Systems Capability Leadership Team

• 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)

Structure

• Lead: Terry Fong (STMD)
• Deputy: Danette Allen (LaRC)
• Members (34): Center SMEs, (S)CLT leads, Mission Directorate reps
AI, Automation, and Autonomy
Artificial Intelligence (AI)

- AI does NOT have a single, simple, universally accepted definition.
- AI is the “capability of computer systems to perform tasks that normally require human intelligence (e.g., perception, conversation, decision-making.” – Defense Science Board 2016
- AI encompasses many technologies and many applications:
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”.
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.

*The Curiosity rover can autonomously drive from point to point using stereo vision and on-board path planning.*
Autonomy involves many functions …

… that can be performed by humans or software
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.)
- Software (e.g., decision support) can make **humans more autonomous** of other humans (air traffic control, mission control, etc.)
Why autonomy?

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
## Where can NASA use Autonomy?

### EARTH LAUNCH AND LANDING SYSTEMS
- Launch Vehicles
- Launch Abort Systems
- Entry, Descent and Landing

### ROBOTIC EARTH-ORBITING SYSTEMS
- Formation Flying
- Constellations and Swarms
- Rendezvous and Docking
- On-Orbit Servicing
- In-Space Assembly
- In-Space Manufacturing
- Instrument Data Analysis
- Sensor Web

### ROBOTIC SPACE SYSTEMS
- Planetary Ascent Vehicles
- Rendezvous and Docking
- Entry, Descent & Landing
- In Situ Access
- Sample Collection
- Orbital Navigation
- Instrument Data Analysis
- In Situ Resource Utilization

### EARTH ATMOSPHERIC SYSTEMS
- Unmanned Aerial Systems
- Vehicle Mission Safety
- Vehicle Performance Enhance
- Human-machine teaming
- National Airspace Management
- Distributed Large-scale Collaborative Systems

### HUMAN EARTH-ORBITING SYSTEMS
- Life Support
- Rendezvous and Docking
- On-Orbit Servicing
- Visualization and Interaction
- Robotic Assistants
- Mission and Data Analysis
- In-space Manufacturing
- In-space Assembly

### HUMAN SPACE SYSTEMS
- Planetary Ascent Vehicles
- Life Support
- Rendezvous and Docking
- Entry, Descent & Landing
- Surface Transport
- Robotic Assistants
- Mission and Data Analysis
- In Situ Resource Utilization

### GROUND SYSTEMS
- Mission Operations
- Visualization and Interaction
- Robotic Inspection and Repair
- Propellant/Commodity Loading
Aeronautics

Transforming civil aviation

Autonomy-Pilot Teaming for Complex Ops

Urban Air Mobility (UAM)

UAS Traffic Management (UTM)

Autonomy-Enabled ATM
Human Exploration
From Earth to the Moon and Mars

**Earth**
- Notional Commercial Platform
- ISS
- Commercial launch Vehicles

**Moon**
- Orion
- SLS
- Commercial Lunar Lander
- Robotic Surface Missions
- Gateway
  - PPE: Habitat – Airlock – Logistics

**Mars**
- Mars robotic exploration, technology development

**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
Science Missions

Discovering the secrets of the Universe
Space Technology

Technology drives innovation

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
NASA Programs with Autonomy R&D

New algorithms (TRL 1-3)
• **ARMD**: Transformative Aero Concepts
• **SMD**: Planetary Science and Technology from Analog Research, COLDTech
• **STMD**: Space Tech Research Grants

Scaling the technology (TRL 4-7)
• **ARMD**: Airspace Operations & Safety
• **HEOMD**: Adv. Exploration Systems
• **STMD**: Game Changing Development

Flight systems (TRL 8-9)
• **HEOMD**: Adv. Exploration Systems
• **STMD**: Small Satellite Technology
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
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)
Astrobee (STMD)

**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**
- Multiple ports for new payloads
- Perform experiments without crew
- 7 guest science projects in devel.

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

Launch: NG-11 in April 2019
**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**

- Integrated to Starling / Shiver mission
- Reusable core software stack
- Dynamic inter-spacecraft coordination for monitoring variable RF signals

*Note: project is completing formulation for FY19 start*
Integrating System for Autonomous and Adaptive Caretaking (STMD)

Caretaking of exploration spacecraft
- Autonomous robots + spacecraft infrastructure (avionics, sensors, networking) + ground control
- Develop and test on ISS for future infusion to Gateway

Crewed periods
- Off-load routine work from astronauts
- Tech: safe human-robot interaction, robust navigation

Uncrewed (“dormant”) periods
- Monitor and maintain systems in the absence of astronauts
- Tech: sw architecture, diagnostics/prognostics, smart downlink
Future Autonomy R&D?

Perception for Extreme Environments
- **Autonomous nav** or **target selection** for icy worlds, interior oceans, caves, pits, etc.
- Requires new 3D sensors (lidar, time-of-flight cameras, etc.) & high-performance computing

Reactive Science
- Observe and/or sample **dynamic & transient phenomena** (plumes, seeps, weather, etc)
- Requires autonomous on-board decision making (planning, scheduling & execution)
- Must manage risk and uncertainty on-board

Collective Operations
- Enable a spacecraft swarm (10-100+) to **collectively perform** distributed activities
- Requires a distributed autonomy architecture (including coordination and collaboration)
- Must perform planning, scheduling, health management, etc. at a “collective” level
Autonomous Systems SCLT Activities

**ARMD**
- TACP TTT: “Autonomous Systems” subproject planning

**HEOMD**
- Deep Space Gateway Technology Utilization Working Group
- Exploration Capabilities Coordination Group (ExCCG)

**SMD**
- 2018 “Autonomy for Future Science Missions” workshop

**STMD**
- “Autonomous Operations” R&D planning (focus on STRG and GCD)
- STRG ESI 2018: "Smart and Autonomous Systems for Space” solicitation
- STRG STRI 2018: "Smart Deep Space Habitats” solicitation
- NSTRF TA04 topic chair
- GCD: advice/feedback to current and proposed projects
- Partnerships: review proposed agreement abstracts
Autonomous Systems SCLT Activities

**OCE**
- Autonomous Systems taxonomy development and infusion (to OCT, MDs, etc)
- Baseline assessment: state of capability in NASA

**OCT**
- Interagency Space Science & Technology Partnership Forum

**External engagement**
- DoD: Autonomy Community of Interest (CoI)
- DARPA: Robotic Servicing of Geosynchronous Satellites (*SME support*)
- NSF: Joint solicitation for the “Smart and Autonomous Systems” (*ESI 2018 topic is a pilot for larger NASA collaboration in FY19+*)
- Briefings from AFRL, ONR, etc.
Top Technical Challenges

**Situation and Self Awareness**
- The availability of qualified sensors (e.g., lidar for planetary rovers) and difficulty assuring data directly impacts perception performance

**Reasoning and Acting**
- Scaling to handle more complex problems (# of constraints, etc) with uncertainty (dynamic environments, etc) is an unsolved problem
- Performance is limited by mission computing (CPU, storage, comm)

**Collaboration and Interaction**
- Humans are complex, but they are a part of any autonomous system. What works for one person may not work for all.
- Human-system integration is a key challenge for NASA (HRP “Risk of Inadequate Design of Human and Automation/Robotic Integration”)

**Engineering and Integrity**
- Autonomous systems are difficult to V&V and to assure
- Autonomy capability cannot simply be “added” as an afterthought
Questions?