Scope Title:

Autonomous Operations Technologies for Ground and Launch Systems

Scope Description:

For the scope of this solicitation, ground systems are considered to be the planetary or lunar surface-based infrastructure and processes used to assemble, validate, support, and maintain launch vehicles and payloads (including non-spacecraft payloads) in preparation for flight. Launch systems are considered to be the planetary or lunar surface-based infrastructure and processes used to transition launch vehicles to flight operation.

Autonomous operations technologies (AOT) are required to manage ground and launch systems activities where human intervention/interaction/presence needs to be minimized or eliminated, such as in hazardous locations/operations and in support of remote operations. AOT are required to reduce operations and maintenance (O&M) costs of flight system and payload processing operations on the ground, and to increase ground systems availability to support mission operations. AOT will also be required for extended surface O&M on the Moon and Mars.

AOT performs functions such as system and component fault prediction and diagnostics, anomaly detection, fault detection and isolation, and enables various levels of autonomous control and recovery from faults, where recovery may include system repair and/or reconfiguration. AOT are enabled by Health Management (HM) technologies, methodologies, and approaches; command, monitoring and control architectures; computing architectures; software for decision making and control; and intelligent components and devices.

AOT will be integrated into activities performed by rocket engine test facilities, propellant servicing systems, and processing and launch of vehicles and payloads. AOT will enable surface O&M, which requires a high degree of autonomy and reliability for unattended operations during extended periods of time. AOT will complement in situ resource utilization (ISRU) operations by supporting ISRU ground systems infrastructure with O&M autonomy. AOT enables Autonomous Propellant Management (APM), which requires unattended or minimally attended storage, transfer, monitoring, and sampling of cryogenic propellants, or other propellants used in launch vehicles and maneuvering systems. APM includes preplanned nominal processes, such as vehicle fill and drain, as well as contingency and off-nominal processes, such as emergency safing, venting, and system reconfiguration.

AOT solutions may enable the autonomous command, monitoring, and control of entire integrated systems, such as a propellant loading system and all other associated support systems involved in the loading process. AOT will also support tasks such as systems setup, testing and checkout, troubleshooting, maintenance, upgrades, and repair. These additional tasks drive the need for autonomous element-to-element interface connection and
separation, multi-element inspection, and recovery of high-value cryogenic propellants and gases to avoid system losses.

AOT software may include prerequisite control logic (PCL) and reactive control logic (RCL), and may utilize machine learning or other forms of artificial intelligence to manage nominal system behavior and adapt to off-nominal conditions.

In addition to propellants, propellant management systems may utilize additional commodities to prepare a vehicle for launch, such as high-pressure gases for purging, pressurization, or conditioning. Propellant management systems may also include power and data interfaces with the vehicle to configure vehicle valves or other internal systems and observe vehicle states during propellant management operations.

Specifically, this subtopic seeks the following:

- Development of technologies for automated/autonomous propellant (including cryogenic propellants) management and the servicing of commodities for launch vehicles and payloads.
- Development of high-fidelity physics-based cryogenic-thermal models and ground process simulations capable of real-time and faster than real-time performance.
  - Development of automated/autonomous algorithms for ground systems applications.
  - Machine learning environments (simulation and learning agent) for ground systems processes and applications.
  - Development of high-fidelity models and simulations for complex payload system processing, servicing, maintenance, etc.
  - Development of test and evaluation (T&E), and verification and validation (V&V) methods for automated/autonomous algorithms, models, and simulations.
- Development of technologies for ground systems Health Determination and Fault Management.
  - Prediction, prognosis, and anomaly detection algorithms and applications.
  - Detection, isolation, and recovery of system and component faults and degradation.
  - Development of T&E, and V&V methods for Health Determination and Fault Management algorithms and applications.
- Development of technologies for automated/autonomous planning and scheduling (P&S).
  - Automated/autonomous assets management tools and applications.
  - Scheduling and prioritization algorithms and applications.
  - Human-machine information interactions and intent inferencing.
- Development of technologies for automated/autonomous inspection, maintenance, and repair (IM&R).
  - Use of robotic caretakers for IM&R needs.
  - Self-diagnosis in systems and components to inform condition-based maintenance.
  - Software to aid robotic agents or systems to learn IM&R functionality.
- Development of technologies for enhanced logistics and reliability.
  - Optimization and/or reduction of logistics needs (design for maintainability, commonality, and reusability).
  - Commonality of maintenance equipment, tools, and consumables.
  - Automated/autonomous asset management.
  - Automated/autonomous personnel location and condition determination.
  - Intelligent devices (sensors, actuators, and electronics with self-diagnosis capabilities, calibration on demand, self-healing capabilities, etc.).
- Standardization of architectures and interfaces for ground and launch systems.
- Standardization of ground systems design (design for maintainability, commonality, and reusability).

For all above technologies, research should be conducted to demonstrate technical feasibility during Phase I, show a path toward Phase II demonstration and deliver a demonstration package for NASA testing in operational or analog test environments at the completion of the Phase II contract. Successful Phase II technologies will be candidates for integration and demonstration in the existing Advanced Ground Systems Maintenance (AGSM)
Integrated Health Management (IHM) Architecture, deployed at Kennedy Space Center (KSC).

Expected TRL or TRL Range at completion of the Project: 5 to 8

Primary Technology Taxonomy:
Level 1: TX 04 Robotics Systems
Level 2: TX 04.6 Robotics Integration

Desired Deliverables of Phase I and Phase II:

- Prototype
- Hardware
- Software

Desired Deliverables Description:

Phase I deliverables: Research, identify, and evaluate candidate technologies or concepts for systems and components fault detection, isolation and recovery, fault prediction and diagnosis, and decision-making algorithms to enable autonomy of ground systems. Demonstrate technical feasibility and show a path towards a demonstration. Concept methodology should include the path for adaptation of the technology, infusion strategies (including risk trades), and business model. It should identify improvements over the current state of the art and the feasibility of the approach in a multicustomer environment. Bench or lab-level demonstrations are desirable. Deliverables shall include a report documenting findings.

Phase II deliverables: Emphasis should be placed on developing, prototyping, and demonstrating the technology under simulated operational conditions using analog ground systems hardware and processes. Deliverables shall include a report detailing performance testing results, a plan for maturing and applying the technology to mission-worthy systems, and other relevant documentation. Delivery of a functional prototype (software and hardware) is expected at the completion of the Phase II contract. The technology concept at the end of Phase II should be at a TRL of 6 or higher.

State of the Art and Critical Gaps:

There are presently critical gaps between state-of-the-art and needed technology maturation levels as follows:

1. High-fidelity, physics-based, cryogenic-thermal simulations with real-time and faster than real-time performance (Current TRL is 5; Required TRL is 9).
2. Simulation component libraries to support rapid prototyping of cryogenic-thermal models (Current TRL is 5; Required TRL is 9).
3. Supervisory control software for autonomous control and recovery of propellant loading systems and infrastructure (Current TRL is 5; Required TRL is 9).
4. Software development tools to support rapid prototyping of autonomous control applications (Current TRL is 5; Required TRL is 9).
5. Architecture for integrated autonomous operations (Current TRL is 5; Required TRL is 9).

Relevance / Science Traceability:

In addition to reducing O&M costs in ground operations, this subtopic provides Human Exploration and Operations Mission Directorate (HEOMD) with an on-ramp for technologies that enable the unattended setup, operation, and maintenance of ground systems and systems on the surfaces of other planets and moons. The directive from the President to accelerate the timeline for landing astronauts on the Moon, with the goal of a sustainable lunar presence after 2028, has made these technologies even more relevant to mission success. These technology development areas are identified in the 2020 NASA Technology Taxonomy, published by the Office of the Chief Technologist, under TX04 - Robotic Systems, TX10 - Autonomous Systems, and TX13 - Ground, Test, and Surface Systems.

This subtopic also produces technologies useful to the Space Technology Mission Directorate (STMD).
References:

NASA Technology Taxonomy (https://www.nasa.gov/offices/oct/taxonomy/index.html)

NASA Strategic Space Technology Investment Plan (https://www.nasa.gov/offices/oct/home/sstip.html)