Z8.10 Modular Systems for Cost-Effective Spacecraft Missions

Lead Center: ARC

Participating Center(s): GRC, JPL, LaRC, MSFC

Scope Title

Wireless Avionics Architectures and Wireless Sensing and Integrated Avionics

Scope Description

This subtopic scope solicits proposals to develop enabling concepts, components, and subsystems based on innovative avionics architectures for spacecraft. Of interest are wireless systems that demonstrate reliable data transfer across avionics components, subsystems, and interfaces to simplify system integration, reconfiguration, and testing. These can range from developmental and flight instrumentation systems used for qualification and diagnostics on large spacecraft to fully wireless avionics for small spacecraft. Solutions that enable new avionic architectures and provide capabilities that expand mission performance while decreasing the size, weight, and power consumption (SWaP) and cost of the resulting spacecraft are highly desirable. The goal of this effort is to mature wireless avionics technology that facilitates the reuse of components, subsystems, and software across multiple spacecraft and missions while reducing production and operating costs. Initial development and demonstration is anticipated to be performed using small spacecraft, but applicability to large spacecraft, lunar outposts, human-rated landers, and robotic elements is highly desirable.

Modularity is defined as utilizing a set of standardized parts or independent units to form a full avionics system, and flexibility allows adapting modular components across different configurations, missions, and design stages. For example, wireless subnets improve modularity by eliminating the physical data connections from each component, simplifying physical integration. The scope is intended to range from simple wireless sensors to complete avionics systems, including software incorporating functions compatible with common spacecraft components. This means being able to integrate a given component or entire subsystem into flight hardware and software using object-oriented frameworks, allowing components or functions to be added to a new or existing spacecraft design without requiring significant changes to the other nonrelated components or subsystems.

This subtopic also solicits proposals to develop techniques, components, and systems that reduce or eliminate the dependency on wires, connectors, and penetrations for sensing and for the transmission of data and power across avionics subsystems, interfaces, and structures. Of interest are techniques that enable new applications through innovative methods such as the use of flexible materials and additive manufacturing. For example, the use of additive manufacturing and 3D printing to embed avionics components such as antennas, sensors, transmission lines, and interface functions into a spacecraft structure during the design and manufacturing process can increase efficiency while maintaining structural integrity. Similarly, the use of thin and flexible materials to construct passive wireless sensors enables sensing systems for structures such as parachutes and inflatable spacecraft without breaching the pressure interface. Systems that are applicable to small spacecraft (typically 6U/12U/24U CubeSats, including ESPA-class (Evolved Expendable Launch Vehicle (EELV) Secondary Payload Adapter class)) but
scalable to large vehicles can result in a significant reduction of risk for more complex and longer duration missions. Near-term missions include cislunar, lunar orbiting, lunar landed, and exploration precursor missions; low Earth orbit (LEO) “swarms” for Earth science and heliophysics; and disaggregated cooperative ensembles and sustained infrastructure for human exploration. New applications might include manned spacecraft inspection, repair, communications support, and related areas. Technology that supports onboard servicing, assembly, and manufacturing is specifically solicited. Proposals that provide reliable performance in extreme environments and that show a path to a flight demonstration are preferable.

The subtopic solicits developments in wireless avionics and wireless sensing for small spacecraft and may include technologies that:

1. Improve the reliability and applicability of wireless avionics for spacecraft with significant improvements in subsystem size, mass, and volume, particularly if the technology can simplify the spacecraft fabrication, test, and integration process.
2. Allow innovative architectures for wireless avionics featuring plug-and-play software supporting modular subsystems that can be easily incorporated into specific small-satellite missions.
3. Improve fault detection aboard spacecraft using wireless sensor systems to augment current wired sensors and which include the capability of adding sensors to address developmental and flight instrumentation use.
4. Use innovative techniques for embedding sensors and other avionics components into a spacecraft to reduce or eliminate large and heavy cables and connectors, or that enable data transfer inside and across rotating mechanisms and pressure interfaces or into remote locations where it is difficult or unfeasible to run cables or where cables are at risk of failure.
5. Use additive manufacturing of wireless components such as antennas, sensors, and processing elements to create new components that may be smaller and lighter than current products. These new components could be embedded into materials and structures that enable in situ structural health management, contributing to the development of smart structures and materials.
6. Include sensors and actuators that can be distributed among cooperative spacecraft to enable automated inspection of space assets or resource detection at the surface of the Moon, Mars, or other celestial bodies.
7. Development of wireless network and component technology that can enable time-critical control loops across spatially distributed elements can produce new avionics capability.

Key performance parameters (KPPs) would include improvements of at least a factor of 2 over existing technology in size, mass, and power consumption for sensors and associated components for a wireless instrumentation system. Improvements of sensor network throughput greater than five times the current 2-Mbps performance is desired, along with reduction of latency and incorporation of timing and position information.

Expected TRL or TRL Range at completion of the Project

3 to 6

Primary Technology Taxonomy

Level 1

TX 02 Flight Computing and Avionics

Level 2

TX 02.2 Avionics Systems and Subsystems

Desired Deliverables of Phase I and Phase II

- Hardware
- Prototype
- Software
- Research
- Analysis
Desired Deliverables Description

Possible deliverables include benchtop hardware systems that demonstrate reliable wireless interconnectivity of two or more modules with a host flight central processing unit (CPU), or payload/developmental flight instrumentation (DFI) processor, inside a CubeSat or small-satellite form-factor bus. This system need not be flight ready, but it should be in a path to a flight demonstration that would serve as technology maturation and risk reduction activity for larger NASA missions such as Gateway and other Artemis projects.

Specific Phase I deliverables include:

- Methods of improving reliability of wireless avionics technology.
- Redundancy methods to broaden mission applicability.
- Improvements in tolerance to extreme environments, including radiation.
- Novel avionics architecture definition and demonstration.
- Software support for redundant modular avionics.
- Plug-and-play methods for handling dynamic changes to avionics configuration.
- Fault detection and recovery for wireless avionics.
- Improvements in spacecraft production.
- Improvements in spacecraft integration and test.
- Technologies that use additive manufacturing technology for embedded avionics systems that reduce cables, connectors, and penetrations and show a path to a full solution.
- Sensors and sensor systems based on current technology needs to develop point solutions that are applicable to NASA missions in near- to mid-range timeframes.

Phase II deliverables should build upon the work completed in Phase I to demonstrate the new technology at a higher Technology Readiness Level (TRL) with alignment to NASA mission needs:

- Demonstration showing the key innovations of the developed technology.
- Demonstration of specific new mission capabilities.
- Delivery of prototype hardware for NASA evaluation.

State of the Art and Critical Gaps

Development of small-satellites missions benefits from a growing number of users worldwide. This means there may be a large pool of commercial off-the-shelf components available for a specific mission (depending on the type and class of mission). A variety of command and data handling (C&DH) developments for CubeSats have resulted from in-house development, from new companies that specialize in CubeSat avionics, and from established companies who provide spacecraft avionics for the space industry in general. Presently there are a number of commercial vendors who offer highly integrated systems that contain the onboard computer, memory, electrical power system (EPS), and the ability to support a variety of input and output (I/O) for the CubeSat class of small spacecraft.

Wireless networks have been incorporated as crew support aboard the International Space Station (ISS). Wireless sensor networks have been flown as demonstrations. Dynamic self-configuring wireless networks have been evaluated in the laboratory. The American Institute of Aeronautics and Astronautics (AIAA) has defined the Space Plug-and-Play Architecture (SPA) standard, and flight demonstrations are planned.

The maturation of additive manufacturing and 3D printing technology are making embedded wireless sensors and avionics a possibility. Embedding transmission lines, antennas, connectors, and sensors onto a spacecraft structure turns that structure into a multifunctional system that reduces or eliminates bulky cables and connectors. Embedded passive wireless sensors can greatly increase sensing and telemetry capabilities, including providing low-cost techniques for vehicle health management in future missions. Moreover, flexible embedded passive sensors created with conductive and functional fabrics are enabling new opportunities for sensing in surfaces and systems where sensing has been traditionally absent, such as parachutes and inflatable structures.

Wireless power transmission is being used commercially for charging cell phones using resonant magnetic couplings. Passive sensors do not require an external power source. Power generation from light, vibration, radio-
frequency (RF) energy, and other methods is needed to eliminate batteries and power connections for wireless sensor systems.

Relevance / Science Traceability

NASA and other space agencies are exploring the application of SmallSats for deep space missions. The availability of modular wireless data connectivity alleviates complexity in testing and integration of systems. Modular components allow easier reconfiguration and late additions to any design. This is a benefit conferred on any spacecraft of any size, with the larger systems benefiting from savings in mass due to a larger reduction in cable harnesses and connectors.

References:

5. Backscatter Systems for WAIC: https://ntrs.nasa.gov/search.jsp?R=20180004760
7. NASA Trade Study: https://pdfs.semanticscholar.org/b7d6/e6d92ec78bb6beee4cfdf5a7f613b90b4508b8.pdf?ga=2.244696965.1804159109.1563897519-1127952606.1563032260

Scope Title

Modular Open Systems Architectures Applied to Small-Spacecraft Platforms

Scope Description

This subtopic scope requests advances within modular open systems architectures for small spacecraft. As the most accessible spacecraft platform logistically and financially, small spacecraft benefit from a heritage based on rapid deployment and cost-effective missions. To further the state of the art (SOA) of both of these considerations, further cost savings may be found by standardizing the system architectures that drive the subsystems for these platforms. Such a realization would enable modular, hot-swappable spacecraft subsystems to accommodate the ever-increasing need for a wider definition of what small spacecraft are capable of and utilized for. Upon demonstration aboard small-spacecraft missions, these technologies could then be adopted by larger unmanned and manned spacecraft missions.

The development of standardized, hot-swappable interfaces should be compliant with and cognizant of NASA spacecraft standards. Of particular interest are designs acquiescent to the Agency standards existing between grounding, thermal, software, and data transfer interfaces.

The adaptability introduced by an open and modular, interchangeable commercial-off-the-shelf (COTS) architecture furthers the ability to tailor current spacecraft designs for novel applications without requiring significant modifications to existing platforms. Also, of interest are advances in modules that minimize complexity in spacecraft manufacturing (such as deterring geometrical modifications by virtue of manufacturing). Advances in additive manufacturing may enable critical enhancements to the performance of small-spacecraft systems by embedding otherwise impractical internal features (such as through holes and cavities for electronics integration). Concepts that can support high specific power generation and management as well as thermal control are also of particular interest.

Systems that are applicable to small spacecraft (CubeSats up to ESPA class (Evolved Expendable Launch Vehicle (EELV) Secondary Payload Adapter class) but scalable to large vehicles can result in a significant reduction of risk for more complex and longer duration missions. Near-term missions include:
Cislunar, lunar orbiting, lunar landed, and exploration precursor.
Low Earth Orbit (LEO) “swarms” for Earth science and heliophysics.
Disaggregated cooperative ensembles and sustained infrastructure for human exploration.

New applications might include manned spacecraft inspection, repair, communications support, and related areas. Proposals that provide reliable performance in extreme environments and that show a path to a flight demonstration are preferable.

The subtopic solicits developments in open modular architectures for small spacecraft and may include technologies that:

1. Provide interchangeable hardware and software with standardized interfaces.
2. Enable spacecraft to be built up from plug-and-play components.
3. Improve the state of the art of open interfacing platforms suitable for small spacecraft, leveraging COTS wherever possible.
4. Leverage novel manufacturing-in-the-loop considerations for small-spacecraft design standardization.
5. Increase the reliability and durability of small-spacecraft hardware and software by integrating subsystem considerations directly into the design process at the architectural level.
6. Demonstrate expanded adaptivity for small spacecraft, allowing for platforms to be rapidly varied with respect to altering objectives and variable risk postures.
7. Exhibit advances in onboard power generation and management and/or improvements in thermal mitigation and dissipation for small spacecraft.

Expected TRL or TRL Range at completion of the Project:
3 to 6

Primary Technology Taxonomy:
Level 1: TX 02 Flight Computing and Avionics
Level 2: TX 02.1 Avionics Component Technologies

Desired Deliverables of Phase I and Phase II:

- Research
- Analysis
- Prototype
- Hardware
- Software

Desired Deliverables Description:

Promising platform architectures that enable the standardization of COTS hardware and software could be demonstrated through benchtop setups validating numerous protocols and compliance with existing NASA design standards for small spacecraft. A demonstration of ease of hot-swapping would be ideal, demonstrating how rapidly such a system could be adapted for altered requirements with new instrumentation and subsystems.

The deliverables should address improvements for ease of integration of varied hardware and software, plug-and-play integration of small-spacecraft subsystems, increased assembly speed of small spacecraft, utilization of advanced manufacturing for ease of integration, automated error assessment for targeted repairability of subsystems, reduced small-spacecraft design complexity, and reduction of small-spacecraft development cost through standardized COTS.

Phase I Deliverable:

Trade study for and demonstration of how NASA small-spacecraft standards, such as thermal, grounding, and
software/data normalizations, could be implemented into hot-swappable, modular architecture.

These architectures must be cognizant of:

- NASA thermal interface standards to demonstrate necessary conductivity and respective thermal isolation.
- NASA grounding interface standards to mitigate unwanted currents through single- or multiple-point grounding framework.
- NASA software and data interfacing standards, complying with Unified S-Band (USB) or Consultative Committee for Space Data Systems (CCSDS) standards.

**Phase II Deliverable:**

A benchtop hardware demonstration of open and modular architectures functioning at TRL 5 or above and using the Standards developed during Phase I. The components should take advantage of supply-chain-compliant, heritage-relevant COTS whenever possible.

**State of the Art and Critical Gaps:**

The current SOA leverages COTS and compiled standards for integrating small spacecraft into a functional system meeting varied mission requirements. A number of in-house developments within NASA have complemented progress in academia and private industry to develop the infrastructure required to expand and normalize the definition of small-spacecraft-compliant subsystems and instrumentation. An issue arises with the software and hardware architecture regulating the agreement of these subsystems with NASA standards. Commercial vendors offering plug-and-play components are often only compliant with a limited number of subsystems, and consequently there exists a need to address this with an open modular architecture to enable more rapid, compliant, and consequently cost-effective small spacecraft that meet NASA's standards.

**Relevance / Science Traceability:**

NASA and other space agencies are exploring the application of SmallSats for deep space missions. Modular architectures would enable a hot-swap adaptivity to altering mission requirements and serve as low-cost, rapid solutions for emerging destinations as they arise. Modular components allow easier reconfiguration and late additions to any design. Small-spacecraft modularity can be analogous for larger systems as well by virtue of defining and standardizing interconnectivity of universal COTS systems, enabling new objectives to be realized with a wide variety of instrumentation with a wide scope of requirements.

**References:**

small spacecraft for a wide variety of missions, addressing objectives ranging from heliophysics to constellation demonstrations and sensor web applications. The ability to fabricate relatively large "batches" of spacecraft will play an important role regarding the throughput required for addressing the needs of the subtopic mission objectives in a cost-effective manner. As an advent in tandem with small-spacecraft swarms, batch-producible spacecraft are an increasing need as larger spacecraft are replaced with many smaller spacecrafts, distributing sensing and collaboratively accomplishing objectives enabled novelty by variable topologies and network-based considerations.

Advances in batch producibility are in tandem with standardization of rapid manufacturing of small spacecraft by private industry and will likely take advantage of advances in throughput-favorable fabrication methods. The manufacturability of batch-producible small spacecraft would need to consider the required throughput of manufacturing as a factor intrinsic to the small-spacecraft design itself. Of particular interest are concepts that integrate reconfigurable subsystems (such as those for power generation) for increased manufacturing throughput as a virtue of reduced point-design. These systems must still remain compliant with existing NASA small-spacecraft protocols for thermal, electrical, communications, and redundancy considerations. However, batch-producible spacecraft should leverage design methodologies that would decrease the cost and increase the compatibility of these standardized requisites by virtue of the manufacturing process itself, exhibiting design-for-standardization through the engineering process.

Such a batch-producible set of small spacecraft should leverage cost-effective supply chain considerations wherever possible and should integrate commercial-off-the-shelf (COTS) components and instrumentation into the design of spacecraft architecture. The result of rapidly manufacturable batches of spacecraft should demonstrate a significant reduction in manufacturing costs for 30 to 100 buses, with quicker turnaround times than otherwise possible over a range of NASA-relevant projects.

Expected TRL or TRL Range at completion of the Project:

3 to 6

Primary Technology Taxonomy:
Level 1: TX 02 Flight Computing and Avionics
Level 2: TX 02.2 Avionics Systems and Subsystems

Desired Deliverables of Phase I and Phase II:

- Research
- Analysis
- Prototype
- Hardware
- Software

Desired Deliverables Description:

Phase I Deliverable:

An overview and technical description of methods for batch producibility of small spacecraft within the range of 30 to 100 buses, demonstrating the integration of COTS as part of the framework. Successful demonstrations of this deliverable should demonstrate an increase in the competency of the following objectives:

- A standardized high-throughput manufacturing method to enable the fabrication of small spacecraft in batches of 30 to 100 buses (within the scope of CubeSats, up to and including ESPA-class spacecraft).
- A systematic decision tree that addresses fabrication turnaround-time considerations as a factor of
spacecraft complexity.
- Demonstrated cost decreases for spacecraft batches with respect to the current state of the art (SOA).
- The integration and normalization of COTS relevant for batch production of small spacecraft as a function of supply chain availability and vendor capabilities.

Phase II Deliverable:

Integrating small-spacecraft standards into batch production and demonstrating an infrastructure that is modular, batch compliant, and cost effective. Successful demonstrations of this deliverable should demonstrate an increase in the competency of the following objectives:

- The integration of common NASA small-spacecraft standards (such as thermal, grounding, communications) directly into batch producibility.
- A method for rapid assembly of batch-produced small spacecraft that accounts for manufacturability directly into the architecture of common subsystems (such as power generation, communications, etc.).

State of the Art and Critical Gaps:

The current SOA of batch-produced small spacecraft relies heavily on the industry-demonstrated heritage of COTS for small satellites. These systems have limited throughput considerations and are currently inappropriate for meeting future mission requisites pertaining to small spacecraft requiring the fabrication and integration of 30 to 100 spacecraft at a time (such as those relevant to heliophysics missions, network demonstrations, and swarm considerations).

Relevance / Science Traceability:

Partnership with industry on batch production of spacecraft will be required for distributed missions including synthetic apertures, disaggregated science observations, rapidly established planetary communications architectures, constellations, and sensor web applications; planned heliophysics missions call for 30 to 100 spacecraft. Technology development missions would also benefit from low-cost and shorter lead-time standardized bus platforms.

References:
