NASA SBIR 2020 Phase I Solicitation

H10.02 Autonomous Operations Technologies for Ground and Launch Systems

Lead Center: KSC

Participating Center(s): ARC, LaRC, SSC

Technology Area: TA4 Robotics, Telerobotics and Autonomous Systems

Scope Description

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

AOT performs functions such as systems and componentsâ€™ 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 in activities performed by rocket engine test facilities, propellant servicing systems, and processing and launch of vehicles and payloads. AOT will complement In-Situ Resources Utilization (ISRU) operations. AOT will enable surface O&M, which requires high degree of autonomy and reliability for unattended operations during extended periods of time. AOT enables Autonomous Propellant Management (APM), which requires unattended or minimally attended storage, transfer, monitoring, and sampling of cryogenic propellants, or other propellants use in launch systems. APM includes pre-planned 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 will enable the autonomous command, monitoring and control of the overall system, resulting from the integration of loading systems 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.

The AOT autonomy software will include both prerequisite control logic (PCL) and reaction control logic (RCL) programming, and may utilize some form of machine learning, neural network or other form of artificial intelligence to adapt to degraded system components or other form of off-nominal conditions.

In addition to cryogenic and other propellants, propellant management systems may utilize additional commodities to prepare a vehicle for launch, such as high pressure gases for purges, pressurization, or conditioning, and may include power and data interfaces with the vehicle to configure vehicle valves or other internal systems and utilize on-board instrumentation to gain visibility into the vehicle during loading.

Specifically, this subtopic seeks the:

- Standardization of architectures and interfaces
- Standardization of ground systems design (design for maintainability, commonality, reusability)
- Development of ground technologies for automated/autonomous cryogenic loading and servicing of commodities for ground and lunar payloads
- Development of high-fidelity physics-based cryogenic-thermal models and simulations capable of real-time and faster than real-time performance
    - Development of high-fidelity models and simulations for complex payload systems
    - Development of automated/autonomous algorithms for ground systems applications
    - 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 systems and components faults and degradation
    - Development of Test and Evaluation (T&E), and verification and validation (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
- Development of technologies for automated/autonomous Inspection, Maintenance and Repair
    - Use of robotic caretakers for inspection, maintenance and repair needs
    - Self-diagnosis in systems and components (Condition Based Maintenance)
- Development of technologies for enhanced Logistics and Reliability
    - Optimization/Reduction of logistics needs (design for maintainability, commonality, reusability)
    - Commonality of maintenance equipment, tools and consumables
    - Automated/autonomous assets and personnel location and condition
    - Intelligent Devices (sensors, actuators and electronics with self-diagnosis capabilities, calibration on demand, self-healing capabilities, etc.)

For all above technologies, research should be conducted to demonstrate technical feasibility during Phase I; show a path toward Phase II demonstration; 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).

References

NASA Technology Roadmaps (https://www.nasa.gov/offices/oct/home/roadmaps/index.html) Â

NASA Strategic Space Technology Investment Plan
(https://www.nasa.gov/sites/default/files/atoms/files/strategic_space_technology_investment_plan_508.pdf)

Expected TRL or TRL range at completion of the project: 5 to 8

Desired Deliverables of 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 for control to enable autonomy of ground systems. Demonstrate the 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 for both operations and systems development and the feasibility of the approach in a multi-customer environment. Bench or lab-level demonstrations are desirable. Deliverables must 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 earth-based systems including dynamic events such as commodity loading, disconnect or engine testing. Deliverables shall include a report outlining the path showing how the technology could be matured and applied to mission-worthy systems, functional and performance test results and other associated documentation. Deliverable 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)Â Â Â Â 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)Â Â Â Â Simulation Component libraries to support rapid prototyping of cryogenic-thermal models (Current TRL is 5; Required TRL is 9)

3)Â Â Â Â Supervisory control software for autonomous control and recovery of propellant loading systems and infrastructure (Current TRL is 5; Required TRL is 9)

4)Â Â Â Â Software development tools to support rapid prototyping of autonomous control applications (Current TRL is 5; Required TRL is 9)

5)Â Â Â Â 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 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. With the recently directive from the President to accelerate the landing of astronauts on the Moon and provide sustainable presence after 2028, these technologies have become more relevant. These types of technology development are identified in the NASA Strategic Technology Area (TA) roadmaps, published by the Office of the Chief Technologist, under TA4 - Robotics and Autonomous Systems, and TA13- Ground and Launch Systems roadmaps.

This subtopic produces technologies which will also be of use to the Space Technology Mission Directorate (STMD) program. Autonomous strategies have crosscutting value in other applications and with other mission directorates.