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Department of Mechanical Engineering

The Generation of Large-Scale Structures by Jet Precession

Ph.D. Thesis

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Abstract

Research at the University of Adelaide into mixing has resulted in the development of several geometric configurations of jet nozzle, which enhance large-scale structure in the flow through jet precession. One of these, the fluidic precessing jet (FPJ) nozzle, has proven significant benefits in industrial gas flames. Precession is used to describe the motion of a vector, which defines the jet (i.e., nozzle exit velocity). The vector is inclined to the nozzle's geometric axis and rotates about that axis. An analogous mechanical precessing jet (MPJ) nozzle has been developed as a tool to allow a fundamental investigation the effects of precession on the mixing field of a well-defined simple jet of a circular cross section. The MPJ nozzle enables independent variation of the angle of inclination of a simple round jet from the nozzle axis and the rotational speed of the nozzle about the axis.

The present work investigates the effects of precession on the scalar mixing field. The hypothesis that precession acts to modify the length scales of mixing throughout the flow is argued. It is demonstrated that there are distinct regions within the flow, each of which has different mixing characteristics. Within the near field the precession of the helical footprint of the emerging jet dominates the flow. In the far field the flow develops into self-similar behavior. The transition region links the near field and far field flow regions. Mixing in the transition and far fields of the flow field is dominated by a length-scale, which is larger than the length-scale of a non-precessing jet at comparable location.

The ability of four dimensionless variables to characterize the flow are compared: the Reynolds number, $V_o d / \nu$, the Strouhal number, $f.d / V_o$, a dimensionless strain rate, $(f.d / V_o).\sin\phi$, and a modified Strouhal number, $V_o/(f.r_h)$, based on half the diameter of the helical footprint of the emerging jet. Extensive data sets have been collected for a parametric analysis into the effects of these parameters on the scalar mixing field. It is shown that the dimensionless strain rate characterizes the near field flow region best, but the helix diameter is important in the transition region.

A planar, laser imaging technique has been developed to provide both qualitative and quantitative characterization of the flow. The mixture field of a passive conserved scalar quantity, which marks the jet fluid, has been determined from planar Mie scattering in air. This technique has been validated by an investigation of a simple round jet, which represents a limiting case of a precessing jet. The data have been processed to determine the concentration statistics, the scalar dissipation and the spatial correlation results from measurements extending well into the far field, up to 100 jet throat diameters. The data provides comparative information about the spread, mixing decay rate and integral length-scale of the flows.

The results of the study confirm that the dimensionless strain rate is the most influential of the four parameters in the near field. The Strouhal number gives good characterization also, but only for a fixed deflection angle of the jet. The deflection angle also has a significant effect but of less importance than the Strouhal number. Reynolds number is seen to have a negligible effect for those values investigated. Statistics of the mixture field show significant variations in axial and radial decay. They are dependent mostly on the Strouhal number.

Measurements of the integral length-scale of the flow, via the two point spatial correlation, show that with increasing Strouhal number the integral length-scale is increased dramatically. This signifies the generation of much larger structures within the transition region of the jet and in the far field. Measurements of scalar dissipation and probability density function show that with increasing Strouhal number there is an increase in the scalar gradient in the far field. Mixing characteristics are modified as a result of large scale engulfment of fluid and the importance of shear in the mixing process is reduced relative to the non-precessing case.

It is concluded that the hypotheses are well supported by the experimental data and together provide a logical description of the dominant features of the complex mixing field associated with jet precession.

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