Air Force SBIR/STTR

Innovation

Air Force SBIR/STTR Innovation Story

SBIR Topic Number:
AF081-067

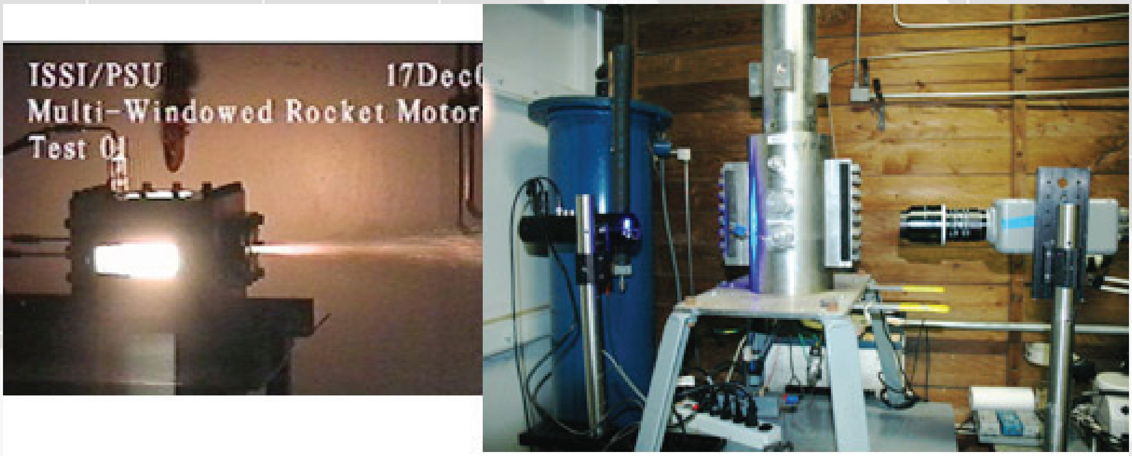
SBIR Title:
Experimental Characterization of Particle Dynamics within Solid Rocket Motors

Contract Number:
FA9300-08-M-3021 (Phase I)
FA9300-10-C-0008 (Phase III)

SBIR Company Name:
Innovative Scientific Solutions, Inc., Dayton, OH

Technical Project Office:
AFRL Propulsion Directorate (West), Edwards AFB, CA

This Air Force SBIR/STTR Innovation Story is an example of Air Force supported SBIR/STTR technology that met topic requirements and has outstanding potential for Air Force and DoD.



ISSI's PSV system monitored solid rocket propellant combustion in the Penn State SRM test chamber (left) and strand burner (right)

Experimental Characterization of Particle Dynamics within Solid Rocket Motors

- The Air Force required technology to improve the computational predictions of solid rocket motor (SRM) performance; this was developed by Innovative Scientific Solutions, Inc (ISSI)
- ISSI's resulting Particle Shadow Velocimetry (PSV) system utilizes low-power pulsed light emitting diodes (LEDs) and high speed cameras to measure the movement of particles in a combustion flow field
- Phase I measurements of particle velocity and size at Penn State were so successful that the AFRL Propulsion Directorate selected this PSV system for immediate Phase III development
- ISSI's PSV systems are capable of flow measurement in artificial cardiovascular devices, flow control, boundary layer and skin friction analysis, and aerodynamic analyses in micro UAV designs

PA 11816-M

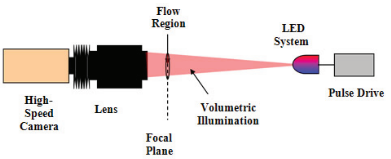
Air Force Requirement

The development of robust and accurate computational models to predict the motor performance, heat transfer, and material response within a solid rocket motor (SRM) can enable significant improvements in launch vehicle performance, development, life cycle cost, and reliability. The Air Force Research Laboratory (AFRL) needs SRM internal two-phase flow field data to validate SRM modeling & simulation codes being developed. Aluminum/ alumina particle size distribution and velocity throughout the motor, from particle creation at the propellant burn surface to the nozzle exit, are needed. These data will be incorporated into ongoing advanced modeling and simulation code development efforts to support the design and optimization of the next generation of solid rocket motors.

A new technology was required. Previous efforts using x-ray radiography, Fraunhofer diffraction, high-speed photography, quench bombs, or capture of particles in the propellant flow, either could not obtain the required information or actually altered the particle motion and combustion process.

SBIR Technology

The goal of this Phase III SBIR is to provide the required experimental data set--including particle size, velocity, and burn rate--to improve the computational predictions of SRM performance. The technology developed and demonstrated by Innovative Scientific Solutions, Inc. (ISSI) is Particle Shadow Velocimetry (PSV) as shown here. It utilizes low-power pulsed LEDs and high-speed cameras to measure the movement of particles in a combustion flow field. Light from a pulsed LED source is directed through the measurement area onto a camera. This inline arrangement allows the shadows created by the particles suspended in the flow to be recorded. Sequential images are processed by standard correlation approaches to obtain velocities. The use of LEDs combined with a high-speed camera results a system with a bandwidth of tens of kHz at much lower cost than using a pulsed laser. Another feature of pulsed LEDs is the ability to utilize multiple exposures on a single frame. This allows one to track a single particle and determine the velocity and acceleration as well as the fluid streamlines. The evolution of the particle size can be correlated with time, and information regarding the burn rate or agglomeration rate of the particles can also be determined.



ISSI Particle Shadow Velocimetry System

Potential Air Force Application

During Phase I, experimental measurements of particle velocity and size were made in two facilities at Penn State University. Data were collected using a high speed PSV system (up to 15,000 kHz) in a small SRM test chamber and in a strand burner. ASRM propellant was used at burn pressures from 50-psia to 300-psia. Sample data from these experiments yielded a mean particle size of about 75-μm, with some particles being as large as several hundred microns. The particle velocity was relatively low near the burn surface and was accelerating as it entered the flow. This particle size dependent velocity can lead to particle collision and agglomeration--a key problem for SRM performance. The AFRL Propulsion Directorate was so impressed with these Phase I results that they selected the PSV system for immediate Phase III development.

During Phase III, ISSI and Penn State University will design and build a hybrid rocket motor test system with the associated PSV instrumentation and demonstrate its use under a variety of test conditions. They will deliver a data set for the validation and enhancement of SRM modeling tools. These tools will expand the Air Force's ability to design solid rocket motors with improved performance, reliability, and life-cycle cost. This new capability is expected to impact current and future Department of Defense ballistic missile and space launch applications.

Company Impact

This PSV system has a variety of applications outside of rocket combustion analysis. This expansion of our PSV capabilities will allow ISSI to pursue them as well. For example, undergraduate institutions want students to work with the newest tools and instruments for flow velocimetry. However, safety concerns related to high-power lasers have prevented this access. The use of low-power LEDs in the PSV system eliminates these safety concerns. Scientists at other government and industry labs, as well as university graduate schools, are beginning to recognize the bandwidth, cost, and capability advantages of PSV. Traditional laser-based velocimetry systems are limited to approximately 1-kHz data capture, whereas a PSV system can easily attain tens of kHz as demonstrated in the Phase I program. In addition, a kHz LED illumination system costs approximately 50-times less than a high-speed pulsed laser.

ISSI's PSV systems offer critical new capabilities for flow measurement in artificial cardiovascular devices, for flow control, for boundary layer and skin friction analysis in wind and water tunnels, and for aerodynamic analyses in ultra-small-scale unmanned air vehicle (UAV) designs.

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