National Aeronautics and
Space Administration

EXPLORE
MOON to MARS

Autonomous Systems and Robotics (ASR) Overview

Aug 2024

ASR Organization

Autonomous Systems and Robotics (ASR) Technical Area

lead: Jose Benavides
deputy: Kim Shish

Advanced Controls and Evolvable Systems (ACES)

lead: Dr. Nhan Nguyen
deputy: Dr. Kelley Hashemi
Membership:
~ 14 CS, 10 SSC

Deployable Autonomy Technologies (DAT)

lead: Dr. Brian Glass
Membership:
~ 5 CS, 10 SSC

Intelligent Robotics Group (IRG)

lead: Maria Bualat
deputy: Dr. Matt Deans
Membership:
~ 8 CS, 41 SSC

Planning and Scheduling Group (PSG)

lead: Dr. Jeremy Frank
Membership:
~ 10 CS, 9 SSC

ASR Group Descriptions

Advanced Control and Evolvable Systems (ACES)

The core focus of the Advanced Control and Evolvable Systems (ACES) Group is to conduct foundational and applied research in guidance, navigation, and control (GN&C) technologies (adaptive, robust, and optimal control), UAS avionics, modeling and simulations.

Deployable Automation Technologies (DAT)

The Deployable Automation Technologies (DAT) Group conducts applied research and development in autonomous metamaterials and structural systems with multi-robot assembly, automated planetary and small-body sample acquisition and handling systems, instrument automation, health monitoring, and visual planning and mapping software and mission simulation testbeds.

Intelligent Robotics Group (IRG)

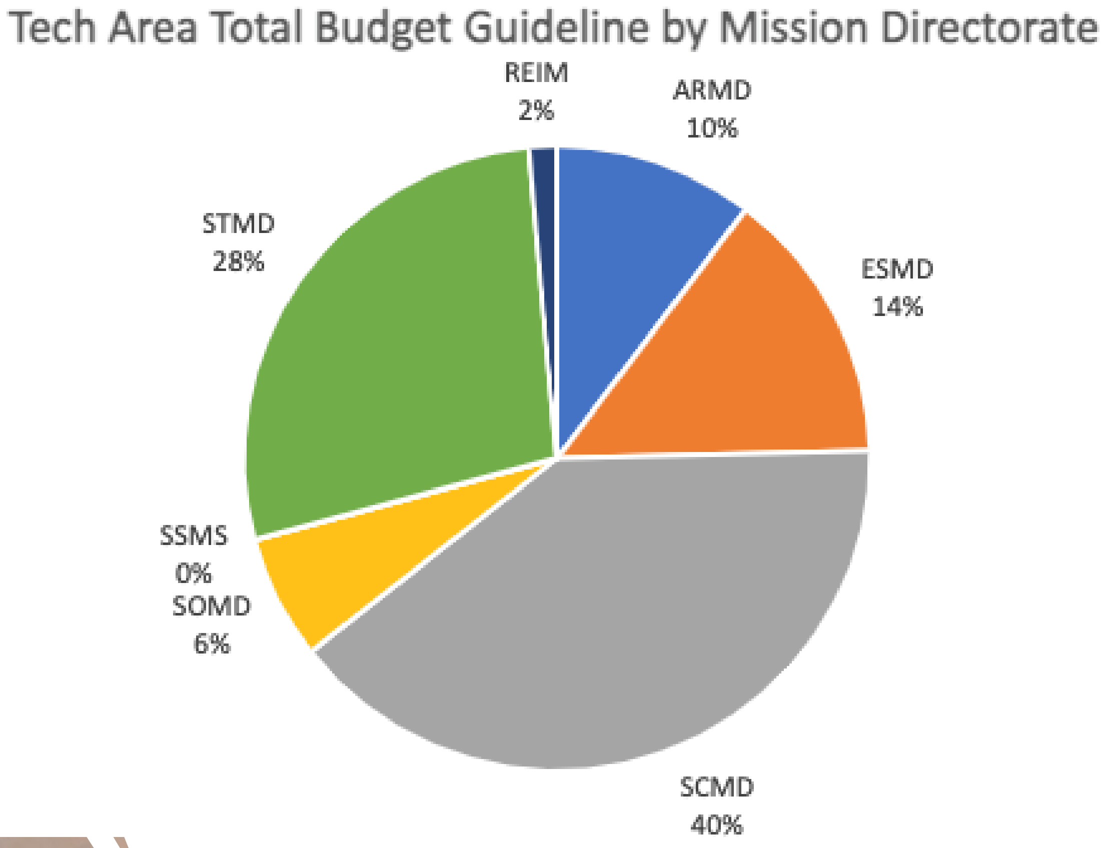
The Intelligent Robotics Group (IRG) is dedicated to exploring extreme environments, remote locations, and uncharted worlds. IRG conducts applied research in a wide range of areas, including computer vision, geospatial data, human-robot interaction, interactive 3D visualization, and robot software architecture.

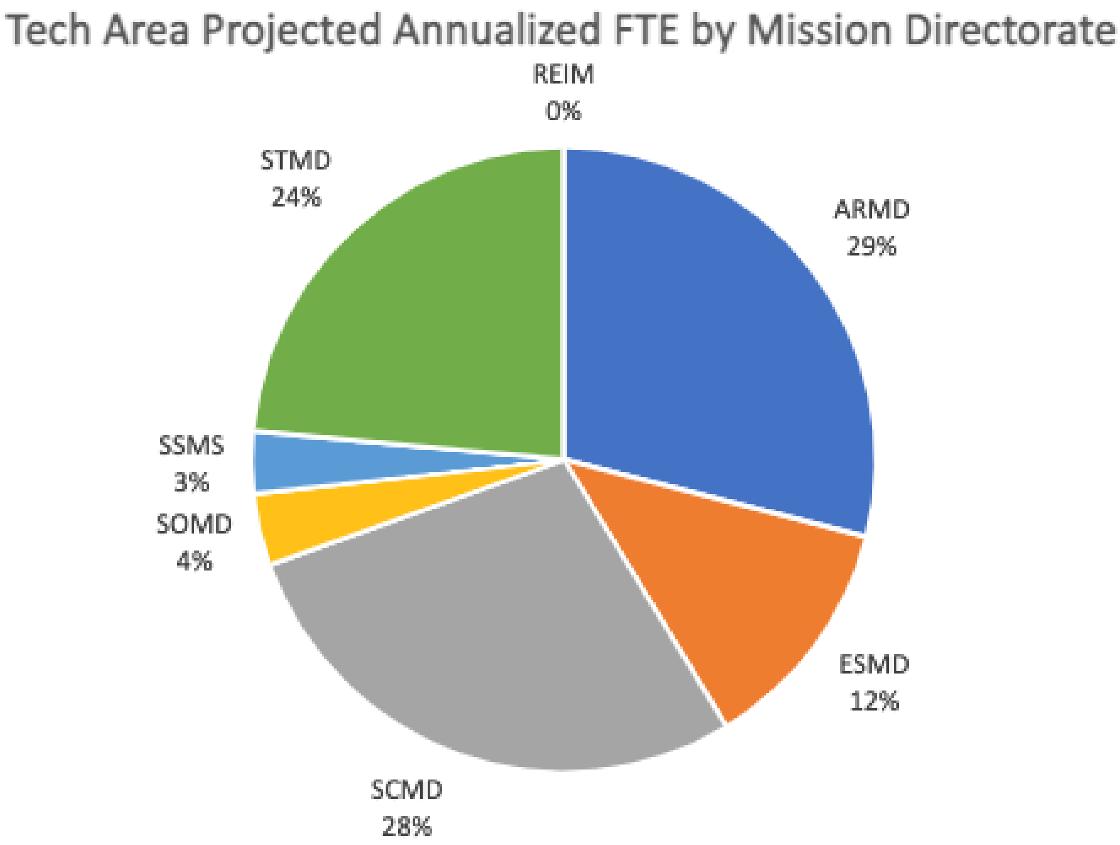
Planning and Scheduling Group (PSG)

The Planning and Scheduling Group (PSG) builds automated planning and scheduling systems for NASA missions. These planning and scheduling systems are essential components of autonomous spacecraft, deep space probes, planetary rovers, and autonomous vehicles.

ASR Tech Area Funding

Approximate FY23 funding by Mission Directorate (in $M)





Autonomous Systems and Robotics (ASR) Executive Summary

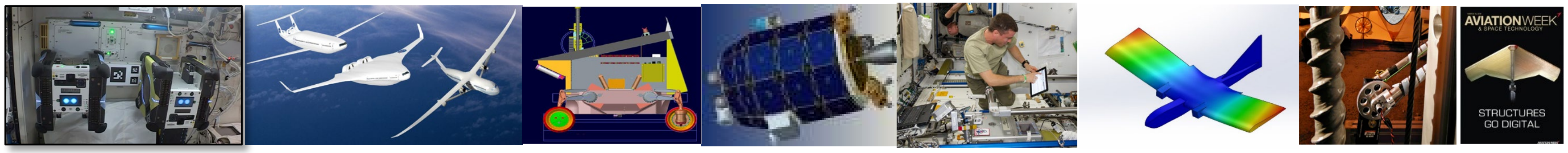
Capabilities:
- Enabling complex systems and operations through the development of technologies that can respond or adapt to changing conditions, knowledge, and constraints
- Creating automated and autonomous behaviors via robotic assistants, robust avionics, intelligent planning and scheduling, and advanced control technologies
- Agency leadership in applying autonomy and robotics expertise to NASA missions and terrestrial demonstrations

Products/Deliverables:
- Avionics software
- Adaptive and optimal control and estimation
- Advanced flight management systems
- Automated planning and scheduling
- Control agent architectures
- Computer vision & digital mapmaking
- Distributed and multi-agent systems
- Drilling automation
- Metamaterials and self-assembling structures
- Space robotics (planetary rovers & free-flyers)

Customers/Projects/Partners: ASR Executes over 30 projects for various mission directorates and external partners.

ARMD Projects -- Performance Adaptive Aeroelastic Wing; Autonomous Systems Distributed Sensing; small UAS Autonomy; Automation Enabled Pilot
SMD Projects -- Volatiles Investigation Polar Exploration Rover; Drilling and Sampling Automation
STMD Projects – Distributed Spacecraft Autonomy; Automated Reconfigurable Mission Adaptive Digital Assembly Systems (ARMADAS); Integrated System for Autonomous and Adaptive Caretaking (ISAAC), ; Tensegrity Robots;
ESMD/SOMD Projects --Autonomous Systems and Operations Vehicle System Management/Gateway; Human Landing Systems; Astrobee Facility ISS ops
External --Nissan Self-Driving Car, USGS, SFO

Resources: Greater than 32 Million Dollars
Workforce (FTE/WYE): 43/70
Facilities/Labs:
1. Advanced Control Technology Lab
2. Coded Structures Lab
3. Astrobee Facility
4. NASA UAS Research Complex
5. Robotics labs and Roverscape



Backup

Advanced Control and Evolvable Systems (ACES)

Space

Aeronautics

ACES at a Glance

ACES Missions

- Conduct research to advance new technologies and capabilities in flight control and autonomy for aerospace vehicles and aviation systems
- Conduct modeling and simulations and control hardware development to support research
- Operate test facilities to support NASA missions

ACES Capabilities

- Aerospace vehicle control and guidance
- Intelligent adaptive learning control
- UAS avionics, autonomy, flight testing
- Piloted and hardware-in-the-loop simulations
- Real-time flight control software
- Trajectory and aircraft performance optimization

Group Overview

- 24 members – 13 civil servants, 1 pathway intern, and 10 contractors
- Funding mission directorates – ARMD (61%), HEOMD (17%), SMD (12%), STMD (8%)

ACES Projects and Facilities

Distributed Spacecraft Autonomy (DSA)

Human Landing System (HLS)

Data Reasoning Fabric (DRF)

Advanced Air Transport Technology (AATT)

Advanced Air Mobility (AAM)

Revolutionary Vertical Lift Technology (RVLT)

Astrobee ISS Operation Facility

UAS Autonomy Test Facility

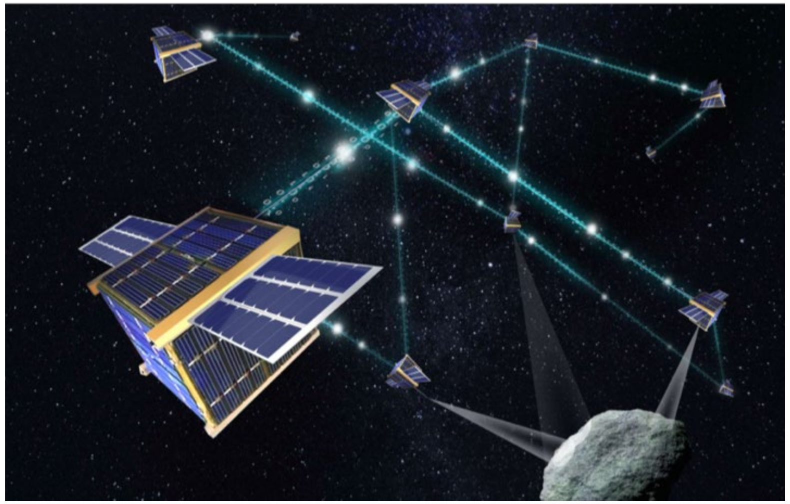
Advanced Control Technology (ACT) Lab

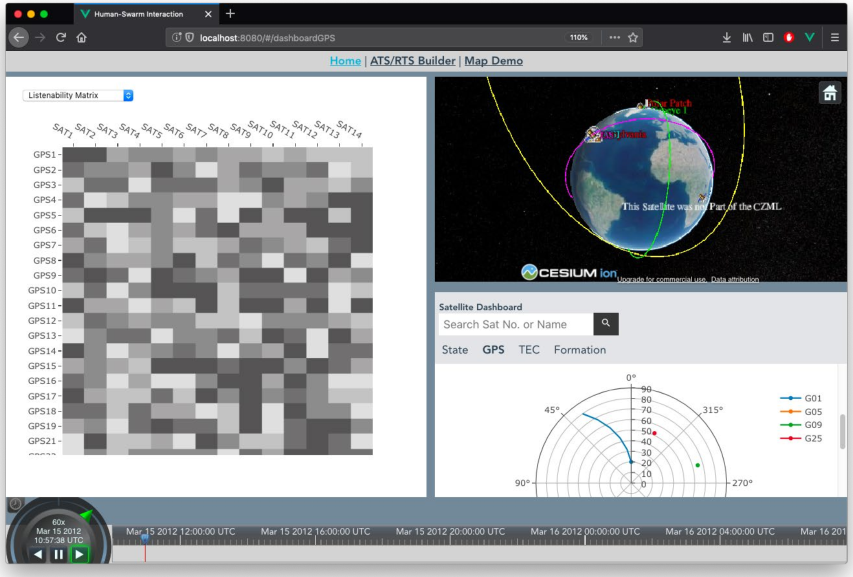
Distributed Spacecraft Autonomy

Advancing multi-spacecraft autonomy through flight tests and at scale. DSA is a software payload on the Starling mission where it will be demonstrating:

- Swarm command and control as a single entity
- Swarm level consistency and decision making
- Autonomous reconfiguration in response to external stimuli

The DSA flight software has been designed for an demonstrative top side ionosphere test but fundamental components of its technology and software will be applied to other application on a 100 processor in the loop test bed.





DSA Human Swarm Interaction UI

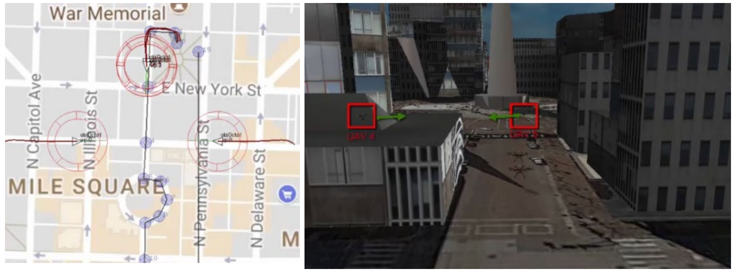
Advanced Aircraft Autonomy and Flight Avionics for High-Density Urban Operations

Flight technologies and avionics for autonomous low-altitude flight in complex urban environments

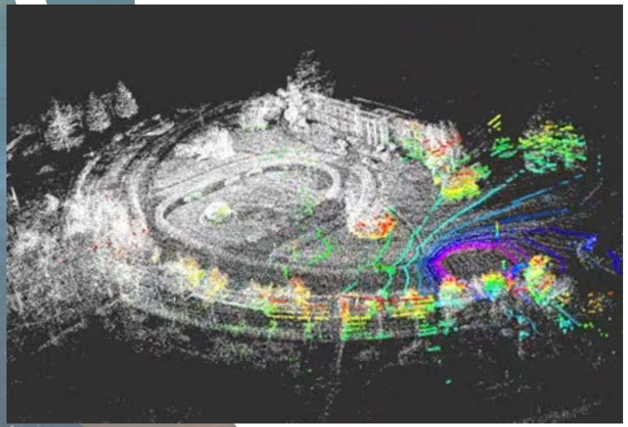
Advanced sensing technologies for robust state estimation and mapping of urban hazards and the environment

Real-time constrained trajectory generation and dynamic ground risk detection and mitigation

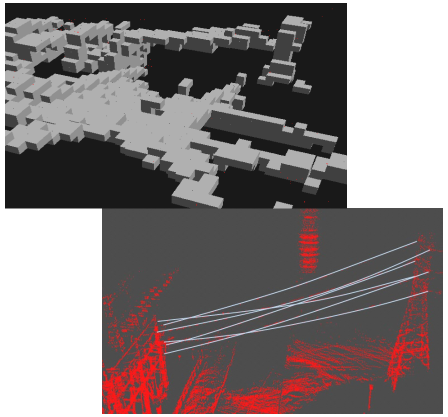
Autonomous separation assurance and collision avoidance for high-density autonomous operations in a decentralized peer-to-peer system



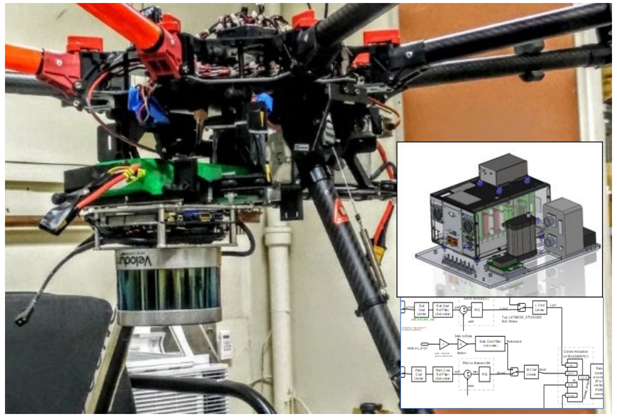
Autonomous Separation Assurance and Collision Avoidance



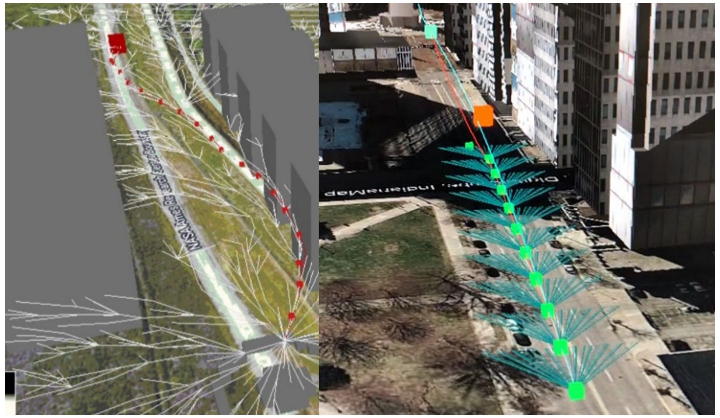
High-Resolution Environment Sensing, with Simultaneous Localization and Mapping (SLAM)



Artificial Intelligence for Hazard Detection and Mapping



Flight Avionics Hardware and Software Stack



Real-time Constrained Trajectory Optimization and Planning

Advanced Air Transport Technology (AATT) N+3 Aircraft Flight Control

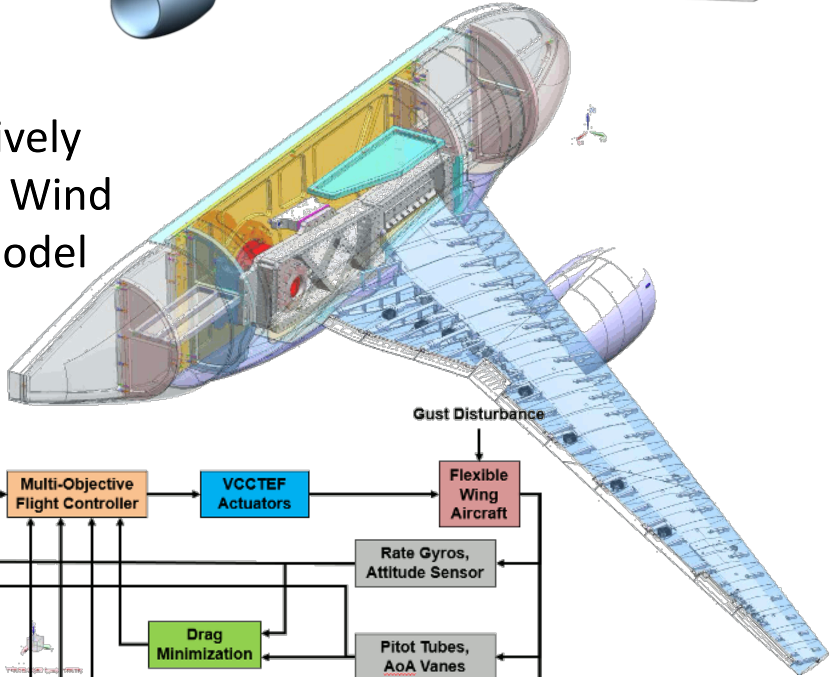
Developing advanced flight control technologies for next-generation transport aircraft

- Multi-objective distributed optimal control
- Real-time drag minimization for increased fuel efficiency
- Gust/maneuver load alleviation for enhanced safety and passenger comfort

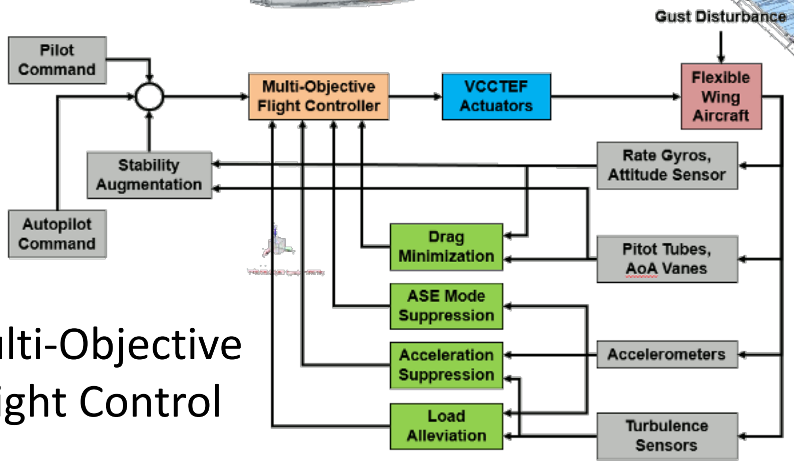
Collaborating with Boeing on multi-objective flight control technology for high-aspect ratio next-generation passenger transport

Validating Ames-developed multi-objective flight control technology in NASA Transonic Dynamic Tunnel (TDT) facility on an actively controlled wind tunnel model in 2021

Boeing AR 13.5 Common Research Model (CRM)

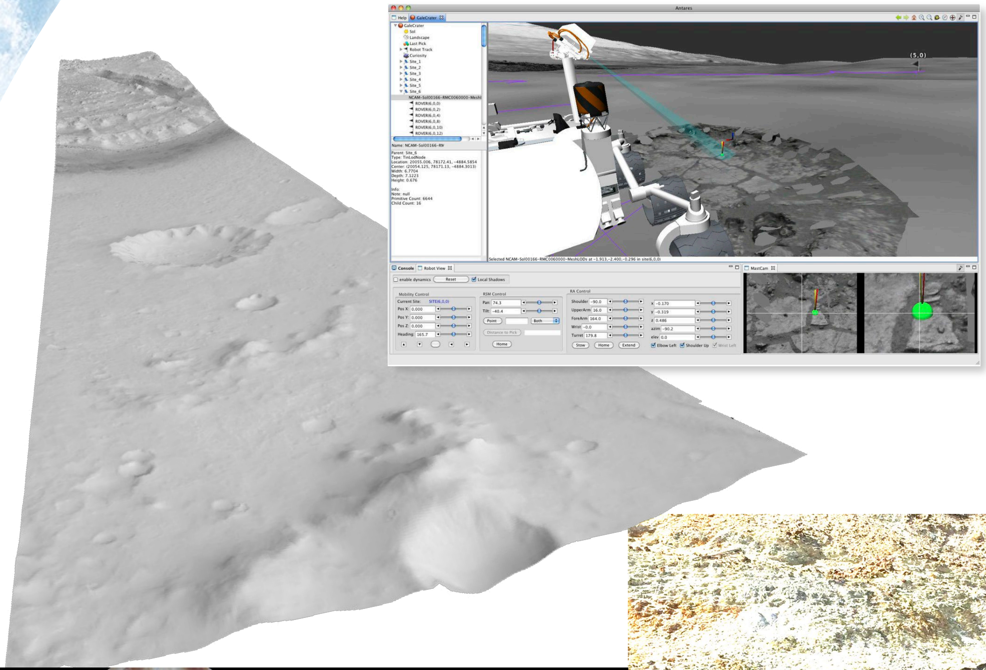
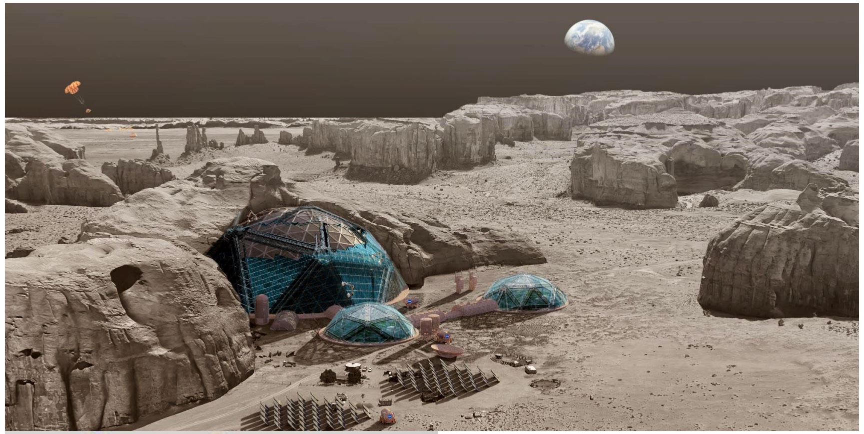
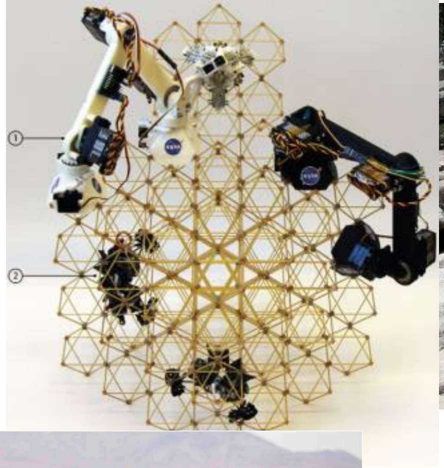


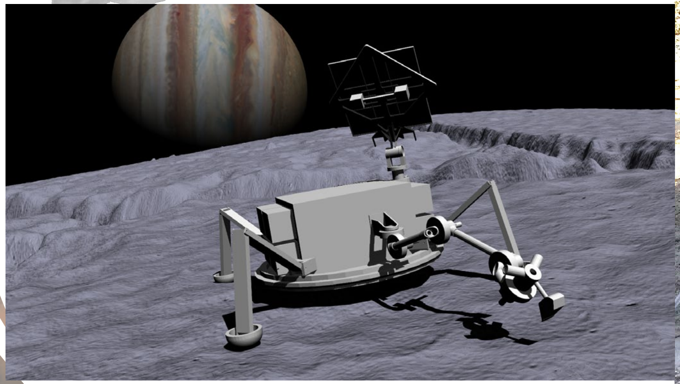
CRM Actively Controlled Wind Tunnel Model



Multi-Objective Flight Control

Deployable Automation Technologies (DAT)



DAT at a glance

Coded Structures Lab (CSL)– Kenny Cheung, Elizabeth Taylor

Autonomous metamaterials and structural systems (multi-robot assembly and reconfiguration with structural building blocks)

Drilling and Automated Sample Acquisition (DASA) Lab – Brian Glass

Autonomous drilling and/or acquiring samples, for planetary/lunar surface missions and ISRU. Fabrication of surface constructs with local materials.

Mission Planning, Simulation and Science Visualization Lab (MPSL) - Larry Edwards

Visual planning and mapping software and mission simulation testbeds

	CSL	***DASA***	***MPSL***
Skills	Advanced Materials and Manufacturing (Structural Mechanics, Robotics, Ultralight Materials)	Adaptive Controls, Contamination Control, VHM, Drilling/sampling analog soils, ISRU surface construction, simulants	3D visualization, mech simulations
Projects	ARMADAS	DIG, Icebreaker, ISRU	OceanWATERS, VIPER, MSL/Curiosity
Skills Gap Areas	Flight Systems / ISRU	AI and adaptive controls	3D interactive visualization, fault injection
Facilities/Labs	N212	503, N269/131	N269 OceanWATERS

CSL: Automated Reconfigurable Mission Adaptive Digital Assembly Systems (ARMADAS)

Mission Directorate: **STMD**

Theme: **Autonomy**

Program: **Game Changing Development (GCD)**

Key Personnel

Elizabeth Taylor (PM)

Email: elizabeth.taylor-1@nasa.gov

Phone: (281) 380-9482

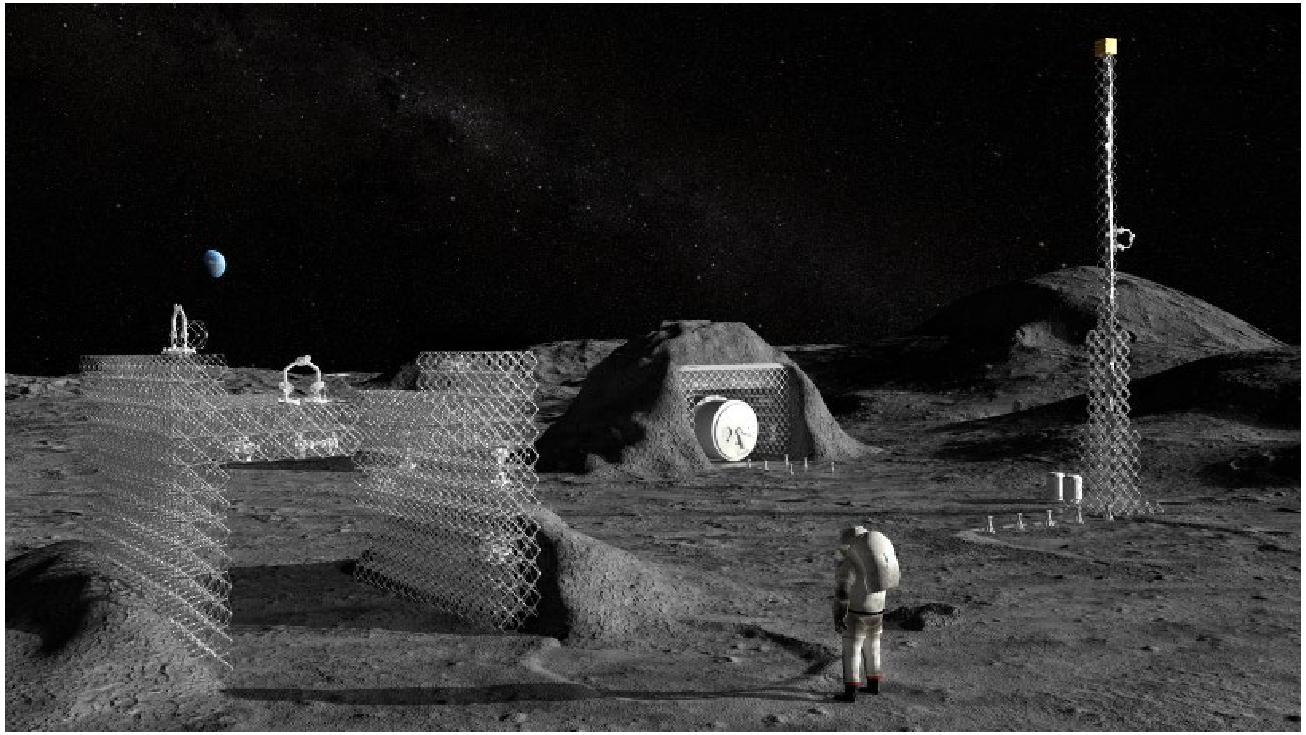
- **Kenny Cheung (PI)**

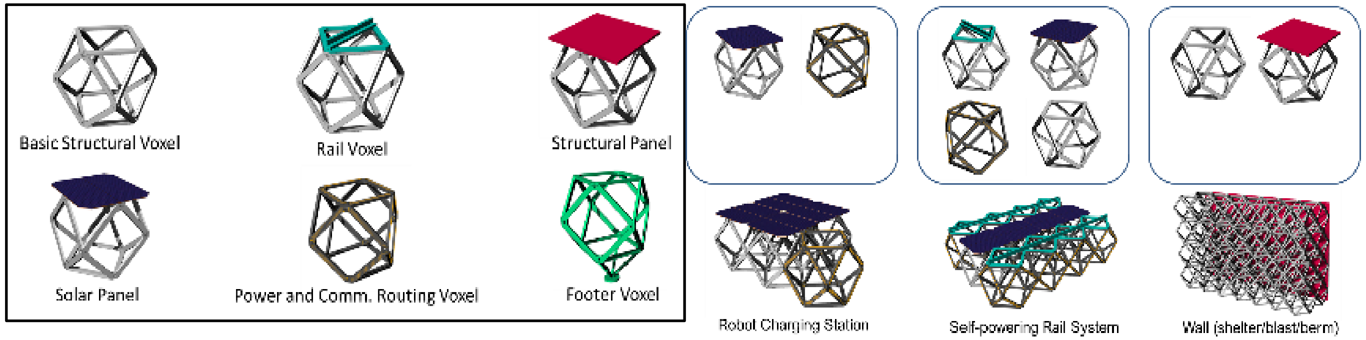
Email: kenny@nasa.gov

Phone: (650) 440-2385

Summary of Project

The Automated Reconfigurable Mission Adaptive Digital Assembly Systems (ARMADAS) project will provide infrastructure that will autonomously assemble itself from a set of packed parts using simple robots.





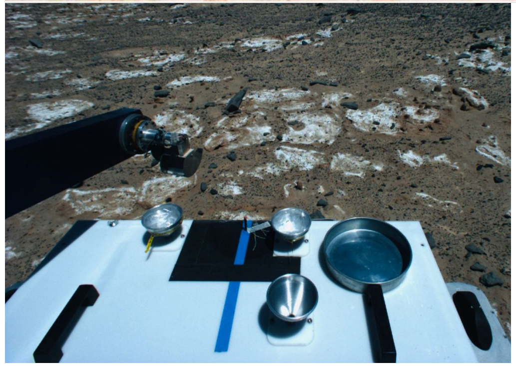
DASA: Atacama Rover Astrobiology Drilling Studies (ARADS)

Motivated by risk-reduction, technology maturation and ConOps development for the Astrobiology Field Laboratory (post-Perseverance) Mars life-detection rover mission concepts.

K-REX2 rover, 2m automated drill (Honeybee drill, Ames automation), robotic sample transfer (MDA arm, Ames scoop) to feed onboard life-detection instruments (from Ames, GSFC, JPL, Spain).

Series of 4 increasing-capability demonstrations at Atacama Desert analog site

NASA Group Achievement and Ames Center Director Reserve Awards; special issue of *Astrobiology* forthcoming.



Sample delivery

MPSL: SMD imaging -- VIPER imagers, MSL interpretation

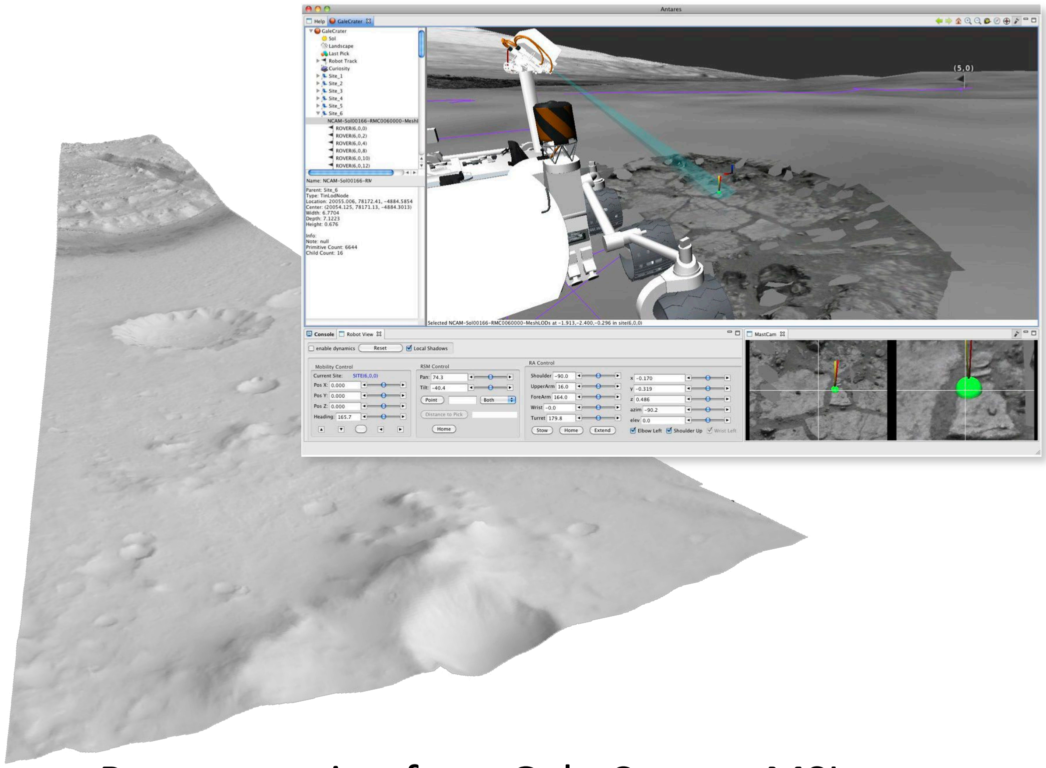
Lead: Larry Edwards

Mission Directorate: SMD

Projects: VIPER, MSL/Curiosity

Industry Partner: Malin Space Systems

Overview: MPSL supports planetary science image acquisition, interpretation and feature extraction. Current VIPER imager design and engineering support. Ongoing 3D image reconstruction from MSL and other science datasets, directly supporting MSS and the MSL mission. Past role in OceanWATERS (with PSG).



Reconstruction from Gale Crater - MSL

Intelligent Robotics Group

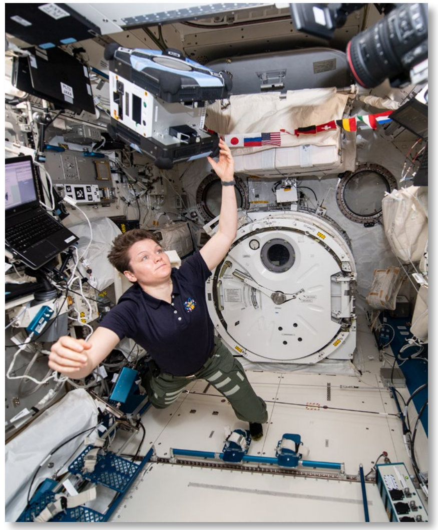
IRG at a glance

Overview

40+ researchers (>1/3 Ph.D.'s)
20+ student interns yearly
90+% NASA work
TRL 1 to 9

Research themes

- **Automated planetary mapping**
  - Base maps & terrain models
  - Geospatial data systems
- **Exploration user interfaces**
  - Robot & science operations
  - Accessible science data
- **Robots for human explorers**
  - Increase human productivity
  - Improve mission planning & execution
  - Transfer **some** tasks to robots (tedious, repetitive, long-duration)



Projects

- STMD
  - GCD ISAAC
  - GCD Day/Night Rover Nav
  - GCD Cuberover Tipping Point
  - GCD SpaceROS ACO
  - GCD Synthetic Terrain Development
  - GCD SQRLi
  - Early Career Fellowship
  - Early Stage Innovation
  - NSTR / NSTGRO Fellowships
  - NIAC TANDEM
  - NIAC BREEZE
  - STTR Phase 2 Sequential: RESET-SEQ
- SMD
  - AIST StreamFlow
  - ASP PDART
  - ASP for Cryo
  - CSM for ASP
  - Stereo2SWE
  - VIPER
- External
  - NGA - DELTA
  - Nissan
  - USGS - SDB

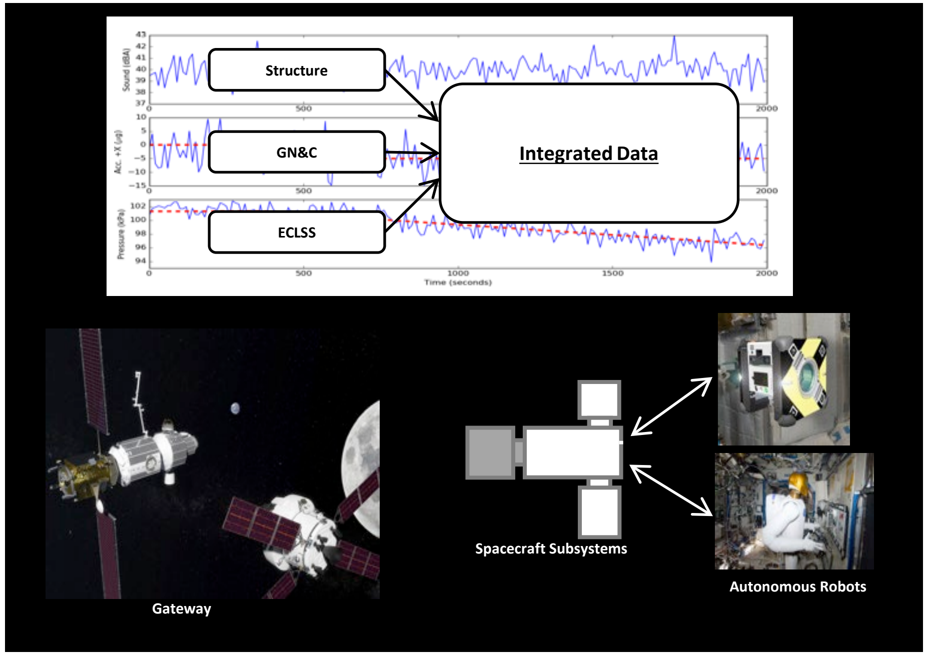
Integrated System for Autonomous and Adaptive Caretaking (ISAAC)

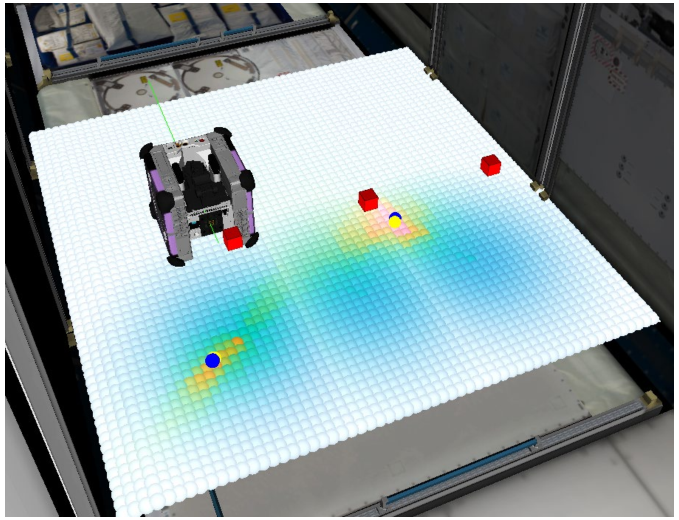
ISAAC is building software for caretaking of exploration vehicles, focusing on uncrewed phases

ISAAC technology enables autonomous operation of the integrated system consisting of intra-vehicular robots (IVR) and other vehicle subsystems

Technology infusion primarily targets Gateway (phase 2), but also applicable to other missions

Technology is tested using existing IVR on ISS (Astrobee) as an analog to future IVR on Gateway





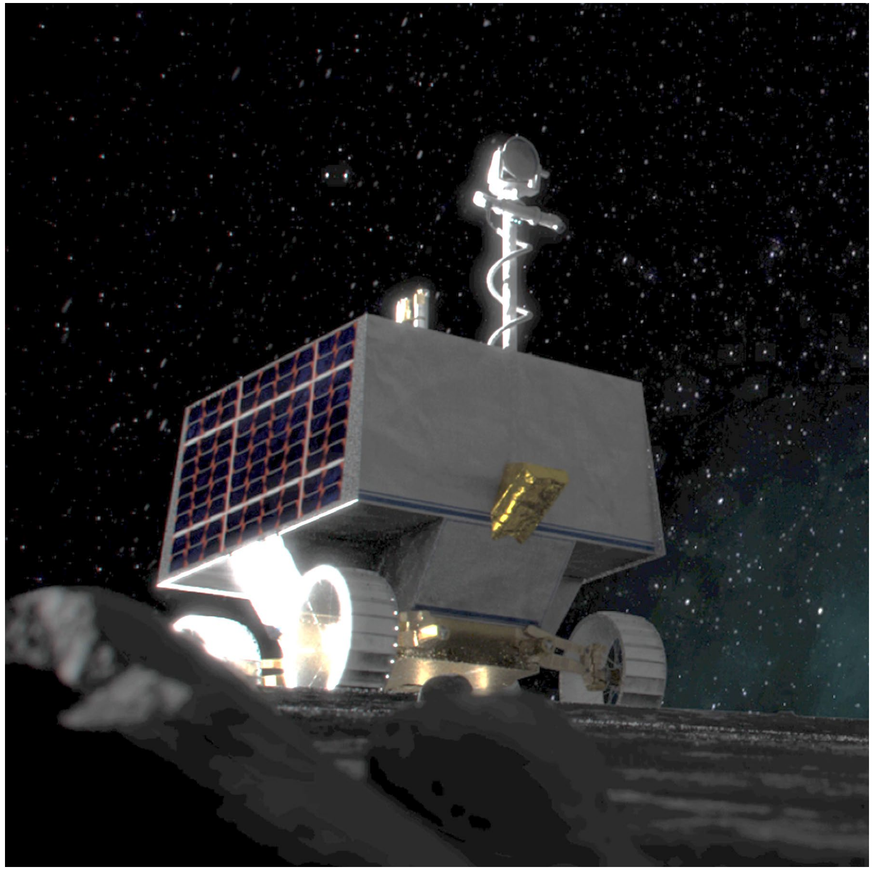
Volatiles Investigating Polar Exploration Rover (VIPER)

2023 rover mission

Search for subsurface volatiles (e.g. water ice) in the polar regions of the Moon

IRG Role:

- Onboard software
- Navigation systems
- Robot driving tools
- 3D Lunar terrain maps from satellite images for mission planning
- Software to support high-tempo science operations



Deep Learning for Flood Mapping (DELTA)

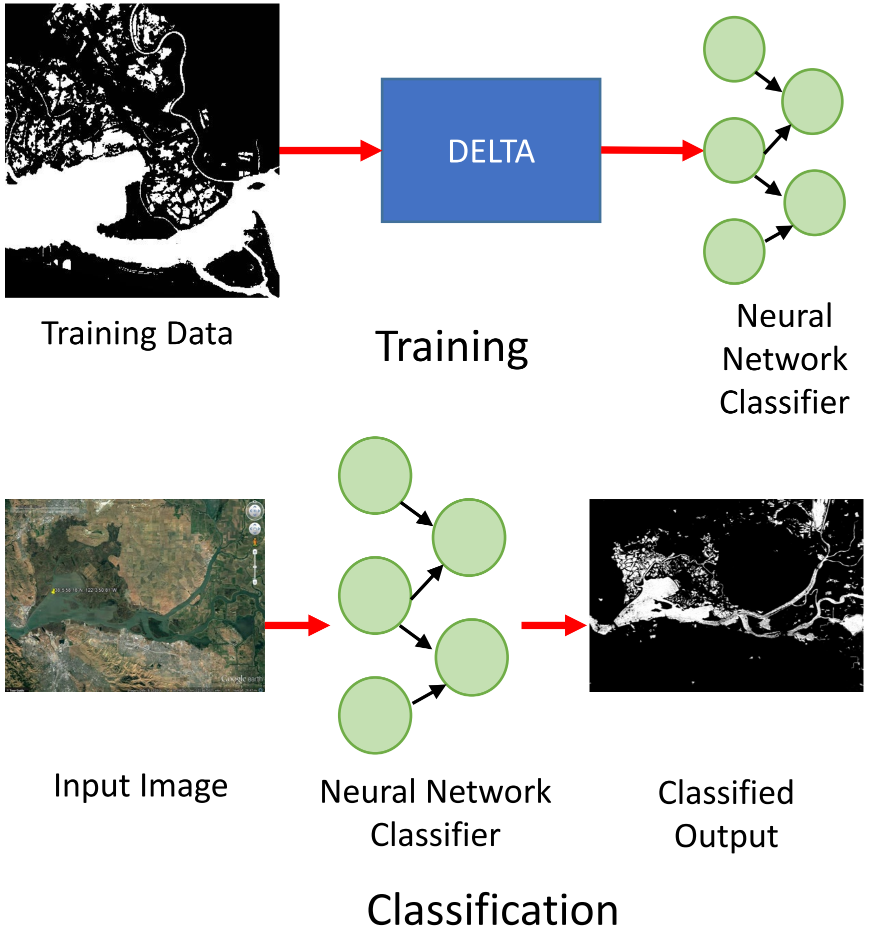
Developing open-source toolkit for deep learning on satellite imagery

Initial application: flood mapping for disaster response

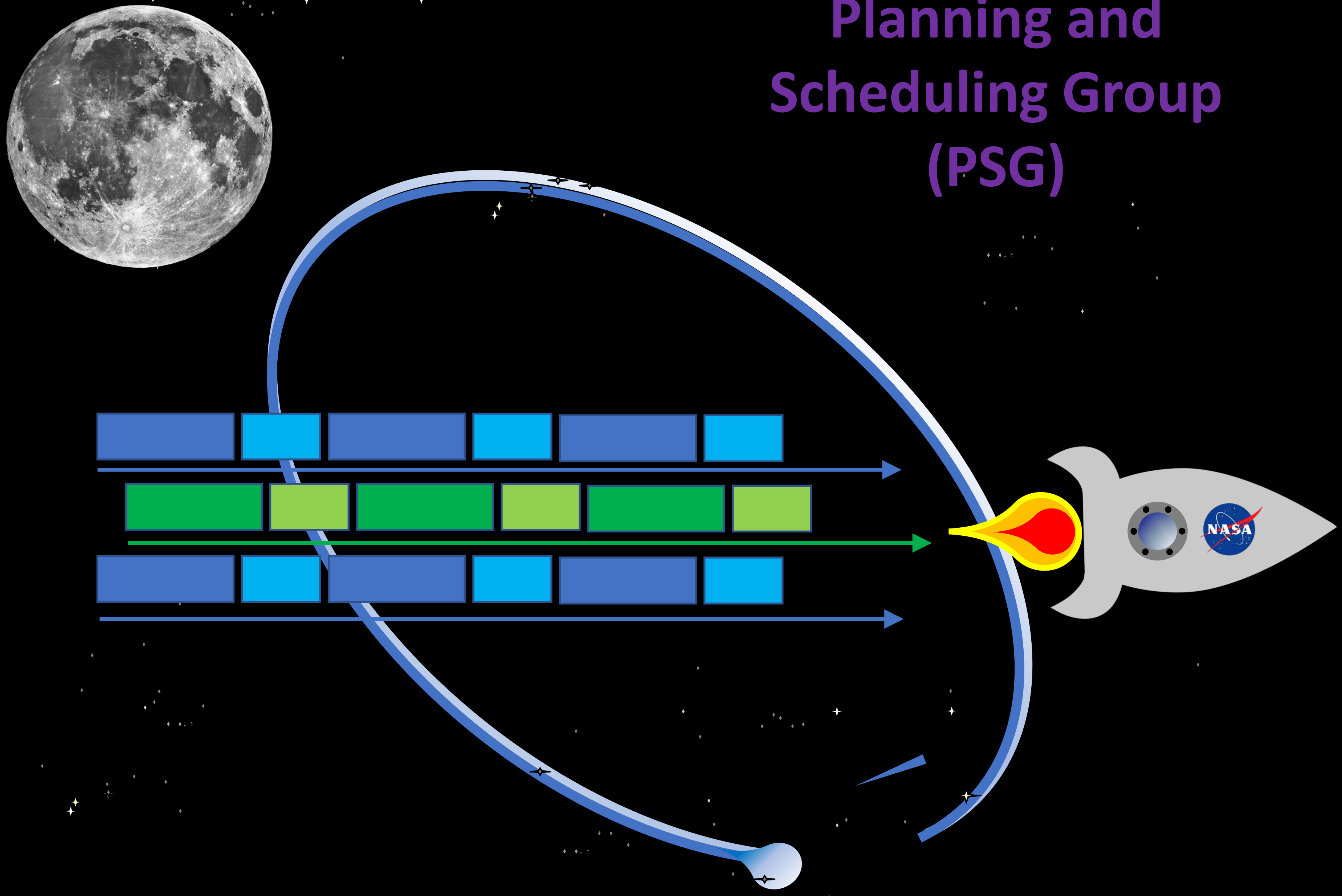
Achieve state of the art classification for Earth scientists with little knowledge of machine learning and limited computing resources

Provides pre-trained compressed representations for various satellites (starting with Worldview, Sentinel-1, and Landsat)

Collaboration between NASA Ames, USGS, NGA, and University of Alabama



Planning and Scheduling Group (PSG)



PSG at a glance

The Planning and Scheduling Group (PSG) develops software to address NASA's many and diverse planning and scheduling needs.

Problems of interest to NASA include the following features:

•**Complex temporal constraints** – Many activities like communication can only be done during certain time windows, while other activities must be done in a particular order.

•**Limited resources** – Rovers and spacecraft have very limited energy and memory available and these assets must be managed carefully.

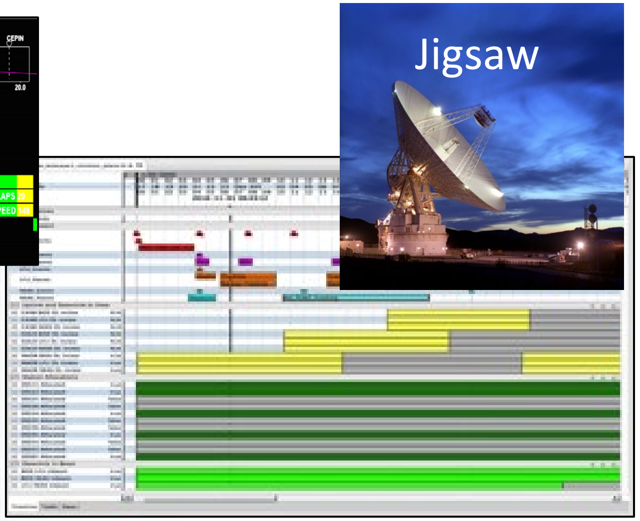
•**Over-subscription and optimization** – Typically there are many more objectives than can be satisfied, and objectives may have differing importance and urgency.

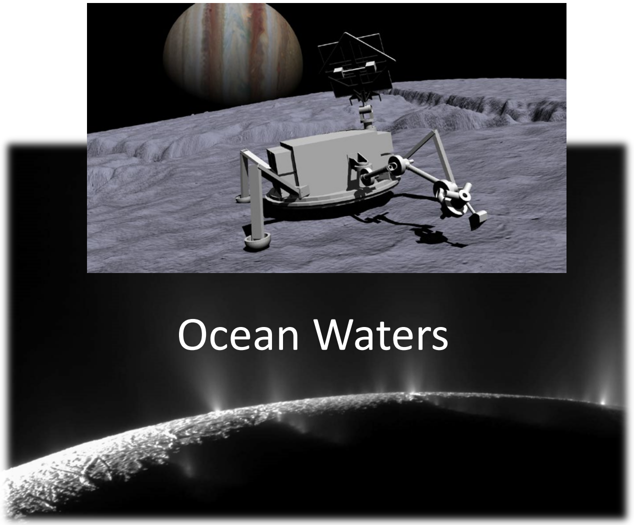
•**Uncertainty** – The time or resources required to act may be uncertain; action outcomes may also be uncertain.

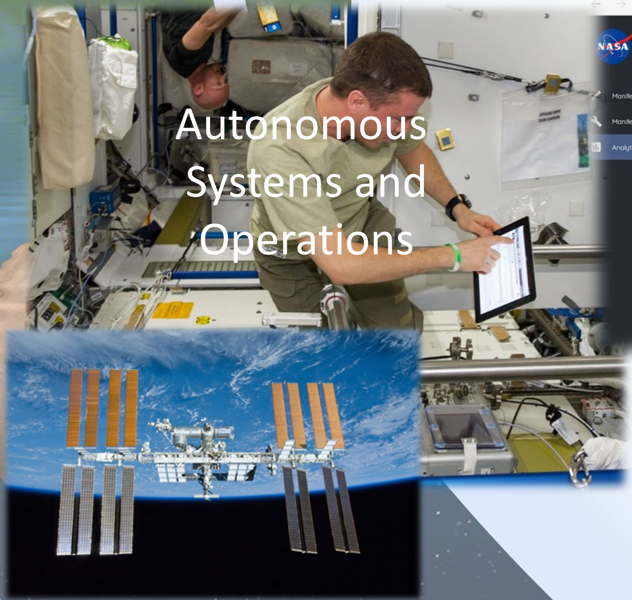
•**Control** – The resulting plan may be executed autonomously.

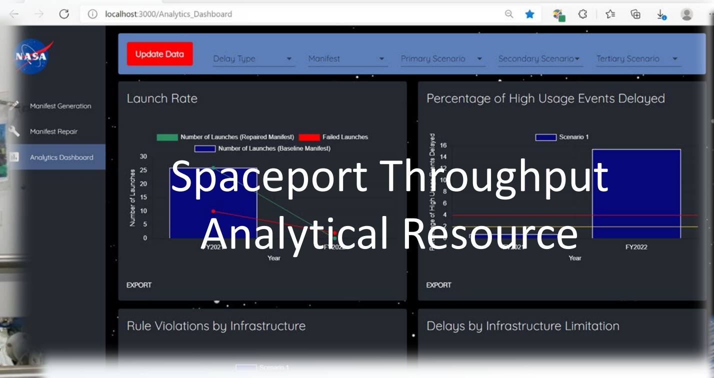
Projects

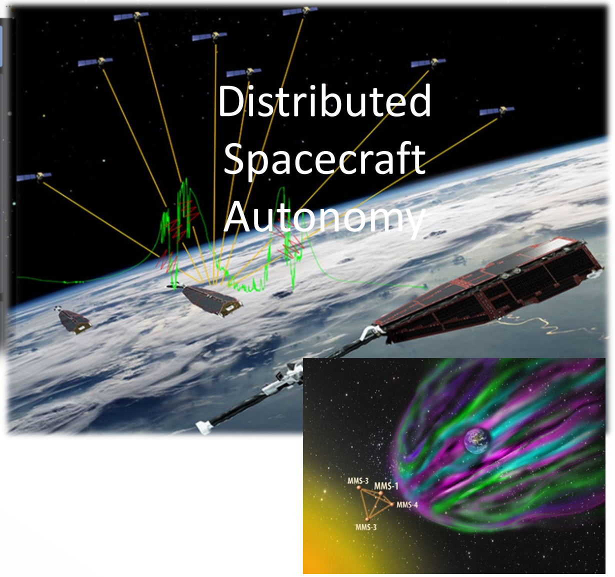

Ferry Building
Advanced Air Mobility


Jigsaw


Ocean Waters


Autonomous Systems and Operations


Update Data
Launch Rate
Percentage of High Usage Events Delayed
Spaceport Throughput Analytical Resource
Rule Violations by Infrastructure
Delays by Infrastructure Limitation

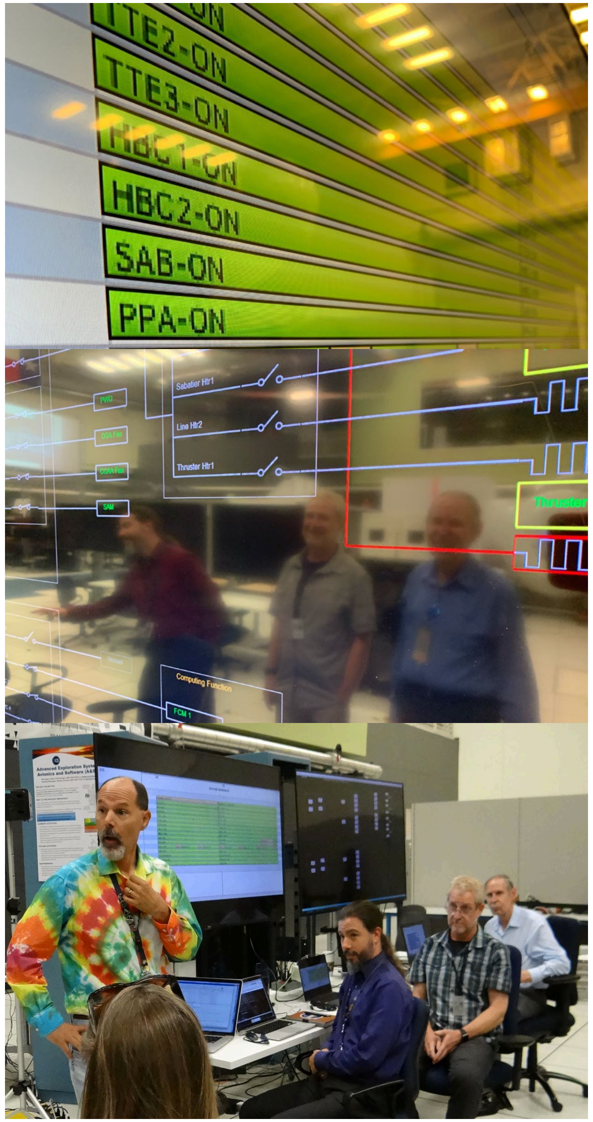

Distributed Spacecraft Autonomy

ASO Habitat Vehicle System Management (VSM)

Develop prototype/reference implementations of Habitat Vehicle System Management (VSM) under MOU with Gateway

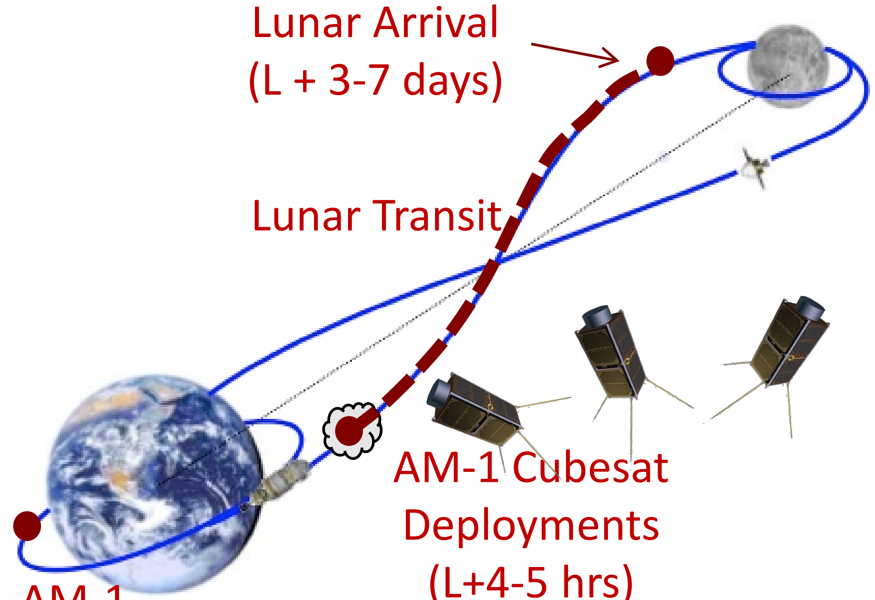
Demonstrate active fault isolation, most functional state restoration of spacecraft habitats (e.g. Gateway and Human Lander System)

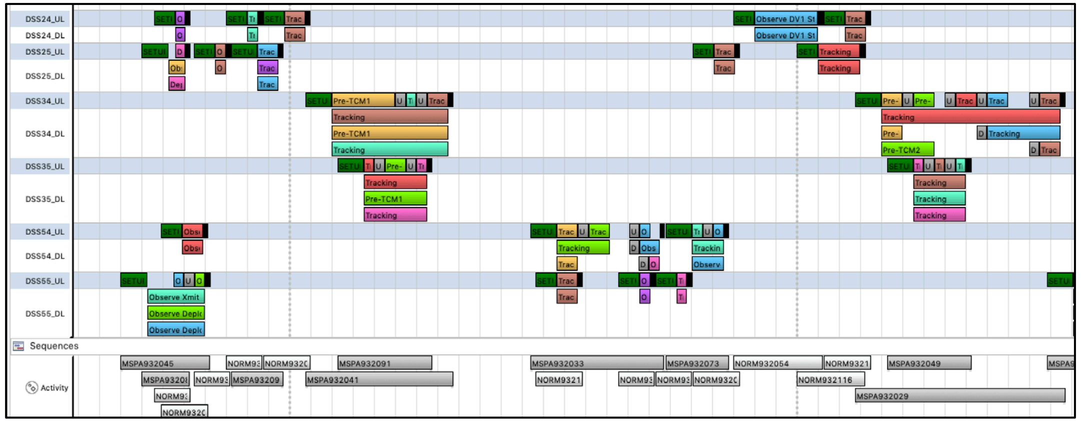
Integrates automated planning, plan execution and fault management technologies with Core Flight Software (cFS)



ASO Jigsaw: Contact Scheduling for AM-1 Cubesats

- Develop AM-1 Cubsesat contact scheduler to facilitate AM-1 mission peer-to-peer schedule deconfliction and interface with JPL Deep Space Network schedulers
- Integrates custom automated planning algorithms, automated reasoning modules, and OpenSPIFe front-end
- Leverage ARC CIF funding and HEOMD ASO funding





Distributed Spacecraft Autonomy: Autonomy technology for Swarms

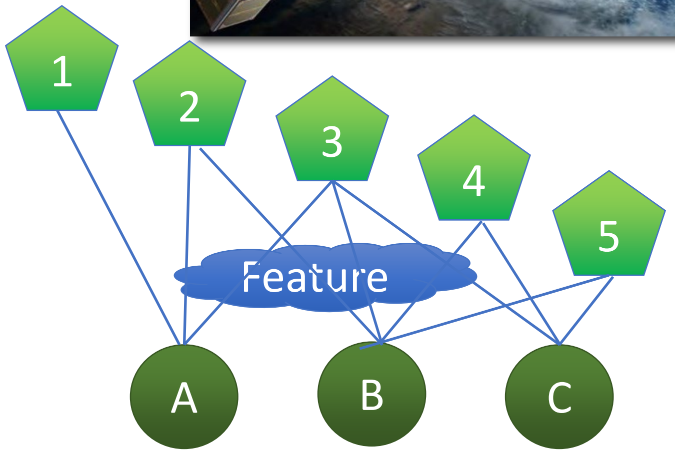
National Aeronautics an
Space Administratio

Autonomy can significantly increase the effectiveness of multiple spacecraft by enabling missions to function as a collective rather than individually.

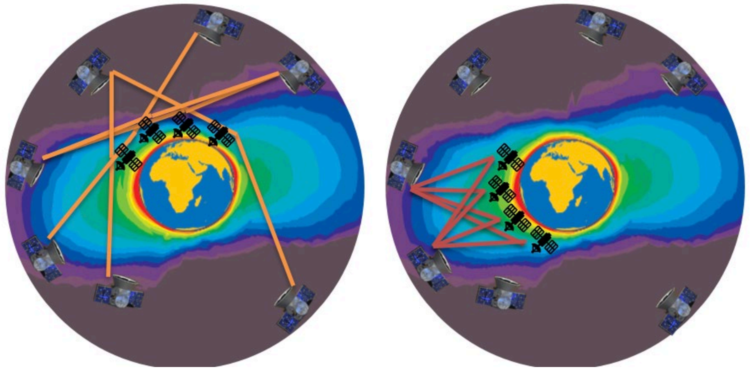
DSA will demonstrate swarm autonomy with four spacecraft as a Starling-1 payload, and in simulation with up to 100 spacecraft using the same algorithm/architecture.

DSA implements automated resource allocation with Core Flight Software (cFS).

GPS:



Swarm:



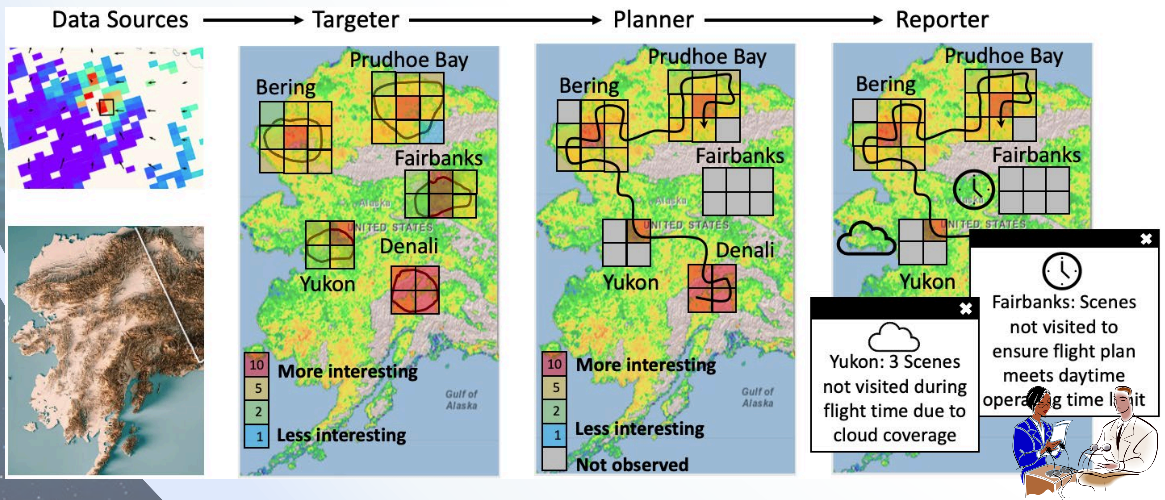
Intelligent Long Endurance Observing System(ILEOS)

A Science activity planning system to enable New Observing Strategies (NOS), consisting of satellites and High Altitude Long Endurance (HALE) UAS-mounted instruments.

Optimize fine-grained spatio-temporal resolution data collection of Earth observations, such as GHG-relevant gases, using HALE UAS.

Incorporates coarse-grained satellite data and near real-time environmental (e.g., wind, weather, airspace constraints) data to generate high-value fine-grained resolution data collection plans.

Designed for human operators; plan explanation and data provenance features will ensure science mission planners understand all key choices made while generating targets and plans.

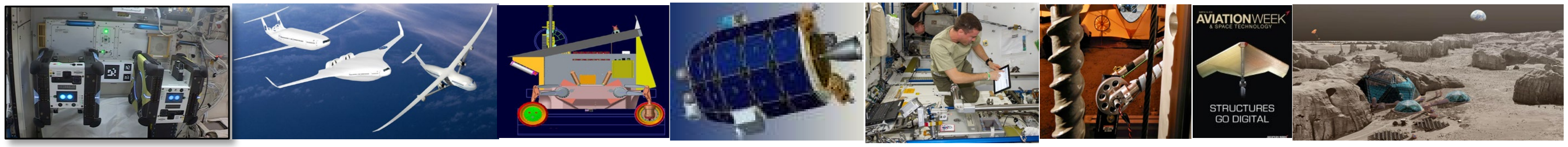


Autonomous Systems and Robotics Summary

NASA's Vision calls for closer cooperation between humans and aerospace systems as we advance state of the art here on Earth, return to sustain a presence on the Moon and continue on to Mars.

This endeavor requires building systems that can adapt their behaviors to environments that are complex, rapidly changing, and not well-understood. ASR has unique capabilities and agency leadership in applying autonomy and robotics expertise to NASA missions, and terrestrial demonstrations.

Creating automated and autonomous behaviors via robotic assistants, robust avionics, intelligent planning and scheduling, and advanced control technologies are the focus of the Autonomous Systems and Robotics Technical Area.



ASR Impact

Enabling complex systems and operations

through the development of technologies

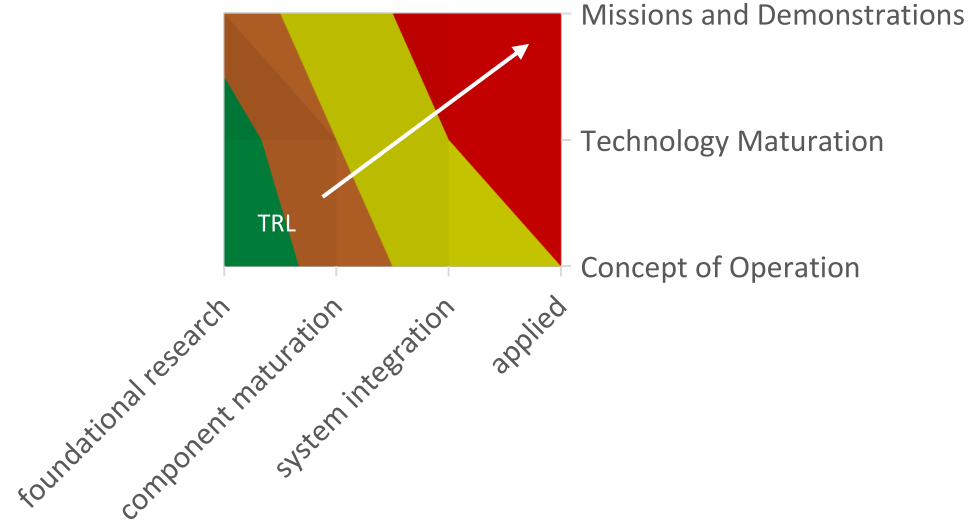
that can respond to changing conditions, knowledge, and constraints

Our advancements are

- increasing performance, productivity and efficiency,
- improving science return,
- enhancing safety,
- informing system design decisions,
- enhancing situational awareness and
- enabling new capabilities

Foundational Research

ASR Span of influence



system design and engineering

concepts of operation

requirements

complex systems and operations

Autonomous Systems and Robotics (ASR) Executive Summary

Charter/Goals/Objectives: NASA Vision calls for closer cooperation between humans and aerospace systems than ever before. Creating automated and autonomous behaviors via robotic assistants, robust avionics, intelligent planning and scheduling, and advanced control technologies are the focus of the ASR technical area. This endeavor requires building systems that can adapt their behaviors to environments that are complex, rapidly changing, and not well-understood. ASR has unique capabilities and agency leadership in applying autonomy and robotics expertise to NASA missions, and terrestrial demonstrations.

Products/Deliverables:

- Avionics software
- Adaptive and optimal control and estimation
- Advanced flight management systems
- Automated planning and scheduling
- Control agent architectures
- Computer vision & digital mapmaking
- Distributed and multi-agent systems
- Drilling automation
- Embedded software systems
- Geospatial data systems
- Model Based Flight Software Development
- Space robotics (planetary rovers & free-flyers)

Customers/Projects/Partners: ASR Executes over 30 projects for various mission directorates and external partners.

ARMD Projects -- Performance Adaptive Aeroelastic Wing; small UAS Autonomy; Autonomous Aircraft Operations;
SMD Projects -- Biosentinel Avionics FSW; Visual Science-Ops for MSL & MRO; Drilling and Sampling Automation;
STMD Projects -- EDSN/NODES FSW; SPHERES/Astrobee; Autonomous Systems Planning and Diagnostics; Tensegrity Robots; Volatiles Investigation Polar Exploration Rover;
HEOMD Projects --Autonomous Systems and Operations; GeoCam Space; Astrobee Facility ISS ops
External -- Google Crisis Mapping (CM); Disaster Response; Moon Express FSW; Nissan Self-Driving Car, USGS, SFO

Resources: Greater than 28 Million Dollars
Workforce (FTE): 40
Facilities/Labs:

1. Advanced Control Technology Labs
2. Flight Software and Avionics Lab
3. NASA UAS Research Complex
4. Robotics labs and Roverscape