In situ Sensors for Monitoring the Space Environment and Its Effect Upon Satellite Materials

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Introduction

Development of advanced materials for space requires both an understanding of the space environment and how a material might be affected by the environment. Despite a long history of space missions, we have insufficient knowledge to fully characterize the exposure that spacecraft materials experience over a mission lifetime, much less the effects that this exposure induces upon spacecraft materials. In addition, the physics of materials/environment interactions is less well understood than optimum owing to the complex nature of the space environment and the challenges in simulating this environment in the laboratory. Our understanding of both the environment and materials behavior in that environment would be advanced by the development of sensors that could be deployed on a variety of missions and collect sufficient data. In-situ environmental sensors would improve both our understanding of spacecraft materials environmental durability and lead to improved ground-laboratory investigations.

There are a number of factors that have limited the development of a widespread network of space environmental sensors intended to fill this need. The cost of deploying space systems generally encourages system designers to minimize any functionality that is extraneous to the main mission of a space vehicle. Deploying additional sensors adds cost, size, weight, power and telemetry bandwidth that could interfere with mission goals. The complexity of the space environment makes it challenging to manufacture a sensor that provides a complete characterization of its environment, especially with a limited impact upon the host. Finally, such a hosted sensor could impact the security or reliability of the main mission.

Challenges

Innovative solutions are needed to develop (1) sensors that provide insight to the space environment and (2) instrumentation that provides knowledge of the response of critical materials properties to this environment, all without causing undue impact to the satellite.

For the environmental sensors, the challenge is complex, as the environment in a particular orbit may contain a wide variety of stressing conditions (vacuum, temperature extremes, atomic oxygen, UV/electron/proton and other high energy radiation), and these conditions are spatially and temporally varying.

For the materials characterization instrumentation, the challenge is to provide insight into the nature and degree of any degradation without interfering with the operations of the space vehicle. For example, measuring the reflectance change of a thermal control paint on orbit could require instrumentation that might actually shield the paint from the environmental exposure, or prevent the painted thermal control surface from performing its intended purpose.

Low cost, miniature non-invasive environmental sensors that are capable of measuring a multitude of properties need to be developed. To be of the most value, these sensors must not only be versatile, but accurate, suggesting that designers must consider a means of in-flight calibration/validation of performance. On-sensor processing to calibrate, collect, interpret and summarize the data would minimize the telemetry bandwidth that such a sensor would consume, but could impact the size, weight and power (SWAP) of such an instrument. Optimization of cost, SWAP and performance would impact acceptance of such sensors for flight on a variety of systems. While it might not be possible to develop a universal sensor that is relevant for every possible environment, and in some cases it may actually be overly complex to deploy a sensor that includes functionality that is not required, the development of a standard interface for a family of sensors (or sensor suites) would be beneficial.

Materials characterization instruments need to be developed that would allow collection of a variety of critical performance parameters. Sensors that are able to use existing spacecraft bus or payload instrumentation to infer materials properties would be ideal, as they would minimize cost and SWAP. An example of this would include the power output of solar cells vs. time. While the collected data would have to be corrected for solar panel orientation and orbital location, overall degradation can be determined. Unfortunately, this degradation could be related to more than one cause (e.g., low energy radiation exposure of the coverglass material and coatings, higher energy radiation effects on adhesive used to attach the coverglass to the cell, and even higher energy radiation effects on the cell itself). The role of temperature of the cells, influenced by other materials on the panel, would need to be considered in the data analysis. If such temperatures aren’t routinely measured, then further instrumentation would be necessary.

Thermal instrumentation of other satellite surfaces (radiators, blankets, painted panels) could also be valuable for assessing the optical degradation of these materials. For parameters that aren't already collected as part of the baseline mission, new sensors would be required. Examples might be (a) contamination monitors sufficiently small and low cost that they could be deployed in multiple locations, or (b) deployable cameras with sufficient resolution/sensitivity to characterize changes in the appearance of spacecraft exterior surfaces. These could be combined with appropriate light sources to enable quantitative measurements.

Opportunities

Better understanding of the space environment encompassing a wide variety of earth orbits and extra-terrestrial missions would allow for more accurate prediction of system performance and lifetimes, and would allow for informed development of advanced materials required for use in stressing environments. Understanding of how materials respond to actual, complex, flight conditions will inform ground based testing that cannot fully simulate the multiple stimuli found in space. If we can reduce uncertainty regarding synergistic effects, it should be possible to reduce the overall costs of materials qualification.

A key benefit that might be realized by deployment of in-situ space environmental sensors would be the ability to monitor the real time environment of a satellite, providing the host vehicle an assessment of whether the current conditions posed a hazard (e.g., solar storms) to their mission/hardware. This assessment could enable an autonomous response (maneuver, protective operation mode) to prevent damage to the system. This functionality could provide incentive to mission planners to host these sensors.

Implementation/Workforce

Developing collaborations between universities, commercial, and government participants will greatly expand the range of sensors that might be developed and the opportunities for flying them in diverse orbits/missions. If the sensors could be deployed on cubesats/small sats, the likelihood of wider acceptance/use would be improved. Small-sat based sensor platforms developed for these purposes could also be proposed as independent space-environment measurement platforms by organizations specifically interested in space weather. The input from this community would further assist development of future advanced sensors.

Funding is required for both sensor development and to provide mission partners the incentive to host these sensors. Existing efforts at NASA, NOAA and other organizations would provide an excellent foundation for a coordinated effort to develop, deploy and interpret the data gathered from current and to-be-developed sensors for these purposes. Polling of the community would provide insight as to the extent and capabilities of existing sensor/test platforms.

To facilitate widespread adoption of these sensors, standards need to be developed for the sensor/host interface. This would need to address protection/security of the host vehicle from interaction with the sensor, and a standard format for data transfer to the ground. As mentioned above, on-board processing may help limit the communications bandwidth that such a sensor might require, but could add cost and SWAP to the device. The potential for gathering large amounts of data suggests that teaming with data science community would be of value. Data developed through these in-situ sensors should be incorporated into a community database.

Outcomes/Impact

A more thorough understanding of the complex space environment would reduce the risk of fielding systems in new orbits, and likely greatly reduce costs incurred from overdesign of shielding/thermal control and power systems. Better understanding of materials response to these complex environments, gathered real-time to enable better insight to causes of degradation, would accelerate development and use of new materials by improving understanding of the validity of ground based tests.

Development and validation of new materials, especially “active” or “smart” materials has the potential of enabling new missions or better system performance with existing missions. Improved understanding of the space environment, and how to best simulate this environment on the ground (aided by the collection of on-orbit materials response to known environments) will enable more rapid development of these game-changing materials. The economic benefits for both new and traditional missions could be significant.