Engine Plume Sensors and Modeling

Engine plume in situ remote measurements during ground testing can provide information on the engine health and the engine performance as well as concentrations of environmentally sensitive species without disturbing the engine testing. In particular, since hydrocarbon fueled rocket engine plumes contain carbon soot because of fuel-rich combustion, soot measurements and modeling are very important. Rocket plume sensors must be able to detect gas species, temperature, and velocity for hydrocarbons (kerosene), and hybrid fuels.

Innovative sensors are required for measuring flow rate, temperature, pressure, rocket engine plume constituents, and effluent gas detection. Sensors must not physically intrude into the measurement space. High accuracy (0.2%), low-millisecond to sub-millisecond response time is required. Temperature sensors must be able to measure both cryogenic and high temperature fluids under high pressure (up to 15,000 psi) and high flow rate conditions (82 ft/sec). Response time must be on the order of a few milliseconds to sub-milliseconds.

Innovative methods in phenomenology, modeling, sensors, and instrumentation for the prediction, characterization, and measurement of rocket engine combustion instability are of interest. Sensor systems should have bandwidth capabilities in excess of 100 kHz. Emphasis is on development of optical-based sensor systems that will be non-intrusive in the test article hardware or exhaust plume.

Sensors must support integration with Integrated Systems Health Management (ISHM) technologies.
**Engine Acoustic Energy Prediction and Sensing**

The high levels of acoustic energy generated by rocket engines can be destructive to both launch vehicles and ground test/launch facilities. Current acoustic energy prediction methods can only provide a rough order of magnitude estimate of the amount of acoustic energy that a rocket engine will generate. Consequently, facilities and vehicles may be unnecessarily over designed to withstand the higher predictions, adding unnecessary weight and complexity.

New and innovative acoustic measurement techniques and sensors are necessary to accurately measure and predict the rocket plume acoustic environment. Current methods of predicting far-field and near-field acoustic levels produced by rocket engines rely on empirical models and require numerous physical measurements. New and innovative acoustic prediction methods are required that can accurately predict the acoustic levels a priori or using fewer measurements. New, innovative techniques based on energy density measurements rather than pressure measurements show promise as replacements for the older models.

**Computational and Modeling Tools and Methods**

The wide range of pressures, flow rates, and temperatures associated with rocket propulsion systems result in complex dynamics. It is not realistic to physically test each component and the component-to-component interaction in all states before designing a system. Consequently, systems must be tuned after fabrication, requiring extensive testing and often component redesign. Tools and methods are necessary that will allow the use of computational methods to accurately model and predict system performance.

Development of tools that integrate simple operator interfaces with detailed design and/or analysis software for modeling and enhancing the flow performance of flow system components such as valves, check valves, pressure regulators, flow meters, cavitating venturis, and propellant run tanks. In addition, new and improved methods to accurately model the transient interaction between cryogenic fluid flow and immersed sensors that predict the dynamic load on the sensors, frequency spectrum, heat transfer, and effect on the flow field are needed.

**Propulsion System Exhaust Plume Flow Field Definition and Associated Plume Induced Environments (PIE)**

An accurate definition of a propulsion system exhaust plume flow field and its associated PIE are required to support the design efforts necessary to safely and optimally accomplish many phases of any space flight mission from sea level or simulated altitude testing of a propulsion system to landing on and returning from the Moon or Mars. Accurately defined PIE result in increased safety, optimized design, and minimized costs associated with:

- Propulsion system and/or component testing of both the test article and test facility;
- Launch vehicle and associated launch facility during liftoff from the Earth, Moon, or Mars;
- Launch vehicle during the ascent portion of flight including staging, effects of separation motors, and associated pitch maneuvers;
• Effects of orbital maneuvering systems (including contamination) on associated vehicles and/or payloads and their contribution to space environments;

• Vehicles intended to land on and return from the surface of the Moon or Mars; and

• Effects of a vehicle propulsion system on the surfaces of the Moon and Mars including the contaminations of those surfaces by plume constituents and associated propulsion system constituents.

In general, the current plume technology used to define a propulsion system exhaust plume flow field and its associated plume induced environments is far superior to that used in support of the original Space Shuttle design. However, further improvements of this technology are required:

• To reduce conservatism, in the current technology, allowing greater optimization of any vehicle and/or payload design while keeping in mind crew safety through all mission phases; and

• To support the efforts to fill current critical technology gaps (below). PIE areas of particular interest include: single engine and multi-engine plume flow field definition for all phases of any space flight mission, plume induced acoustic environments, plume induced radiative and convective ascent vehicle base heating, plume contamination, and direct and/or indirect plume impingement effects.

Current critical technology gaps in needed PIE capabilities include:

• An accurate analytical prediction tool to define convective ascent vehicle base heating for both single engine and multi-engine vehicle configurations;

• An accurate analytical prediction tool to define plume induced environments associated with advanced chemical, electrical and nuclear propulsion systems; and

• A validated, user friendly, free molecular flow model for defining plumes and plume induced environments for low density external environments that exist on orbit, as well as interplanetary and other planets.