

3D VELOCITY AND SCALAR FIELD DIAGNOSTICS
USING MAGNETIC RESONANCE IMAGING WITH
APPLICATIONS IN FILM-COOLING

by

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Prepared with support from the
General Electric Aircraft Engines and Army Research Office

Report No. TF - #123

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April 2011

Abstract

A new Magnetic Resonance Imaging (MRI) technique was developed to measure the three-dimensional, time-averaged scalar concentration distributions in turbulent mixing applications. The diagnostic was initially developed and tested in a turbulent free shear layer experiment where it was validated using planar laser induced fluorescence (PLIF) experiments. The remainder of the study examined a three-dimensional mixing flow motivated by trailing edge film cooling of an aircraft gas turbine blade. The apparatus consisted of a NACA 0012 airfoil mounted in a contracting channel to produce an overall favorable pressure gradient. A modern slotted trailing edge cutback geometry was added in which coolant was discharged from rectangular slots separated by tapered lands. Water, and water with copper sulfate were the working fluids, and the MR-based experiments were conducted at Reynolds numbers based on airfoil chord and bulk velocity from 100,000-250,000.

The magnetic resonance concentration (MRC) technique was further refined in the film cooling apparatus to reduce the uncertainty and to provide robust measurement of the surface concentration. A series of best practices were developed which reduced the concentration measurement uncertainty to 6.0% near surfaces and 5.1% elsewhere. Further validation of the MRC technique was accomplished by conducting thermal measurements along the surface of the trailing edge and calculating the resulting surface effectiveness, which was compared to surface effectiveness inferred from surface concentration measurements.

Combined magnetic resonance velocimetry (MRV) and MRC measurements were acquired for a generic trailing edge cutback geometry. The effect of variations in the blowing ratio and Reynolds number were examined. Reynolds number was found to have no significant effect while the variations in blowing ratio produced relatively small changes. Combined MRV and MRC data sets were analyzed in detail for insight into the mean flow structures primarily responsible for rapid mixing of the mainstream and coolant flows. Longitudinal vortices formed inside the slot feed channels and at

the edges of the lands played a critical role as did the separation bubble behind the slot lip. Three modifications to the breakout geometry were designed with the goal of minimizing the adverse effects of these flow structures. Performance improvements with the redesigned trailing edge geometries indicate as much as a 40% improvement in the averaged surface effectiveness using a non-dimensional performance parameter.