Phase 2 Project Summary

Firm: MetroLaser, Inc.
Contract Number: NNX09CB74C
Project Title: ***Hydroxyl Tagging Velocimetry for Rocket Plumes***

Identification and Significance of Innovation:

In the development of rocket engines, it is often desired to measure exhaust gas velocities so that engine performance can be measured directly, as well as for understanding flow field stability phenomena related to shock patterns. However, traditional velocimetry methods involving pitot tubes or hot wires can fail under the extreme temperatures, vibrations, and dynamic pressures of a typical rocket engine. Conventional laser techniques, such as laser Doppler velocimetry (LDV) and particle imaging velocimetry (PIV), avoid such mechanical degradation issues but are difficult or impossible to implement in a rocket exhaust because they require the flow to be seeded with particles. Hydroxyl tagging velocimetry (HTV) is a new laser-based diagnostic technique that enables two-dimensional velocity measurements at multiplier points in a plane and does not require flow seeding for flows containing H2O. HTV involves “tagging” lines in the flow with OH molecules via laser-induced dissociation, and using laser-induced OH fluorescence after a short delay to observe how far the tagged lines have moved. By using a grid of lines, it is possible to track tagged points defined by the crossings of the lines, and thus to obtain a field of velocity vectors in a hostile unseeded flow.

Technical Objectives and Work Plan:

The objectives of this Phase II effort were to:

1. Extend the OH chemistry modeling and experimental validation of OH tag lifetimes to include a range of operating conditions that represent throttling, including rich and lean mixture ratios and variations in temperature.
2. Experimentally characterize the OH laser-induced fluorescence excitation spectrum near 266 nm to enable a simpler, cheaper “read” laser: the Nd:YAG.
3. Extend the performance predictions of the optical detection system made during the Phase I effort to include various forms of noise and optical aberrations.
4. Design and fabricate a working prototype HTV system for rocket applications.
5. Demonstrate the prototype system with velocity measurements in a rocket engine exhaust.

Technical Accomplishments:

A prototype HTV system was constructed and demonstrated by measuring the instantaneous planar 2D velocity field in the cap shock pattern of a small rocket engine. The technique comprises three steps: 1) OH tag lines are written into the flow via dissociation by a 193-nm laser, 2) after a delay, a light sheet from a 266-nm laser induces fluorescence from the OH tag, and 3) the fluorescence image is captured by an ICCD camera, and the velocity is computed from the measured displacement and the known delay time. Because the exhaust temperatures were less than 1000 K, it was necessary to use a read laser with a wavelength of 282 nm instead of 266. The measurements have been compared to an axisymmetric, single-equation turbulence numerical model with generally good agreement at high pressure ratios but with significant discrepancies at low pressure ratios where the cap shock pattern is formed. This data would provide excellent quantitative validation for a detailed simulation of boundary layer separation, non-equilibrium chemistry, thermal losses, and variable thermodynamic properties. These results demonstrate the utility of the HTV method as one that requires no flow seeding and is not adversely affected by high temperatures or high velocities.

Phase 2 Project Summary, continued

NASA Application(s):

As NASA prepares for the next generation of human voyages beyond low earth orbit, future plans present formidable challenges that will require new levels of efficiency in the development of hardware. For programs to stay within their budgets, new experimental test methods will likely be needed. In the past, engine development has relied largely on expensive trial-and-error testing. However, advanced experimental methods, such as HTV, can be used for validating computer models. Once validated, models can enable simulation in place of testing to arrive at optimum designs more rapidly and cost effectively.

Non-NASA Commercial Application(s):

A successful velocity diagnostic for high-temperature high-velocity exhaust flows would have broad application across the worldwide aerospace propulsion industry. Military applications include rockets, missiles, scramjets, and turbine engines, as well as new concepts in propulsion such as pulse detonation engines. Commercial applications include the development of new turbofan designs that will require improved diagnostics for achieving increased efficiency.

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