

NASA Space Autonomy

Research, development, and operations



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2024-06-14

Autonomy

- **Autonomy is the ability of a system to achieve goals while operating independently of external control.**
 - *2015 NASA Technology Roadmaps*
 - Requires **self-directedness** (to achieve goals)
 - Requires **self-sufficiency** (to operate independently)
- A **system** is the combination of **elements** that function together to produce the capability required to meet a need. The elements include all **hardware, software, equipment, facilities, personnel, processes, and procedures** needed for this purpose
 - *2016 NASA Sys. Eng. Handbook*



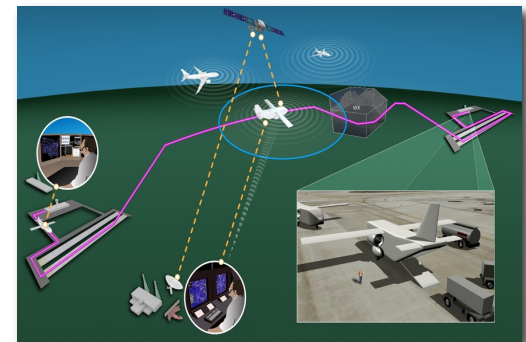
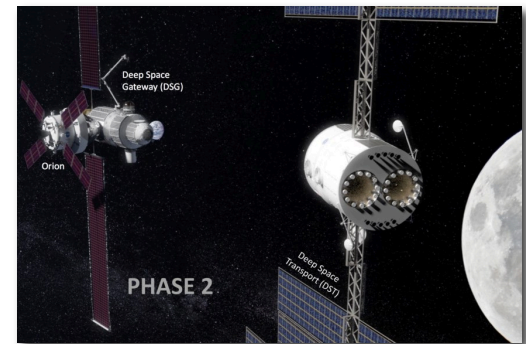
The Curiosity rover can use “AutoNav” to autonomously drive from point to point using stereo vision and on-board path planning.



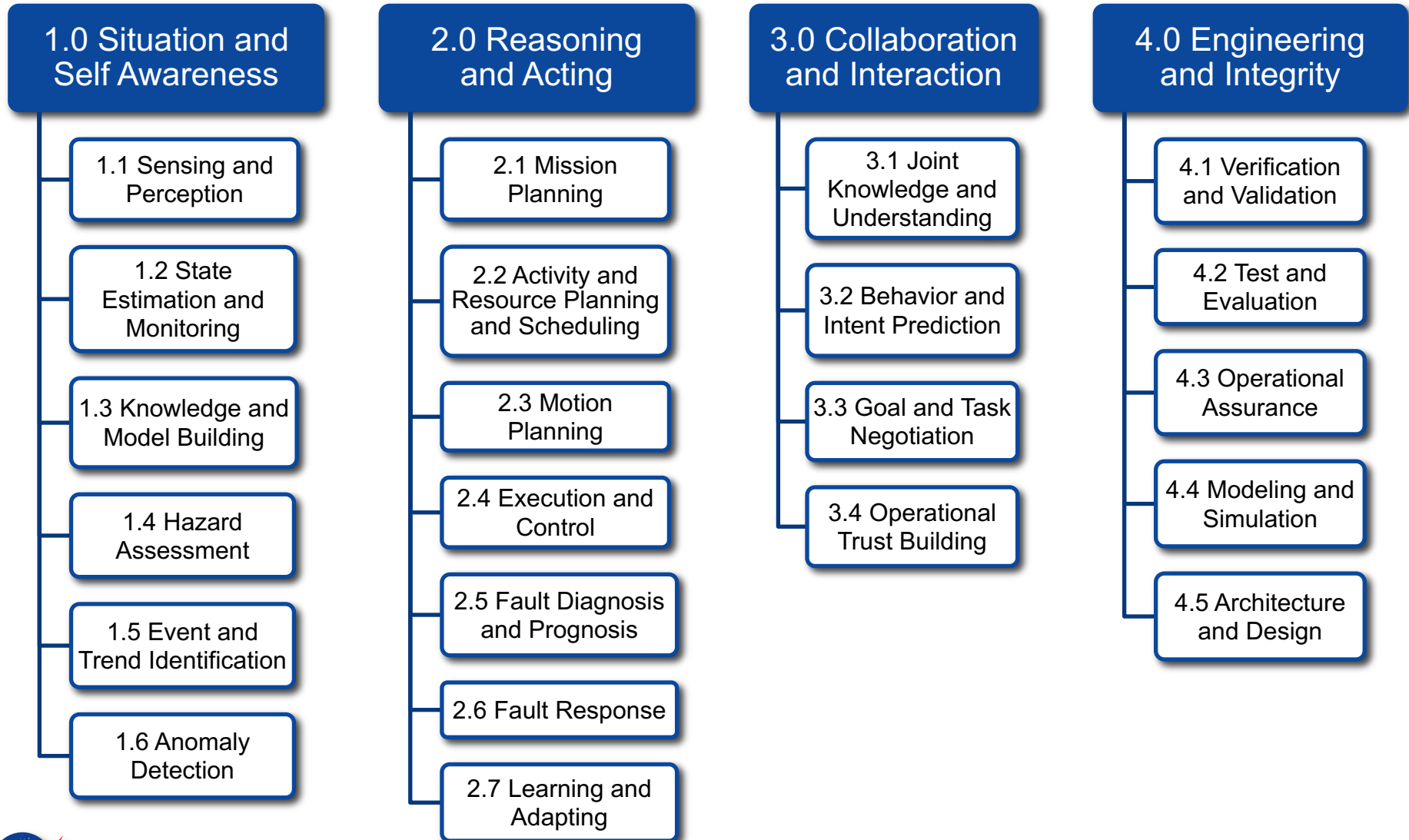
NASA Missions

Autonomy is needed ...

- When the cadence of decision making exceeds **comm constraints** (delays, bandwidth, and communication windows)
- When **time-critical decisions** (control, health, life-support, etc) must be made on-board
- When decisions can be better made using **rich on-board data** compared to the limited amount of data that can be downlinked
- When local decisions **improve robustness** and **reduces risk** of the concept of operations
- When autonomous operations **significantly improves performance** or **reduces cost**
- When **variability in training, proficiency**, etc. due to manual control is unacceptable
- When it is the only way to achieve a **mission objective** or **requirement**



NASA Autonomous Systems Technology Taxonomy



Decomposing Capability to Technologies

**System-Level
Capability**

**Autonomous
Planetary Rover**



Effect of autonomy on mission operations

Conventional missions

Ground Operators with Human-in-the-Loop verification



Command sequences



Detailed spacecraft state (at time of downlink) available to operator



Communication tracks scheduled months in advance



Mission-specific requirements focus for deterministic operations



Control Authority

Aspects shift from ground to spacecraft with onboard autonomy

Spacecraft Commanding

Instructions transformed from what to *execute* to what to *achieve*

Situation Awareness

Operator moves from micro-managing state to macro-managing goals

Space Communications

From pre-defined communications to agile communications when needed

Testbed Capabilities

From requirements-based development to goal-based system-level capability

Fully autonomous missions

Spacecraft-oriented allowing dynamic perception, sensing, response under uncertainty



Goals executed onboard using AI/ML, data fusion, perception, and real-time optimization



Execution outcomes and essential state conveyed to operator



Spacecraft demand-driven, asynchronous, with delay tolerant networking (DTN)



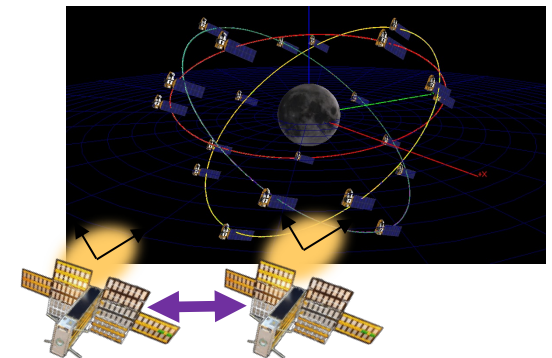
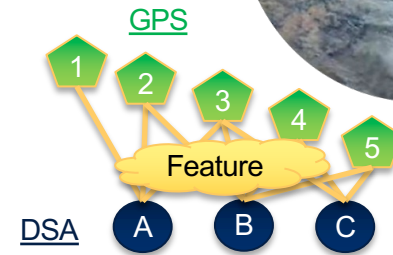
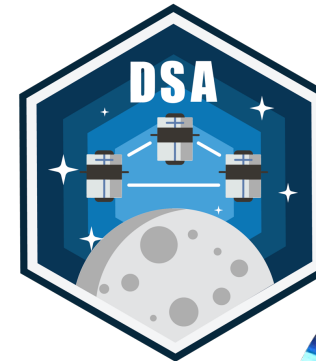
Large-scale exploration of operational parameter space with probabilistic outcomes and system-level V&V



Distributed Spacecraft Autonomy (DSA)

Multi-spacecraft ensemble

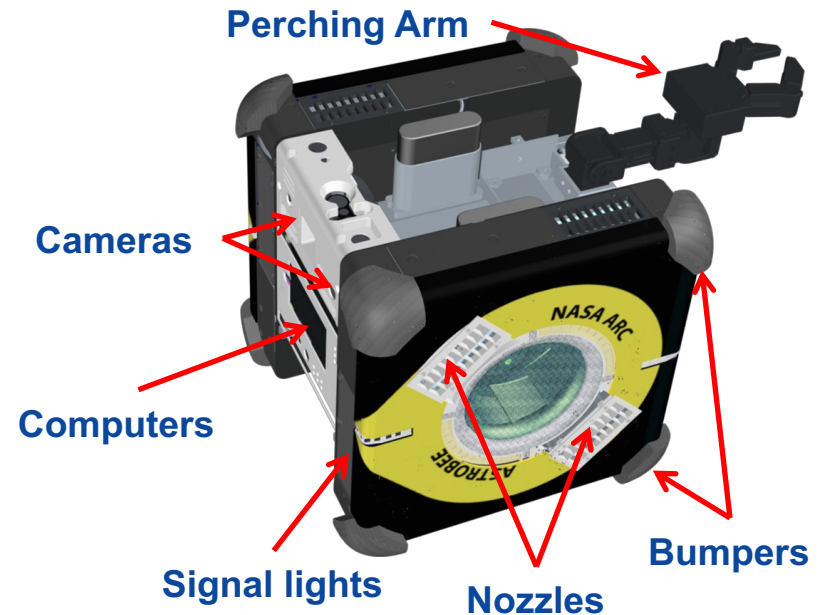
- Efficiently **allocate tasks between spacecraft** via ad-hoc networking and **enable human-swarm commanding**
- **DSA-Starling** is a software payload on the Starling space mission, consisting of 4 spacecraft in Low Earth Orbit. DSA-Starling uses the GPS receivers as a science instrument – DSA allocates GPS satellites to spacecraft in a fully distributed and autonomous manner (at a cadence of 1 Hz).
- **DSA-LPNT** is a processor-in-the-loop scalability study building on the same DSA-Starling software suite. DSA-LPNT increases the size and scale of the mission (20-100 spacecraft) and increases complexity (reorienting communication antennas instead of monitoring GPSIDs).
- **DSA** software is implemented with Core Flight Software (cFS) and builds upon open-source automated reasoning and communications software.



Astrobee & ISAAC

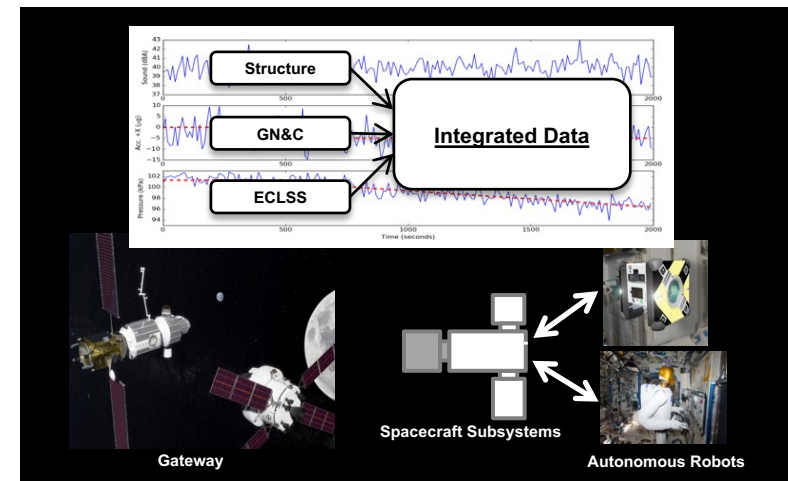
Astrobee: ISS IVA robot facility

- Autonomous free-flying robot
- All electric with fan-based propulsion
- All software released open-source
- Expansion port for new payloads
- Dock for recharge & data download
- Astrobee Working Group
- ~30x30x30 cm, ~8 kg



ISAAC

- ISAAC = Integrated System for Autonomous and Adaptive Caretaking
- Autonomous multiple **intra-vehicular robots** (IVR) and spacecraft systems
- Astrobee serves as an analog for future IVR systems on Gateway and in lunar surface habitats



Astrobee



<https://www.nasa.gov/astrobee>



Space autonomy: research, development, and operations

Where do we go from here?

Research & Development

- Autonomy algorithms (for space and adapted from terrestrial uses)
- Data sets for development, test, training, and V&V
- System-level autonomy architecture and integration
- New data communications capabilities for autonomous mission operations
- Operations culture change: practices, roles, training
- Human-system integration, interaction, and teaming
- Testbeds for integration, test, and requirements V&V

