



Autonomy@NASA for Aeronautics

**Presented by:
Dr. William (Bill) R. Van Dalsem
Deputy Director of Aeronautics
NASA Ames Research Center**

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NASA's Missions:



Autonomy has been critical to both air and space flight based exploration for over 30 years.

Autonomy for Space Flight Exploration



2012 ISS MCC

Integrated Attitude, Power and Crew Activity Planning for Mission Operations at JSC, MSFC, ESA and JAXA



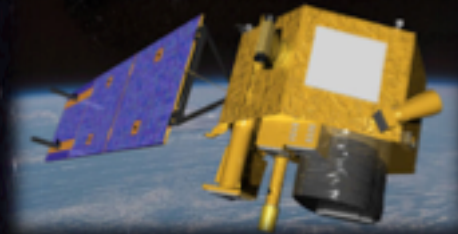
2019 Astrobeer Free-Flyer

Autonomous nav, docking and recharge, and mobile sensor IVA work on the ISS.



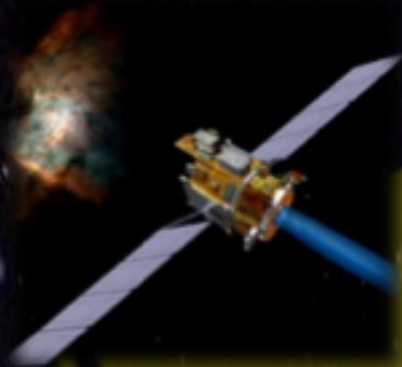
2005 Earth Observing - 1

Livingston on-board model-based diagnostic



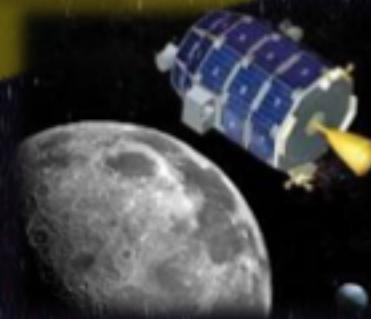
1997 Deep Space 1 Remote Agent

The first demonstration of an onboard autonomous spacecraft control system



LADEE 2012

Assisted re-planning



2018 ISS Crew Self-Scheduling

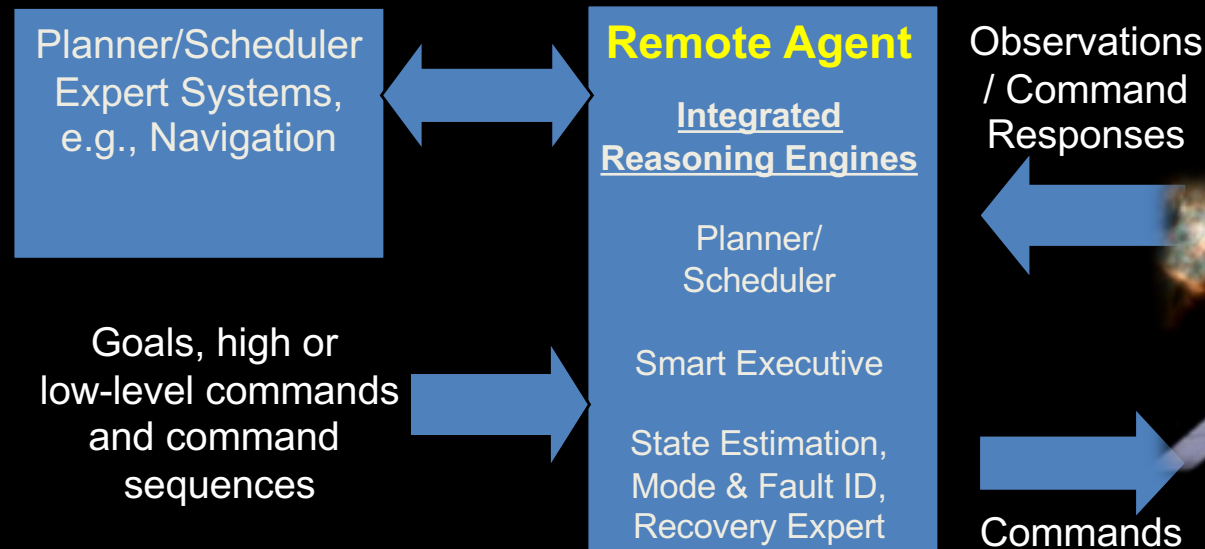
Six month on-board study of assisted planning and scheduling system for crew



Deep Space 1 – Remote Agent (1997)



The first onboard artificially-intelligent adjustably-autonomous flight system to control a spacecraft – **1999 NASA Software of the Year** winner



Capabilities

- Planner expands high-level goals into flexible plans
- Executive decomposes plans into low-level spacecraft commands and monitors that the states commanded to are achieved and maintained
- Logically-Consistent State Estimator and Fail-operational fault recovery
- Identifies faults and suggests recoveries that the Executive uses to continue plan execution
- If necessary, Executive requests the Planner to generate a new plan

ISS Crew Self-Scheduling (2018)



Autonomous crew scheduling

- ISS astronauts can self-schedule mission activities independent of ground control
- Intelligent support system for planning to avoid and de-conflict plan violations and allow for rapid re-planning
- Technology demo on the International Space Station using tablet computers



Future human exploration missions

- Deep space missions (Mars, etc) will require crew to be more autonomous of mission control
- Activity scheduling is critical for mission execution and operations, but is tedious and complex
- Tools that support crew self-scheduling are essential for mission success



ISS Astrobees Space Robot (2019)



Overview

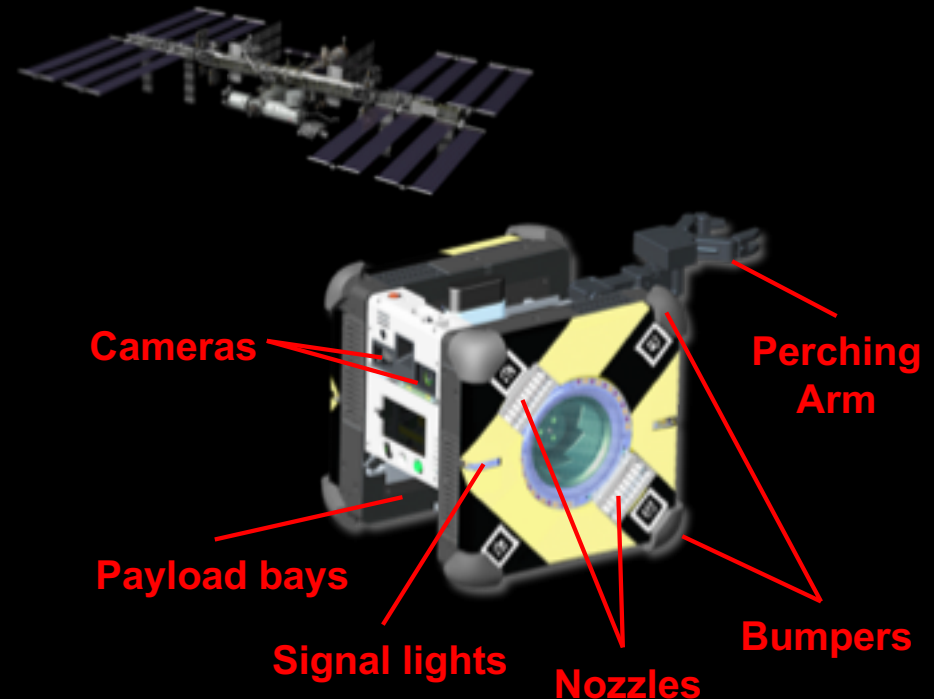
- Free flying robot for inside the ISS
- Astrobees will be used by flight controllers for mobile sensing
- Astrobees will be used as a robotic testbed (like SPHERES)

Safe autonomous operations

- Task execution / notification
- Perching & station keeping
- Docking & resupply

Concept of operations

- Mission control uploads plans to robot for autonomous execution
- Astrobees has on-board fault recovery (stop, terminate, return)
- Mission control can remotely intervene if needed

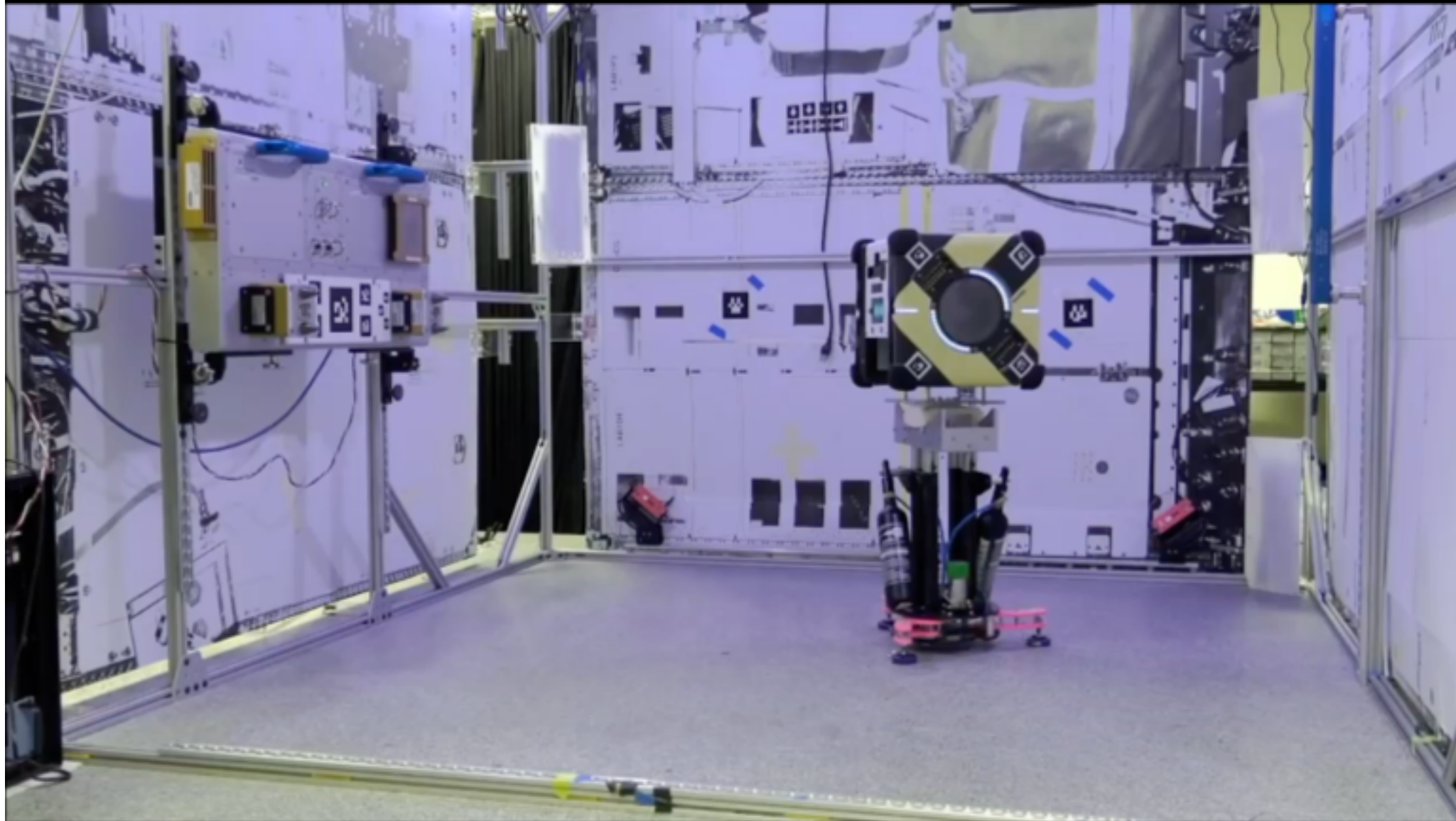


*Certification Unit
(8/2018)*



*Two Astrobees moving cargo
(artist concept)*

ISS Astrobee Space Robot (2019)



Autonomy for Robotic Exploration



2005 Autonomous Visual Inspection

Robotic “walk around” inspection for future lunar sortie operations. Universal Executive and PLEXIL.



2012 Mars Science Lab

Virtual collaborative activity planning & scheduling by science teams

2002 Single Cycle Instrument Placement

Approach and place an instrument in one command cycle. Method has since been used on MER.



2007 Robotic Site Survey

Systematic autonomous survey with rovers. Field testing at Houghton Crater.



2014 Planetary Lake Lander

Adaptive science for dynamic phenomena in deep-space missions. Field testing in Chile.



2014 Advanced Navigation

Autonomous map and feature-based localization for future planetary rover missions.

Mars 2020

Goal-based rover activity planning



2015 Self Driving Car

Adapt space robotics technology to “fleet management” use.



Single Cycle Instrument Placement (2002)



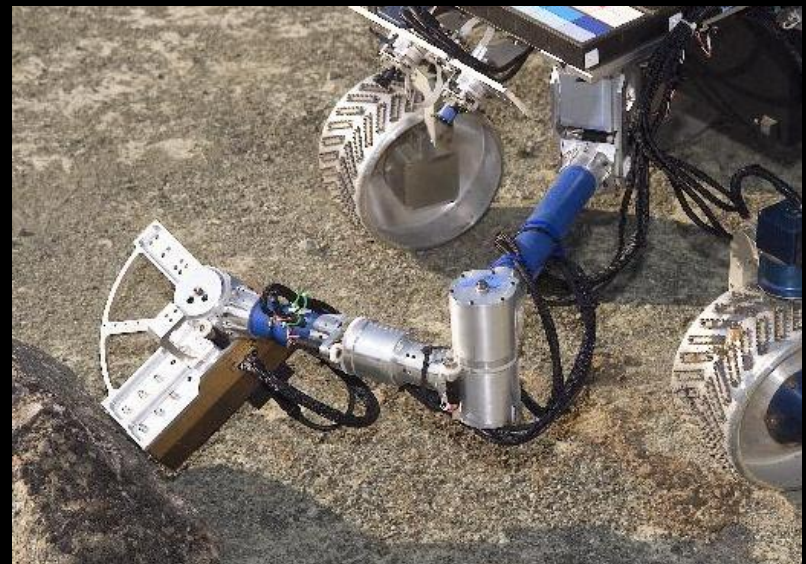
Overview

- Remote designation of targets for contact instrument measurement
- Autonomous navigation, arm deployment, and data collection
- Increased productivity, lower workload for ground operators



On-board Autonomy

- Robust, precision visual feature detection and tracking
- Autonomous vision-based navigation for terminal guidance
- Autonomous safe trajectory planning for robotic arm and contact instrument placement



Advanced Navigation (2014-)

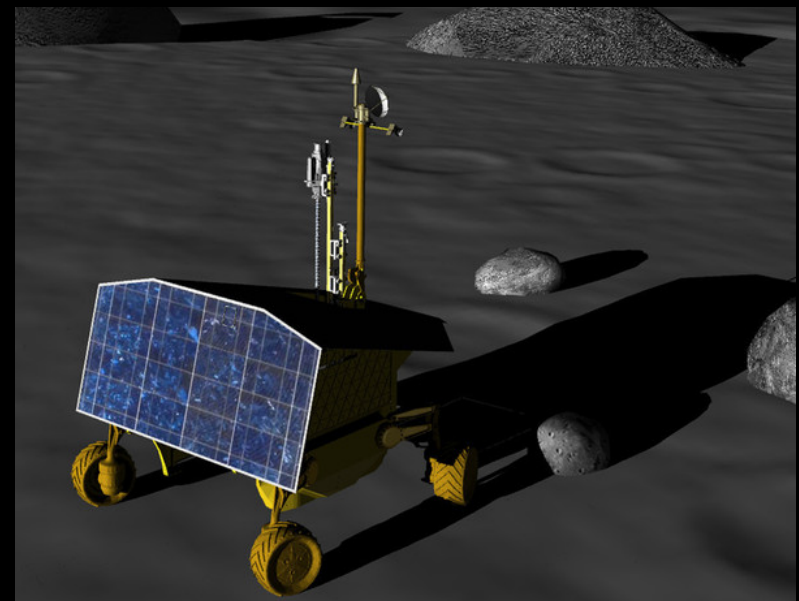
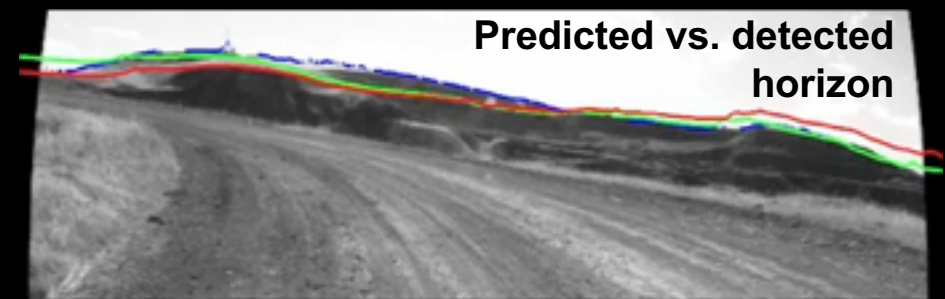


Overview

- Enabling technology for increased planetary rover autonomy
- Real-time surface positioning (“GPS without satellites”) via on-board processing
- Infusion to Mars Science Lab (Curiosity) and Resource Prospector missions

Approach

- Stereo vision + 3D terrain model derived from orbital imagery
- Determine position by comparing the horizon / terrain to 3D terrain model



Planetary Lake Lander (2011-2014)

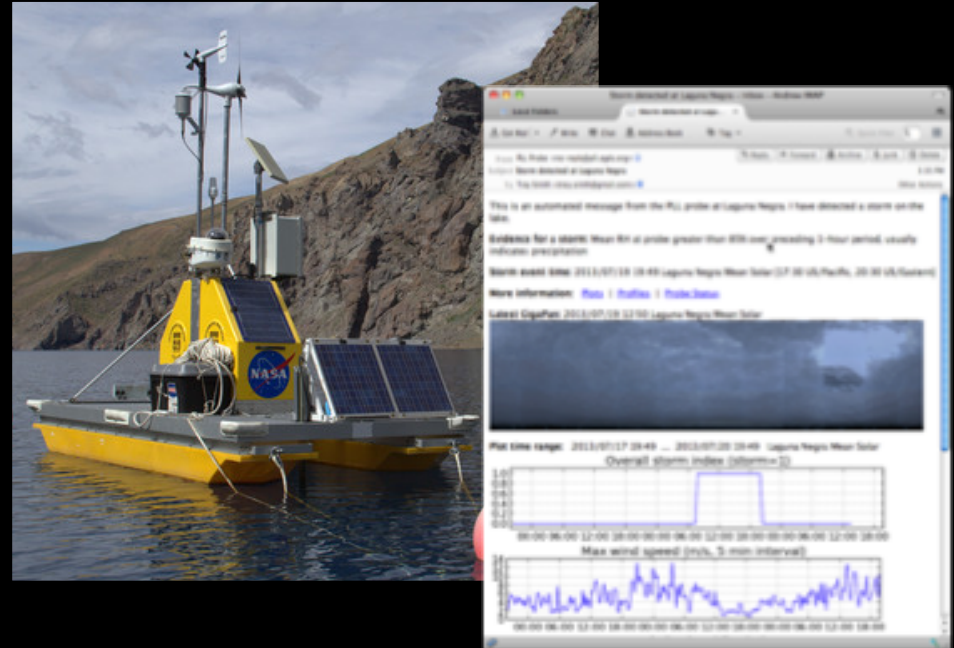


Overview

- Analog for future probes to the methane seas of Titan (Titan Mare Explorer mission)
- Autonomously learns about dynamic environment
- On-board focusing of limited resources to improve science

Adaptive science

- Adaptive sampling (water column profiling)
- Dynamic event monitoring (storm detection / measurement)
- Adaptive shore approach
- Adaptive telemetry uplink (dynamic data triage)



NASA-Nissan Partnership (2015-)

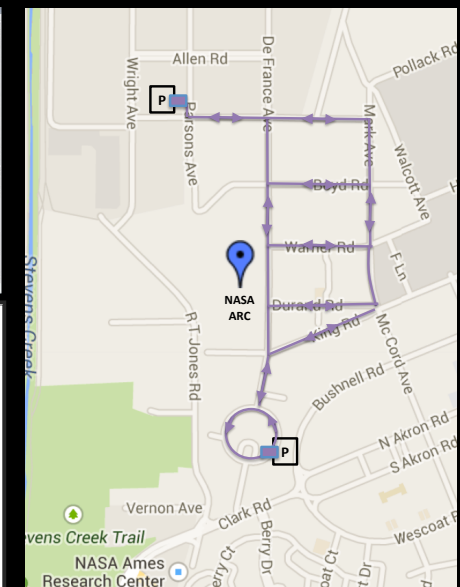
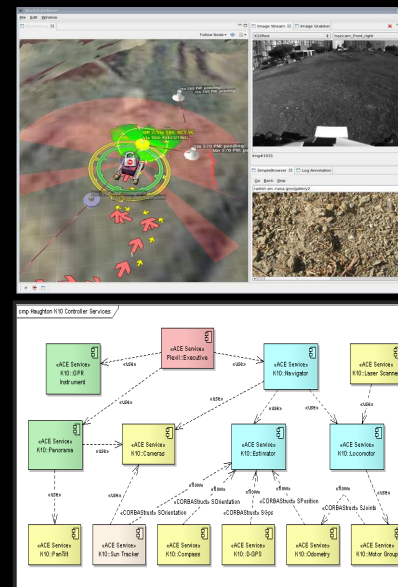


R&D agreement (5 year term)

- Autonomous vehicle systems
- Human-machine interface
- Network-enabled applications
- Software V & V
- Vehicle testing at NASA Ames

Current activities

- Adapt NASA telerobotic technology originally developed for planetary exploration
- Conduct joint development, testing, and assessment at Ames (urban scenario with dynamic hazards)
- Jan 2016 demo for Nissan CEO Fleet management of multiple autonomous vehicles



Autonomy for Aeronautics



2004 Autonomous Rotorcraft

Automated reasoning in the context of autonomous rotorcraft operations.



1999 Neural Net Learning

Dynamic Cell Structure
NN based learning for
adaptive control

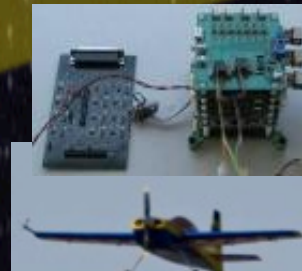
2010 Emergency Landing Planner

Decision support to the pilot of a
damaged commercial transport
aircraft



2012 Function Allocation

Automated ground-based
separation assurance across
increasing levels of autonomy



2011 Real-Time Prognostics

Predict remaining useful
battery life



2015- UAS Autonomy

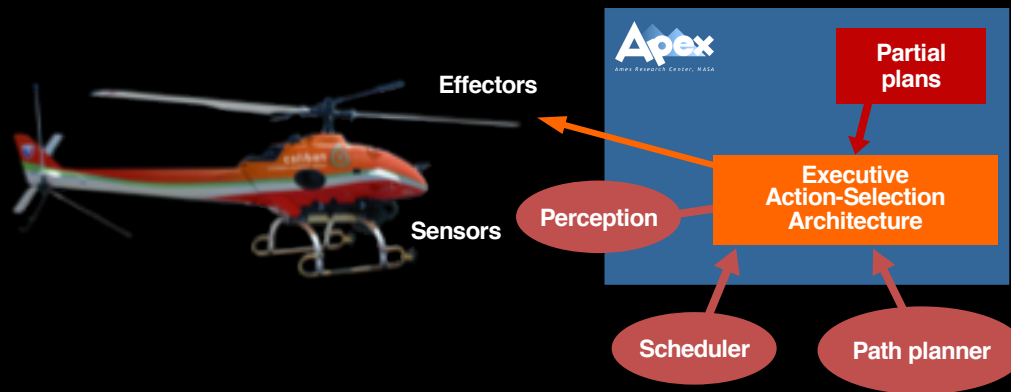
Fully Autonomous urban
deployment of UAS—
Vehicle Technologies and
Airspace Management

2013 Prediction Uncertainty

Operators compensating
for imperfect autonomy



Autonomous Rotorcraft (2004/2006)



PROBLEM: Proof of autonomy in uncertain environments, by developing and evaluating automated reasoning technologies in the context of fully-autonomous rotorcraft operations.

ACHIEVEMENTS: Flight demonstrated aggressive maneuvering in the presence of obstacles, coupling of a reactive planner to a navigation system (APEX), incorporation of mission goals and vehicle health into path planning, and mission planning rapid enough to satisfy the short time scale environment of small UAS.

IMPACT: The accomplishments validated autonomy in uncertain environments for autonomous ISR missions, robust control laws, GPS-denied localization, passive ranging for obstacle detection, and were transitioned to project partners for the benefit of aeronautics and space technology, including NASA, JPL, Army, industry (Northrup Grumman), and several universities.

Intelligent Flight Control (2006/2008)



PROBLEM: Develop flight systems that can be produced and tested at lower cost, and that can accommodate changes to aircraft stability and control characteristics resulting from uncertainties, failures or accidents.

ACHIEVEMENTS: Demonstrated safe in-flight failure recovery, implementation on high performance aircraft and flight critical hardware, and developed initial verification and validation process guides.

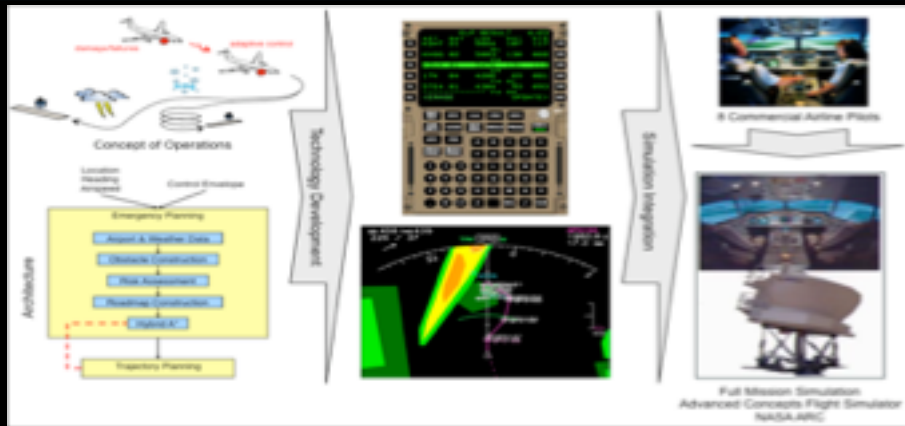
IMPACT: During the tests, the angle-of-attack feedback to the canards was modified to create a destabilizing condition. The system behaved as predicted in the presence of real world turbulence and noise to correctly compensate for the destabilizing condition.

Intelligent Flight Control (2006/2008)



F-15 IFCS
APG Milestone Flight
February 14th, 2006

Emergency Landing Planner (2010)



Pilot feedback overwhelmingly positive:

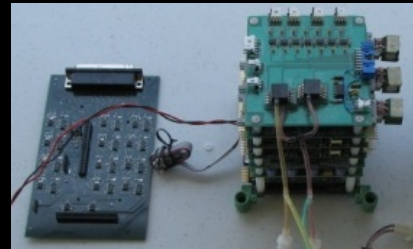
“ ... your software program alleviates the uncertainty about finding a suitable landing site and also reduces workload so the crew can concentrate on “flying” the aircraft.”

PROBLEM: Provide decision support to the pilot of a damaged commercial transport aircraft, or decision support for air traffic controllers for medical emergencies to quickly and easily assess 100s of airports/runways, dynamics, path quality, and ‘soft’ obstacles.

ACHIEVEMENTS: Successfully evaluated in a pilot-in-the-loop motion-based transport aircraft simulator. The tool determined the lowest risk paths to runways within a 150 mile radius considering a large number of factors including: flight envelope of the damaged aircraft, airport facilities, runway length, and weather.

IMPACT: The Emergency Landing Planner was considered a key ‘Design Reference Mission’ for the Inter-Center Autonomy Study Team (ICAST), chartered by the Aeronautics Research Mission Directorate to support initial planning for strategic thrust 6: Assured Autonomy for Aviation Transformation. The capability was transitioned into the technical challenge for reduced crew operations.

Real-Time Prognostics (2011)



Dave Hare, LaRC Subscale Test Vehicle Flight Operations Director

“ ... Battery health prognostics feedback adds valuable safety benefits to mission operations... We are now allowing longer flights because we have Battery Health Management”.”

PROBLEM: Current health capability provides alerting when component is at threshold, which results in conservative flight planning leading to wasted potential flight time.

ACHIEVEMENTS: Successful flight tests were performed for a Health Management and Prognostics capability to predict Remaining Useful Life (RUL) during flight of an Edge 540T Flight Testbed at NASA LaRC. Achievements include first validation runs of on-board algorithms implemented on batteries for electric aircraft, first ever fielding of prognostic capability in electric air vehicle, and providing condition based run time updates of available aloft time.

IMPACT: Early and consistent Remaining Useful Life estimates, including amber and red alert warning has resulted in near “doubling of flight time” due to trust in the health management system.

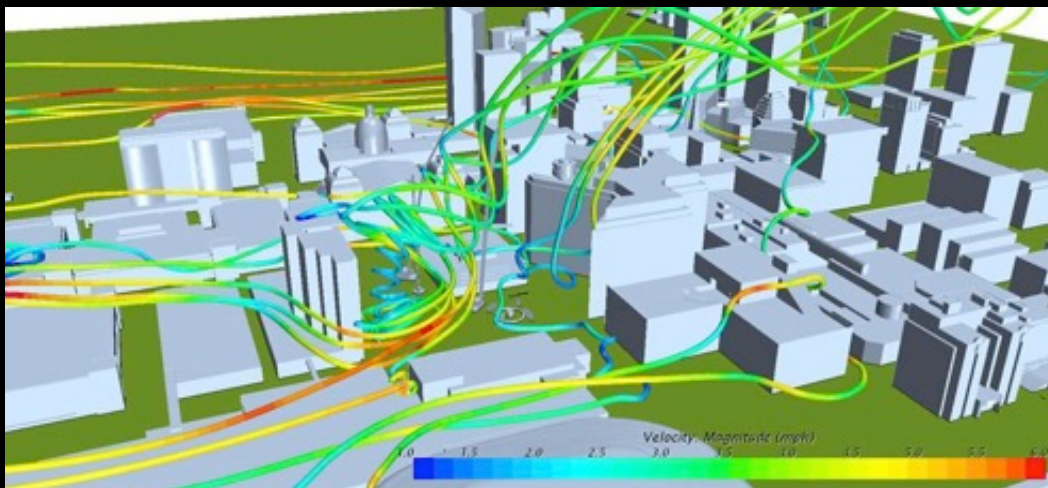
UAS Autonomy (2015-)



The UTM architecture addresses mission planning and execution strategies for UAS operations to encompass:

>> Non-autonomous UAS operations – for spontaneous launching of one or more UAS by operator(s) to address an urgent need (e.g., for law enforcement and first responder scenarios)

>> Autonomous UAS operations – for deliberate planned autonomous UAS flights (e.g., search & rescue, cargo delivery, surveillance).



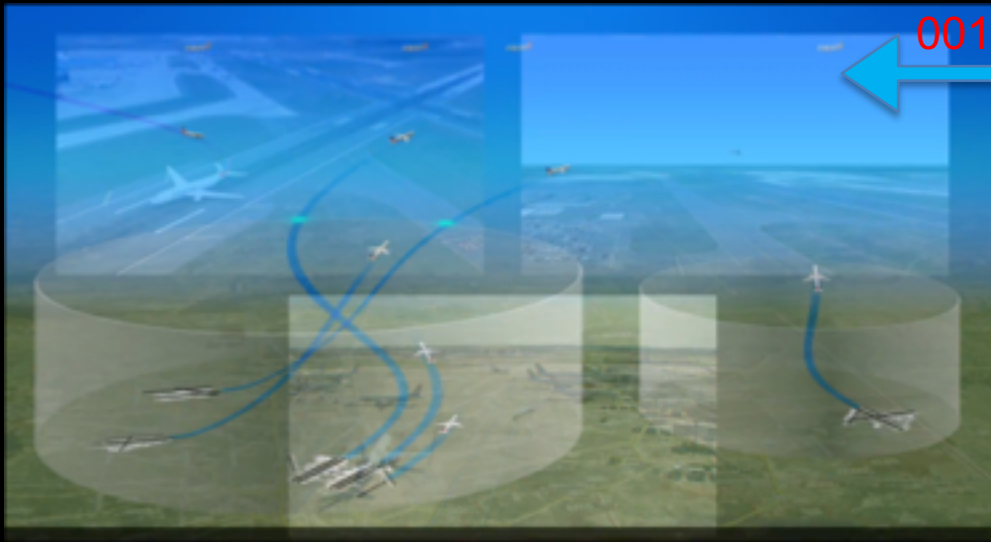
Research Focus:

1. Beyond visual line-of-sight
2. Reservation of airspace volume
3. Urban environments, higher density
 - >> Wind Accommodation
 - >> Sense and Avoid
 - >> On-board Autonomy

Air Transportation Data & Reasoning Fabric



SMART AIRSPACE



SMART VEHICLES



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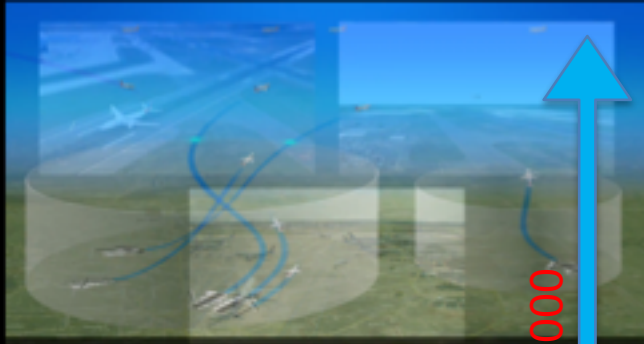
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SMART CITIES

Air Transportation Data & Reasoning Fabric



SMART AIRSPACE



SMART VEHICLES



SMART CITIES



Attributes

- All relevant real-time knowledge available where decisions need to be made.
- Seamless sharing of reasoning & actions between humans & machines.
- Continual progress towards distributed & edge data collection, sharing, and reasoning.

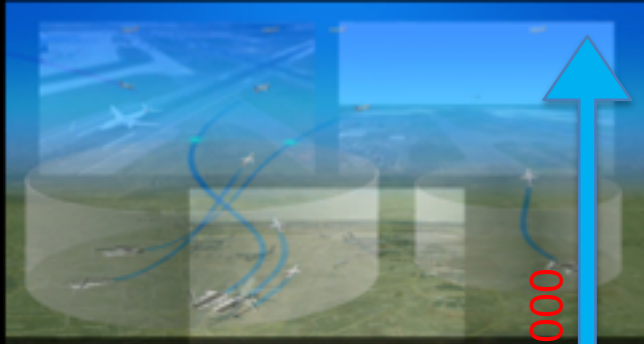
Opportunities

- Retain current levels of safety even with increased air travel density and complexity.
- Optimized transportation
 - Door-to-door (rather than gate-to-gate)
 - Multi-modal (ground, sea, air)

Air Transportation Data & Reasoning Fabric



SMART AIRSPACE



SMART VEHICLES



SMART CITIES



Enabling Technologies

- Real-time heterogeneous data aggregation & knowledge extraction and sharing.
- Transparent machine reasoning with human insight/oversight capable of safely resolving complex contingencies.
- Cloud-to-the-Edge sensors & reasoning systems.

System-Level Challenges

- Autonomous decisions in complex environments.
- Cybersecurity of distributed safety critical systems.
- Complex system-of-smart systems engineering.

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Autonomy@NASA for Aeronautics



Heritage:

- NASA has a 25+ year heritage of conducting autonomy R&D and deploying autonomy in support of NASA's aeronautics and space missions

Currently:

- NASA has a robust and engaged autonomy activity:
 - Workforce: Over 500 staff members
 - Partnerships: Over 50 active partnerships with industry, academia, and government
 - Applications: Applying autonomy to support NASA's aeronautics and human and robotic space missions, and actively engaged with industry partners in exploring additional application domains

Future:

- NASA Aeronautics will continue to enable more autonomous operations of the airspace & air vehicles, all living on a data & reasoning digital fabric extending to the residents of the smart cities of the future.

A composite image featuring a view of Earth from space at the bottom, showing city lights. Above it is the Moon, and further up is a bright star. The background is a dark space filled with stars, overlaid with a pattern of diagonal stripes in dark red and grey, separated by dashed lines.

Questions?