Title: Monitoring of Thermal Protection Systems and MMOD using Robust Self-Organizing Optical Fiber Sensing Networks

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Objectives: The general aim of this work is to develop and demonstrate a prototype structural health monitoring system for thermal protection systems that incorporates piezoelectric acoustic emission (AE) sensors to detect the occurrence and location of damaging impacts, such as those from Micrometeoroid Orbital Debris (MMOD). The approach uses an optical fiber Bragg grating (FBG) sensor network to evaluate the effect of detected damage on the thermal conductivity of the TPS material. Following detection of an impact, the TPS would be exposed to a heat source, possibly the sun, and the temperature distribution on the inner surface in the vicinity of the impact measured by the FBG network. A similar procedure could also be carried out as a screening test immediately prior to re-entry. The implications of any detected anomalies in the measured temperature distribution will be evaluated for their significance in relation to the performance of the TPS during re-entry. Such a robust TPS health monitoring system would ensure overall crew safety throughout the mission, especially during reentry.

Background: Thermal protection systems (TPS) used for spacecraft heat shields are subjected to various thermal-mechanical loads which can negatively impact heat shield performance. There are currently no in-flight inspection methods that can accurately and thoroughly assess the health of TPS and thereby ensure safe operation prior to reentry. The objective of this project is directly aligned with NASA Office of Chief Technologists Space Technology Roadmap TA09.1.5 – Entry Descent & Landing Systems, Instrumentation and Health Monitoring. In this roadmap, entry instrumentation for vehicle health monitoring is identified as "crucial for improving the design of current systems, and for ensuring sufficient system reliability prior to deployment or use." Furthermore, the roadmap recommends NASA invest in advanced instrumentation systems utilized in this project.

Technical Approach: The project work elements first included the development of a robust optical fiber network. An important aspect of this project is the development of a robust, electronically-reconfigurable FBG network that employs the optical frequency domain reflectometry (OFDR) technique to measure temperature-induced strains in the Bragg gratings. The network has a high degree of redundancy to ensure its continued effectiveness in the event of damage to one or more fiber segments. Light can be routed around damaged fiber segments, so that the network can continue to operate even when some regions of it are damaged. The demonstrator architecture and structure developed loosely simulates a segmented, circular ablative thermal protection system. A comprehensive program of measurement of the acoustic and thermal properties of the materials used in the demonstrator structure has been carried out in order to underpin the development of computational models of acoustic and thermal propagation within the structure. Acoustic and thermal modeling was used to determine sensor densities and placements: piezoelectric AE sensors are bonded to one surface of the TPS material and the FBG network described above is embedded in the bond layer, in between two layers to the TPS material. The demonstrator systems, below middle, will undergo testing with simulated impact events and damage evaluate impact detection/localization and a functional demonstration of TPS health monitoring. The final outcome of the project will be incorporation of the monitoring system into a larger-scale TPS experimental structure at Dryden in FY14, below right.

Customers: All of NASAs current and future space vehicle programs will benefit significantly from this project. This project targets the Reliability/Life Assessment/Health Monitoring in the NASA Office of the Chief Technologist Roadmap TA12, Materials, Structures, Mechanical Systems and Manufacturing Element 2.5 NDE and Sensors, wherein the key technological challenge is to develop methodologies for high fidelity detection and characterization of flaws and degradation in complex built-up structures.

Metrics: Publications and test reports outlining results, procedures and progress.

Products: Results will be compiled and published at various conferences and symposia. Final report will be provided to the appropriate offices within NASA.

Accomplishments during this period:

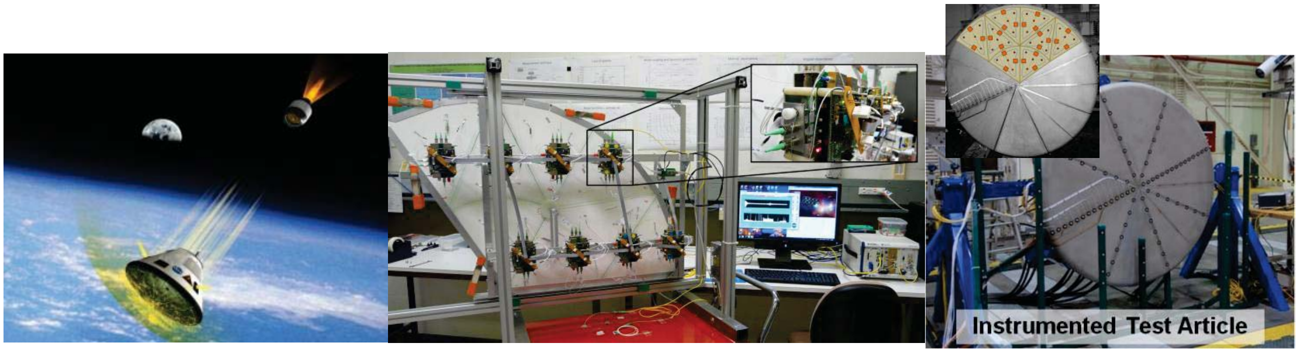
- Design and fabrication of an 8 tile TPS health monitoring system (HMS) has been completed
- Demonstration on two tiles with NASA staff in December 2012 has verified basic impact detection and thermography functionality
- Self organization of the FBG network paths has been demonstrated using the 8 tiles agents
- Quartz lamp heat source installed and tested
- Heat shield carrier structure delivered to CSIRO for TPS HMS installation

Status and Plans:

- Laboratory testing will evaluate the TPS health monitoring system
- Complete system thermal scan for health check or to establish base line
- Impact simulation using high energy Nd:YAG laser
- Localization of impact location by processing of AE sensor signals
- Simulation of damage by removal of insulation material plug
- Thermal measurements of damaged region – comparison to base line gives evaluation of functional damage

Key Facilities

- NASA Dryden Flight Loads Laboratory
- Commonwealth Scientific and Industrial Research Organisation (CSIRO) Sydney Australia



CSIRO Australia has worked with NASA LaRC to develop and demonstrate monitoring of impact damage with multi-agent architecture. The TPS health monitoring system at CSIRO Sydney (middle). A test heat shield at NASA Dryden has been fabricated and shipped to CSIRO for system integration. The heat shield and integrated health monitoring system will be shipped back to Dryden for testing in FY15.