The Exploration Systems Avionics and Software Topic focuses on the technologies, systems, and software that will enable the Vision for Space Exploration to achieve its goals. Integrated system health management technologies to track the state of spacecraft and instruments; spacecraft autonomy capabilities to enable greater operational flexibility and support dynamic missions for exploration vehicles and habitats; robust software engineering technologies to take programming from an art to an engineering science; and the radiation hardened and low-temperature tolerant processing and avionics to enable the advance software to work in physically demanding environments.

Subtopics

X2.01 Integrated Systems Health Management

Lead Center: ARC
Participating Center(s): GRC, JPL, JSC, MSFC

In order to increase the safety and effectiveness of future spacecraft and launch vehicles, innovative health management technologies are required throughout the system lifecycle including design, development, test, validation, integration, operation, maintenance, and disposition. Traditional means of supporting vehicle health, such as invasive inspections, are extremely limited in their utility for exploration missions. Other solutions, such as ground-based monitoring of telemetry data, become less useful as communication delays or bottlenecks increase. Under these circumstances, autonomous and automated solutions to systems health management provide the best means of increasing crew safety and mission success probability for future space exploration missions.

Another significant concern is the high cost of ground and mission operations. Future ground operations will require quick and efficient turnaround and processing of spacecraft for launch. In addition, new mission operations concepts must be developed to provide appropriate levels of safety and mission success factors while reducing support staff.

Proposals should be responsive to the overall goals and objectives of NASA's Constellation and Lunar Precursor and Robotic Programs. Proposals may address specific vehicle health management capabilities required for exploration system elements (crewed spacecraft, launch systems, habitats, rovers, etc.). In addition, projects may
focus on one or more relevant subsystems such as propulsion, structures, thermal protection systems, power, avionics, life support, and communications. Proposals that involve the use of existing NASA health management testbeds (power, propulsion, systems integration, life support, diagnostics, networking, etc.) for technology validation are strongly encouraged.

Specific technical areas of interest related to integrated systems health management include the following:

- Methods and tools to enable concurrent design of system function and health management systems. These methods and tools should provide a means to optimize health management system design at the functional level to decide on failure detection methods, sensor types and locations, and identify additional functionality to safeguard against failures before costly design decisions have been made.

- Health monitoring and management technologies for increased situational awareness of system health, safety, and margins. Of special interest are innovative methods for sensor validation, robust state estimation, and model-based methods for fault isolation. Proposals should focus on data analysis and interpretation rather than development of new sensors.

- Data-driven methods for detection of failure precursors and recognition of anomalous patterns in large data sets. A specific emphasis is on methods that utilize propulsion system data sets.

- Concepts for advanced built-in-tests for spacecraft avionics that reduce or eliminate the need for extensive functional verification. Methods for reducing or disambiguating false alarms on built-in-tests are also of interest.

- Methods for robust control of critical components, subsystems, and systems and robust execution of critical sequences during flight. Of special interest are robust recovery methods and innovative approaches to functional redundancy for the purpose of enhancing safety, availability, and maintainability.

- Prognostic techniques able to anticipate system degradation and enable further improvements in mission success probability, operational effectiveness, and automated recovery of function. Proposals in this area should focus on systems and components commonly found in spacecraft.

- Human-system integration methods that are capable of summarizing sensor readings, presenting system status, assessing spacecraft capability and mission readiness, and proposing corrective actions in a manner that does not exceed the capacity of human understanding, especially in high-risk situations requiring rapid human response. Innovative ways for the health management system to convey a wealth of information quickly and effectively are desired.

X2.02 Spacecraft Autonomy

Lead Center: ARC

Automation and autonomy techniques are key elements in realizing the vision for space exploration. Intelligent automation of systems on crewed vehicles is instrumental for decreasing workload, reducing dependence on Earth-based support staff, enhancing response time, and reducing operations cost. Increased system autonomy for unmanned and manned vehicles reduces operations costs, while increasing operations efficiency and spacecraft
capability by reducing the time required for humans to staff flight control positions and interact with the vehicles. To enable the application of intelligent automation and autonomy techniques, configuration and validation issues need to be addressed.

Reusable automation software must be adaptable to new applications without undue difficulty, and easily adjusted as the application operations change. The overhead of applying automation techniques to new applications is one of the two key obstacles to acceptance of such techniques in operations. A variation of the same issue is that of adjustment as requirements and application contexts change, which is inevitable in spacecraft operations.

The software and the adaptation to a given application must also be trusted before it can be accepted. Testing and other techniques are keys to establishing such trust and ensuring the correct function of automation systems. However, in both testing and validation, the complexity of intelligent software has proven to be a major obstacle. This has led to trust and correctness issues being another key obstacle to adoption of intelligent automation systems in both unmanned, and most importantly, in crewed vehicles.

Proposals in this area should include autonomy and automation software architectures that facilitate adaptation and ensure correctness. Specifically, proposals in the following technical areas are of high interest:

- Architectures for decision-making and closed-loop control that can be adapted to new applications with minimal reliance on intelligent systems expertise;
- Methodology and techniques for adapting autonomy software to applications, as well as for reconfiguring the software in response to changes;
- Representation and reasoning techniques for specifying properties for application interfaces, operations flight rules and autonomy software behaviors, and for deriving overall properties for autonomy software applications.

X2.03 Software Engineering Technologies for Human-Rated Spacecraft

Lead Center: ARC
Participating Center(s): GSFC, JPL, JSC

The objective of this subtopic is to bring to fruition software engineering technologies that enable engineers to cost-effectively develop and maintain NASA mission-critical software systems. Particular emphasis will be on software engineering technologies applicable to the high levels of reliability needed for human-rated space vehicles. A key requirement is that proposals address the usability of software engineering technologies by NASA (including NASA contractors) engineers, and not only specialists.

Many of the capabilities needed for successful human exploration of space will rely on software. In addition to
traditional capabilities, such as GNC (guidance, navigation, and control) or C&DH (command and data handling), new capabilities are under development: integrated vehicle health management, autonomous vehicle-centered operations, automated mission operations, and further out - mixed human-robotic teams to accomplish mission objectives. Ensuring that these capabilities are reliable, and can be developed and maintained affordably, will be challenging but critical to NASA’s exploration objectives. Proposals should clearly indicate how the technology is expected to address the challenge of reliability and affordability. Mission phases that can be addressed include not only the software life-cycle (requirement engineering through verification and validation) but also upstream activities (e.g., mission planning that incorporates trade-space for software-based capabilities) and post-deployment (e.g., new approaches for computing fault tolerance, rapid reconfiguration, and certification of mission-critical software systems).

Software engineering tools and methods that address reliability for exploration missions are sought. Projects can address technology development and maturation that provide for the following and related capabilities:

- Automated software generation methods from engineering models that are highly reliable;
- Scalable verification technology for complex mission software, e.g., model-checking technology that addresses the ‘state explosion’ problem and static-analysis technology that addresses mission-critical properties at the system level;
- Automated testing that ensures coverage targeted both at the system level and software level, such as model-based testing where test-case generation and test monitoring are done automatically from system-level models;
- Technology for calibrating software-based simulators and test-beds against high-fidelity hardware-in-the-loop test-beds in order to achieve dependable test coverage;
- Technology for verifying and validating autonomy capabilities including intelligent execution systems, model-based diagnosis, and ISHM;
- Software-based radiation fault tolerance for computation;
- Methods and tools for development and validation of autonomic software systems (systems that are self protecting and self healing).

X2.04 Low Temperature, Radiation Hardened Avionics

Lead Center: MSFC

Participating Center(s): GSFC, JPL

Moon equatorial regions experience wide temperature swings from -180°C to +130°C during the lunar day/night cycle, and the sustained temperature at the shadowed regions of lunar poles can be as low as -230°C. Mars diurnal temperature changes from about -120°C to +20°C. All exploration endeavors, including robotic, habitat, and ISRU systems that are expected to reliably operate on the Moon or Mars surface for years will need electronics that are able to survive and operate in a wide temperature range and thermal-cycling environment. In addition, the electronics must operate reliably after a total ionizing dose (TID) \( \geq 50 \) krads (Si) and provide single-event latchup
immunity (SEL) $\geq 100$ MeV cm$^2$/mg. The lunar and Martian temperatures are well outside the specification range of military and commercial electronics. While many types of devices, especially Si CMOS transistors, can operate down to low temperatures, there are significant circuit design challenges that need to be addressed, especially in the case of mixed-signal and analog circuits.

In addition, thermal cycling present in lunar and especially Mars environments introduces reliability concerns associated with mechanical stress and fatigue of the IC package. For example, compounds optimized for Earth-like packaging of electronic systems have glass transition temperatures that are within the cycling range of these environments, and cycling of electronic systems packaged using these materials will likely result in package failures. Hence, the choice of packaging technology and material combination used is extremely critical for these missions.

Proposals are sought in the following specific areas:

- **Wide temperature** (-180°C to +130°C) and low-temperature (-230°C), radiation-tolerant and SEL immune, low power, mixed-signal circuits including analog-to-digital converters, digital-to-analog converters, low-noise pre-amplifiers, voltage and current references, multiplexers, power switches, microcontrollers, and integrated command/control/drive electronics for sensors, actuators, and communications transponders.

- **High-density packaging** able to survive large numbers of thermal cycles (hundreds) and tolerant of the extreme temperatures of the Moon and Mars, including appropriate selection of packaging materials combinations (substrates, die-attach, encapsulants, etc.) modular system level electronics packaging, including power, command and control, and processing functions, enabling integration of electronics with sensors and actuators elements.

- **Radiation-tolerant, SEL immune, wide temperature** (-180°C to +130°C), and **ultra-low temperature** (-230°C) RF electronics for short range and long-range communication systems.

- **Computer Aided Design (CAD)** tools for predicting the electrical performance, reliability, and life cycle for low-temperature electronic systems and components.

- **Physics-based transistor device models** valid at temperature ranging from -230°C to +130°C to enable design, verification and fabrication of custom low power mixed-signal and analog circuits.

- **Low-temperature** (-230°C) circuit design methodologies facilitating novel layout designs for integrated mixed-signal and analog circuits.

Research should be conducted to demonstrate technical feasibility during Phase 1 and show a path toward a Phase 2 hardware/software demonstration, and when possible, deliver a demonstration unit for functional and environmental testing at the completion of the Phase 2 contract.