Autonomous Systems
NASA Capability Overview

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NASA Autonomous Systems

Charter

• Serve as a **community of practice** in autonomous systems

• **Identify barriers** that impact the development and infusion of autonomy capabilities into mission systems

• Identify and **assess the NASA workforce** and facilities needed to advance autonomous systems

• **Recommend research and development** in autonomous systems technology for NASA

• **Recommend investment/divestment** to improve the use of autonomous systems in aeronautics (ARMD), human exploration (HEOMD), science (SMD), and space technology (STMD)

Team

• Lead: **Terry Fong**

• Deputy: **Danette Allen**

• Members (34): Julia Badger, Lorraine Fesq, Jeremy Frank, Kai Goebel, Issa Nesnas, Alonso Vera, etc.
AI, Automation, and Autonomy
Artificial Intelligence (AI)

- AI does NOT have a single, simple, universally accepted definition.
- AI is the “science and engineering of making computers behave in ways that, until recently, we thought required human intelligence.”
  
  – Andrew Moore in Forbes

- AI encompasses **many technologies** and **many applications**:

  - deep learning
  - predictive analytics
  - translation
  - classification & clustering
  - information extraction
  - speech to text
  - text to speech
  - machine learning
  - natural language processing (NLP)
  - speech
  - expert systems
  - planning, scheduling & optimization
  - robotics
  - image recognition
  - machine vision
  - vision
Automation

- Automation is the automatically-controlled operation of an apparatus, process, or system by mechanical or electronic devices that take the place of human labor – *Merriam-Webster*
- Automation is not “self-directed”, but instead requires command and control (e.g., a pre-planned set of instructions)
- A system can be automated without being autonomous

The “Afternoon Train” (A-Train) is a coordinated group of Earth observing satellites that follows the same orbital “track”.

![Diagram of the A-Train](image-url)
Autonomy

- **Autonomy** is the ability of a system to achieve goals while operating independently of external control.
  
  - 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.
  

The Curiosity rover can autonomously drive from point to point using stereo vision and on-board path planning.
What is NOT autonomy?

**Autonomy is NOT artificial intelligence, but may use AI**
- Machine learning (deep learning, reinforcement learning, etc.)
- Perception (object recognition, speech recognition, vision, etc.)
- Search, probabilistic methods, classification, neural networks, etc.

**Autonomy is NOT automation, but often relies on automation**
- Most robotic space missions rely on automation
- Command sequencing (event, order, time triggered)

**Autonomy is NOT only about making systems “adaptive”, “intelligent”, “smart”, or “unmanned / uncrewed”**
- Autonomy is about making systems **self-directed** & **self-sufficient**
- Systems can **include humans** as an integral element (human-system integration / interaction, human-autonomy teaming, etc.)
- Autonomy requires reasoning about consequences, understanding when specific actions are inappropriate, & dealing with uncertainty
Why Autonomy is Hard*

The real world is highly uncertain and changing

• “There are known knowns. There are things we know that we know. There are known unknowns. That is to say, there are things that we now know we don't know. But there are also unknown unknowns. There are things we do not know we don't know.”
  – Donald Rumsfeld, 2002

The real world is a heavy-tailed distribution

• High probability of encountering unexpected events when operating for a long time or when performing many activities

All models are approximations

• Modeling unknowns and uncertainty is really hard
• Computation is (not yet!) instantaneous and infinite

* thoughts from Reid Simmons
Autonomy and NASA Missions

Autonomy is needed …

• When the cadence of decision making exceeds **communication constraints** (delays, bandwidth, and communication windows)

• When **time-critical decisions** (control, health, life-support, etc) must be made on-board the system, vehicle, etc.

• When decisions can be better made using **rich on-board data** compared to limited downlinked data (e.g., adaptive science)

• When local decisions **improve robustness** and **reduces complexity** of system architecture

• When autonomous decision making can **reduce system cost** or **improve performance**

• When **variability in training, proficiency**, etc. associated with manual control is unacceptable
Aeronautics

Transforming civil aviation

- Thin-haul, on-demand regional travel
- Long-haul, commercial transport
- Multi-modal, context-driven alerting
- Simplified, bi-directional information sharing
- Machine-assisted, integrated skill retention and learning

Autonomy-Pilot Teaming for Complex Ops

Urban Air Mobility (UAM)

UAS Traffic Management (UTM)

Autonomy-Enabled ATM
UAS Air Traffic Management

Overview

• The UTM architecture addresses mission planning and execution strategies for UAS operations
• Provide cooperative, interoperable, digital ability to plan and schedule airspace resources; track vehicles; and assist with contingencies
• Support autonomous and remotely piloted vehicle operations

Research Focus

• Capability for operators to interact with each other through predefined data exchanges and application protocol interfaces
• Provide complete situation awareness of airspace use and constraints
• Urban environments and high density operations
Unique aspects

Large-scale systems (extent and number), high diversity (applications, platforms & ops), highly regulated, public safety and security
Human Exploration

Technologies and systems for human spaceflight

Earth

Moon

Mars

In LEO
Commercial & International partnerships

In Cislunar Space
A return to the moon for long-term exploration

On Mars
Research to inform future crewed missions
Objectives

- Advance autonomy technology for human spaceflight (crew and vehicle)
- Planning and scheduling, fault detection, isolation and impact reasoning, plan execution, and crew decision support

Current activities

- Demonstrate crew decision support system on-board the ISS
- Demonstrate advanced caution and warning for infusion into Orion (for EM-2)
- Demonstrate vehicle systems automation in the iPAS simulation facility (JSC)
Unique aspects

Few systems (large, high-value, reusable), high complexity, high reliability (human rated), limited computing/comm, astronauts
Science Missions
From Earth to deep space and beyond
Distributed Spacecraft Autonomy

Scaleable autonomy for multi-spacecraft

- Comm: resilient data distribution
- Fault management: distributed diagnostics engine
- Distributed planning, scheduling, and task execution
- Ops: scaleable ground data system and human-system interaction

Flight demonstration (2020)

- NASA Starling + AFRL Shiver mission
- Reusable core software stack
- Dynamic inter-spacecraft coordination for monitoring variable RF signals
Unique aspects

Few systems (one-off and high-value), high complexity, limited computing/comm, very diverse missions (platforms, ops, etc)
Space Technology

New capabilities for space missions

Early Stage Innovation
- NASA Innovative Advanced Concepts
- Space Tech Research Grants
- Center Innovation Fund/Early Career Initiative

Technology Maturation
- Game Changing Development

Partnerships & Technology Transfer
- Technology Transfer
- Prizes and Challenges
- iTech

Technology Demonstrations
- Technology Demonstration Missions
- Small Spacecraft Technology
- Flight Opportunities

SBIR/STTR

Low TRL

Mid TRL

High TRL

TECHNOLOGY PIPELINE
Astrobee

Free-flying robot for ISS IVA
- 3 robots + docking station
- Open-source software
- Autonomous / telerobotic operations

IVA tasks in human spacecraft
- Mobile surveys (inventory + IVA environment monitoring)
- Mobile camera for mission control

Successor to SPHERES
- Microgravity robotics test facility
- Multiple ports for new payloads
- Perform experiments without crew

Tech development for Gateway
- Support IVA robotics engineering
- Autonomous caretaking during uncrewed periods
- In-flight maintenance & logistics

Launch: NG-11 in April 2019
Unique aspects

Technology development pipeline (multiple programs), focus on tech demonstrations, one-offs (prototypes and proof-of-concept)
Autonomy involves many functions …

… that can be performed by humans or software
### Autonomous Systems Taxonomy

<table>
<thead>
<tr>
<th>1.0 Situation and Self Awareness</th>
<th>Interrogation, identification, and evaluation of both the state of the environment and the state of the system.</th>
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</thead>
<tbody>
<tr>
<td>2.0 Reasoning and Acting</td>
<td>Analysis and evaluation of situations (present, future or past) for decision making and for directing actions to achieve a goal or a mission.</td>
</tr>
<tr>
<td>3.0 Collaboration and Interaction</td>
<td>Two or more elements or systems working together to achieve a defined outcome.</td>
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<tr>
<td>4.0 Engineering and Integrity</td>
<td>Design considerations, processes, and properties necessary to implement autonomy.</td>
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</table>
Autonomous Systems Taxonomy

1.0 Situation and Self Awareness

1.1 Sensing and Perception
1.2 State Estimation and Monitoring
1.3 Knowledge and Model Building
1.4 Hazard Assessment
1.5 Event and Trend Identification
1.6 Anomaly Detection

2.0 Reasoning and Acting

2.1 Mission Planning
2.2 Activity and Resource Planning and Scheduling
2.3 Motion Planning
2.4 Execution and Control
2.5 Fault Diagnosis and Prognosis
2.6 Fault Response
2.7 Learning and Adapting

3.0 Collaboration and Interaction

3.1 Joint Knowledge and Understanding
3.2 Behavior and Intent Prediction
3.3 Goal and Task Negotiation
3.4 Operational Trust Building

4.0 Engineering and Integrity

4.1 Verification and Validation
4.2 Test and Evaluation
4.3 Operational Assurance
4.4 Modeling and Simulation
4.5 Architecture and Design

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Mapping Capability to Technologies

System-Level Capability

Autonomous Planetary Rover

Integrated Functions

- Mobility
- Manipulation
- Planning, scheduling, & execution
- Health mgmt.

Taxonomy

- Sensing & perception
- Model building
- Mission planning & scheduling
- Fault diagnosis and prognosis
- Fault response
- Learning & adapting

Technologies

- visual odometry
- inertial measurement
- stereo vision
- 3D lidar
- monitor/response
- model-based
Questions?