# An Experimental Study of Flame/Wedge Interaction in Turbulent Premixed Combustion

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#### **Extended Abstract**

This paper presents an experimental investigation of the transient interaction between propagating turbulent premixed flames and a wedge-type obstacle mounted inside a laboratory scale combustion chamber. The interaction was visualised by various laser-based optical diagnostic techniques including high-speed digital imaging and digital particle image velocimetry (DPIV). This interaction between the gas movement and the obstacle was found to create turbulence by both vortex shedding and local wake/recirculation, whereby the flame is wrapped in on itself, increasing the surface area available for combustion and the rate of local reaction rate. The influence of such local events on the overall flame propagation process and the generated overpressure as a measure of burn rate is presented and discussed. The main focus of the current work is to establish the nature of premixed combustion in the wake of sharp edged obstacles, which is of practical importance in explosion hazard and gas turbine combustion analysis.

In recent years considerable effort has been devoted to the development of experimental (e.g. Hargrave et al. [2000] and Ibrahim et al. [2001]) and numerical research tools (e.g. Patel et al. [2001]) for studying the interactions between propagating flames and solid obstructions in premixed combustion systems. In these systems, the role of turbulence is well established as a mechanism for increasing burning velocity by fragmenting the flame front and increasing the flame surface area hence the burning rate. Abdel-Gayed and Bradley [1981] have produced a range of correlations which allow the turbulence enhancement of burning velocity to be predicted. However, in real situations, such as those found in gas turbine combustors, or complex process plant areas offshore, the flame acceleration results from a complex interaction between the flame front and the local blockage caused by presence of sharp-edged bluff-body type obstructions. Such blockage causes local acceleration of the flame front in the form of jetting and also a complex interaction between the flame and the local flow fields generated around these obstacles. This interaction between the gas movement and the solid obstructions creates both turbulence by vortex shedding and local wake/recirculation whereby the flame can be wrapped in on itself, increasing the surface area available for combustion and potentially producing localised high rate of chemical reaction. The influence of such local events on the overall premixed combustion process and burn rate and/or overpressure is not well understood. It is clear, however, that any localised increase in burn rate and/or overpressure will have important implications for the efficiency of combustion in gas turbine applications or for the safe operation of chemical processing plants. The important issue at the focus of this paper is to establish the nature of premixed combustion in the wake of sharp edged solid obstructions.

In this paper, high quality time-resolved imaging of the flame is used to examine the interaction between a sharp-edged (wedge type) obstacle and a propagating premixed flame generated inside a laboratory scale combustion chamber. Laboratory scale experiments have a number of distinctive advantages. They provide highly detailed and reliable information about premixed flame development, and the generated overpressure (both location and timing). Furthermore, the experimental approach can cope with highly complex and/or irregular geometries. In situation such

as the design of new instillation, where specific information is required rather than the global peak overpressure offered by many computational methods, small-scale experiments offer a cost-effective solution.

The flame images have been used to calculate the flame speed and acceleration. In addition, the mechanisms by which over-pressures (magnitude and timing) are produced under various obstacle sizes are described and discussed. These images were accomplished by the application of both single-shot and time-resolved Particle Image Velocimetry (PIV) together with detailed digital imaging of the structure of the propagating flame.

The combustion chamber (150 mm by 75 mm rectangular cross section) was constructed from clear polycarbonate to allow optical access for visualisation purposes. The chamber was closed at the ignition end and partially open at the vent end. A blockage ratio of 37% was generated at the vent end of the chamber, which prior to ignition was sealed to contain the premixed charge using a thin plastic membrane. The wedge was fixed in place 150 mm above the ignition point/base of the combustion chamber, see Figure 1. The wedge was removable and so could be changed to generate the blockage ratio's required. A premixed stoichiometric mixture of technical grade Methane supplied from a high pressure cylinder and Air from the laboratory compressed air system was used for the investigation.

The measurement diagnostic used to visualise the interaction between the flame and wedge was schlieren imaging. This technique involved the use of an Oxford Lasers Copper Vapour Laser model LS20-50 to provide the point light source and a Kodak 4540 Motion Analyser digital CCD camera. The laser produced light of emitted wavelengths 511nm green or 578nm yellow, generating 30ns laser pulses with pulse energy of 2 mJ. Using an external trigger source the laser could be driven at Pulse Repetition Frequencies allowing it to be synchronised with the Kodak camera to run at 4500 Hz. A Nikon 105mm lens was used to obtain the images

Samples of the results are shown in Figures 2-5. These figures show a sequence of high speed imaging of the flame structure at different times after ignition for different wedge area blockage ratios of 10, 20 and 40% (Fig.2), high-speed drum camera images of flame interaction with the turbulent wake downstream from the wedge obstruction (Fig.3), the change in flame speed as it interacts with the wedge obstruction (Fig.4) and the generated over-pressure history (Fig.5). The results show the formation of vortex shedding downstream of the solid wedge as the flame starts to engulf into the recirculation zone. This interaction between the flame and the formed vortices found to result in the production of high pressure. The magnitude of the generated peak pressure found to increase with the size of the wedge. Detailed description of the mechanism of this interaction together with more results will be presented and discussed in the colloquium.

### REFERENCES

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 Data Storage PC

 Figure 1. Schematic of Experimental Rig and Laser Diagnostic Technique



Figure 2. Flame Propagation Images for (a) 10 (b) 20 and (c) 40mm wedges

Figure 3. Sequence of high-resolution images to show eddy formation during flame/wedge interaction.



Figure 4. Graph showing flame speed versus flame position for the three test cases.



Figure 5. Graph showing generated overpressure versus time for the three test cases.