# Space Materials Center

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## Introduction and Summary

Materials used on the exterior of spacecraft or space structures are subjected to many environmental threats that can cause degradation. As an example, in low Earth orbit (LEO) these threats include photon radiation, ultraviolet (UV) radiation, vacuum ultraviolet (VUV) radiation, x-rays, solar wind particle radiation (electrons, protons), cosmic rays, radiation belt ions and electrons, temperature extremes, thermal cycling, impacts from micrometeoroids and orbital debris (MMOD), spacecraft self-contamination, and atomic oxygen (AO). These environmental exposures can result in various types of materials degradation such as erosion, embrittlement, changes in charging properties, and optical property degradation threatening spacecraft performance and durability [Townsend 1999, de Groh 2015]. Hazardous environmental threats exist in all space environments.

Because spaceflight materials exposure opportunities are rare, expensive, space-limited, and time-consuming, ground laboratory testing is most often relied upon for spacecraft material environmental durability prediction and measurements of fundamental material properties. However, differences exist between ground facilities and actual space exposures, which may result in differences in material responses. For example, ground-based environmental durability tests conducted by the Hubble multilayer insulation (MLI) Failure Review Board members indicated that exposing materials in accelerated tests to environmental model predicted spacecraft mission exposures can underestimate the extent of damage that occurs in the space environment [Townsend 1998, Dever 1999]. Therefore, actual spaceflight data are needed to validate the durability of a material for spacecraft mission applicability. In addition, data from actual materials spaceflight experiments can be used to determine correlations or validations between exposures in ground test facilities and space exposure, allowing for more accurate predictions of in-space materials performance based on ground facility testing [Stambler 2011].

Materials spaceflight experiments have been flown on the Space Shuttle, the Long Duration Exposure Facility (LDEF), the Russian space station Mir, and other spacecraft [de Groh 2008]. More recently, experiments have been flown as a part of the Materials International Space Station Experiment (MISSE) missions on the exterior of the International Space Station (ISS) along with the European Space Agency's and Japan Aerospace Exploration Agency's ISS space exposure facilities [Finckenor 2020, de Groh 2010, de Groh 2021]. As stated, these flight experiments are rare and expensive. A Space Materials Center is being proposed to *facilitate the sharing of spaceflight samples, retrieved spacecraft component materials, and flight data with the space community*. In addition, ground-tested materials would also be shared. A second important part of the proposed Space Materials Center is being responsible for a Space Materials Database. The Space Materials Database would include the materials available for community sharing, along with other ground test and flight materials data.

Spaceflight samples, and returned spacecraft materials, are very unique. When a principal investigator (PI) has completed all desired testing, it is proposed that they make the samples available to the space materials community for additional testing and analysis via the Space Materials Center. In addition, ground-testing samples for spaceflight qualification could also be shared. Storage of samples may be at either the PI's location with retained ownership of the samples, or at the Space Materials Center. But, information on the material, location, prior testing, space exposure or other pre-conditioning of samples, and availability for destructive or non-destructive testing would be curated by the Space Materials Center. Materials and points of contact would be electronically accessible to users.

The proposed Space Materials Center would have two main divisions, a Space Materials Samples Division and a Space Materials Database Division. The Space Materials Samples Division would have three subdivisions: one for space exposed materials, one for ground-tested materials exposed to simulated space environmental effects, and one for pristine untested space material samples. The Space Materials Database Division will house a database listing flight materials, along with material properties relevant for use of materials in the space environment, to advance science and engineering of materials in space. The database is complementary to the Space Materials Samples Division since it functions as a repository of information on material properties collected from the work on space-exposed and ground-tested materials. An example of the proposed organization is provided in Figure 1.

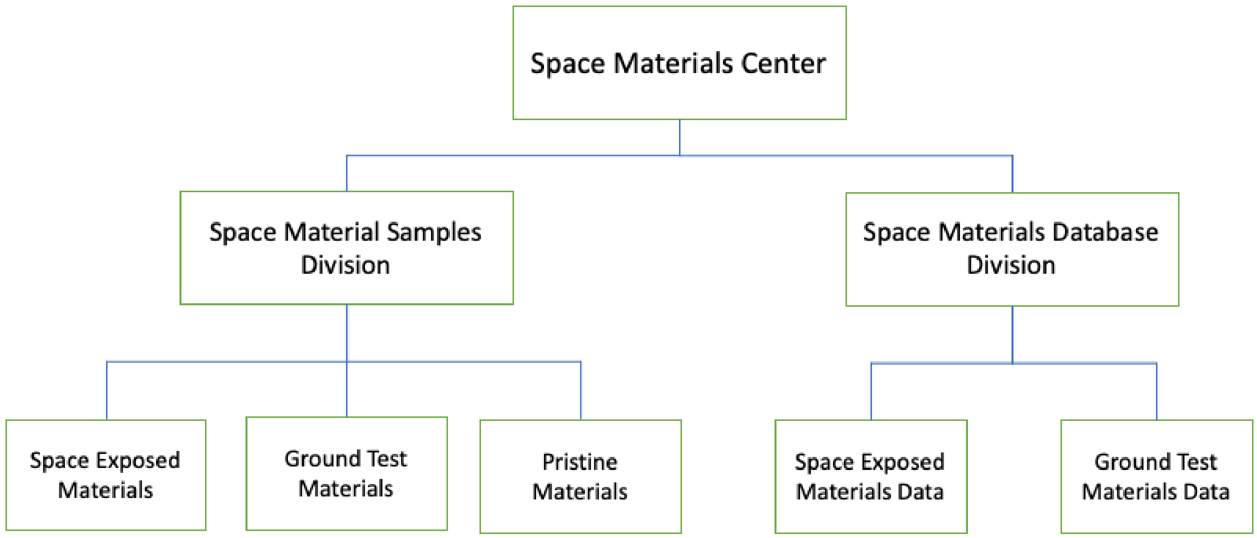


Figure 1. Proposed organizational chart for the Space Materials Center.

Examples of existing material databases include NASA's Materials and Processes Technical Information System (MAPTIS), Physical Sciences Informatics, and MISSE databases (within MAPTIS) as well as the outgassing databases maintained by NASA GSFC and JAXA. NASA's Spacecraft Charging Materials Database (SCMD) and ONERA's Characteristics of Material Interactions with the Space Environment (ChaMISEn) are examples of databases of electrical properties materials used in spacecraft charging applications. GRANTA is a commercial material database management tool distributed by Ansys, Inc. that can be integrated into many of the Ansys design and analysis tools. The proposed Space Materials Database would include materials information and relevant properties of the space materials available for testing, along with a wider variety of materials data than currently available in the existing databases. For example, the Space Materials Database would include data from the Long Duration Exposure Facility, Shuttle mission experiments, Russian Space Station Mir space exposure experiments, etc. Export controlled or other limited distribution information can be addressed by structuring the Space Material Samples and Space Materials Database with material available to the public in one section and restricted distribution materials sequestered in a separate section that is only available to eligible users. The Materials Space Center Database would also be available to international researchers for the open-access materials data.

While not specifically material property databases, some interesting examples of database software tools used by the space engineering community include NASA's Coordinated Data Analysis Web (CDAWeb) and JAXA's Data Archive and Transmission System (DARTS) space environment data archives and the Seradata commercial satellite database and space market analysis system. Many of these existing archives could provide useful models and features as examples for consideration when developing a space material database.

## Challenges

Several challenges need to be considered when developing the Space Materials Center. First, an organization would need to come forward to accept the responsibility for funding, development, and maintenance of the Space Materials Center to assure long term commitment to the project. This organization, The Space Materials Center, would serve as the administrative lead for the database and work with the space materials technical community to determine what material properties are to be included in the archive, how to best distribute the data, and respond to user questions regarding the data. The Space Materials Center would also be responsible for determining where the data is located and what sources will provide data including government, industry, and academia from both domestic and international sources.

For the Space Materials Samples Division, obtaining buy-in from the community to provide access to their material samples could be challenging. The owners of the materials will need to determine whether they will maintain storage of the material, and whether the material can be destructively tested or needs to remain intact (non-destructive testing only). Also, the environmental history for some of these samples may not be well-known or documented, however a method will need to be developed to document as much as possible.

In developing the Space Material Database Division, technical issues include selecting a format for data entry and determining what properties would be included in the database. Many material properties are lot specific and/or application specific so a method for identifying material lots and specific applications for material treatments (surface roughness, coatings, etc.) would need to be included.

A significant challenge that will need to be overcome is the hesitancy within the space materials community, particularly in the private sector, to share data in a public forum due to proprietary, export control, competition sensitive issues, and other distribution restrictions. These issues have already been shown to exist for current databases.

Finally, a decision will need to be made whether the Space Materials Center would be free for users (which would likely require a government sponsor) or would use a paid subscription or licensed access to support the project in part or in full. A free database would allow for greater access to the community but it might be difficult to find a sponsor to agree to allocate the resources to support the project long term.

## Gaps and Opportunities

Spaceflight materials samples, either space-exposed or from ground testing in simulated space environments, are often not fully tested and characterized before projects end. These materials typically remain stored and maintained by different organizations through the spaceflight community, and are not always known or accessible to others who could benefit from further testing and characterization of these materials.

Some of these samples have a very unique environmental exposure history either in space or in simulated space environment ground testing, providing an opportunity to reduce or eliminate the need for further simulated environmental exposure of materials for qualification testing. Giving the spaceflight community access to leverage past materials test data could also eliminate duplicate or repeat test efforts. Although there is an existing library of some material samples that have been exposed to the space environment at NASA JSC, this library could potentially be linked to this Space Materials Center to enable a single point source for obtaining flight materials samples or data from many organizations and facilities (both space exposed and ground tested). In addition, providing access to these flight materials will enable round-robin testing of materials properties from a wide range of organizations.

The Space Materials Database would address the current gap that arises when space environments personnel try to obtain information on material properties relevant to the space environment. This information is needed both for research applications as well as spacecraft design. There is likely a large amount of retesting of materials due to limited access to information on materials that have already been tested for use in space, as well as flight data from past missions. A space material database would serve as a clearing house where users can obtain information from past testing and flights, offering opportunities to reduce the scope of test campaigns or eliminate testing altogether.

Even if material properties from ground testing and space flight are available, often the test methodologies used to obtain the data are not well documented. Including detailed test reports and analysis of flight records including telemetry records, in-situ tests of materials in space, and records of material success and failures will need to be included in the database to document the source of information. The reports will provide the critical information on data quality, relevant environments, and test methods used to obtain the material data that is often difficult to find in the open scientific literature.

In order to satisfy the space materials community needs, the Space Materials Database will need to be flexible and able to incorporate a variety of data types. Examples could include (but are not limited to) fundamental physical properties such as density, chemical composition, surface treatments (rough or smooth, coatings, and other surface properties), fatigue and fracture properties, coefficients of thermal expansion, alpha and epsilon optical parameters required for thermal analyses, and electrical properties of materials for spacecraft charging work. In addition, how these properties vary after exposure to ionizing radiation, atomic oxygen, UV/VUV, and other space environments is an important consideration to be included in the database. Since many properties are temperature dependent, information on material properties from cryogenic temperatures to very hot environments is needed to fully inform the user for space applications.

A number of important features should be included when developing a centralized database to hold the space material information including the ability to search based on material types, properties, environment exposures, and other information needed for specific applications. An ability to vet the test reports to assure accurate and useful data without compromising export control or proprietary restrictions would allow data to be collected from a large user community. Finally, linking the test data and flight data to test reports within the database will provide the critical information for users to understand how the data was collected and the quality of the data. Periodic round-robin testing can be used to validate data quality across the community. In addition, tagging the material samples and database entries with a digital object identifier (DOI) number would provide the useful ability for users to search for material information when using a DOI resolver (search tool) on the internet.

An additional functionality to include in the Space Materials Database are lists with links for existing ground-based and ISS exposure facilities. This feature would help spacecraft designers and users of the material samples and material property database to locate appropriate facilities for testing of materials in simulated space environmental effects.

## Workforce

Realizing this vision necessitates a workforce at the Space Materials Center, along with the scientists, engineers, and researchers (universities, commercial, and government participants) who are providing the space materials and data.

The Space Materials Center would also have a goal for STEM outreach. It would leverage the materials available to motivate research at universities. It could provide internship opportunities for university students to participate in data collection, populating the database, and reaching out to organizations. Thus, another goal for the Space Materials Center would be to support the pipeline for future space materials research, by getting students and early career researchers involved in flight research.

The initial development of the Space Materials Center would require an organizing team to initially determine what data and materials are to be included. This organizing team will need to work with a sponsoring organization who is responsible for the financial resources required to develop and support the center and database. Development of the database could follow the format and features used in NASA's MAPTIS database and incorporate features from many of the other existing material databases listed in the introduction.

Long term success of a Space Materials Center will require administrative and IT support to develop and maintain the material sample repository and database as well as engagement from materials science and engineering subject matter experts at all stages of development and operation to assure the database contains relevant and accurate records.

## Outcomes

There are three main key goals that drive the need for a Space Materials Center. These include: 1). More people would have access to flight materials data, 2). More comprehensive characterization of unique flight materials, and 3). Better correlations of flight data with ground-test data with additional flight data and corresponding modeling.

In addition, the vision of the Space Materials Database is to create a framework or system for the space materials community to share information on material properties relevant for space applications, results from laboratory tests of materials, and information on success and failures for material applications in space missions. This system would serve as a resource for the space material community to report results from laboratory tests and flight experiments, find out what has been accomplished by other users, and show where additional work is required.

## Impact

The scientific and technological impacts of the Space Materials Center are wide ranging. The Center provides a one-stop location for space materials data and space-exposed or ground-tested flight materials. Currently, it is difficult to know where to go to find specific spaceflight data (i.e. what materials have flown in space, what data is available for specific materials, the location of certain ground-test facilities, etc.). This effort would also generate more data from space-exposed and ground-tested space materials that would then be available to the space community. For example, some materials might have had limited post-flight testing, due to lack of test capabilities or funds, and other organizations would be able to conduct supplementary post-flight analyses of the samples. There are also instances where spaceflight samples were returned, but the samples were not tested at all, post-flight. These untested flight samples could be provided to the Materials Space Center for potential analysis by others. The increased availability of data on space-exposed materials would also be widely available to validate ground-test procedures, so ground-testing can more accurately simulate the degradation of materials in space. More data would enable improved models for better prediction of materials behavior in spaceflight.

The Space Materials Database not only provides a resource for sharing laboratory test and flight results, it also begins to collect information on a variety of material sources, preparations, surface treatments, and other variables in physical properties of a material that can be used to look for trends in material behavior in the space environment. The Space Materials Database and the Space Materials Samples repository are complementary functions since the database serves to archive information collected from the space exposed materials and laboratory test samples available through the Space Material Samples repository.

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