IAF-01-I.5.02

THE OBJECTIVES OF NASA'S LIVING WITH A STAR SPACE ENVIRONMENT TESTBED

Janet L. Barth, NASA Goddard Space Flight Center, Greenbelt, MD
Janet.L.Barth.1@gsfc.nasa.gov
Kenneth A. LaBel, NASA Goddard Space Flight Center, Greenbelt, MD
Dana Brewer, NASA Headquarters, Washington DC
Billy Kauffman, NASA Marshall Space Flight Center, Huntsville, AL
Regan Howard, Orbital Sciences Corporation, Greenbelt, MD
Geoff Giffin, Consultant, Annapolis, MD

Abstract— NASA is planning to fly a series of Space Environment Testbeds (SET) as part of the Living With A Star (LWS) Program. The goal of the testbeds is to improve and develop capabilities to mitigate and/or accommodate the affects of solar variability in spacecraft and avionics design and operation. This will be accomplished by performing technology validation in space to enable routine operations, characterize technology performance in space, and improve and develop models, guidelines and databases. The anticipated result of the LWS/SET program is improved spacecraft performance, design, and operation for survival of the radiation, spacecraft charging, meteoroid, orbital debris and thermosphere/ionosphere environments. The program calls for a series of NASA Research Announcements (NRAs) to be issued to solicit flight validation experiments, improvement in environment effects models and guidelines, and collateral environment measurements. The selected flight experiments may fly on the SET experiment carriers and flights of opportunity on other commercial and technology missions. This paper presents the status of the project so far, including a description of the types of experiments that are intended to fly on SET-1 and a description of the SET-1 carrier parameters.

1. BACKGROUND

The Sun and its Variability

The Sun, the astronomical object most significant to humanity, affects the entire geospace region. Because of the consequences to the Earth of the Sun's dynamic behavior and the rapidly expanding utilization of this region for human activities, a thorough understanding of the Sun's effects is becoming increasingly essential. The Sun radiates both electromagnetic energy and fast-moving electrically-charged particles. The electromagnetic radiation across a broad spectrum of wavelengths originates from the photosphere, the Sun's surface. This energy proceeds unimpeded directly from the Sun to the Earth's atmosphere, with a majority reaching the surface of the Earth.

The streaming of electrically-charged particles away from the Sun results from the energizing of gases in the solar corona. This continuous, but highly variable stream, called the solar wind, has speeds of up to 1000 km per second. Its variability is closely connected to events on the Sun and its corona. In contrast to electromagnetic radiation, the transit of energy in this form through space is very complex, especially as it interacts with magnetospheres and atmospheres to produce a wide variety of phenomena and consequences. The LWS Program[1] will permit comprehensive study of the cause-and-effect relationships between events at the Sun and the effects in geospace that influence life on Earth and humanity's technological systems. An overview of the role of the LWS program in assuring performance in space and atmospheric environments is given in ref. [2].

A goal of the LWS program is to address environment accommodation issues for future technological systems. The program architecture, illustrated in Fig. 1, consists of the following elements:

- Theory and Modeling to define the external environment;
- Science Missions to collect data, and understand the effects of solar variability on our Earth;
- Space Environment Testbeds to define the environment interaction with components; and
- Evolution of established and expanded partnerships.

The complex environment of Sun-Earth space consists of time varying ultraviolet, x-ray, plasma, and high energy particle environments. The particle environment is composed of fluxes of electrons with energies up to 10s of MeV and protons and heavier ions with energies up to 10,000s of MeV. Variations depend on location in space and on the year in the solar cycle, both somewhat predictable. However, large variations that depend on events on the Sun

Copyright

"Copyright © 2001 by the American Institute of Aeronautics and Astronautics, Inc. No copyright is asserted in the United States under Title 17, U.S. Code. The U.S. Government has a royalty-free license to exercise all rights under the copyright claimed herein for Governmental purposes. All other rights are reserved by the copyright owner."

are not predictable with reasonable certainty and are known only statistically based on past history.

The natural space environment and its solar induced variability pose a difficult challenge for designers of technological systems. Space and atmospheric environments interact with aircraft and spacecraft components to induce effects in systems. The effects include degradation of materials, thermal changes, contamination, excitation, spacecraft glow, charging, communication and navigation errors and dropouts, and radiation damage and induced background interference. The accommodation of environmentally induced effects is accomplished in design and operational phases of system development.

Large uncertainties in space and atmospheric environments and effects models preclude cost effective use of environmentally sensitive technologies in the space environment. To successfully infuse a new technology into a system, accurate environment models, ground test protocols, and interaction models are required, and the models must be validated with in-flight experiments.

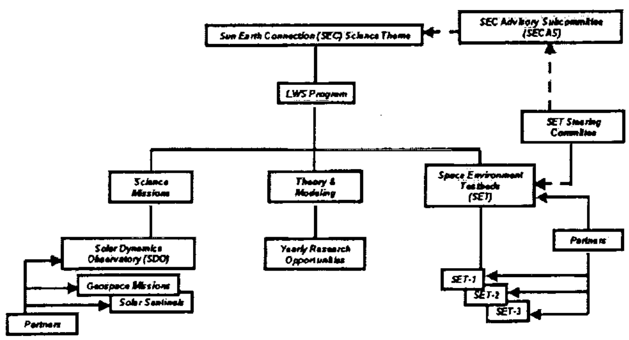

Fig. 1: This figure illustrates the program architecture of the LWS program.

Technology infusion

The aerospace industry is driven to utilize newer technologies to achieve performance goals, while reducing satellite mass and volume[3]. Microelectronics technologies in particular are becoming more sensitive to the space radiation environment. New and increasingly negative effects are being observed during routine ground radiation experiments. In addition, the growing trend toward smaller spacecraft and the use of materials such as composites provide less shielding assistance from the environment than in earlier missions. All told, less assistance reduces the levels of protection from the space environment while using potentially more environment-sensitive technologies. In fact, with the death of radiation-hardened foundries (two remaining in the U.S.), it is difficult, at best, to find electronics capable of both high-performance and radiation tolerance.

It takes three items to successfully infuse a new technology for space utilization (Fig. 2). First and most obvious is technology development. This is simply the development of a new technology that has enabling performance characteristics such as increased bandwidth or reduced volume. Second, a technology must be "qualified" via a series of ground tests prior to infusion into a critical space system. But how does one determine the proper tests required for a new technology? And how accurate are these test results? Are they a worst case bound or a nominal case average? These questions lead to the need for the third portion of the triumvirate: on-orbit flight experiments for validation and development of test protocols and performance prediction techniques.

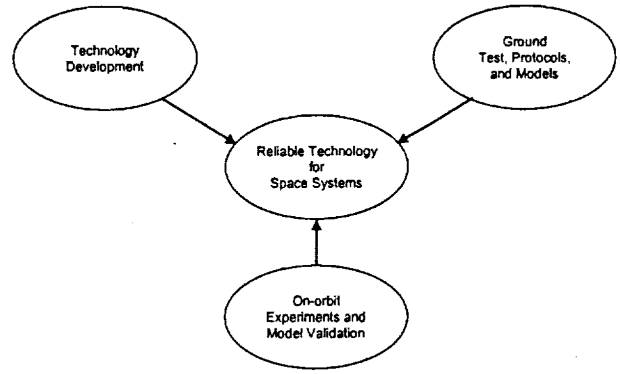

Fig. 2: Technology Triumvirate for Infusion into Space Systems.

The goal is to not only qualify an individual component but to validate a ground test protocol or prediction technique that then enables reliable ground test qualification to occur.

2. SET OBJECTIVES AND GOALS

The primary objective of the LWS Space Environment Testbeds (SET) is to infuse new technologies into space programs. The SET purpose is to complete the transition from science to applications with the objective of improving the engineering approach to accommodate and/or mitigate the effects of solar variability on spacecraft design and operations. The SET has three goals:

- Enhance the technical and scientific capability of satellite systems by enabling easy, low cost, and fast access to space for validation of technology typically sensitive to solar variants.
- Function as a pathfinder for future spacecraft deployment in space environments for commercial, government, and science interests by improving environment definitions, models and guidelines.
- Infuse the improved technology and predictive capability with space weather prediction, spacecraft design and operations, and terrestrial/aircraft operations.

The LWS Program will develop new environment specification models and predictive capability for:

- Mission planning
- Spacecraft design
- Spacecraft operations, and
- Risk analysis

Within this approach the SET seeks to better understand environment interaction with spacecraft and instrument components, including:

- Microelectronics

- Sensors/detectors
- Materials, and
- Spacecraft charging and discharging

This SET goal will be achieved through the planned flights of a series of orbiting testbeds that will:

- Validate technologies in flight
- Collect data in space to validate ground test protocols
- Collect data in space to validate application model/engineering tool development

The result of the SET Program will be an improved engineering approach to accommodate and/or mitigate the effects of solar variability on spacecraft design and operations.

In the remainder of this section, we expand upon the SET concept. The SET Program is intended to fill knowledge gaps in the interaction between spacecraft and environment in all Earth orbits of interest, and to validate technologies of interest in this variable environment.

Operation in MEO

One SET objective is to provide an adequate knowledge base to enable routine operations in mid earth orbit (MEO). MEO is considered to be those orbits of 2,000 to 20,000 km altitudes. It is characterized by a severe radiation environment of trapped particles from the Van Allen belts, and a highly volatile radiation environment between the belts due to geomagnetic storms. Currently, this severe environment greatly limits space mission lifetimes and performance. Capability of MEO operation opens the pathways for new science, communication, and government applications that are currently compromised due to the extremities, volatility and lack of data in this region.

For example, commercial communications typically consider the less harsh radiation environments of low earth orbit (LEO) or geostationary orbits (GEO)[3]. Both of these orbital arenas offer drawbacks due to their close proximity or great distance from Earth. LEO, for example, requires a relatively large number of satellites (i.e., IRIDIUM which utilized 66 satellites in its constellation) to meet adequate global coverage requirements. In contrast, GEO constellations require few satellites but have challenges with propagation delays and efficient utilization of bandwidth. MEO, thus, is a compromise of the two global coverage methods requiring a reasonable number of spacecraft with capabilities for high performance. The ability for commercial communications builders to utilize the MEO arena provides a very cost-effective solution for their needs.

Science-based missions have their own unique challenge for MEO operation. Take for example the desire to operate an imager in a MEO orbit. It is well known that detector technologies such as charge-coupled devices (CCDs) and infrared detectors are deleteriously affected by radiation hazards[4]; this includes both long-term damage issues as well as transient particle effects. The development and flight validation of hardened detector technologies and software transient mitigation techniques would open this regime for science operation.

Ground test and performance prediction improvement

The second SET goal includes validation of new technology ground test protocols, performance prediction methods and environment models. SET is concerned primarily with the interaction between spacecraft and environment, whereas the role of the science missions and the Theory and Modeling program is to characterize and understand the Sun-Earth variable environment in broader terms. Performance predictions for flight is based on the existence of ground test data and applicable space environment predictions. If either or both of these factors can improve accuracy, there are significant benefits for space system design.

Take for example the issue of how simulated conditions on the ground compare to actual flight conditions. The accuracy of a ground test is only as good as the correlation of the test protocol used for flight validation. In addition, as noted in Table 1 previously, test protocols and technology models are often technology specific. Increased accuracy of ground testing and the induced environment (the environment that effects technology) clearly requires a correlation with actual space performance.

Reduced design margins

Design margins for systems are based on the accuracy of environmental predictions and ground test protocols (technology factors). By improving the accuracy of both elements, design margins can be significantly reduced. Fig. 3 illustrates the factors utilized in setting design margins. If one can reduce the size of the "target" in this figure, the number of available choices in electronics and materials that meet the requirement is increased, including potentially less expensive, higher performing, and reduced mass technologies.

Take, for example, the case of ionizing and non-ionizing radiation damage on linear bipolar electronics[5]. Although linear bipolar technology has been around for several decades, recent changes in manufacturing processes and circuit designs have made many of these devices more sensitive to damage from the non-ionizing portion of the environment, as well as to low ionizing dose rates more closely resembling the actual space environment. The problem is that the majority of ionizing radiation tests are performed at accelerated rates in order to be cost and time efficient (i.e., not requiring a three-year test for a three-year mission). Thus, to use these accelerated tests and to account for the non-ionizing damage issue, large margins (on top of margins included for environmental uncertainties) are often included. This inclusion can create difficulty for projects in obtaining technology that meets performance requirements or requires the use of higher cost components or addition of design mitigation strategies such as extra shielding (i.e., extra weight that equals extra cost), as well as potential resources for additional ground tests.

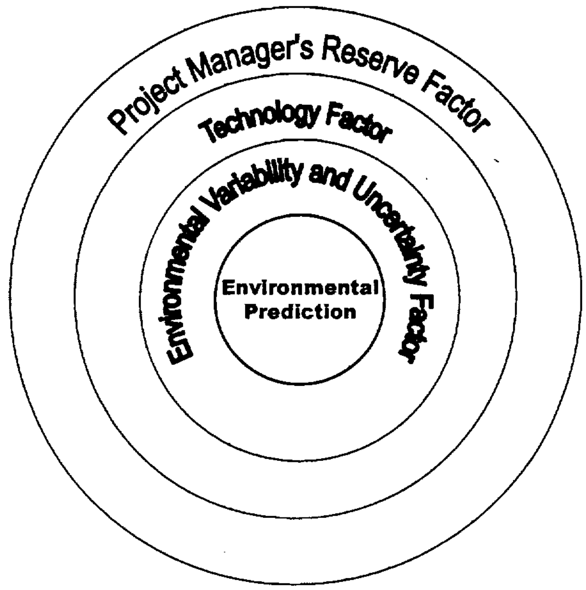

Fig. 3: Design Margin Factors

What these measures imply is a resource burden on spacecraft systems. If one can validate improved ground test protocols (more accurate and less conservative), as well as dynamic environmental models, design margins would be reduced. Thus, resources currently spent on spacecraft technology may be saved or, conversely, available to increase science performance. This approach is consistent with a "faster, better, cheaper" approach to modern space design, manufacture, and test. In addition, having an improved knowledge-based design reduces risk for space systems.

Environment-tolerant technologies and mitigation strategies

In order to operate successfully under the influence of the Sun's variability, technologies must either be available that meet the mission requirements or design means of mitigating the effects must be available. One of the SET objectives is to validate these technologies and techniques.

A relevant example is the plasma-induced charging issue by spacecraft that traverse energetic electrons during the course of their orbits[6]. Orbits such as GEO and Geo-Transfer (GTO) are particularly of great concern for this issue. In the past, large spacecraft with a Faraday cage-like structure were used to mitigate this issue. With today's movement towards small, lightweight spacecraft, the unwieldy structures of the past are simply not feasible. New and novel approaches to mitigation of charging are required. Due to complexities of environment and to design complications, flight validation of these technologies is required.

Human Exposure to the Variable Space Environment

For periods following solar energetic particle events, large fluxes of very penetrating protons reach low altitudes and pose dangers to extra-vehicular activities and high altitude human flight. The South Atlantic Anomaly also has high energy particle precipitation.

The primary goal of LWS related to human exposure to radiation is to develop the capability to predict solar activity with sufficient lead-time to ensure crew safety. The LWS/SET will also investigate the relationships between solar variability, materials, and biological systems. Microelectronics also represents an increasingly important component of life support systems and SET will validate technologies that add to the safety and effectiveness of flight operations.

Flight validation of LWS science instruments

A final SET goal is to provide a testbed to validate the performance of science instruments from other elements of the LWS program. For more information on these missions please see ref. [7].

3. SPACECRAFT TECHNOLOGY AND THE SET

As discussed earlier, emerging and novel technologies are required by both government and commercial organizations in order to provide viable cost-effective and high-performance satellites for science, industry, and defense needs. Unlike previous missions which chiefly measured technology performance and may have had limited ground test protocol validation plans, the concept for SET focuses on correlating the flight and ground portions. In this section, we provide a general discussion of technologies and the SET, and cite examples of technology experiment concepts.

SET Technology Experiments

Potential experiments on solar-variant sensitive technologies for NASA's SET are widespread[8,9,10]. The areas of interest include, but are not limited to:

- Microelectronics
- Photonics and optoelectronics
- Detectors
- Materials
- Nanotechnologies
- Microelectromechanical systems (MEMS)
- Microoptoelectromechanical systems (MOEMS)
- Subsystems
- Environment tolerance methods
- Spacecraft charging/discharging

The initial planned experiment concepts revolve around component and small subsystem-level technologies. This is due to the obvious resource constraints including cost. Because of these constraints, experiments that drive high-cost mission scenarios such as those that require retrieval are not part of the SET conceptual baseline. Thus, experiments such as those on material properties that would ordinarily require retrieval after exposure to the space environment become problematic or require innovative remote measurement methods. All of these issues will likely be revisited if, for example, a partner provides the SET a spacecraft bus and launch opportunity that allows for larger experiment concepts to be broached.

The advantages of novel technologies for space performance are well documented[3]. However, issues such as ionizing radiation, spacecraft charging, and micrometeoroids may, at times, prove problematic. Space test data can be used to improve our knowledge of proper ground test protocols and prediction techniques. The idea remains constant: improve/validate ground test protocols, technology performance models, and means to reliably operate in a solar-variant space environment. While not covering all environments of concern to SET, further discussion of technology-based radiation effects issues on microelectronics may be found in ref. [5].

Sample Technology Scenario - SiGe

In order to clarify what might constitute suitable technology experiments for SET, we shall describe a potential experiment concept based on solar-variant technologies and ground test programs. This example is based on concepts gathered at workshops designed to aid identification of candidate technologies and requirements for SET[8,9,10]. The concept presented here for an experiment is SiGe microelectronics.

SiGe is an emerging microelectronics technology with traits that show clear traceability to NASA's needs[3]. The technology is fully compatible with existing Si technology but offers distinct advantages over these older technologies in terms of speed (>40 GHz possible), noise, and power performance. These performance properties can be tuned or traded by choosing selective doping levels, thus allowing for power and bandwidth trades to be performed. In addition, SiGe lends itself to mixed analog and digital applications; potentially pushing the envelope for true system-on-a-chip (SOC) designs.

From the aerospace perspective, the advantageous features of SiGe have widespread applications ranging from radio frequency (RF) systems to SOCs to power circuitry. However as discussed earlier, the space environmental concerns (radiation, reliability, etc.) must also be understood to reliably insert this emerging technology. From this regard, the aerospace community has begun ground-based research on SiGe. For example, the NASA Electronic Parts and Packaging (NEPP) program along with its partners such as the Defense Threat Reduction Agency (DTRA) have begun evaluation of SiGe devices in order to model the technology and predict performance in a space environment.

The question for SET is: does this technology's performance in space vary with the solar cycle? From the solar-variant particle populations that induce radiation effects, the answer appears to be yes. Early ground test data on radiation issues shows promise for long-term dose and damage concerns[11]. However, the limited dataset on single event performance indicates an increased sensitivity with high-speed technologies to the transient particle environment[12,13]. Since this data shows that the models being developed for SiGe may vary significantly from standard Si technologies, flight validation of the ground test protocols and prediction techniques is required.

4. SET Plans and Requirements

SET Plans

The SET is planning to focus on flight experiments, as well as on data mining and analysis as they apply to application models on solar variability and technology. This is a multi-mission program with launches planned at two-year intervals. The characteristics of the SET are:

- Multi-mission series of flight testbeds starting with a launch in FY04
- Support of relevant experiments on non-SET carriers
- Data analysis for environment and technology application models of SET flight experiments
- Data analysis for environment and technology application models of flight experiments from non-SET space testbeds and spacecraft (There is also the potential for support of these experiments, as well.)
- Data mining of existing data sets
- Development of tools and guidelines

In addition, the acquisition of a core set of flight qualified collateral environment sensors applicable to the SET is planned.

Funding for flight experiments, collateral environment sensors, and engineering tool development will be via a series of NASA research announcements (NRAs), the first of which will be released in FY02.

The intent is for NASA and its partners to provide the launch and core testbed capabilities as defined below. The Program also projects the availability of funds for analysis of the flight experiments data.

SET Partners

SET partnering is expected to provide flexible and cost-effective means to gather sufficient resources to meet SET objectives. Standard SET partners come in three forms. They are:

- SET Program Partners: contribution to the overall success of the LWS/SET Program. This level of partner agrees with NASA on objectives and requirements, and participates in all Program aspects.
- SET Carrier Partners: contribution to the success of the SET Carrier. They retain separate requirements and objectives, and they receive an allocation of spacecraft resources to achieve their objectives.
- SET Payload Partners: contribution of "payloads" in exchange for on-orbit operation, launch, and data return. "Payload" is here defined to include ground test data if appropriate, on-orbit data after reduction, and funding for integration and on-orbit operations. Variations in definitions of "payloads" are negotiable: "funding" can include in-kind exchanges.

Other partnering arrangements will be considered on a case-by-case basis.

The experiment results and data access must be open to the aerospace community. Platform partners may, however, propose "black box" experiments or unshared data access. Inclusion of these experiments is a function of the partner contribution.

SET Carrier Concept

The SET flight element is envisioned as a secondary payload attached to a host spacecraft on launches of opportunity. This approach should accommodate the requirements of most technology experiments. Once attached to the host, the SET will manage its experiments with little interaction with the host. On orbit, applying power to the SET brings it into a standby mode. The host then commands the SET to turn all the experiments on and begin collecting data. Periodically, the host commands the download of telemetry from the SET command and telemetry storage into host storage.

Telemetry data from the SET is passed through the host communications and ground system and then forwarded to the SET mission payload operations center. Commands to the SET will be sent from the SET mission payload operations center to the host mission operations center for processing and upload. The SET will produce a health and safety telemetry stream that will be collected by the host, in addition to the experiment data telemetry, for processing by the host mission operations center.

As part of its normal operations, the SET will sample its environment sensors. Should the sensors indicate a condition of interest (e.g., a solar event), the SET may be programmed to send predetermined sets of commands to those experiments that require them. The SET will also support diagnostic operations for itself and those experiments that support them.

The SET is designed to provide technology experiments with the necessary voltages, as well as commanding and telemetry services. Technology experiments in standard mechanical form factors are to be provided to the SET integrator who will then configure the group of experiments so that all of them are exposed to the same environment.

SET Carrier Requirements

The top level requirements for the missions that will implement the Space Environments Testbed are as follows:

1. The Space Environments Testbed shall be implemented as a series of space missions into a range of orbits depending on the SET technologies being tested on each mission.
2. To accomplish the general SET objectives within the projected funding, each SET mission shall be implemented as a payload to be integrated onto a host spacecraft not funded by the SET project.
3. Each SET payload shall consist of one or more technology experiments integrated onto a carrier that supports the experiments and isolates them from the host spacecraft.
4. A goal in implementing the payload shall be to minimize the impact of the payload to the host spacecraft resources.
5. Each SET carrier shall be capable of correlating the experiment telemetry with the host spacecraft orbit position.
6. Each SET carrier may have one or more collateral environment sensors that will be used to characterize the environment exposure, and, if required, initiate actions by the carrier or the technology experiments.

The following paragraphs present overall mission requirements:

Mission Duration

SET missions require an on-orbit operational period sufficiently long for the technology experiments to generate the characterization data required to support the experiment goals. Based on NASA, DoD and industry experience, 1 year shall be the minimum time required for a mission duration with 3 years as a goal. Note that some technologies or technology experiments may fail in a shorter time depending on the mission orbit and the nature of the technology.

Orbit Requirements

SET has preferred orbits of interest, however other orbits can be utilized depending on the needs of the experimenters. GEO-transfer orbit (GTO) is good for a wide range of environmental experiments, including ultraviolet (UV) and atomic oxygen (AO) degradation found in the lower altitudes, plus the trajectory passes through both radiation belts, exposing the experiments to a wide range of radiation energy levels. Geostationary (GEO) is good for solar particle events (SPEs) as well as spacecraft charging/discharging experiments. SEE issues arise in near-polar LEO orbits, while "high" polar LEO (> 1,000 km) is useful for proton damage experiments, both regions expose the spacecraft to degradation/contamination, and spacecraft charging phenomena. Table 1 summarizes the phenomena of interest to SET in the different orbit regimes.

Orbit	Phenomena
GEO	Solar flare protons, trapped electrons, spacecraft charging/discharging
GTO	Trapped protons
LEO - Low Inclination	Surface charging and erosion
LEO - High Inclination	Galactic ions

Table 1: SET Orbits and Environment Phenomena

Serviceability/Retrieval/Disposal

Neither on-orbit servicing nor retrieval is required. All the required data from each technology experiment will be telemetered to the ground.

5. SET Carrier Architecture

The carrier is the entity that supports the technology experiments and collateral environment sensors with power, commanding, telemetry, mechanical and other services, and isolates them from the host spacecraft. Fig. 4 illustrates the carrier architecture segments and their interactions.

Concept of Operations

A SET carrier mission is operationally simple. Upon power being applied some weeks after launch, the carrier will autonomously boot itself, apply power to the sensors and experiments, and begin to collect telemetry. Should telemetry from an experiment or sensor give an out of limit indication, the power will be removed and an indication sent to the SET operations center in the carrier telemetry stream.

Telemetry will be collected from the carrier on command from the host spacecraft. When operational the carrier will always be ready to receive commands from the host.

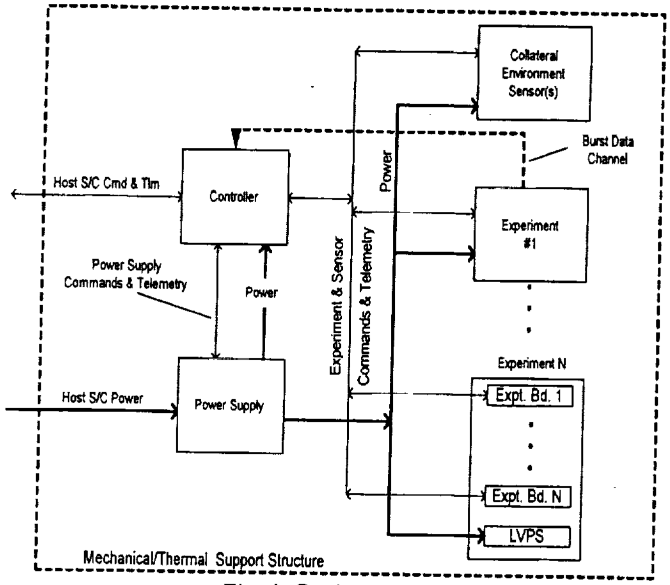

Fig. 4: Carrier Architecture

Communication between the sensors and the controller over the command and telemetry bus will be implemented using an architecture control protocol such as MIL-STD-1553B. If a burst data channel is implemented for a particular experiment, the burst data transfer will be performed on a command from the controller after it receives telemetry indicating that data is available for transfer.

Sensors and experiments may be used to detect events of interest (e.g. solar storms), and then trigger changes in the operation of particular experiments. This will be accomplished by using the controller to examine the sensor or experiment telemetry stream for indications of an event. Should the indication occur, the controller will execute a command script.

Architecture Segment Definition

Controller - A controller is envisioned as a multiple board assembly housed in its own structure that effectively isolates the technology experiments and collateral environment sensors from the host spacecraft data system. The controller provides to the experiments and sensor the following services:

- commanding
- telemetry
- data processing
- burst data

Power Supply - The carrier power supply provides power conversion, fusing, switching and distribution services to the experiments, sensors and the controller. It will be fused to protect the host spacecraft.

Technology Experiments - This segment consists of one or more technology experiments at the "box" or board level. These experiments will be arranged into structures that ensure that each has the necessary exposure to the space environment.

Collateral Environment Sensors - Collateral environment sensors are either in their own structure or contained within the controller. These sensors are mission dependent and may consist of total dose, single event, particle, charging and other sensors required to characterize the environment in the presence of the experiments suite. An element of this sensor set collects the temperature housekeeping data for the carrier.

Thermal/Mechanical Flight Support - This segment consists of a mission dependent mechanical interface structure that supports the controller, power supply, collateral environment sensor set, and the technology experiments. It is the mechanical element of the carrier that is attached to the host spacecraft structure. Depending on the host spacecraft, the interface structure will also support limited conducted heat transfer.

6. SUMMARY

We have provided an overview of the SET's goals and objectives as they relate to solar variability and technology validation. This summary has included a background discussion of the Sun and its effects on the space environment, as well as details on reliably infusing technology into space systems.

This was followed by the discussion of goals for the SET. The expected results of the LWS/SET Program are:

- Routine operation in MEO
- Ground test and performance prediction improvement
- Reduced design margins
- Environment-tolerant technologies and mitigation strategies
- Flight validation of LWS science instruments

Another element of the SET that was discussed is the mining of existing data from engineering systems or environmental monitors that have or are being flown. In some cases, these data were used for science purposes and can now be applied to engineering purposes.

Finally, we discussed the SET plans, which included expected capabilities provided to experimenters, as well as a discussion of partnering. We are strongly encouraging partnering from all aerospace areas (government, industry, university, and foreign participation).

REFERENCES

[1] Living with a Star (LWS) is a NASA initiative that will develop the scientific understanding necessary to effectively address those aspects of the coupled Sun-Earth system that directly affect life and society, http://lws.gsfc.nasa.gov/lws.htm.

[2] J. L. Barth, K. A. LaBel, D. Brewer, G. Withbroe, and B. Kauffman, "The Living with a Star Program, NASA's Role in Assuring Performance in Space and Atmospheric Environments," Presented at AIAA Aerospace Conference, Reno, NV, January 8-11, 2001.

[3] K. A. LaBel, "Applying State of the Art Commercial and Emerging Technologies to Space Systems," IEEE NSREC Short Course, IV1-59, July 1998.

[4] P. W. Marshall, and C. J. Marshall, "Proton Effects and Test Issues for Satellite Applications," IEEE NSREC Short Course, IV1-110, July 1999.

[5] K. A. LaBel, A. H. Johnston, J. L. Barth, R. A. Reed, and C. E. Barnes, "Emerging Radiation Hardness Assurance (RHA) Issues: A NASA Approach for Space Flight Programs," *IEEE Trans. Nucl. Sci., Vol. 45, 6, 2727-2736,* December 1998.

[6] M.S. Gussenhoven, E.G. Mullen, and D.H. Brautigam, "Improved Understanding of the Earth's Radiation Belts from the CRRES Satellite," *IEEE Trans. Nucl. Sci., NS-43, 2, 353-369,* April 1996.

[7] Living with a Star (LWS) The LWS program is a cross-cutting initiative linked with four NASA Strategic Enterprises: Space Science, Earth Science, Human Exploration and Development, and Aeronautics and Space Transportation. *http://lws.gsfc.nasa.gov/,* 1999.

[8] NASA Space Technology Partnering/Provider Workshop, Arlington, VA, *http://nmp.jpl.nasa.gov/workshop/proceedings.html*, August 2000.

[9] LWS Mission Requirements Workshop, NASA/GSFC Greenbelt, MD, *http://lws.gsfc.nasa.gov/lws_resources_presentations.htm*, February 2000.

[10] Orbiting Technology Testbed Initiative (OTTI) Final Report, *http://see.msfc.nasa.gov/otti/Final_Report.htm*, July 1998.

[11] C. J. Marshall, "ERC Advanced Technology Efforts", NASA/GSFC, IMAPS Advanced Technology Workshop on Electronic Parts and Packaging for Space and Aeronautic Applications, *http://radhome.gsfc.nasa.gov/radhome/papers/IMAPS_Tech.htm*, May, 2000.

[12] P. W. Marshall, M. A. Carts, A. Campbell, D. McMorrow, S. Buchner, R. Stewart, B. Randall, B. Gilbert, and R. A. Reed, "Single Event Effects in Circuit-Hardened SiGe HBT Logic at Gigabit per Second Data Rates" (not published).

[13] R.A. Reed, C.J.Marshall, J.A.Barth, K.A.LaBel, NASA/GSFC, C. Poivey, SGT, Inc. P.W.Marshall, QSS, Inc. S.Kniffin, Orbital, C.Seidleck, Raytheon. "Assessing the Impact of the Space Radiation Environment on Parametric Degradation and Single Event Transients in Optocouplers", to be published in *IEEE Trans. Nucl. Sci.,* December 2001.

SUMMARY OF TECHNICAL SESSIONS

A.	**ASTRODYNAMICS SYMPOSIUM** (7 sessions)		
A.1.	Mission and Constellation Design	Oct. 1 Monday	pm
A.2.	Attitude Dynamics	Oct. 3 Wednesday	am
A.3.	Attitude Control	Oct. 2 Tuesday	pm
A.4.	Multibody Dynamics	Oct. 2 Tuesday	am
A.5.	Optimization	Oct. 4 Thursday	pm
A.6.	Orbital Dynamics	Oct. 4 Thursday	am
A.7.	Guidance and Control	Oct. 5 Friday	am
B.	**SYMPOSIUM ON EARTH OBSERVATION** (6 sessions)		
B.1.	Earth Observation Missions and International Cooperation	Oct. 1 Monday	pm
B.2.	Future Earth Observation Systems	Oct. 2 Tuesday	am
B.3.	Earth Observation Sensors & Technology	Oct. 2 Tuesday	pm
B.4.	Data for Environmental Applications and Global Change Studies	Oct. 3 Wednesday	pm
B.5.	Earth Observation Business Development and Economic Benefits	Oct. 4 Thursday	am
B.6.	Data Processing and GIS	Oct. 4 Thursday	pm
C.	**SPACE AND NATURAL DISASTER REDUCTION SYMPOSIUM** (2 sessions)		
C.1.	Existing Space Programs and Applications for Natural Disaster Mitigation	Oct. 2 Tuesday	am
C.2.	International Cooperation and New Concepts	Oct. 3 Wednesday	am
G.	**JOINT IAF/IAA LIFE SCIENCES SYMPOSIUM** (5 sessions)		
G.1.	New Approaches to Medical Care: Telemedicine and New Technologies	Oct. 3 Wednesday	am
G.2.	Exobiology and Planetary Protection	Oct. 3 Wednesday	pm
G.3.a.	Space Human Factors: Psychophysiology and Models	Oct. 3 Wednesday	pm
G.3.b.	Space Human Factors: Group and Cultural Issues	Oct. 4 Thursday	pm
G.4.	Hybrid Life Support Systems for Space and Terrestrial Applications	Oct. 5 Friday	am
I.	**MATERIALS AND STRUCTURES SYMPOSIUM** (6 sessions)		
I.1.	Development and Verification	Oct. 1 Monday	pm
I.2.	Space Structures – Dynamics and Microdynamics	Oct. 2 Tuesday	am
I.3.	New Materials and Structural Concepts	Oct. 2 Tuesday	pm
I.4.	Smart Materials and Adaptable Structures	Oct. 3 Wednesday	am
I.5.	Environmental Effects and Structural Protection	Oct. 3 Wednesday	pm
I.6.	Space Vehicles – Mechanical / Thermal Subsystems	Oct. 4 Thursday	am
J.	**MICROGRAVITY SCIENCES AND PROCESSES SYMPOSIUM** (6 sessions)		
J.1.	Gravity and Fundamental Physics	Oct. 2 Tuesday	am
J.2.	Microgravity Engineering Sciences	Oct. 2 Tuesday	pm
J.3.	Results of Microgravity Experiments	Oct. 3 Wednesday	am
J.4.	Results from Ground-Based Experiments	Oct. 3 Wednesday	pm
J.5.	Facilities and Operations of Microgravity Experiments	Oct. 4 Thursday	am
J.6/T.5.	Joint Session on Physical Science Microgravity Activities on Board the ISS	Oct. 5 Friday	am
M.	**SATELLITE COMMUNICATIONS SYMPOSIUM** (6 sessions)		
M.1.	Global Information Infrastructure - Key Policy	Oct. 1 Monday	pm
M.2.a.	Advanced Systems and Technologies	Oct. 2 Tuesday	am
M.2.b.	Advanced Systems and Technologies	Oct. 3 Wednesday	am
M.3.	Mobile Communications and Satellite Navigation	Oct. 3 Wednesday	pm
M.4.	Non-Geostationary Systems	Oct. 4 Thursday	pm
M.5.	Fixed and Broadcast Services	Oct. 5 Friday	am
P.	**JOINT IAF/ISSAT/ ISU SPACE AND EDUCATION SYMPOSIUM** (4 sessions)		
P.00	Opening Session	Oct. 3 Wednesday	am
P.1.	"Hands-On" Education	Oct. 3 Wednesday	pm
P.2.	Educational Structures	Oct. 4 Thursday	am
P.3.	Educational Outreach	Oct. 4 Thursday	pm
P.4.	Beyond Education	Oct. 5 Friday	am
Q.	**SPACE EXPLORATION SYMPOSIUM** (6 sessions)		
Q.1.	Space Based Astronomy	Oct. 1 Monday	pm
Q.2.	Solar System Exploration	Oct. 2 Tuesday	pm
Q.3.a.	Mars Exploration	Oct. 3 Wednesday	am
Q.3.b.	Mars Exploration	Oct. 4 Thursday	pm
Q.4	New Mission Concepts for Space Exploration	Oct. 4 Thursday	pm
Q.5.	Small Bodies Missions and Technologies	Oct. 5 Friday	am

R.	**SPACE POWER SYMPOSIUM** (4 sessions)		
R.1.	Power from Space - Prospects for the 21st Century	Oct. 1 Monday	pm
R.2.	Advanced Space Power Systems and Technologies	Oct. 2 Tuesday	pm
R.3.	Special organized session "Case Studies in Market Analyses of Solar Power"	Oct. 4 Thursday	am
R.4/IAA.13.4.	Joint session on Energy-Rich Approaches to Human Exploration of Mars and Beyond Innovative Space Power Concepts and Technologies	Oct. 4 Thursday	pm
S.	**SPACE PROPULSION SYMPOSIUM** (6 sessions)		
S.1.	Space Propulsion Systems I	Oct. 1 Monday	pm
S.2.	Space Propulsion Systems II	Oct. 2 Tuesday	am
S.3.	Space Propulsion Technology	Oct. 3 Wednesday	am
S.4.	Electric Propulsion	Oct. 4 Thursday	am
S.5.	Hypersonic and Combined Cycle Propulsion	Oct. 3 Wednesday	pm
S.6	Advanced Propulsion – Non Chemical, non Electric Energy Sources ...	Oct. 4 Thursday	pm
T.	**SPACE STATIONS SYMPOSIUM** (5 sessions)		
T.1.	Overview of Space Stations	Oct. 1 Monday	pm
T.2.	Design, Development, Verification and Integration of Space Stations ..	Oct. 3 Wednesday	pm
T.3.	Operations of Space Stations	Oct. 4 Thursday	am
T.4.	International Utilization of Space Stations	Oct. 4 Thursday	pm
T.5./J.6.	Joint Session on Physical Science Microgravity Activities on Board the ISS	Oct. 5 Friday	am
U.	**SPACE SYSTEMS SYMPOSIUM** (5 sessions)		
U.1.	System engineering and Design Techniques	Oct. 2 Tuesday	am
U.2.	Technology Transfer, Strategy + Plans	Oct. 2 Tuesday	pm
U.3.	New Technology for Space Systems	Oct. 3 Wednesday	pm
U.4.	Software for Space Systems	Oct. 4 Thursday	am
U.5.	Innovative and Visionary Systems Concepts	Oct. 4 Thursday	pm
V.	**SPACE TRANSPORTATION SYMPOSIUM** (6 sessions)		
V.1.	Launch Vehicles	Oct. 2 Tuesday	am
V.2.	Launch Services	Oct. 3 Wednesday	am
V.3.	Space Transfer & Re-Entry	Oct. 3 Wednesday	pm
V.4.	Advanced Launch Vehicle Systems	Oct. 4 Thursday	am
V.5.	Advanced Launch Vehicle Technologies	Oct. 4 Thursday	pm
V.6.	Missions, Facilities & Operations	Oct. 5 Friday	am
W.	**STUDENT CONFERENCE** (2 sessions)		
W.1.	Student Conference 1	Oct. 2 Tuesday	am
W.2.	Student Conference 2	Oct. 2 Tuesday	pm
IAA.1.	**31st SYMPOSIUM ON ECONOMICS AND COMMERCIALIZATION OF SPACE ACTIVITIES** (3 sessions)		
IAA.1.1.	Launch Vehicles' Cost Engineering and Economic Competitiveness ...	Oct. 1 Monday	pm
IAA.1.2.	Commercialization of Space Activities / Financing / New Business Opportunities	Oct. 4 Thursday	am
IAA.1.3.	Space Tourism and other Novel Space Applications	Oct. 4 Thursday	pm
IAA.2.	**35TH HISTORY OF ASTRONAUTICS SYMPOSIUM** (3 sessions)		
IAA.2.1.	Memoirs	Oct. 1 Monday	pm
IAA.2.2.	Organizational Histories	Oct. 3 Wednesday	pm
IAA.2.3.	Scientific and Technical Reviews	Oct. 4 Thursday	am
IAA.3.	**15TH INTERNATIONAL SPACE PLANS AND POLICIES SYMPOSIUM** (2 sessions)		
IAA.3.1.	International Cooperation and Competition Policies and Plans Affecting Competition and Commericialization of Space Enterprises	Oct. 3 Wednesday	am
IAA.3.2.	Cooperation and Competition in Advanced Propulsion Systems	Oct. 4 Thursday	pm
IAA.4.	**14th INTERSTELLAR SPACE EXPLORATION SYMPOSIUM** (1 session)		
IAA.4.1.	Space Exploration at the Kuiper Belt, the Heliosphere Boundaries, the Solar Gravitational Lens and Beyond	Oct. 1 Monday	pm
IAA.5.	**MULTILINGUAL ASTRONAUTICAL TERMINOLOGY SYMPOSIUM** (1 session)		
IAA.5.1.	Practical uses of Terminology in Space Activities	Oct. 4 Thursday	am

IAA.6. 34TH SAFETY, RESCUE AND QUALITY SYMPOSIUM (7 sessions)

IAA.6.1.	Risk Versus Cost: why did "Faster, Better, Cheaper" fail and how to Solve the Issue?	Oct. 1 Monday	pm
IAA.6.2	Risk Assessment and Management: A Key Discipline for Successful Program Management	Oct. 2 Tuesday	am
IAA.6.3.	Space Weather Issues and Space Environment Effects	Oct. 3 Wednesday	am
IAA.6.4	Measurements and Modelling of Space Debris and Meteoroids	Oct. 3 Wednesday	pm
IAA.6.5.	Risk Analysis and Protection	Oct. 4 Thursday	am
IAA.6.6	Mitigation Measures and Standards	Oct. 4 Thursday	pm
IAA.6.7.	Knowledge Management	Oct. 2 Tuesday	pm

IAA.7. 19th IAA/IISL SCIENTIFIC-LEGAL ROUNDTABLE (1 session)

IAA.7.1.	Scientific and Legal Implications of Establishing Solar Power Systems on the Geostationary Orbit	Oct. 3 Wednesday	pm

IAA.8. 12TH SPACE ACTIVITIES AND SOCIETY SYMPOSIUM (2 sessions)

IAA.8.1.	Round Table: Ethical Issues Arising from Space Activities	Oct. 4 Thursday	am
IAA.8.2	Internet: Gateway to Space	Oct. 3 Wednesday	am

IAA.9. 30th REVIEW MEETING OF THE SEARCH FOR EXTRATERRESTRIAL INTELLIGENCE (2 sessions)

IAA.9.1.	SETI I: Science and Technology	Oct. 2 Tuesday	pm
IAA.9.2.	SETI II: Interdisciplinary Connections	Oct. 3 Wednesday	am

IAA.10. EVA AND SPACE SUIT SYMPOSIUM (1 session)

IAA.10.1.	The EVA Wall for ISS Assembly	Oct. 3 Wednesday	pm

IAA.11. SMALL SATELLITE MISSIONS SYMPOSIUM (5 sessions)

IAA.11.1.a.	UN/IAA Workshop on Small Satellites serving Developing Countries, with Particular Emphasis on Africa	Oct. 2 Tuesday	am
IAA.11.1.b.	UN/IAA Workshop on Small Satellites serving Developing Countries, with Particular Emphasis on Africa	Oct. 2 Tuesday	pm
IAA.11.2.	Small Planetary Missions: The Next Generation	Oct. 2 Tuesday	pm
IAA.11.3.	Small Satellite Operations	Oct. 4 Thursday	pm
IAA.11.4.	Small Satellites for Earth Observation - Lessons Learned and New Generation	Oct. 3 Wednesday	pm

IAA.12. ADVANCED MATERIALS SCIENCE SYMPOSIUM (1 session)

IAA.12.1.	Gravity Effects on Materials Processing	Oct. 1 Monday	pm

IAA.13. SYMPOSIUM ON INTERNATIONAL MOON/ MARS EXPLORATION (4 sessions)

IAA.13.1.	Rationale for Human Exploration of Space Beyond Low Earth Orbit - Near- and Long-Term Goals	Oct. 2 Tuesday	am
IAA.13.2.	Human Lunar Mission Development Session	Oct. 3 Wednesday	pm
IAA.13.3.	Strategies and Plans for Human Mars Missions	Oct. 4 Thursday	am
IAA.13.4./R.4.	Joint Session on Energy-Rich Approaches to Human Exploration of Mars and Beyond - Potential Applications of Innovative Space Power Concepts and Technologies	Oct. 4 Thursday	pm

IISL. 44th COLLOQUIUM ON THE LAW OF OUTER SPACE (4 sessions)

IISL.1.	Emerging Issues of Interpretation and Applications of Space Treaties	Oct. 2 Tuesday	am
IISL.2.	Emerging Legal Issues in Satellite Telecommunications	Oct. 2 Tuesday	pm
IISL.3.	Legal Issues Arising from the Commercial Availability of High Quality Remote Sensing Imagery	Oct. 3 Wednesday	am
IISL.4.	Other Legal Matters including:	Oct. 5 Friday	am

- the teaching of space law at the dawn of the new millennium
- space debris
- conflicts relating to space activities
- legal aspects of human habitations in outer space
- emerging legal issues in the field of navigation by satellite