LAD-C: A LARGE AREA COSMIC DUST AND ORBITAL DEBRIS COLLECTOR ON THE INTERNATIONAL SPACE STATION

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ABSTRACT

A 10 m^2 aerogel and acoustic sensor system has been under development by the U.S. Naval Research Laboratory (NRL) with main collaboration from the NASA Orbital Debris Program Office at Johnson Space Center. This Large Area Debris Collector (LAD-C) is tentatively scheduled to be deployed by the U.S. Department of Defense Space Test Program (STP) on the International Space Station (ISS) in late 2007. The system will be retrieved, after one to two years of data and sample collection, for post-flight analysis. In addition to cosmic dust and orbital debris sample return, the acoustic sensors will record impact characteristics for potential orbit determination of some of the collected samples. Source identification based on their dynamical signatures may be possible. The LAD-C science return will benefit orbital debris, cosmic dust, and satellite safety communities. This paper presents an overview of the mission objectives, basic configuration, deployment consideration, and science return of the experiment.

1. BACKGROUND

Cosmic dust particles, or micrometeoroids, are known to exist throughout the Solar System. The main sources of micrometer-to-centimeter sized micrometeoroids in the inner Solar System are asteroids and comets (both long-period and short-period). Once released from their large parent objects, these small particles will spiral slowly toward the Sun under the influence of Poynting-Robertson drag. It is this sun-ward motion that brings micrometeoroids from sources well outside the regions of 1 AU to the near-Earth environment. The Earth's accretion rate of micrometeoroids is estimated to be about 15,000 to 40,000 tons per year [1, 2]. *In situ* measurements and sample return of these particles in the near-Earth environment provide direct and inexpensive ways to study primitive materials from other constituents of the Solar System.

In addition to micrometeoroids, man-made orbital debris, from micrometer-sized solid rocket motor exhaust and satellite breakup fragments to meter-sized retired spacecraft and rocket bodies, also occupy the near-Earth space from about 100 km altitude up to the geosynchronous orbit region around 36,000 km altitude [3, 4]. Currently more than 9,000 objects are tracked by the U.S. Space Surveillance Network and maintained in the U.S. satellite catalog [5]. Due to sensor detection and tracking limitations, catalog objects are limited to about 10 cm and larger in size. There are many more smaller objects that cannot be detected or tracked by ground-based sensors. As human space activities continue to intensify, and with no viable means to remove large and massive objects from space, it is expected that the orbital debris population will continue to grow significantly in the foreseeable future [6].

The existence of micrometeoroids and orbital debris in the near-Earth environment also poses challenges for the satellite operations and safety community. The impact speed between a satellite and debris can be as high as 15 km/s. The impact speed between a micrometeoroid and a satellite can easily exceed that. The outcome of such hypervelocity impacts can be catastrophic. For example, the damage caused by an impact from debris smaller than 0.1 mm can lead to the replacement of a Shuttle window [7]. Therefore, the micrometeoroid and orbital debris impact risks to operational satellites, Space Shuttles, ISS, and future space transportation systems must be evaluated carefully. The appropriate shielding design must be implemented to protect valuable space assets and mission objectives. To meet this challenge, both ground-based sensors and space-based *in situ* measurements are needed to characterize the micrometeoroid and orbital debris populations. Since the orbital debris population continues to evolve over time, a regular monitoring is also needed to update the environment definition. However, since the return of the Long Duration Exposure Facility (LDEF) in 1990, there

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has been a lack of large area *in situ* sensors in the low Earth orbit region to monitor the environment.

2. LAD-C OVERVIEW

LAD-C consists of two major components: aerogel cells and acoustic sensors. The former are used for intact capture of hypervelocity impact particles while the latter are designed to record impact characteristics of the collected samples. The basic structure of LAD-C is an upside down T-shaped system. The three arms are connected to a base hub mounted on a truss on ISS. Each one of the three arms consists of four 1 m × 1 m × 2.5 cm trays. Each tray is further divided into two half-panels. Each aluminum panel contains many small aerogel cells and twelve acoustic sensors attached to the aluminum frame. The total aerogel collection area is about 10 m^2. An illustration of the basic LAD-C system configuration is shown in Figure 1.

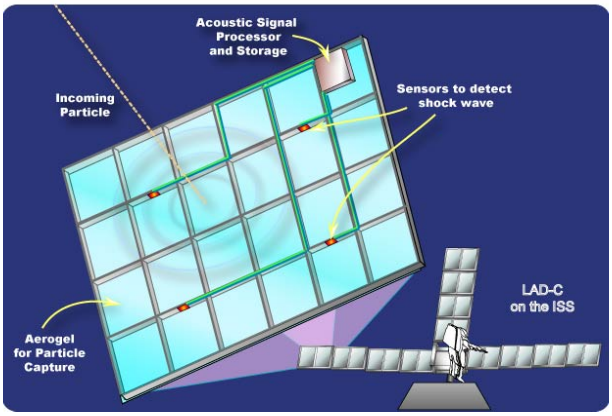

Figure 1. Illustration of LAD-C aerogel collector and its integrated PINDROP acoustic impact detector subsystem (and configuration to be deployed on the ISS).

Aerogel has been used to capture orbital debris and micrometeoroids in the near-Earth environment. For example, the Orbital Debris Collector (ODC) was deployed on the *Mir* Station between 1996 and 1997 [8] and the Micro-Particles Capturer (MPAC) was placed on ISS in 2001 [9]. Two key differences make LAD-C stand out from previous experiments. First, the collection area of LAD-C aerogel is 10 m^2 (with a density of 0.04 g/cm^3). It is more than one order of magnitude larger than all previous experiments combined. With a long mission duration (one to two years), the LAD-C aerogel collector will be able to capture a significant number of large particles - particles 0.1 mm and larger, for laboratory analysis. Second, the acoustic sensors attached to the aerogel frame will record impact time and location (from signal triangulation), signal strength, and acoustic waveform of each impact. After the aerogel collector is returned, the acoustic signals will be analyzed and correlated with samples embedded in the aerogel. The dynamical impact signature of each large collected sample will be identified.

Many hypervelocity impact tests on aerogel have been performed to correlate impact speed, impact angle, projectile properties, and aerogel density with impact features embedded in aerogel [10-13]. The impact direction can be reconstructed, from a good track, to within 2°. Due to the difficulties in projectile characterization and aerogel quality control, however, other correlations are less certain. Nevertheless, within the range of 7 km/s impact speed, there are clear trends that relate impact speed to track length, track volume, and other features. Additional calibrations will be carried out for the specific LAD-C aerogel to aid the post-flight analysis and data interpretation.

The LAD-C acoustic sensor system is called PINDROP (Particle Impact Noise Detection and Ranging On Autonomous Platform) [14, 15]. It was developed under the support of the NASA Planetary Instrument Definition and Development (PIDD) Program. The sensor design was optimized by fabricating and testing sensors of various configurations and materials. The sensor material selected is a PVDF (poly-vinylidene fluoride) copolymer, which has high sensitivity, low mass, and good transient response [14, 15]. Acoustic propagation was also examined in an airgun facility using an aerogel-populated tray. It was an acoustically complicated mechanical structure, involving at least four wave types each with distinct characteristics (i.e. speed, damping). Mode conversion between these wave types was prevalent during signal propagation, complicating the algorithm needed to estimate the impact location from the acoustic time records. This complication was partly resolved by matching the sensor amplifier to reduce undesired wave components.

At the conclusion of the PIDD-supported project, the PINDROP system capability was evaluated in a series of successful hypervelocity impact tests. These tests were conducted at University of Kent at Canterbury using particles of various sizes, and speeds of 2 to 5 km/sec. The tests confirmed the ability of the system to detect and locate impacts from particles at least as small as 30 μm, and illustrated the relationship between signal amplitude and impacting particle size and speed.

3. DEPLOYMENT CONSIDERATION

LAD-C deployment consideration is driven by two factors: to maximize the science return and to minimize contamination. The micrometeoroid and orbital debris impact rates and impact speeds are very sensitive to the orientation of the collection surface. A good balance is needed to maximize the sample collection for both micrometeoroids and orbital debris. A simple orbital debris flux estimate is shown in Figure 2. It is clear that port and starboard facing orientations lead to the highest orbital debris impact rate (between debris 0.1 and 1 mm in size) while the forward (ram) facing orientation has a slightly lower rate. The reason ram facing direction does not yield the maximum flux is due to the fact that the orbital debris population does not have a uniform inclination distribution in the environment.

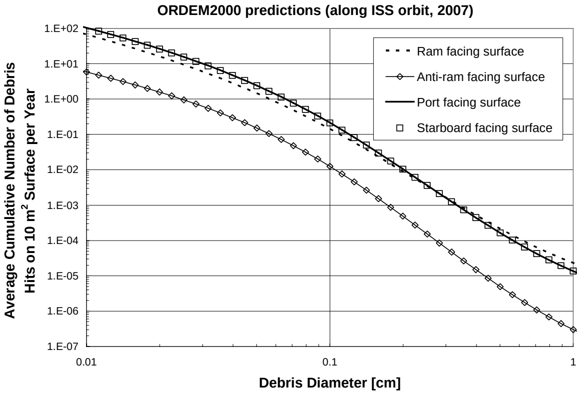

Figure 2. Estimated orbital debris impact rates on sensors with four different orientations mounted on ISS in 2007.

The calculation of Figure 2 is based on the NASA Orbital Debris Engineering Model ORDEM2000 [16]. A similar calculation can be made to estimate the impact speed distributions on the same four orientations. As shown in Figure 3, a significant portion of impacts on the port and starboard surfaces is less than 7 km/s, where the impact characteristics are better understood and the tracks embedded in aerogel are better preserved for impact speed estimation.

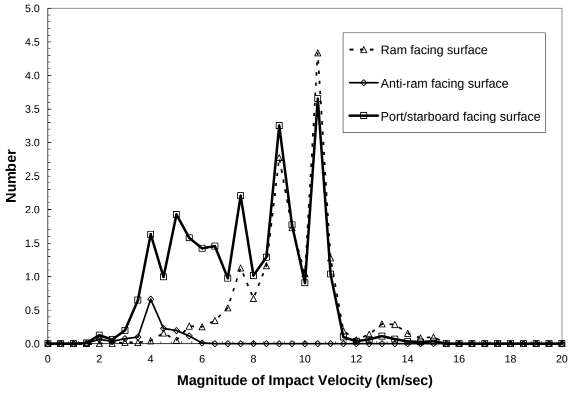

Figure 3. Estimated orbital debris impact speed distributions on sensors with four different orientations mounted on ISS. The curves are normalized to the impact rates as shown in Figure 2.

Micrometeoroid impact flux and impact speed distributions are different from those of orbital debris. Since micrometeoroids appear to enter Earth's atmosphere with an isotropic distribution, the highest flux is expected on a ram facing surface. The distribution on surfaces with different orientations depends on the velocity distribution of micrometeoroids in interplanetary space [17]. Asteroidal particles typically have a lower velocity distribution than cometary particles [18]. The combined velocity distribution depends on the asteroidal-to-cometary micrometeoroid ratio, which is, unfortunately, highly uncertain. Additional factors such as Earth's gravitational focusing and shielding effects also make the estimate more difficult. The best estimate appears to suggest the port/starboard side flux is about a factor of 2 lower than the ram side flux [19]

Any *in situ* sample capture experiments on ISS must evaluate the contamination issue carefully. Possible sources of contamination include thruster plume (from Space Shuttle, Progress, and Soyuz), water/waste dumps from ISS, and outgassing from other ISS components. For example, Shuttle thruster plume releases gas, solid, and liquid droplets with speeds up to about 2 km/s [20]. Some of the particles may be as big as 10 μm in size. Recent analysis on MPAC, mounted near the Russian module with ram and anti-ram facing surfaces, indicates that the aerogel was heavily contaminated, possibly by plume particles [9]. Figure 4 shows the planned location of LAD-C on ISS. The LAD-C location is indicated by the white cross.

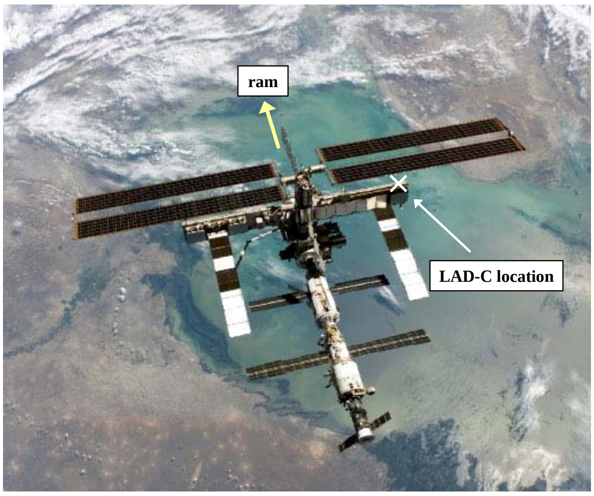

Figure 4. The configuration of ISS as of January 1, 2006. The starboard side (right) is less contaminated than the port side where water/waste dumps occur. LAD-C aerogel tiles face the starboard direction (toward the right).

According to the ISS contamination analysis, the port side environment is heavily contaminated. Therefore, the location on the starboard side truss, indicated by "X", appears to be ideal. The aerogel surface faces the starboard direction. When Shuttle is approaching, docked to, and departing from ISS, the Reaction Control

System (RCS) thrusters on the nose of the Shuttle release significant amount of plume particles. A starboard facing orientation can mitigate the contamination problem. The plume particles will only hit the back side LAD-C and will have minimum effect on the aerogel. The starboard side facing orientation also reduces the chances of the aerogel surface being hit by other contaminants release from ISS.

As NASA moves forward to complete the construction of ISS, additional modules and components will be brought up and assembled. It is highly likely that before the deployment of LAD-C, the truss will be extended and two rotating solar panels will be added to the right of the LAD-C location. An analysis is currently underway to evaluate potential shadowing effects. It may become necessary to rotate the aerogel surface by some small angle toward the ram direction to reduce the effects.

4. CONCLUDING REMARKS

LAD-C attempts to utilize ISS as a scientific platform to characterize the near-Earth micrometeoroid and orbital debris environment in the size regime where few data exist. With the addition of acoustic sensors, impact characteristics of the aerogel-collected samples will be recorded. This will enable the potential source identification of some of the collected samples. This dynamical link can be combined with laboratory analysis of the collected samples to further our understanding of orbital debris and the sources of micrometeoroids – asteroids and comets.

Acknowledgement

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