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Optical Diagnostics for Turbulent and Multiphase Flows: Particle Image Velocimetry and Photorefractive Optics

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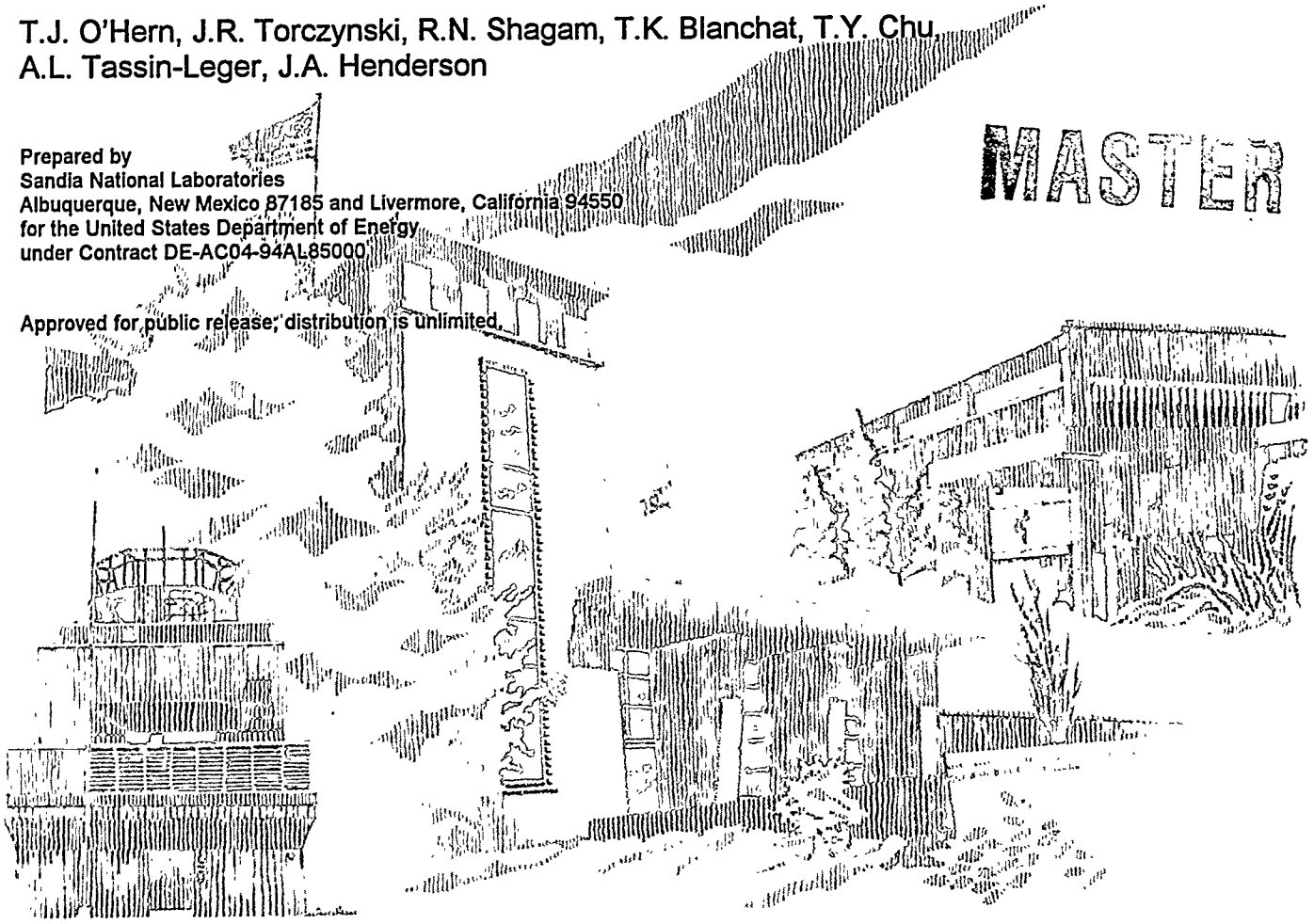

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Abstract

This report summarizes the work performed under the Sandia Laboratory Directed Research and Development (LDRD) project "Optical Diagnostics for Turbulent and Multiphase Flows."Advanced optical diagnostics have been investigated and developed for flow field measurements, including capabilities for measurement in turbulent, multiphase, and heated flows. Particle Image Velocimetry (PIV) includes several techniques for measurement of instantaneous flow field velocities and associated turbulence quantities. Nonlinear photorefractive optical materials have been investigated for the possibility of measuring turbulence quantities (turbulent spectrum) more directly.

The two-dimensional PIV techniques developed under this LDRD were shown to work well, and were compared with more traditional laser Doppler velocimetry (LDV). Three-dimensional PIV techniques were developed and tested, but due to several experimental difficulties were not as successful. The photorefractive techniques were tested, and both potential capabilities and possible problem areas were elucidated.

Acknowledgment

This work was supported by the United States Department of Energy under Contract DE-AC04-94AL85000. Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy. The support of DOE/Sandia Laboratory-Directed Research and Development (LDRD) funds is gratefully acknowledged. The technical assistance of T. W. Grasser in optical configuration, flow facility setup and maintenance, and data acquisition, is greatly appreciated. V. A. Amatucci assisted on the nonlinear optics evaluation.

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Nomenclature

C_{ij}	Correlation coefficient - used in cross-correlation tracking technique
CCT	Cross-Correlation Tracking
D_{ij}	Amount that the diameters of overlapping particles i and j - used in cross-correlation tracking technique
MFT	Multi-Frame Tracking algorithm
N_{ij}	Number of particles that overlap between Images i and j - used in cross-correlation tracking technique
R_{ij}	pair reliability index - used in cross-correlation tracking technique
R_n	Radius of search circle - used in multi-frame tracking technique
Re	Reynolds number for cavity flow = $\bar{u}(2h)/\nu$
D	Cavity Depth = 3.68 cm (Figure 2.5)
L	Cavity Length in Streamwise direction = 3.70 cm (Figure 2.5)
h	channel depth upstream of cavity = 1.56 cm (Figure 2.5)
w	channel/cavity cross-stream width = 7.76 cm (Figure 2.5)
u_x	velocity component in the x direction
u_y	velocity component in the y direction
u_z	velocity component in the z direction
u_{av}	channel mass-flow velocity
X_C	X center of main eddy in cavity flow (Figure 2.11)
Y_C	Y center of main eddy in cavity flow (Figure 2.11)
σ_l	Standard deviation from the mean for the lengths of the vectors
σ_θ	Standard deviation from the mean for the angles in the x-y plane
σ_Φ	Standard deviation from the mean for the angles from the z axis
σ	Total standard deviation
L_{x-y}	Length between particles between frames x and y
θ_{1-3}	Angle in the x-y plane between l_{1-2} and l_{2-3}
θ_{2-4}	Angle in the x-y plane between l_{2-3} and l_{3-4}
Φ_{1-3}	Angle from the z axis between l_{1-2} and l_{2-3}
Φ_{2-4}	Angle from the z axis between l_{2-3} and l_{3-4}
$\bar{L}$	Average displacement of particles between frames = $(L_{1-2} + L_{2-3} + L_{3-4})/3$
$\bar{\theta}$	Average θ of the track = $(\theta_{1-3} + \theta_{2-4})/2$
$\bar{\Phi}$	Average Φ of the track = $(\Phi_{1-3} + \Phi_{2-4})/2$

Executive Summary

This report summarizes the work performed under the Sandia Laboratory Directed Research and Development (LDRD) project "Optical Diagnostics for Turbulent and Multiphase Flows."

Advanced optical diagnostics have been investigated and developed for flow field measurements, including capabilities for measurement in turbulent, multiphase, and heated flows. Particle Image Velocimetry (PIV) includes several techniques for measurement of instantaneous flow field velocities and associated turbulence quantities. Nonlinear photorefractive optical materials have been investigated for the possibility of measuring turbulence quantities (turbulent spectrum) more directly.

The two-dimensional PIV techniques developed under this LDRD were demonstrated to work well and were compared with more traditional laser Doppler velocimetry (LDV), and with computational simulations. Two-dimensional benchmarking experiments included flow in a driven cavity and natural convection in a simulated magma chamber. Three-dimensional PIV techniques were developed and tested on the thermal convection experiment but were unsuccessful due to several experimental difficulties.

The nonlinear photorefractive crystal $BaTiO_3$ has been demonstrated as a significant visualizer of turbulent vs. steady-state flow. However, we have identified two potentially significant limitations in that it (1) appears to visualize gradients differently, depending upon the relative orientation of the gradient to the crystal fanning orientation, and (2) visualizes refractive gradients, not absolute phase change, as previously reported in the literature. The desired quantification of photorefractive measurements proved to be very difficult for these reasons.