

Title: Monitoring of Thermal Protection Systems 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, and 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.

FY13 Schedule/Milestones:

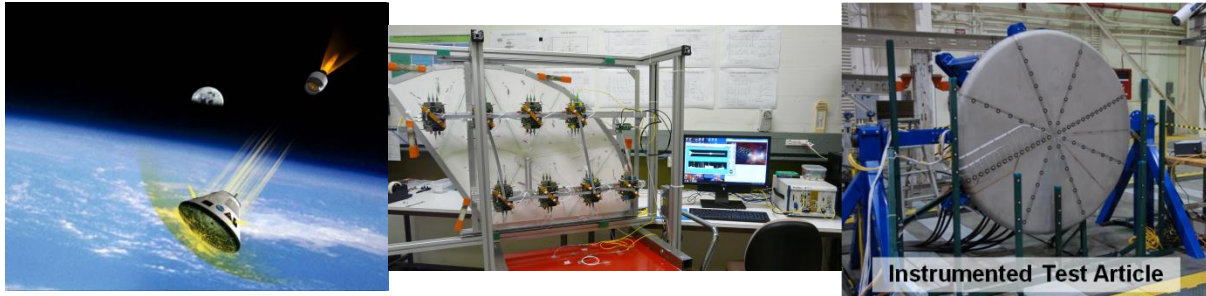
Status & Accomplishments during this period:

- NASA PI was served as a keynote speaker at an international workshop on structural health monitoring in Melbourne Australia in December 2012.
- Results of the research on optical fibre sensor networks were presented at the 2012 Australasian Conference on Optical Fibre Technology.
- Final design of the TPS health monitoring demonstrator has been completed and reported on.
- The demonstrator components including the tiles with embedded optic fiber systems, acoustic emission sensors and electronics have been constructed and assembled together.
- The software for data acquisition, processing, communications and control has been completed.

- The self-organized configuration of the optical sensing network in response to impact events has been demonstrated.
- During FY13 testing aim to demonstrate TPS impact detection and location followed by a functional demonstration of full TPS health monitoring.

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 for thermal protection health monitoring.