TMZ. The predicted ideal velocity of the incident shock wave is 1728 m/s. The discrepancy between the two values is under investigation. The initial conditions for the detonation are the same as in Fig 4a. The TMZ in Fig. 4b also contains a large piece of the Mylar diaphragm that initially separated the two mixtures.

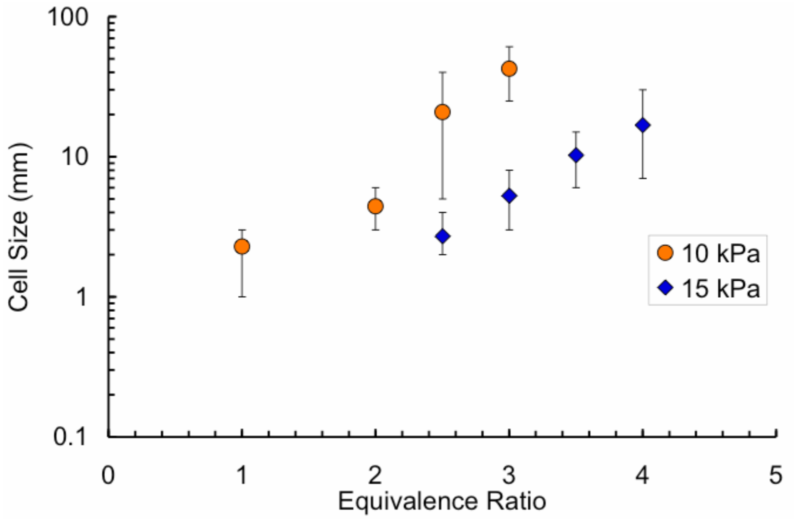
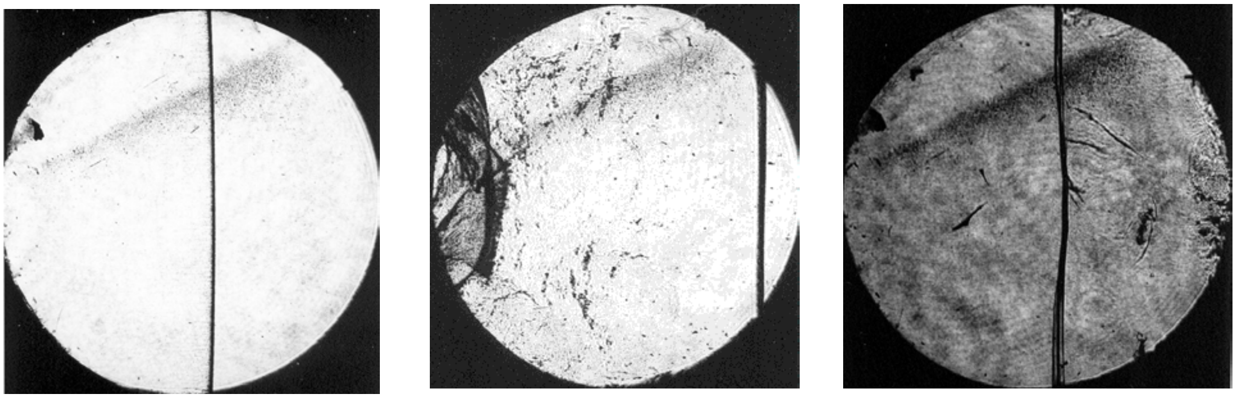


Figure 3: Cell size versus equivalence ratio for an ethylene-oxygen mixture at 10 and 15 kPa. The initial temperature is 297 K.

Figure 4c is a schlieren image of a reflected shock and TMZ (at the far right edge of the image) after their interaction.

Summary

These results are preliminary. Currently, modifications are being made to optimize the technique for separating the two mixtures so that there is a minimum impact on the results. The equivalence ratio will be varied to determine at which conditions the secondary combustion is maximized. Nitrogen will be used instead of oxygen in the driven section as a control for experiments with oxygen. The thickness of the TMZ will be measured from the visualizations and compared with existing data and models of TMZ evolution. Pressure signals, chemiluminescence, and laser-induced fluorescence will be used to examine combustion in the TMZ.



(a) **(b)** **(c)**

Figure 4: (a) Ethylene-oxygen detonation wave with a $\Phi = 2.5$ at 15 kPa initial pressure. (b) Incident shock in oxygen with TMZ. (c) Reflected shock and TMZ. Images b and c are of ethylene-oxygen detonations at a $\Phi = 2.5$ and initial pressure of 15 kPa propagating through a Mylar diaphragm into oxygen at 15 kPa.

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References

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