The University of Adelaide

Department of Mechanical Engineering

SUB CRUCE LUMEN

Mixing and Combustion in Precessing Jet Flows

Ph.D. Thesis

submitted by

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Contents

Abstract

A wide range of qualitative and quantitative experimental techniques are used to investigate the effect of jet precession on the mixing and combustion characteristics of a simple turbulent jet flow. Here precession of the jet flow results from the addition of a chamber section downstream from the throat of the simple jet which issues from a sharp edged orifice. The chamber generates a fluid mechanical instability so that the emerging jet precesses about the nozzle axis. The nozzle is termed the fluidic precessing jet (FPJ) nozzle. This nozzle has been the subject of ongoing research at the University of Adelaide because of the benefits that FPJ gas flames offer to industry.

The flow and flame characteristics associated with FPJ flows are compared with those of simple turbulent jets by use of laser sheet visualisation, particle image velocimetry and mixture field diagnostics for non-reacting flows and by use of high-speed flame visualisation and reaction zone imaging for reacting flows.

The non-reacting jet flow emerging from the FPJ nozzle is seen to form large-scale roller structures that are responsible for entrainment of significant ambient fluid. Velocity measurements demonstrate that the flow velocities in the region immediately downstream from the nozzle are dramatically reduced, by two orders of magnitude relative to the jet throat. The mixing characteristics throughout a jet produced by the sharp edged orifice are shown to be different from that produced by a nozzle with a smooth contraction. Measurements of the mean and RMS jet concentration fields, concentration half-widths and centre-line unmixedness, intermittency, integral length-scale and scalar mixing rate are compared for the simple jet flow and the FPJ flow. The findings of this comparison support the conclusion that the effect of precession is to change the underlying structure of the turbulence in a manner that reduces the magnitude of the local strain rate in the flow. The results also demonstrate conclusively that *the effect of precession of a jet is to enhance large-scale engulfment of ambient fluid and to suppress fine-scale mixing between the jet and ambient fluid streams.*

Mixing and combustion characteristics of FPJ flames have been considered in relation to the possible stabilisation mechanisms. Large-scale buoyant structures, which propagate through the unconfined FPJ flames, are concluded to be the result of, rather than the cause of, the flame stabilisation. It has been demonstrated that combustion occurs in reaction zones that are located at the edge of the flow field. The instantaneous structure of the reaction field can be seen qualitatively to coincide with the structure of the flammable region in the non-reacting flow case. The reaction layers are thick compared with the thickness of dissipation layers in the region in which reaction occurs. High values of scalar dissipation are only found within the jet as it emerges from the FPJ nozzle, which is well upstream from the mean stabilisation point.

The results demonstrate that *the physical mechanisms discussed here which have been proposed for simple jet flame stabilisation, other than those which include the existence of a premixed flame zone, are inappropriate for the fluidic precessing jet diffusion flame.* That is, stabilisation depends upon the mixing characteristics upstream from the reaction zone providing regions of sufficiently low velocity that are within the flammability limits.

Mixing and combustion characteristics of FPJ flames have been considered in relation to the reduced NO_x emissions and increased emissivity that have been measured elsewhere. The strain rate at the tip of the flame has been measured using local flame conditions for the FPJ and shown to be an order of magnitude lower than the local strain in simple jet flows based on calculations from data reported in the literature. It is demonstrated that the effect of radiation on the temperature of jet flames can become significant when the structure of jet turbulence and hence the mixing characteristics have been modified to reduce the characteristic strain rate of the reacting flow and thereby promote soot formation. A mechanism by which NO_x emissions can be reduced and simultaneously radiant heat transfer increased by proper control of turbulent mixing parameters has therefore been demonstrated.