EXPERIMENTS IN COMBUSTION
Lecture 1
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1. Introduction

This series of four lectures entitled "Experiments in Combustion" are revised versions of similar lectures presented in 2001 at the VKI Lecture Series "Introduction to Turbulent Combustion". Since they are largely devoted to experimental aspects in the current lecture series, they serve the purpose of introducing the reader to a broad range of experiments in combustion. Some of these use conventional measurement techniques now several years old, while others use the very latest in laser-based diagnostic approaches. Always, the results of the experiment are of primary interest, and in particular, what we learn about the mixing and combustion process in turbulent reacting flows. In every case the diagnostic technique used to obtain the results will first be discussed as it is introduced, to provide limitations and bounds upon the results themselves, thus allowing the reader to develop a sense of their applicability and reliability. Rather than introduce a series of experimental techniques and provide examples of their use, the approach taken here is phenomenological in nature so that the reader may develop a sense of:

1. How does entrainment, mixing and reaction take place in turbulent flows?
2. What is the structure of a turbulent mixing layer?
3. What is the structure of a jet diffusion flame?
4. How does fuel and air mix and burn in such flames?
5. What is the role of heat release upon the flame itself?
6. How do such flames stabilize themselves?

Given this approach, it should be stated that these lectures do not have the aim of providing broad-brush overviews of the many on-going experiments in combustion; the biannual International Combustion Symposium is useful for this purpose and the reader is also referred to a recent publication *Applied Combustion Diagnostics (2002)* edited by Kohse-Höinghaus & Jeffries which is a very useful compilation of modern diagnostic techniques in combustion and the Sandia National Laboratories sponsored Turbulent Nonpremixed Flames Workshop, http://www.ca.sandia.gov/TNF/. Instead, the four lectures will only be able to provide some limited insight into the questions posed above, and it is to be recognized that full answers will only be provided by a combination of theoretical investigations, numerical modeling and modern experimentation, all taken together. As such, these lectures provide a portion of the overall understanding and should be considered in the context of the other lectures presented in the VKI Lecture Series.

The schedule of the four lectures is as follows:

Lecture 1 will first examine the mixing and combustion process in two-dimensional turbulent mixing layers, a flow configuration common in many combustion devices. The use of simplified combustion chemistry will be highlighted as well as the probability density function (*pdf*) of mixture fraction. The challenges associated with accurately measuring the *pdf* will be described, thus motivating the need for chemically reacting experiments. Some essential differences between conventional mean and conditioned mean concentrations will be described. The mixing transition will also be described. We will then briefly discuss some single point measurements as performed in flames including Laser Doppler Velocimetry (LDV) for velocity, thermocouple measurements for temperature and Raman scattering for species.

Lecture 2 will provide similar insights into the structure of jet diffusion flames as revealed by various visualization techniques. These will include the approaches of schlieren photography, direct flame imaging, CH imaging, the use of movie sequences, and volume rendering. Laser Doppler Velocimetry (LDV) for point velocity measurements, Planar Laser Induced Fluorescence (PLIF) for flame structure, Rayleigh scattering and Raman scattering for quantitative measurements of temperature and species will be described.

Lecture 3 will be devoted largely to velocity measurements using Particle Image Velocimetry (PIV) as this approach has now begun to provide detailed field velocity measurements including vorticity and strain rates. Some of the limitations on using PIV in flames will be described to provide estimates on the accuracy of the technique. New insights into the effects of heat release, jet entrainment and flame liftoff behavior will be examined.

Lecture 4 will explore combined PIV and PLIF techniques where both velocity and scalars are measured in flames to demonstrate the difficulties and challenges of such approaches as well as the new knowledge to be derived. Recent experiments which use combined techniques will be discussed to provide descriptions of flame structure, vorticity, strain rates, the velocity of the flame surface itself, and recent findings on the transition from flame liftoff to blowout.

2. Studies of Two-Dimensional Mixing Layers

The two-dimensional turbulent mixing layer, Fig. 1 is perhaps the simplest of turbulent flows and sees application in many combustion devices including flameholders, dump combustors and backstep combustors (Coats, 1996). Since the flow is largely two-dimensional, with well-defined boundary conditions for the free-stream velocities, (U_1, U_2) and free-stream concentrations of fuel and oxidizer (c_{10}, c_{20}) the problem is also well-suited to fundamental computational studies. Figure 1 shows the expected mean velocity and mean temperature for a reacting shear layer. In this lecture, we will investigate mixing and reaction in this flow with an aim towards understanding the process by which fuel and oxidizer mix and burn, the overall efficiency of this process, the distribution of product instantaneously and in time-average, and finally, the effects of finite-rate chemistry upon this process. These studies have been performed at low-heat release, so there is no coupling of density and viscosity changes to the fluid mechanics itself. In later lectures, we will begin to address the changes that are