

Space Environments and Spacecraft Effects Concept: Transitioning research to operations and applications

Edwards D.L.¹ Burns H.D.², Clinton, R.G.³, Schumacher, D.³, Spann, J.F.⁴

¹ NASA, Marshall Space Flight Center, EV40, MSFC, AL 35812

² NASA, Marshall Space Flight Center, EM50, MSFC, AL 35812

³ NASA, Marshall Space Flight Center, ZP01, MSFC, AL 35812

⁴ NASA, Marshall Space Flight Center, ZP10, MSFC, AL 35812

Abstract

The National Aeronautics and Space Administration (NASA) is embarking on a course to expand human presence beyond Low Earth Orbit (LEO) while expanding its mission to explore the solar system. Destinations such as Near Earth Asteroids (NEA), Mars and its moons, and the outer planets are but a few of the mission targets. NASA has established numerous organizations specializing in specific space environments disciplines that will serve to enable these missions. To complement these existing discipline organizations, a concept is presented focusing on the development of a space environment and spacecraft effects organization. This includes space climate, space weather, natural and induced space environments, and effects on spacecraft materials and systems. This space environment and spacecraft effects organization would be comprised of Technical Working Groups (TWG) focusing on, for example: a) Charged Particles (CP), b) Space Environmental Effects (SEE), and c) Interplanetary and Extraterrestrial Environments (IEE). These technical working groups will generate products and provide knowledge supporting four functional areas: design environments, environment effects, operational support, and programmatic support. The four functional areas align with phases in the program mission lifecycle and are briefly described below. Design environments are used primarily in the mission concept and design phases of a program. Environment effects focuses on the material, component, sub-system and system-level selection and the testing to verify design and operational performance. Operational support provides products based on real time or near real time space weather observations to mission operators to aid in real time and near-term decision-making. The programmatic support function maintains an interface with the numerous programs within NASA and other federal agencies to ensure that communications are well established and the needs of the programs are being met. The programmatic support function also includes working in coordination with the program in anomaly resolution and generation of lesson learned documentation. The goal of this space environment and spacecraft effects organization is to develop decision-making tools and engineering products to support the mission phases of mission concept through operations by focusing on transitioning research to application. Products generated by this space environments and spacecraft effects organization are suitable for use in anomaly investigations. This paper will describe the organizational structure for this space environments and spacecraft effects organization, and outline the scope of conceptual TWG's and their relationship to the functional areas.

1. Introduction

NASA has identified six strategic plan goals for 2011¹. These goals are the top level challenges for the Agency and drive Agency decisions for the future. The exploration of space beyond Low Earth Orbit (LEO) is identified in many of the strategic goals for 2011. Specifically, these goals are: 1) 'extend and sustain human activities across the solar system'; 2) 'expand scientific understanding of the Earth and the universe in which we live'; 3) create the innovative new space technologies for our exploration, science, and economic future'; and goal 5) 'enable program and institutional capabilities to conduct NASA's aeronautics and space activities.' These goals describe an achievable and technically challenging objective. Integrated within these goals are robotic precursor missions to destinations such as Near Earth Objects (NEO), the lunar surface, solar system planets, and the Lagrange points.

Additional facets of this goal include commercial crew and cargo to transport humans to the International Space Station (ISS), the development of Earth and climate observatories, expanded planetary, astrophysics, and heliophysics science missions. These initiatives and missions will be executed within multiple Directorates and require the expansion of existing Programs and establishment of new Programs. An Agency-level Space Environments and Spacecraft Effects (SESE) organization would provide a cost-effective means to increase the National collective knowledge and provide a peer-reviewed suite of tools for engineers and designers to use in support of exploration Programs. The SESE would develop and maintain a National capability providing coordination amongst existing space environments and spacecraft effects-related organizations, develop products to support design, development, and operation of spacecraft systems that will accommodate or mitigate effects due to the presence of the space environment. The SESE would disseminate that information for Agency, inter governmental, industry, academia, and international use while providing a cost-effective means to increase our collective knowledge and provide a peer-reviewed suite of tools for scientists, engineers, and designers to use. The goal of the space environment and spacecraft effects organization is to transition research to applications enabling the collection, development and dissemination of space environment knowledge that are required to perform mission concepts studies, design, manufacture, and operate reliable, cost-effective spacecraft for the government and commercial sectors that accommodate or mitigate these effects of the space environment while ensuring continuity of SESE knowledge. This space environment and spacecraft effects organization will strive to ensure synergy by working in coordination with existing space environment, space weather, and spacecraft effects organizations. The term 'coordination' in this context is defined as two or more organizations working together in a way that enhances their capabilities through multiplication of efforts, and does not render either organization dependent on the other.

2. Organization Function, Structure and Responsibilities

The space environment and spacecraft effects (SESE) organization consists of a management office whose responsibilities include performing knowledge gap analysis in the National space environments and spacecraft effects community, competitively funding the development of products to close the knowledge gap, management of the contractual agreements, dissemination of products, communicating with Programs, Agency leadership, and the National space environments technical community. The SESE management office consists of a chief, a deputy, subject matter experts, administrative and communication support personnel. International partnerships will be coordinated by the SESE management office.

The Space Environments and Spacecraft Effects organization will communicate with the existing space environments related organizations and facilitate coordination across the space environments disciplines. The SESE organization will develop products and provides technical knowledge in four functional areas that align with mission life cycle phases, as shown in figure 1. These functional areas are not staffed organizations; rather they serve as an indicator to the nature and usage of the product being generated. The functional areas are; Design Environments, Environment Effects, Operational Support, and Programmatic Support. Design environments are used primarily in the mission concept and design phases of a program. Environment effects focuses on the material, component, sub-system and system-level selection and the testing to verify design and operational performance. Operational support provides products based on real time or near real time space weather to mission operators to aid in real time and near-term decision-making. The programmatic support function maintains an interface with the numerous programs within NASA and the federal government to ensure that communications are well established and the needs of the programs are being met. The programmatic support function also includes working in coordination with the program in anomaly resolution and generation of lessons learned documentation.

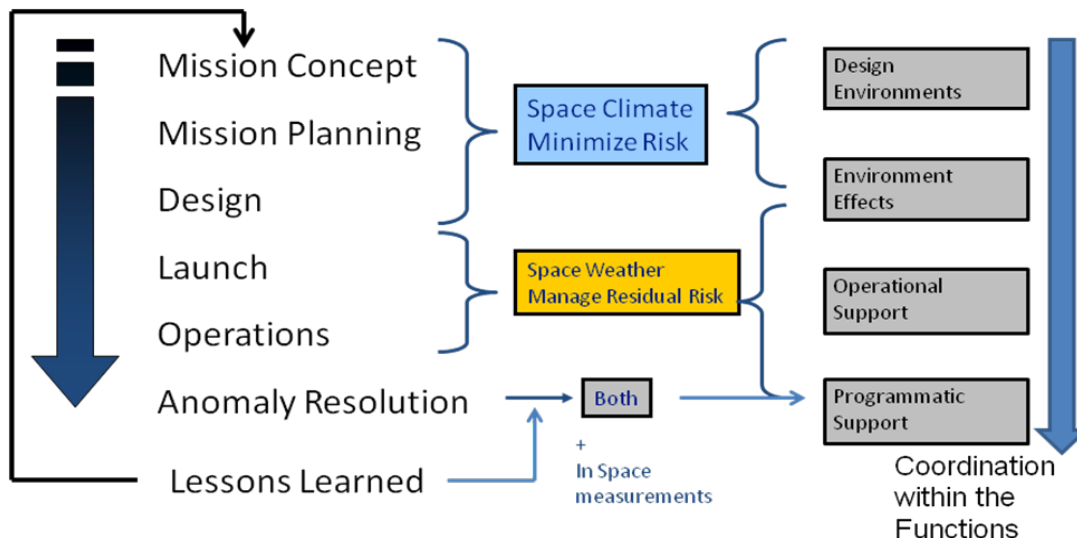


Figure 1. Space Environment Model Use in the Mission Life Cycle

An example of a space environments and spacecraft effects organizational structure is shown in figure 2. The SESE has a management office to oversee the operations of the SESE organization. The SESE office is responsible for ensuring product development alignment with Agency goals and objectives, coordination amongst pre-existing space environment, space weather, space environmental effects organizations to identify, reduce or eliminate unwanted redundancy in the development of space environment related products. The SESE office is responsible to conduct workshops, meetings, surveys, and use available means to determine gaps in the discipline of space environment and spacecraft effects. Once gaps are identified then coordinate with, if warranted, existing organizations to develop strategies, advocate for, or provide funding to develop knowledge and close identified gaps. The SESE office is responsible for the appropriate dissemination of products.

The part of the organization that significantly influences the year to year direction and activities resides within the technical working groups (TWGs), which are in turn comprised of subject matter experts (SMEs) in their respective disciplines. These SME's are the scientists and engineers supporting government and commercial spacecraft development flight programs, professors in academia, experts residing in science and engineering organizations throughout Nation. The SME's that constitute membership in the TWG's are also associated with professional societies, other national, and international, space environment organizations and thus are able to serve as a common interface that links the existing discipline specific existing organizations to the SESE and vice-versa. The SESE will host a workshop every year to assemble the TWG SME's in a structured forum. This forum will be used to gather information for gap assessments, and provide technical interchange within the SME's through technical presentation format. The yearly workshop, hosted by the SESE will also serve to 'stitch' together the various space environment-related organizations within NASA, other government agencies, the commercial sector, academia, and internationally.

Products developed by the TWG's will support all phases on the Program mission life cycle. For example, a Charged Particle (CP) TWG could develop a data set of design environments suitable for early mission concept studies and near-real time empirical models that provide spacecraft operational support. A Space Environmental Effects (SEE) TWG could provide systematic data of radiation effects on the latest materials used in spacecraft components. An Interplanetary and Extraterrestrial Environments (IEE) TWG could provide expected outgassing of near-earth asteroids. These conceptual TWGs are described in more detail in the next three sub-sections.

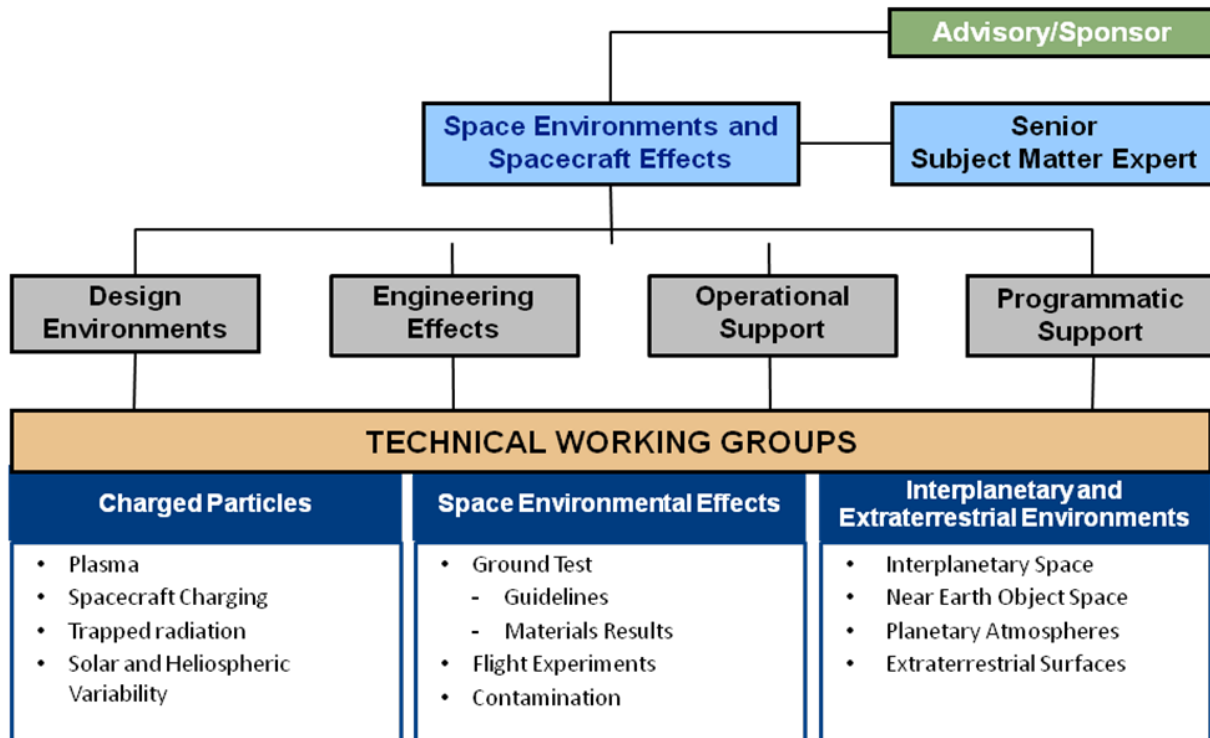


Figure 2. An example of an organizational structure concept for the space environments and spacecraft effects organization

Charged Particles (CP) TWG

The CP TWG will use co-chairs and working group members chosen based on their expertise in various aspects of the discipline area. The TWG will meet yearly to define products and their priorities based on needs of the various stakeholders in the spacecraft design and operations communities. There is considerable synergy with the IEE TWG which will be leveraged to insure efficient product prioritization and development.

Charged particle radiation can be categorized in several ways, including ionizing versus non-ionizing, highly directed beams versus isotropic populations, those dominated by collective behavior versus single particle effects, *etc.* A multitude of charged particle effects can impact mission effectiveness. Communication and navigation systems are severely impacted by erratic ionospheric storms. Spacecraft surface charging can lead to electrostatic discharge currents between differentially charged spacecraft, between space vehicles, or between astronauts and spacecraft during Extra-Vehicular Activities (EVAs). Penetrating charged particles can accumulate on internal cables, circuit boards, and isolated conductors within a space vehicle, resulting in electrostatic discharge currents internal to the spacecraft Faraday cage with effects varying from noise in electronic circuits, to phantom commands, and even catastrophic damage to sensitive circuits. Charged macroscopic dust particles and ionized outgassed materials can be attracted to a charged space vehicle, resulting in contamination of sensitive surfaces. These are only a few examples of the many things that can go wrong during a space mission.

Our long term vision is to develop specific products to cover all phases of the mission development cycle. First would be the proper space environment characterization by drawing on the latest research and data resources. This would essentially form the specification of the natural space environment with all of its variability, both statistical over the long term and impulsive over the short term. Secondly, these data coupled with materials/component/subsystem property measurements would support spacecraft designers, as well as tool/model development. The third step addresses model validation with flight data or system performance, which is essential to insuring an optimized solution for space system applications. The fourth and final step is tool implementation for subsequent predictions of events that may affect astronaut and system safety or performance. The long term goals would be to provide timely updates to charged particle environment models (both climate and weather) and their interactions with spacecraft. Additionally, we would potentially serve as partners with customers to assist them with their mission-specific modeling needs.

Space Environment Effects TWG

The SEE TWG is responsible for addressing the effects of the space environment on materials and systems. This includes ground test, analysis, and flight experiments. This working group will coordinate with the other two groups to address the materials systems analysis and test priorities of their areas. Like the other two working groups, the SEE TWG will use co-chairs and working group members chosen based on their expertise in various aspects of the discipline area.

Many space environment test capabilities exist across the agency and most are complementary in function. These test facilities are utilized by NASA, its contractors, government agencies, industry, academia and international partners. Many unique capabilities offer opportunities to evaluate materials and sub-system components performance in simulated flight environments including weather encounter impact during ascent, micrometeoroid /orbital debris impact, atomic oxygen for low earth orbit, ultraviolet radiation, charged particle radiation, plasma/charging, thermal extremes, and vacuum exposure. Test data and information are maintained at the test location and test reports are usually provided to the specific customer. These test reports are generally not readily available to the space environments and effects user community as a whole. This limitation results in duplication of effort and in some cases, testing under conditions that may vary from the actual environment the component will experience due to test system limitations. This approach is not the best use of limited resources and in the latter case, results in a Program possibly accepting additional risk. As new materials and technologies are developed, adequate ground testing to evaluate applications into flight demonstrations or spacecraft is essential to maximize potential for success. A coordinated approach will support space material advancement and space system improvements that enable game changing technology implementation during the design, development, testing and orbital operations.

Another key component is continued use of flight experiments for environment characterization, material/component evaluation, and operational verification. Flight experiments are essential to insure environmental models are up to date utilizing the latest data. Flight data also helps insure ground based testing is as representative as possible to real space exposure conditions and helps validate ground test protocol and provide model validation.

Interplanetary and Extraterrestrial Environments (IEE) TWG

The IEE TWG structure will be similar to that of the other 2 working groups. Co-chairs and working group members will be chosen based on expertise in various aspects of the subject area. They will meet to define products and their priorities based on needs of the various stakeholders in the spacecraft design and operations communities. There is considerable synergy with the Charged Particle TWG which will be exploited in product prioritization and development.

The IEE TWG is responsible for the space environments encountered in interplanetary space, in the proximity of various solar system destinations, the atmospheres of those destinations, and their surfaces. This includes such diverse locations as Earth-Moon L2, Earth geosynchronous orbit, lunar orbit, Near Earth Asteroid (NEA) surfaces, and Mars' atmosphere. The technical issues include NEA geology, dust transport in the presence of plasma, planetary atmospheres, and plasma depletion in the lunar wake, etc. The products will be used during the design, development, verification, and operations phases of the programs. The tools will also be useful for anomaly resolution and forensic analysis.

Although some extraterrestrial environments have been characterized by previous missions, the engineering demands of human exploration such as high reliability and extreme weight limitations require a thorough knowledge of the environment. Unmanned mission science return can be enhanced when more precise design environments allow reduction in design margin and more mass available for instruments. For instance, performance of hermetic seals in the presence of dust released from the surface of an NEA during its exploration requires detailed knowledge of the characteristics of that dust and its transport depends on interaction with the solar wind and solar ultraviolet. Aerobraking of an unmanned spacecraft using Neptune's atmosphere requires a precise model of the atmosphere so propellant margin can be reduced. Improved models and tools to define these sorts of environments to allow more efficient design and more reliable operation of manned and unmanned spacecraft are needed. This TWG will identify those products and see that they are properly developed to suit the needs of users. The TWG will consist of environments specialists, space scientists, and planetary scientists who have supported programs to or have done research on these destinations. Their knowledge of the design and operations issues as well as their familiarity with existing models and datasets will ensure proper prioritization and development of the products needed for future missions.

3. Summary

The scope of this proposed SESE organization will be to enable transition of research to applications to support design, development, and operation of spacecraft systems that will accommodate or mitigate effects due to interaction with the space environment. The purpose of the SESE organization includes developing products that define the space environment, increasing our understanding of spacecraft-environment interactions from the materials to the systems-level, establishing space environments related engineering guidelines, and establishing an organization that enables coordination for the National space environments, space weather, and spacecraft effects communities.

The establishment of an Agency level Space Environment and Spacecraft Effects (SESE) organization would provide: a venue enabling transition of research products to applications and product development management, product dissemination to the aerospace community, gap analysis of the current state of products/knowledge, and a coordination point for the National space environments, space weather, and spacecraft effects communities.

Presently, no agency-level organization exists to enable coordination with the many varied space environments and spacecraft effects related organizations. These organizations include chartered and well-structured program offices focused on a specific environment domain, and test facilities specializing in critical aspects of material test and analysis.

NASA Programs and projects are currently responsible to develop their own space environment products, at times without significant guidance from (SME's). This is an inefficient use of NASA resources since it results in duplication of effort in product development and ground testing of materials and systems.

Smaller budget programs have accepted the risk of performance degradation due to space environment interaction with their spacecraft rather than spend the resources to ensure their systems will accommodate the influence of the space environment. This is especially true of the emerging commercial satellite industry that is driven by affordability.

The near-term approach to establish the SESE organization is to secure appropriate resources, identify and initiate tasks that will have significant and rapid impact on spacecraft programs, launch the SESE organization, develop a communication strategy, and generate a 5-year plan.

The longer-term approach will build on the accomplishments of FY12 and include hosting yearly meetings to evaluate the state-of the art in space environments and spacecraft effects, perform a gap analysis with inputs from the Nations' experts in the field and use this information to assist in determining funding strategies for the following year. International partnerships are desired and will be pursued to the fullest extent possible.

Acknowledgments

The authors would like to acknowledge Ms. Janet Barth, Dr. Mike Xapsos, and Dr. Raymond Ladbury at the Goddard Space Flight Center, Dr. Sharon Miller and Dr. Jim Gaier at the Glenn Research Center, Ms. Karla Clark, Dr. Brian Muirhead, and Dr. Henry Garret at the Jet Propulsion Laboratory, and Dr. Rob Suggs, Dr. Linda Krause, and Ms. Mary Nehls at Marshall Space Flight Center for their support and comments in the development of the concept.

References

1. http://www.nasa.gov/pdf/516579main_NASA2011StrategicPlan.pdf, February 14, 2011

Extraterrestrial Environments

Meteoroids

Magnetic Fields

Ionization Radiation



Vacuum

Thermal Cycle

Interplanetary Environments

Plasma/Space-Craft Charging

Material Contamination

Earth Albedo

Atmospheric Drag

Atomic Oxygen

Solar Ultraviolet

Orbital Debris



Space Environments And Spacecraft Effects Concept: Transitioning Research to Operations and Applications

D.L. Edwards,
H.D. Burns,
R.G. Clinton,
D. Schumacher,
J. F. Spann

Current State:

- NASA policy, since 2005, is for each program and project to fund their own efforts to characterize their space environment and spacecraft effects needs.
- There are numerous, well functioning, entities staffed with subject matter experts, scoped to advance the state-of-the-art in distinct disciplines, disseminate information, and develop products relative to space environment, space weather forecasting, and space systems effects.
 - US Gov't (LWS, MEO, SWPC,..)
 - International (ESA, JAXA, DLR,RKA,CNES, ONERA)
 - Academic (USU, Texas A&M, Vanderbilt)
 - Industry (Boeing, Aerospace, Lockheed-Martin)
- There is minimal progress on long-lead time space environment and spacecraft effects products that focus on the needs of the spacecraft developer
- Numerous existing tools need updating (last update prior to disbanding of SEE program in 2005)
- Dissemination of information occurs through a variety of means:
 - Technical publications,
 - Test report to Program,
 - Analysis delivery to customer,

Problems:

1. There is no single resource for either government or commercial spacecraft designers/developers to aid them in understanding the space environment and its impact on spacecraft design. The result is dependence on ESA websites, personal contacts, a costly overdesign approach, or the acceptance of unknown risks.
2. There is no single coordinating function in space environments, space weather, and spacecraft effects. This has resulted in duplication of effort, gaps in coverage and lingering disagreements over key technical issues.

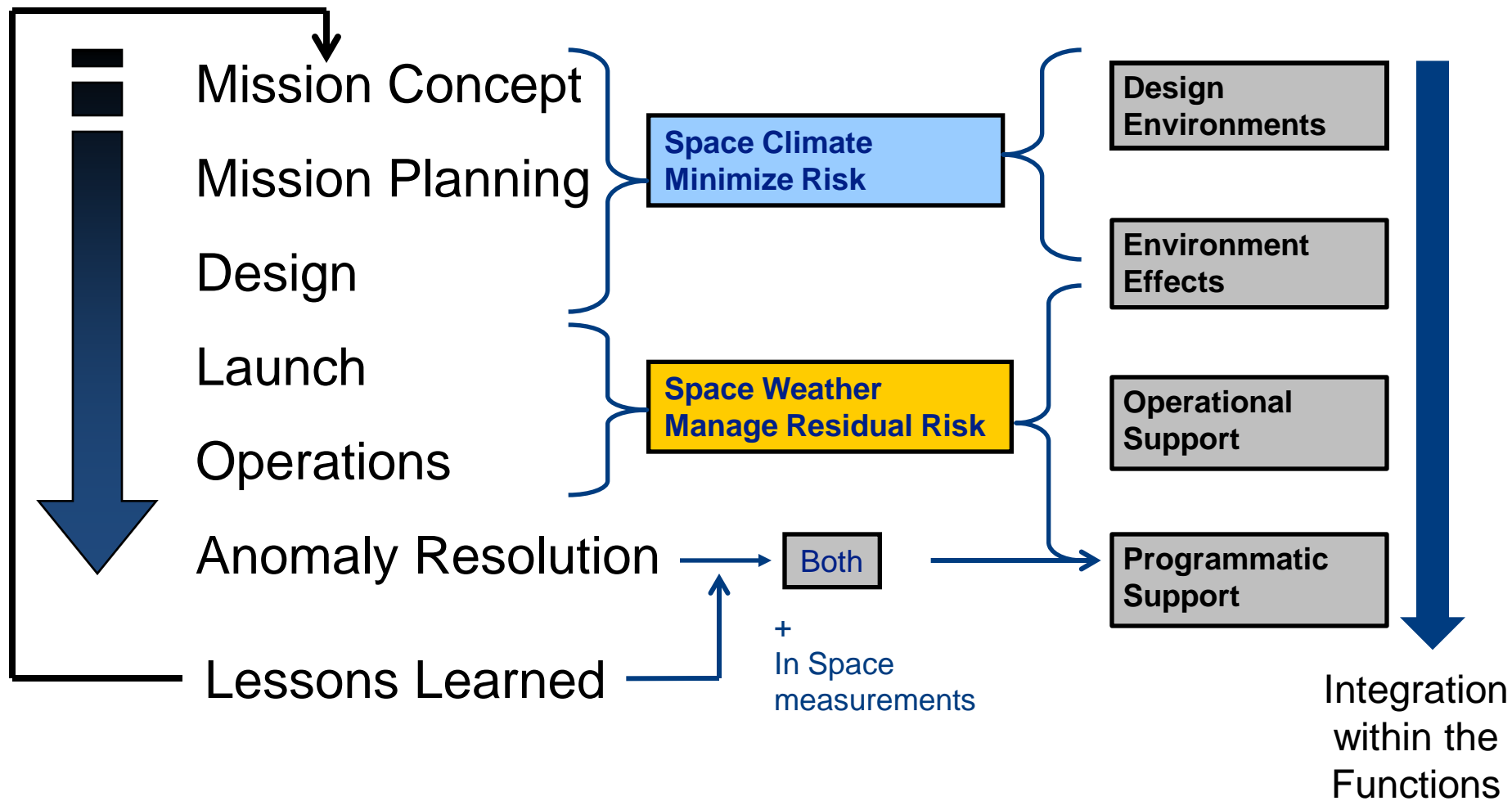
Changing Climate:

- Continued emergence of commercial sector developing spacecraft, NASA's goal of exploration beyond LEO, shrinking budgets, and focus on optimization of limited Agency resources have strained abilities to mitigate and manage risk associated with spacecraft interaction with the integrated space environment.

Solution:

- Establish an organizational structure to focus on developing and funding space environment and spacecraft effects products, performing gap analysis, and facilitate coordination amongst well established discipline areas within NASA, other federal agencies, commercial space industry, academia, and subject matter experts (SME). The scope of this proposed Space Environments and Spacecraft (SESE) organization will be to develop products using a research to applications model to support design, development, and operation of spacecraft systems that will accommodate or mitigate effects due to interaction with the space environment.

Space Environment Model Use in Mission Life Cycle



Borrowed and modified with Permission from J. Barth & M. Xapsos (GSFC)

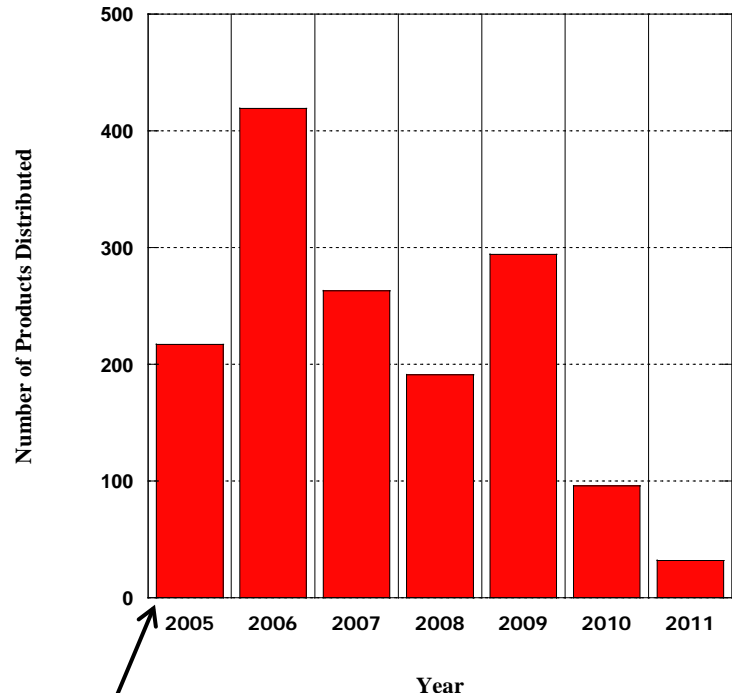
Grand Challenges

- Achieve a comprehensive understanding of the Space Environment and its influence on spacecraft performance
- Facilitate National coordination in the discipline of space environments and spacecraft effects
- Enable stable and sustainable funding for near-term and long-term product development



New SESE Organization will Build on the SEE Program and Expand Scope

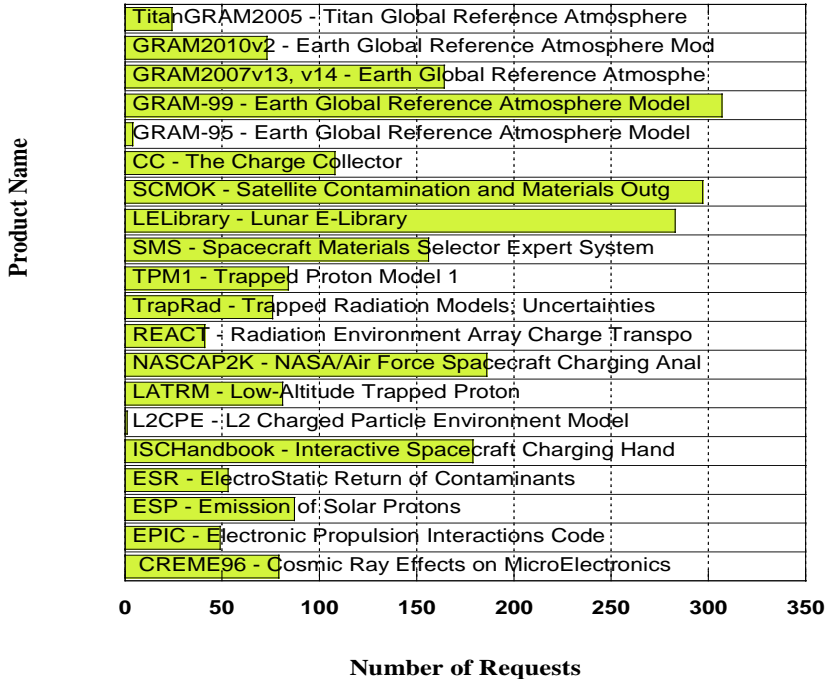
SEE Products distributed from Web Site



SEE Program Office terminated 2005 (approx. \$2M)

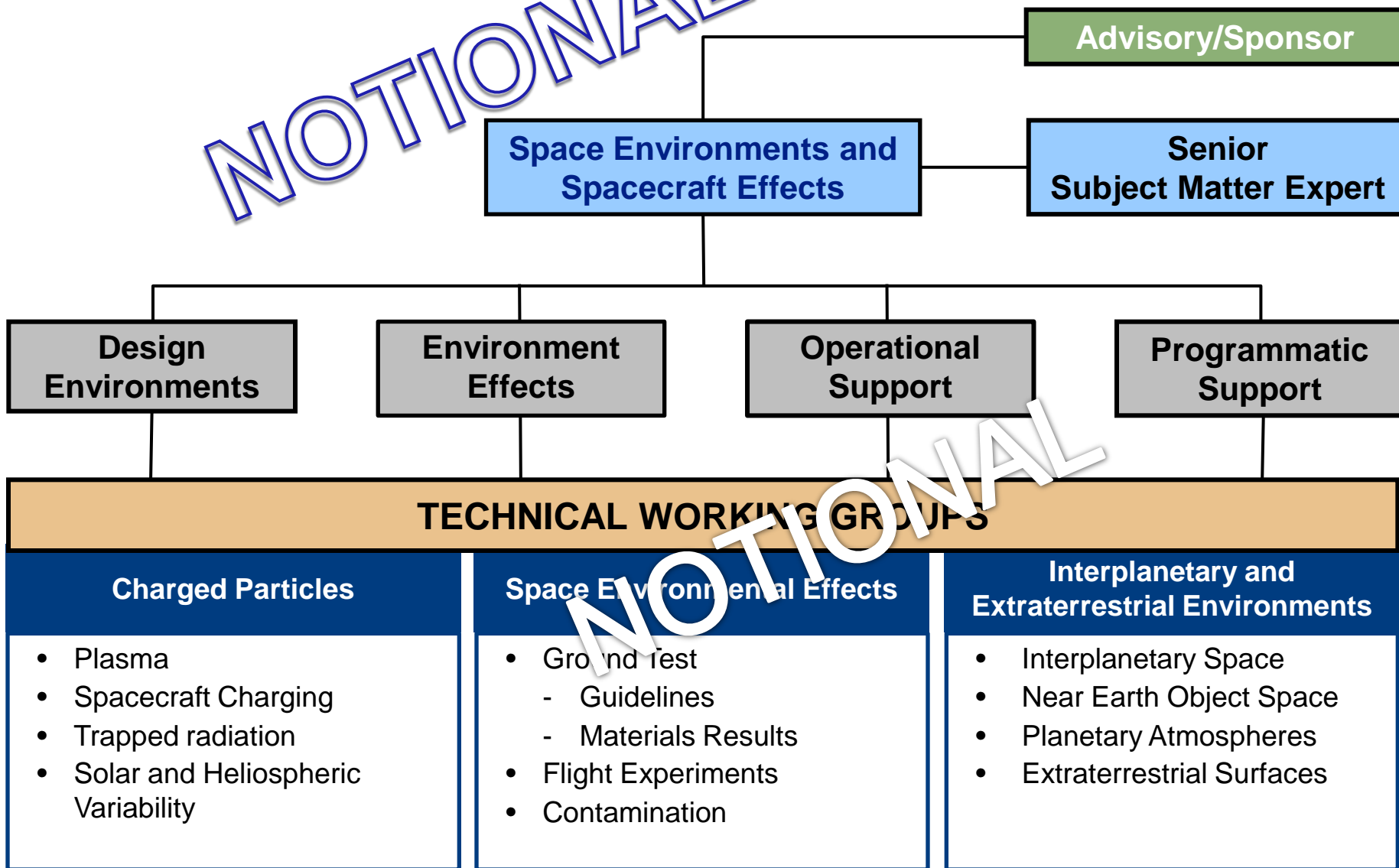
- SEE Program Technical Working Groups
- [Electromagnetic Effects & Spacecraft Charging](#)
 - [Ionizing Radiation Environment](#)
 - [Materials and Processes](#)
 - [Meteoroids and Orbital Debris](#)
 - [Neutral External Contamination](#)
 - [Ionosphere & Thermosphere](#)

SEE Product Requests



SEE Product User Community
 NASA Programs,
 NASA Science, and Engineering Organizations,
 Federal Agencies,
 Academia,
 Commercial,
 International Space Agencies.

NOTIONAL



- The scope of this proposed SESE organization will be to fund the development of products using a research to applications model to support more affordable design, development, and operation of spacecraft systems that will accommodate or mitigate effects due to interaction with the space environment.
- The purpose of the SESE organization includes;
 - developing products that define the space environment,
 - increasing our understanding of spacecraft- environment interactions from the materials to the systems-level,
 - establishing space environments related engineering guidelines,
 - establishing an organization that enables coordination for the national space environments, space weather, and spacecraft effects communities
- The establishment of an Agency level Space Environment and Spacecraft Effects (SESE) organization would provide;
 - a venue enabling transition of research products to applications and product development management,
 - product dissemination to the aerospace community,
 - gap analysis of current state of the products/knowledge,
 - a coordination point for the national space environments, space weather, and spacecraft effects communities



Additional Charts

Technical

- Focus on those items that are in demand by the user community and can be accomplished in FY12
 - Improved Emission of Solar Protons (ESP) code.
 - Earth-Sun and Earth-Moon Lagrange points charged particle radiation environment characterization.
 - Update the existing Satellite Contamination and Materials Outgassing Knowledgebase
 - Assemble data sets of materials flight hardware data

Organizational

- Focus on establishment of the Space Environments and Spacecraft Effects organization
 - Develop communication strategy
 - Establish management office and leadership at other field Centers
 - Define and implement roles and responsibilities
 - Set up business office infrastructure
 - Initiate agreements, MOU's.
 - Set up web site for communication and product distribution
 - Define product distribution process
 - Develop educational package on the SESE organization and initiate conducting training courses.
 - 2 weeks of organizational planning
 - Host 'Kick-Off' Workshop for SESE participants, commercial user, programs, academia, International