Phase I Project Summary

Firm: MetroLaser, Inc.
Contract Number: NNX11CD83P
Project Title: Simultaneous Temperature and Velocity Diagnostic for Reacting Flows

Identification and Significance of Innovation:

A diagnostic technique was investigated for measuring temperature and velocity simultaneously in a high temperature reacting flow for aiding research in propulsion. The technique involves introducing particles of a ceramic thermographic phosphor into the flow and illuminating them with two overlapping pulsed laser sheets. Laser-induced luminescence from the particles would be measured to obtain temperature from its effects on luminescence lifetime. Velocity would be obtained simultaneously from the same particles using conventional particle image velocimetry (PIV). For the thermometry technique, pixel intensity ratios of delayed to undelayed images would be related to temperature via a calibration function. For velocity, particle displacements between the images would be used. The diagnostic was expected to enable 2D measurements of two key variables in combustion modeling that cannot be obtained in most high temperatures flows using available methods. This Phase I effort focused on the thermometry aspect of the technique, seeking to demonstrate feasibility measurements in a particle-seeded flame. However, the findings of this study showed that luminescence signal levels from Dy:YAG phosphor particles at reasonable seeding levels (up to 25 mg/m^3) are too weak to be of any use for gas phase thermometry at flame temperatures.

Technical Objectives and Work Plan:

There were four technical objectives of the work performed. The first objective was to determine the fundamental limits of phosphor thermometry in a high temperature flame, through a combination of system analysis and experimental data. The second objective was to identify the main sources of inaccuracy, and methods to mitigate them. For instance, what is lacking is a method for minimizing the error of luminescence lifetime estimates using gated imaging in the presence of multi-exponential decay kinetics. The third objective was to provide an experimental demonstration of phosphor thermometry in a flame using micron-sized particles up to approximately 1500°C. The fourth objective was to determine the requirements for accurate simultaneous gas phase temperature and velocity imaging using thermographic phosphor particles in a range of combustion environments. In particular, such measurements involve a trade-off between precision and temporal and spatial resolution.

The Work Plan consisted of the following nine tasks:

1. Kickoff Meeting
2. Construct Burner System
3. Imaging Experiments of Phosphor Particles in a Flame
4. Calibration of Phosphor Particles
5. Optimization of Dual Gate Technique
6. Demonstration of Whole Field Thermometry
7. Compatibility of PIV
8. Feasibility of PIVT
9. Reporting

Technical Accomplishments:

Of the four technical objectives, only the first two were met. Work on the first objective focused on measurements of luminescence intensity from Dy:YAG particles in flames ranging from 1200°C to 1450°C. It was found that signal levels were significantly lower than what was hoped for. In fact, no luminescence signal was obtainable in the flame. Although signal levels were too low to be measured, the results were consistent with previous work in that the new upper bound on the quantum efficiency fell within the expected range. The second objective was met in that the main source of inaccuracy was determined to be the low signal level at flame temperatures. The remaining two objectives, unfortunately, were not met due to a lack of signal. It was not possible to achieve the third objective since there was no signal on which to perform thermometry processing. However, a rudimentary image processing procedure was done on an image pair of a room temperature flow that showed some promise of the technique at low temperatures. Since phosphor thermometry measurements were not possible in the flame, there was no point in trying to achieve the fourth objective of accurate simultaneous velocity and thermometry.

NASA Application(s):

If it would have been successful, the technology that was studied would have benefitted NASA in the development of future air-breathing aerospace vehicles by providing an experimental way to verify models of turbulent reacting flow. Cross correlations of velocity and temperature are fundamental to physics based models of combustion processes, yet very little experimental data of this nature currently exists. This diagnostic would enable experimental investigations of combustors and combustion rigs that would help advance development in the areas of extremely-low-emission engines, propulsion control and engine health management, and modeling and simulation.

Non-NASA Commercial Application(s):

A diagnostic for simultaneously measuring temperature and velocity in a high temperature reacting flow does not currently exist on the market and would find widespread use in combustion research. Government labs, research institutions and universities, aircraft engine manufacturers, and automobile engine manufacturers would have been targeted as potential users of this technology.

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