This Topic covers a range of key technology options associated with future space exploration systems and architectures that involve a variety of combinations of advanced robotic and human capabilities, ranging from remotely telesupervised robotic systems, through locally-teleoperated systems, to focused human presence (with robotic agent assistance). Technologies that enable in-space assembly, maintenance, and servicing are also included. Key objectives derive from the goals of safe/reliable, affordable, and effective future human and robotic space exploration in support of the U.S. Vision for Space Exploration. These efforts will be closely coordinated with spacecraft subsystem, system, and related R&D within the Advanced Space Platforms and Systems Topic.

Subtopics

X6.01 Intelligent Operations Systems

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

The goal of this subtopic is to develop intelligent systems and technologies that could dramatically improve the affordability and productivity of long-duration human space operations, while preserving the high degree of safety and flexibility offered by state-of-the-art approaches. The current operations models used for the Space Shuttle and International Space Station, which require large ground teams continuously managing the daily operation of the spacecraft and the activities of the crew, are a major cost driver for these programs. As the human exploration campaign ventures farther into deep space, the communications time delays and longer-duration missions will require greater crew autonomy from Earth-based support. To achieve NASA's exploration goals, technologies are needed that can enable a new paradigm for human space operations.

Intelligent Planning and Execution Systems for Crew Autonomy

Greater autonomy from Earth-based support implies that crewmembers will need to manage their exploration missions holistically. This will be possible only if automation helps the crew to integrate the complex interactions among many spacecraft subsystems efficiently and to manage and prioritize human and automated activities. Intelligent systems will need to be seamlessly integrated with operational procedures so that all the information required to make key decisions is continuously updated and presented to the crew in a rapidly comprehensible fashion. Crew interfaces (e.g., displays, voice recognition, etc.) will need to be intuitive and reliable. Validated, automated systems are needed that help a spacecraft/habitat crew coordinate and prioritize plans and execute
nominal/off-nominal procedures in accordance with codified mission rules and objectives. These systems should improve upon capabilities already demonstrated in human space exploration missions (e.g., Space Shuttle and International Space Station).

To evaluate proposed intelligent systems technologies, it is important to identify measurable performance objectives. Such performance measures include: (1) the speed and ease by which astronauts can plan and schedule future activities and understand the consequences of exercising various planning options; (2) the reliability, speed, and ease by which astronauts can maintain comprehensive situational awareness of a complex spacecraft/habitat without cognitive overload; (3) the reliability, speed, and ease by which astronauts can derive (on demand, or in response to detection, of an off-nominal condition) sufficiently detailed knowledge of the spacecraft/habitat, to issue commands that isolate anomalies, perform recovery procedures, and make other safety/mission-critical decisions.

Modular designs that employ open architectures and interface standards are very important to assure cost-effectiveness and flexibility of intelligent operations systems. These architectures should promote extensibility/evolvability and accommodate future system upgrades. Such designs could include standalone tools that capture and manage corporate knowledge about manned spacecraft operations.

Also of interest, though of lesser priority, are innovative technologies that can significantly enhance ground operational efficiency and performance.

**Intelligent Modular Training Systems**

Intelligent training systems are needed that enable flight crews to operate complex spacecraft safely and effectively, retain proficiency during long-duration missions, adapt easily to an evolving and expanding set of flight systems during the course of the exploration campaign, and achieve flight certification faster and more cost-efficiently than is possible with existing systems. Plug-and-play crew training systems that employ open architectures and interface standards are very important. These architectures should promote extensibility/evolvability and accommodate future system upgrades. The intelligent training systems should enable connectivity with models from various sources, with simulated or flight data (real-time and archived), with students and teachers at multiple locations, and with various platforms including ground-based/desktop environments and in-space, zero-g/partial-g portable or control station systems. When integrated with an operational environment, these systems must demonstrate effectiveness while ensuring that the performance of the vehicle or facility is unaffected.

Focus should be on the following applications:

- **Intelligent onboard technologies for human space exploration; and**
- **Intelligent human space exploration mission control technologies.**

Note: Related technologies of interest but covered under other SBIR subtopics include:
X6.02 Space Assembly Maintenance & Servicing

Lead Center: GSFC
Participating Center(s): JSC

The goal of this subtopic is to develop technologies that enable reliable and affordable in-space assembly, maintenance, and servicing for human and robotic exploration missions in Earth orbit and beyond. Systems that enhance crew safety and mission reliability by automating these functions (whether robotically, tele-robotically, or with integrated human/robotic teams) are needed. Technologies that enable robust and reliable Earth-orbit assembly of spacecraft components (both modular and non-uniform), and thus alleviate the difficulties of launching larger, pre-integrated payloads, are of particular interest. Long-duration maintenance and servicing systems that are modular and generically applicable to a variety of orbital or transfer exploration spacecraft are also of interest.

Focus should be on the following applications:

- Earth-orbit assembly of large spacecraft systems (e.g. heat shields, propellant stages);
- Autonomous inspection of spacecraft systems using either small free-flying inspection spacecraft or attached, highly-mobile inspection robots; and
- Autonomous removal and replacement of failed spacecraft systems.

Specific technologies of interest in addressing these challenges include:

- Self-contained collision prevention/avoidance systems for robots (free-flying or attached) in close proximity to spacecraft, instruments, astronauts, etc.;
- Dexterous robotic end-effectors/manipulators for robotic assembly and maintenance, including systems that accommodate instability between robotics and target surfaces;
- Robotic non-destructive structural inspection technologies;
• Advanced robotic control systems (e.g., systems that provide active damping of robotic arms to reduce uncommanded motion, high degree-of-freedom (DOF) systems, systems that function in multiple mission environments, and systems that incorporate intuitive man-machine interfaces and/or virtual reality simulation);

• Robotic tele-operation control systems that accommodate latency and enable "real time" robotic operations;

• Vision systems for both autonomous and tele-robotic operations, including systems that demonstrate: autonomous and rapid object recognition, affordable zoom/focus lens control, robust spatial perception of working environments, ability to operate under various lighting conditions, economical video compression and 3-D mapping techniques, and low power autonomous visual inspection systems;

• Robotically operable structural/precision interface attachment systems;

• Modeling of contact dynamics in zero gravity for capture and manipulation;

• Test beds to validate robotic systems, including 6-DOF simulated weightless testing; and

• Orbital mechanics optimization of libration point rendezvous for assembly and servicing.

Note: Related technologies of interest but covered under other SBIR subtopics include:

• Robot-mounted sensors for on-orbit assembly/construction (X1.03 Sensing and Imaging), and

• Plug-and-play avionics and attachment technologies for autonomous rendezvous and docking (X8.02 Intelligent Modular Systems).

X6.03 Launch Site Technologies

Lead Center: KSC
Participating Center(s): GSFC, MSFC

The purpose of this subtopic is to develop technologies and concepts that will improve launch processing safety through the use of automated systems with limited human contact; make launch operations more cost- and time-efficient through standardization, commonality, and interoperability of launch systems and spaceport infrastructure; and improve the flexibility and adaptability of spaceport infrastructure in order to accommodate multiple vehicle types and diverse missions. Improvements in launch site operations can enable airport-like efficiencies at reduced cost and shortened processing turnaround time, thereby contributing significantly to the goal of a sustained and affordable space exploration program. Additionally, advanced launch operations technologies and concepts that may significantly improve launch vehicle specific energy or otherwise improve launch performance, affordability, and sustainability for space exploration missions are of interest. Topic areas that will be emphasized for improvements in launch site operations include:
- Propellant handling systems: autonomous propellant loading; automated umbilicals; improved control of cryogenic mass loss; hazardous leak and flame detection; and improved cryogenic cooling, insulation, and sealing technologies;

- Common integrated command and control system technologies for launch site operations: ground integrated health management systems, work control, configuration management, and other support systems;

- Test equipment: universal avionics test equipment and automated and wireless built-in test equipment that reports launch vehicle and/or payload status;

- Launch acoustic modeling and mitigation systems; and

- Payload and launch vehicle systems handling equipment.

Modular designs that employ open architectures and interface standards are very important to assure cost-effectiveness and flexibility of launch site technologies. These architectures should promote extensibility/evolvability and accommodate future system upgrades. Topic areas related to advanced launch operations technologies and concepts include:

- Horizontal launch assist ground systems, including systems that preclude the need for vehicle take-off gear. Specific technology areas of interest include: vehicle acceleration mechanisms, vehicle structural support or levitation systems, control and stabilization systems, separation mechanisms, runway or track stability and maintenance systems, and energy storage and delivery systems; and

- Other novel launch operations technologies and concepts.

Focus should be on the following applications:

- Earth-based launch site systems for human and robotic space exploration missions.

Note: Related technologies of interest but covered under other SBIR subtopics include:

- X6.01 Intelligent Operations Systems.