Experimental investigations of DDT

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1 Introduction

To achieve detonation, two different strategies are available. The first one is to direclty initiate detonation using either pre-detonator or a very high spark. The second approach relies on the transition from a deflagration to a detonation combustion (DDT). Generally, the deflagration is accelerated so as to promote turbulence and at a certain point detonation is obtained. The exact mechanisms for DDT is qualitatievely understood ([1]) even though the direct visualization of DDT events are relatively limited ([2]). One of the main problem is the exact definition of the DDT point which can not really be predicted. The present approach uses a rather simple definition for the DDT point based on a time-space diagram and is used to trigger high-speed Schlieren measurements around the DDT. The findings of the DDT within the images confirmed the simple approach used.

2 Description of the experimental facility

High-speed Schlieren is used to investigate the transition between deflagration to detonation. The characteristics of the camera used are a resolution of 312x260 pixels (Shimadzu). It has a storage capacity of 100 frames and can be easily triggered using a TTL. The maximum frame rate is 1 million with an exposure time of 250ns. The experiments were done at a repetition rate of 250 kHz with an exposure of 500ns. The camera is triggered by the pressure signal placed before the visualization region so that images are taken when the reaction front is within the test section. The test section has an overall accessible length of 160mm.

The detonation tube is filled with a mixture of hydrogen-air (stoichiometry 1.0) at an overall pressure of 67kPa. The associated Chapman-Jouguet velocity is around 2800m/s. The tube is first set to vacuum and a premixed gaseous hydrogen-oxygen is afterwards supplied until the desired pressure is obtained. The minimum pressure obtained in the tube was 1.3kPa and typical fill time requiring about 30s, it was estimated that an additional air leakage would be responsible in the worst cases of an increase of 0.4kPa. Therefore, for the lowest pressure used in the current study, the uncertainty in the mixture fraction, and actual gaseous composition is 0.015 and a possible concentration of 2%. To initiate the detonation, Schelkin wire is used. Its characteristics are 100mm long, 15mm pitch, with a diameter of 3.5mm. A discrete number of pressure sensors are used in the detonation tube and their sampling frequency is 1MHz. In the present case, only 3 pressure traces are displayed.

3 Results

To determine the position of the DDT point, several experiments are first done with pressure sensors only. On each pressure signal, the traces for the deflagration, and possibly the detonation and the retonation waves are educed. A typical example of pressure traces is given in Figure 1. To determine the position of the DDT (or at least an estimate) a space-time diagram is created ([3]).

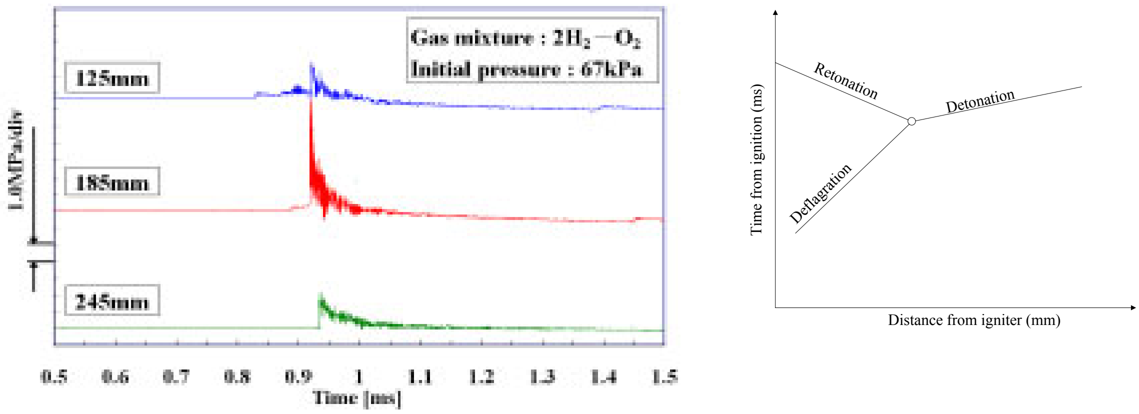

Figure 1 Examples of pressure traces and their use for the space-time diagram

Then, to estimate the DDT point, the following procedure is used. On each raw signal of pressure, determine the time for which the deflagration (if any) arrived. Report on the space-time diagram this information. Similar procedure applies for points containing either deflagration, retonation or detonation events are localized in this space-time diagram. The DDT point can then be visualized. This of course does not take into account overdriven effects for instance and serves merely as a visualization tool.

Of course, the true nature of the DDT is more complex than this ideal vision, especially as one expects overdriven conditions just after the DDT. This would lead to a velocity higher than the CJ condition. The exact position of the DDT will be determined with the high-speed schlieren systems and therefore only a qualitative information is required from the pressure sensors.

Experiments are repeated and once a proper length of the detonation tube is obtained for which the DDT point is within the visualization window, experiments are repeated with the high-speed Schlieren systems. A typical sequence of images around the DDT is discussed (see Figure 2). One can clearly see the propagating deflagration from left ro right. DDT occurs for a relative time of 32 microseconds, leading also to the developement. The exact position of the DDT is not known with accuracy but from those images it is possible to compute the different velocity using adequate digital processing tools. Each image is first binarize to retain only the information of the shock. For clarity purpose, the processed image is inverted. The planar displacement of the front is computed and leading to one velocity measurement, based on the entire width of the test section. The uncertainty achieved should be lower than 0.5 pixels with this approach, which leads to an uncertainty in the velocity of less than 100m/s.

The velocity infered from image processing are displayed in Figure 3. It is interesting to see that the measured velocity for the detonation is equivalent to the Chapman-Jouguet's velocity. From Schlieren images, no overdriven effects are seen. The concordance with CJ velocity shows that the accuracy of the processing may be better than estimated. Two main conclusions may be drawn from those mesaurements. The first one is that the DDT occured certainly at a point between frame 6 and frame 7. This is seen in both the space-time diagram and the Schlieren. The second information is that in the present case the value of the velocity before detonation was only 1000 m/s. This value corresponds to only 35% of the CJ velocity. This velocity does not change with space from the entering into the test section to the DDT point.

It is possible with this high-speed Schlieren technique to exactly know the velocity between two frames. It may be used

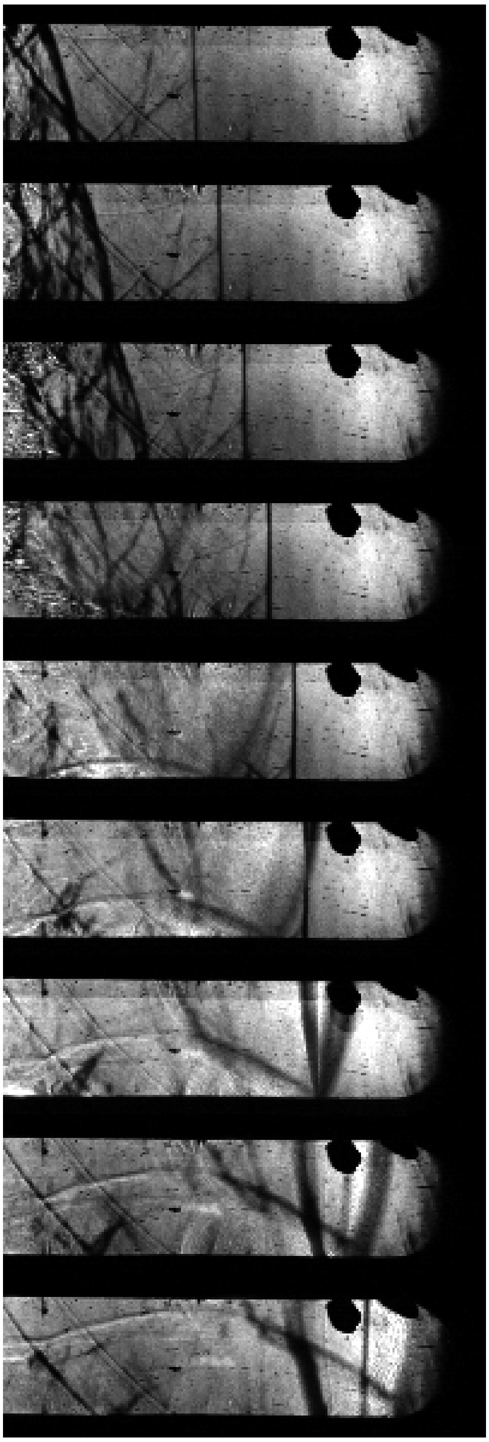

Figure 2 Sequence of DDT. The field of view corresponds to 160mm, starting 105mm from spark plug (first four images delay of 8 μs, then 4μs)

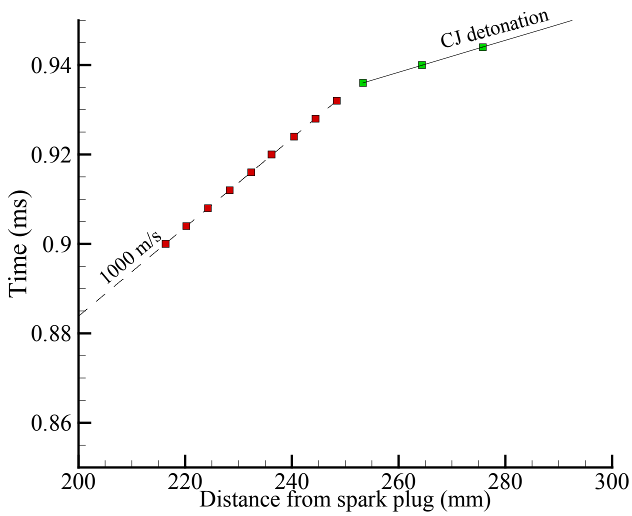

Figure 3 Velocity measured from Schlieren images

4 Conclusions

The visualization of an actual DDT event validates the relatively simple approach used to estimate the DDT point. This enables to use further optical diagnostics to study deflagration to detonation transition. Among very promising techniques, the Planar Laser Induced Fluorescence of the OH molecule, as recently introduced [4]. The interesting challenge would be to get two shots within few microseconds to actually measure the reaction front and the changes induced when DDT occurs. Technical problems like synchronization for the laser with respect to the detonation event as well as problems for enabling a strong laser power are among the most challenging issues to solve.

References

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