Trustworthy Autonomy Development and Flight Demonstration

Multi-Monitor Run Time Assurance Research Update

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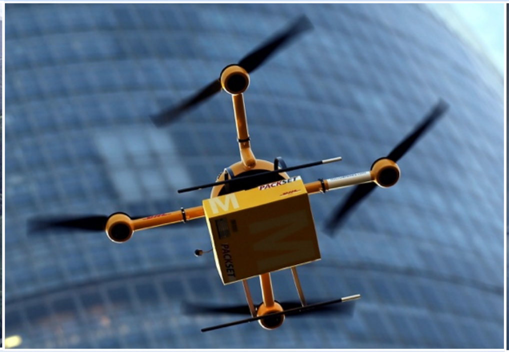
June 2017





Summary Description

Trustworthy Autonomy Development and Flight Demonstration

Thrust 6 Assured Autonomy	Research Theme Vehicle-Centric Autonomy	Mission Programs Advanced Air Vehicle Program (AAVP) and Transformative Aeronautics Concepts Program (TACP)

Needs: This effort addresses methodology for certifying autonomous systems

Goals/Objectives

Broaden NASA, Federal Aviation Administration (FAA), and Department of Defense (DoD) collaboration to develop a coordinated government position on the relevance of using a run time assurance architecture to address flight safety for an autonomous aircraft to execute select real-world missions

Technical Approach

- Leverage Safe Autonomous Systems Operations (SASO) development of a run-time assurance architecture sufficient to support all safety aspects of the selected missions
- Collect test data of the system sufficient to support the safety case on a sub-scale aircraft
- Conduct a joint NASA/FAA review of the safety risks of the selected missions identifying performance or data gaps to make the proposed safety case
- Conduct the autonomy flight demonstrations using procedural and test safety mitigation where gaps exist

Deliverables: Joint FAA/NASA assessment on the use of a run time assurance approach to address the flight safety requirements of an autonomous aircraft

Next logical step: Upon successful completion:

- Address gaps identified in the safety review
- Move system to full-scale aircraft

Benefit to community: Develops a path to certifying autonomous aircraft

Partnerships, Workforce, and Facilities

- **Partners:** FAA, DoD, Industry
- **Workforce:** $247,000 procurement
- **Facilities:** NASA Armstrong and Edwards test ranges
- **Impacts:** This proposal augments an ongoing NASA Armstrong SASO effort

Research Timeline

1980	2000	2010	2016

Advanced Fighter Technology Integration (AFTI)/F-16

Automated Maneuvering Attack System (AMAS)

AUTOMATION RESEARCH

AFTI and Automated Collision Avoidance Technology (ACAT)/F-16

Automated Collision Avoidance

Integrated

DEDICATED SAFETY WORK

Small Unmanned Air Vehicle (sUAV)/Improved Ground Collision Avoidance System (iGCAS)/SR22

Ground Collision Avoidance

sUAS

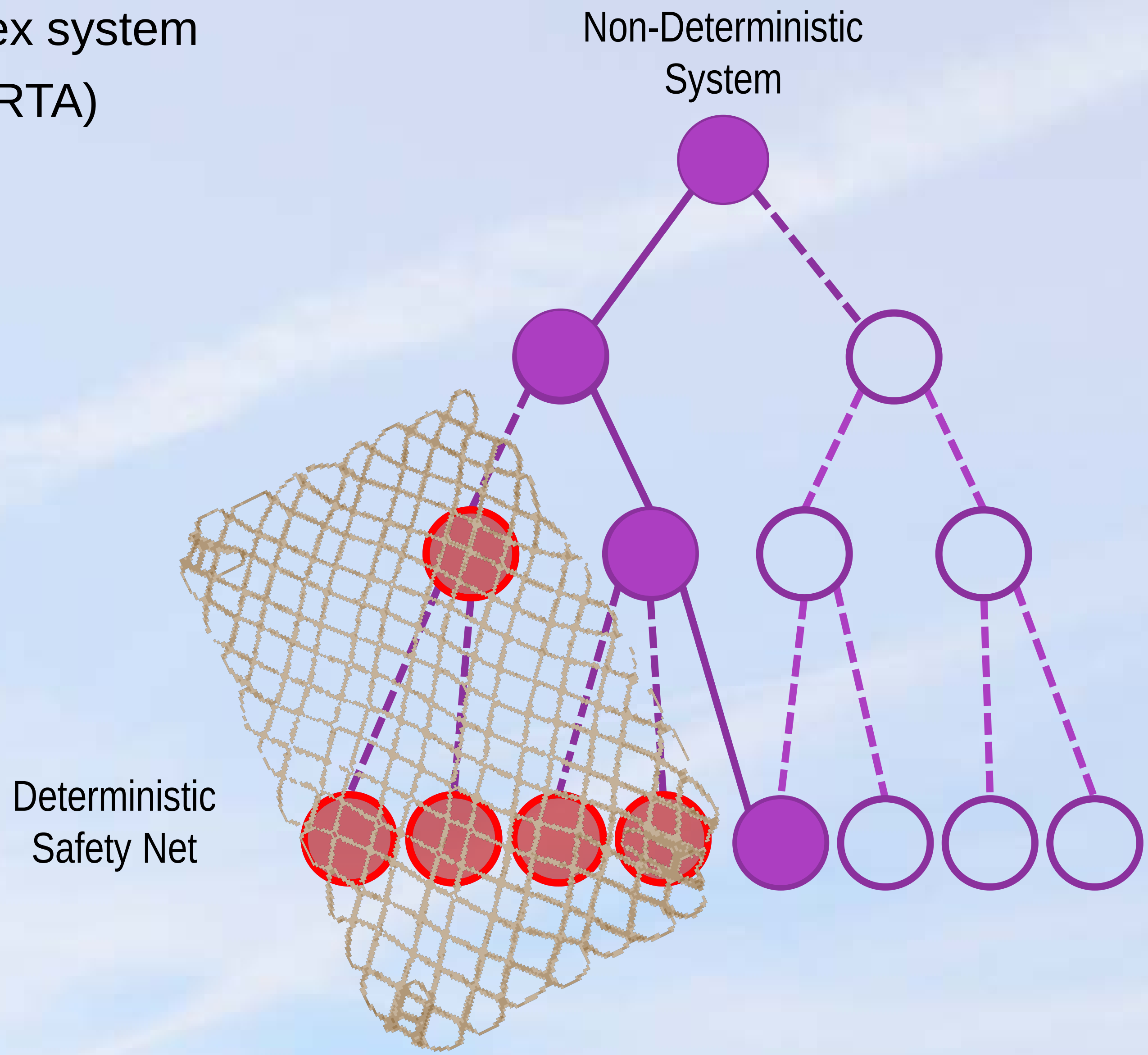
General Aviation

Quad-rotor

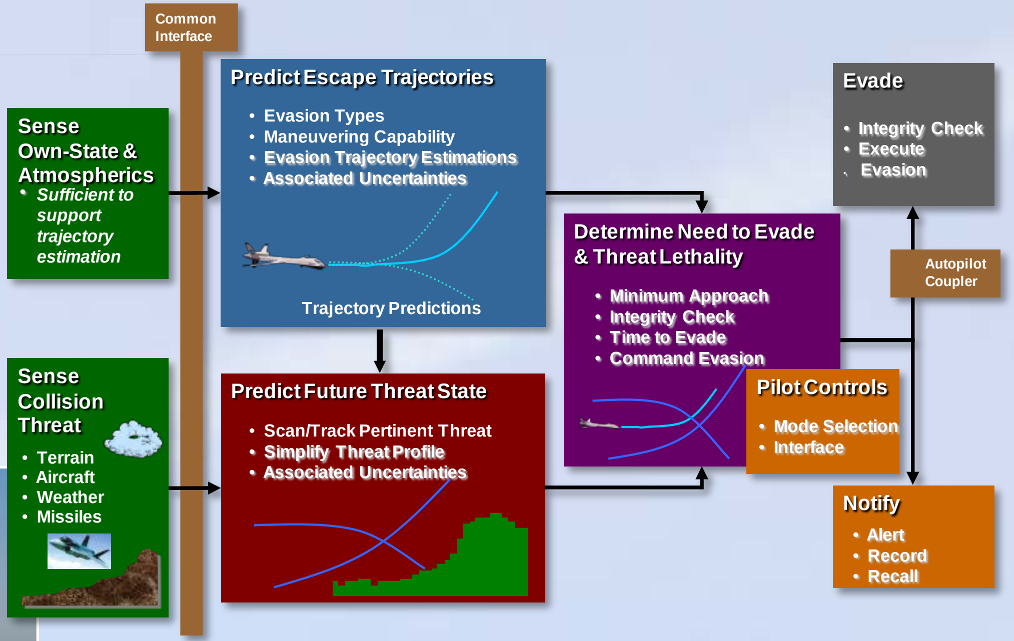
PLATFORM DIVERSITY

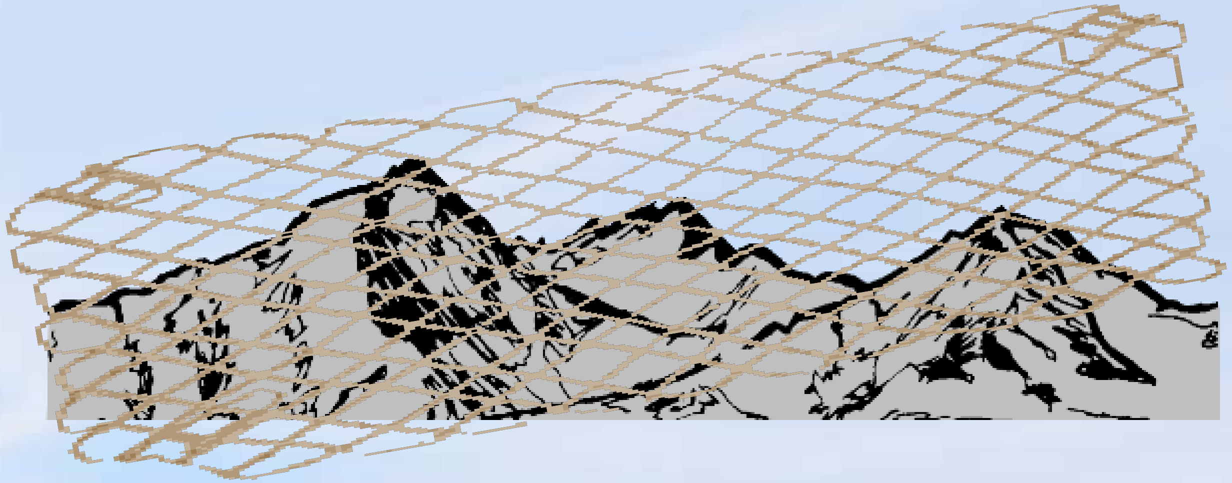
The Challenge of Autonomy

- Verification and certification of a complex system
- Possible solution: run-time assurance (RTA)



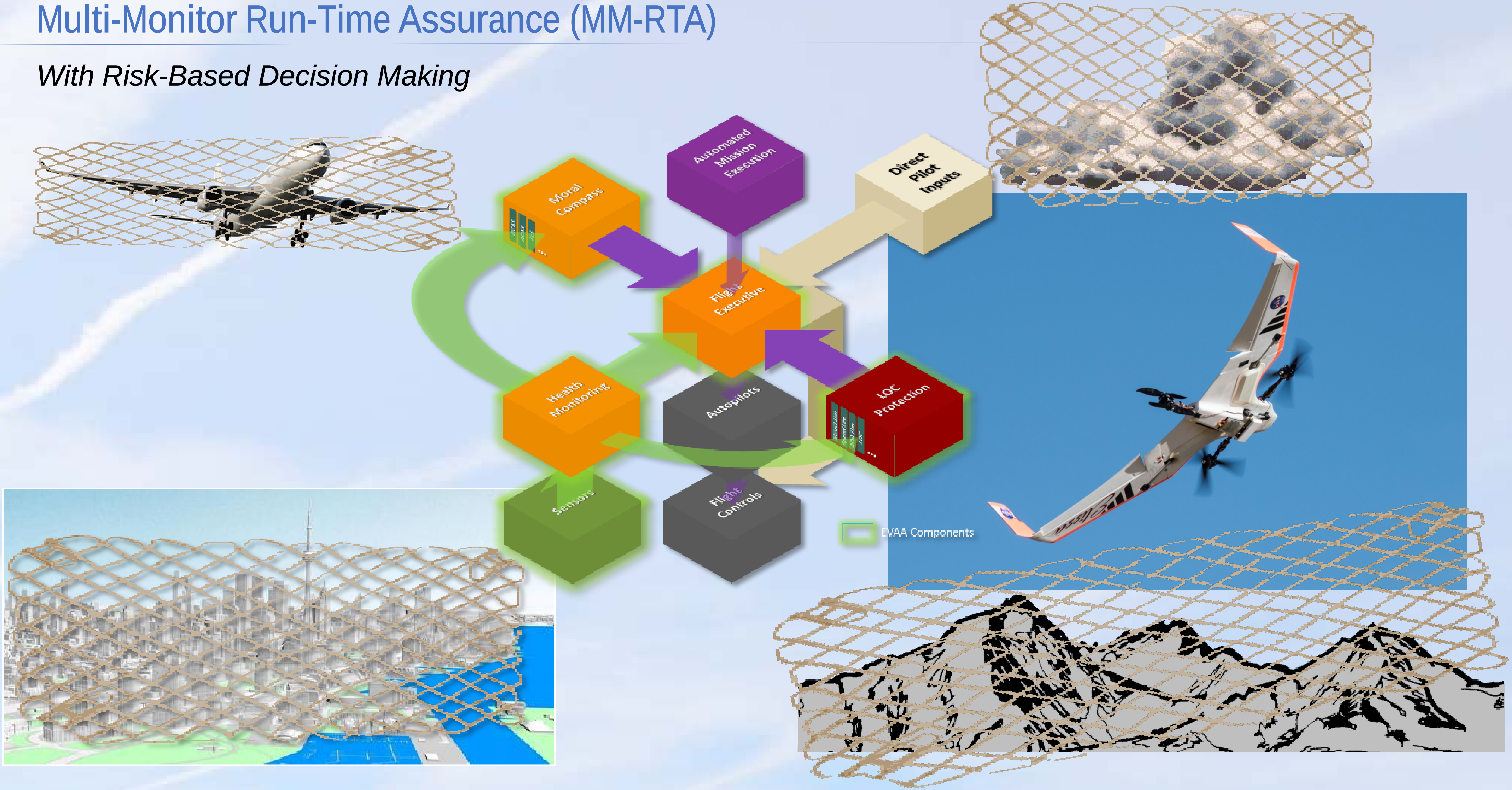
Safety Systems





Multi-Monitor Run-Time Assurance (MM-RTA)

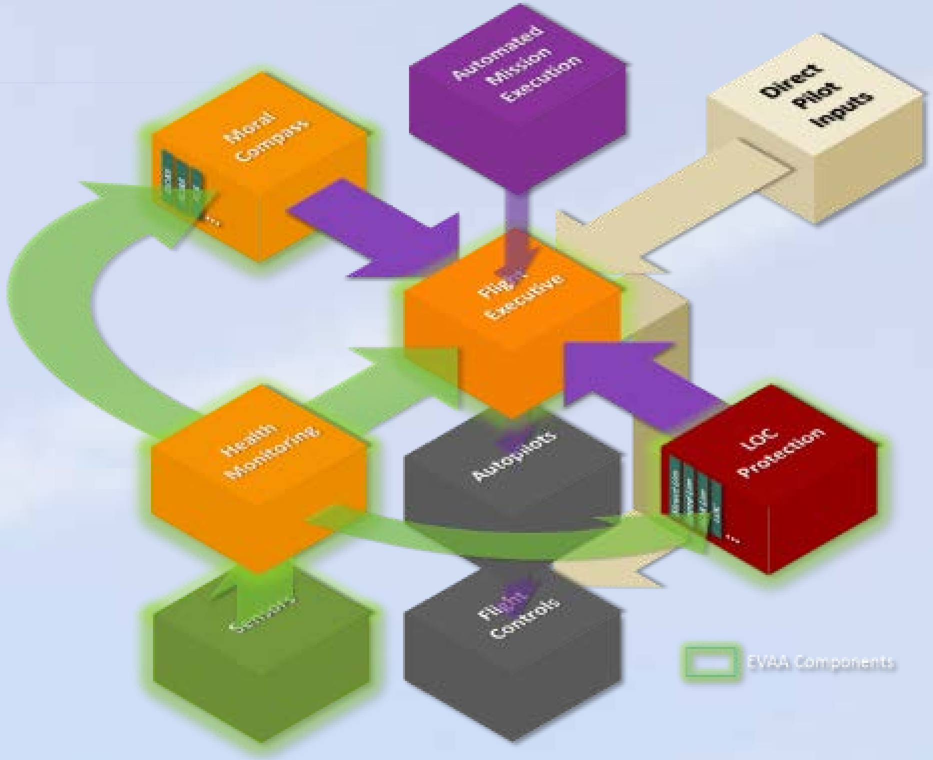
With Risk-Based Decision Making



Multi-Monitor Run-Time Assurance (MM-RTA)

Research Goal: Develop a methodology for certifying unmanned and autonomous systems using software architecture testbeds

- Use research findings to **inform standards** and best practices which will accelerate the certification of autonomous systems
- **MM-RTA** research findings using Low-Altitude Small Unmanned Aircraft System Test Range (LASUTR) and Expandable Variable Autonomy Architecture (EVAA) realistic environment capabilities
- Develop a **methodology for generating the artifacts** necessary to develop an **an airworthiness case** for unmanned and autonomous systems



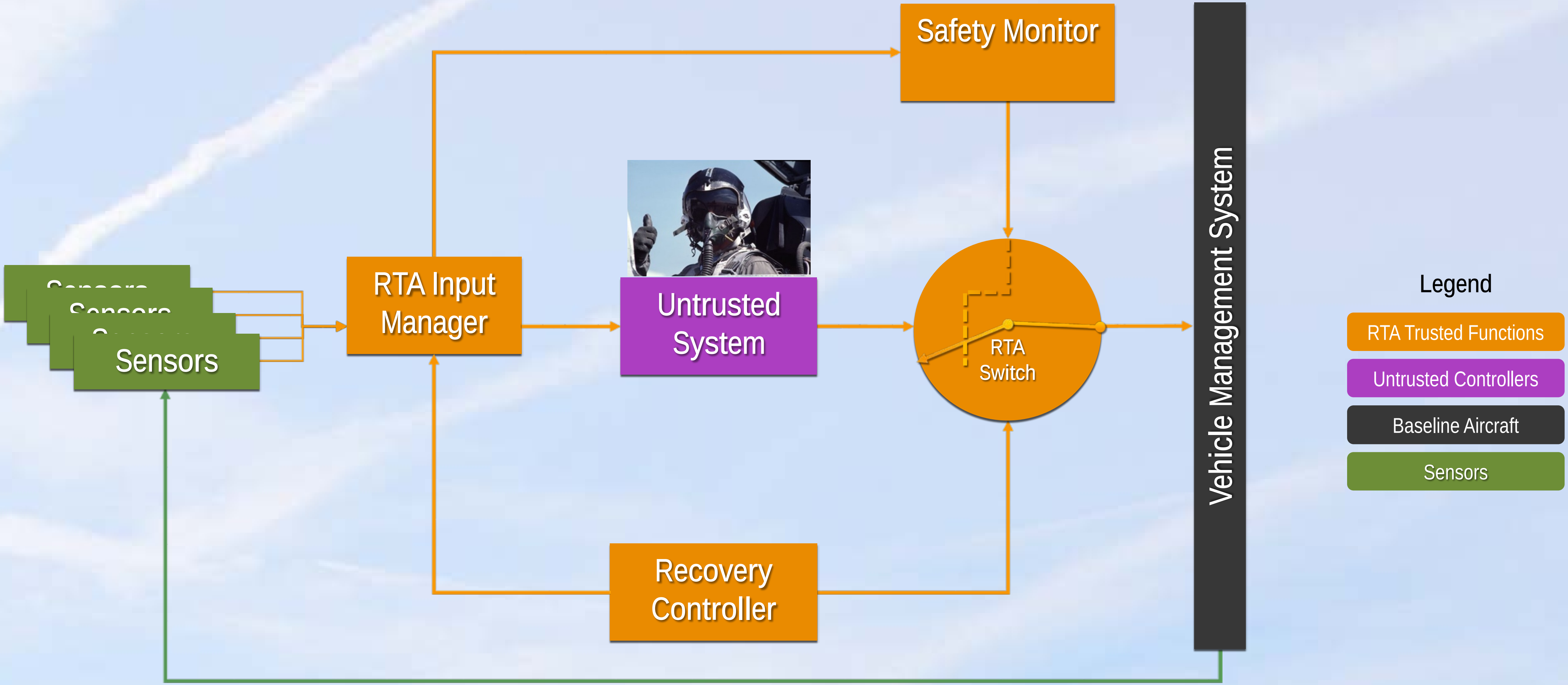
Informing Standards

Engaging the Standards Community

Research findings vetted with ASTM International through Working Group 53403 (WK53403)

- **WK53403 Goal:** Develop a standard practice that safely bounds the flight behavior of autonomous unmanned aircraft system (UAS)
- Involvement originated from NASA Armstrong collaboration with FAA regarding automated ground collision avoidance system (GCAS) and integrity management work on early autonomy concepts
- NASA Armstrong is collaborating with the FAA and ASTM by sharing research findings, techniques, best practices, and lessons learned throughout development of MM-RTA

Traditional RTA Framework



Informing Standards – Accomplishments

COMPLETE

FAA

- NASA Armstrong coordination of MM-RTA (Summer 2015)
- National workshop (November 2015)
- ASTM request (December 2015)
- Initiation of research toward a Part 23 rewrite (May 2016)

Joint Review

- Traveler Phase 1 testing (June 2017)
- NASA Armstrong gap feedback to ASTM (June 2017)

ASTM

- WK53403 established (February 2016)
- Draft standard practice complete (November 2016)

PLANNED

- Published standard practice (Summer 2017)
- NASA white paper augmenting standard practice (Summer 2017)

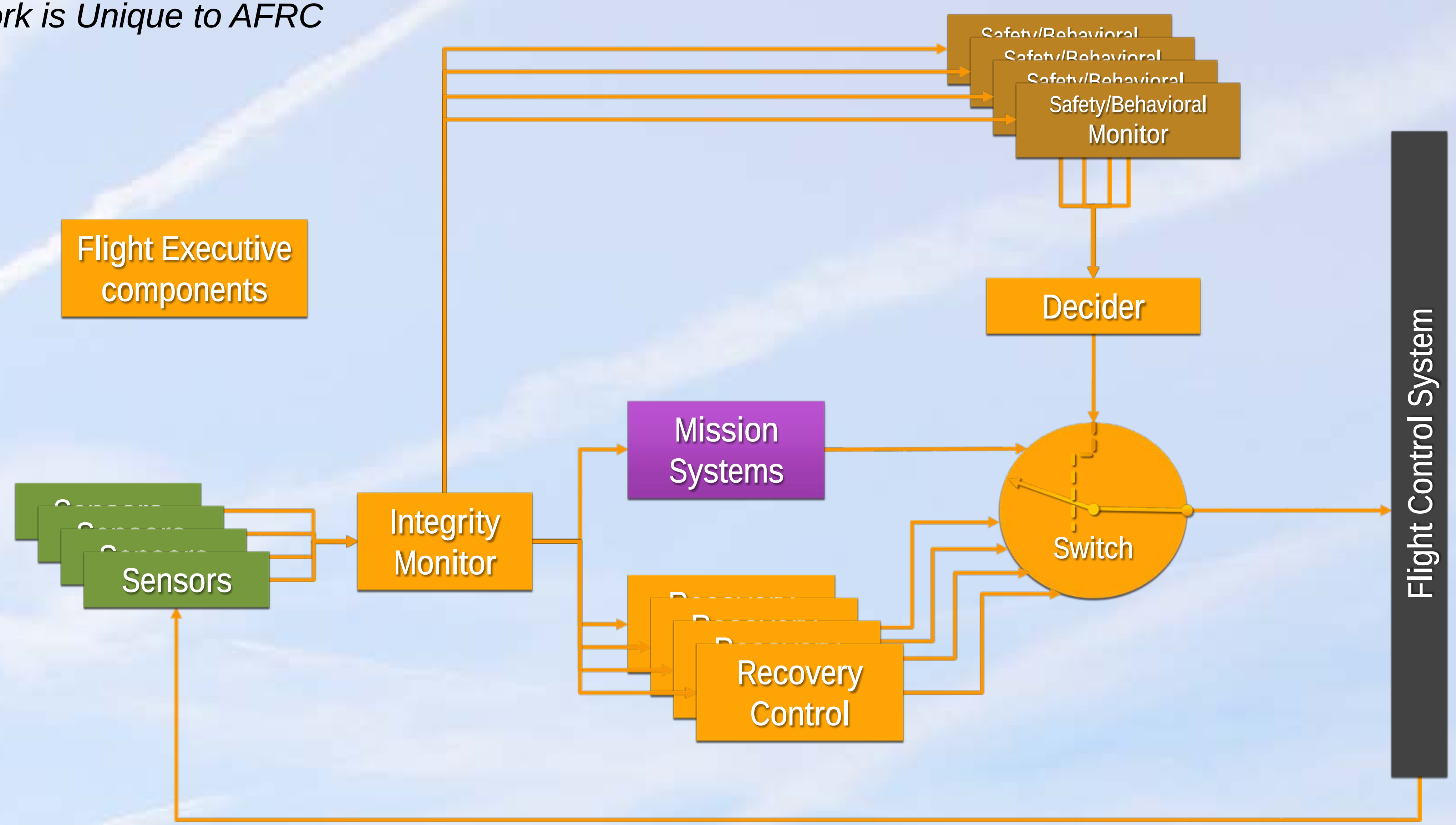
Use of NASA Armstrong MM-RTA and Enhanced Standard

- Industry package delivery use (starting in Spring 2017)

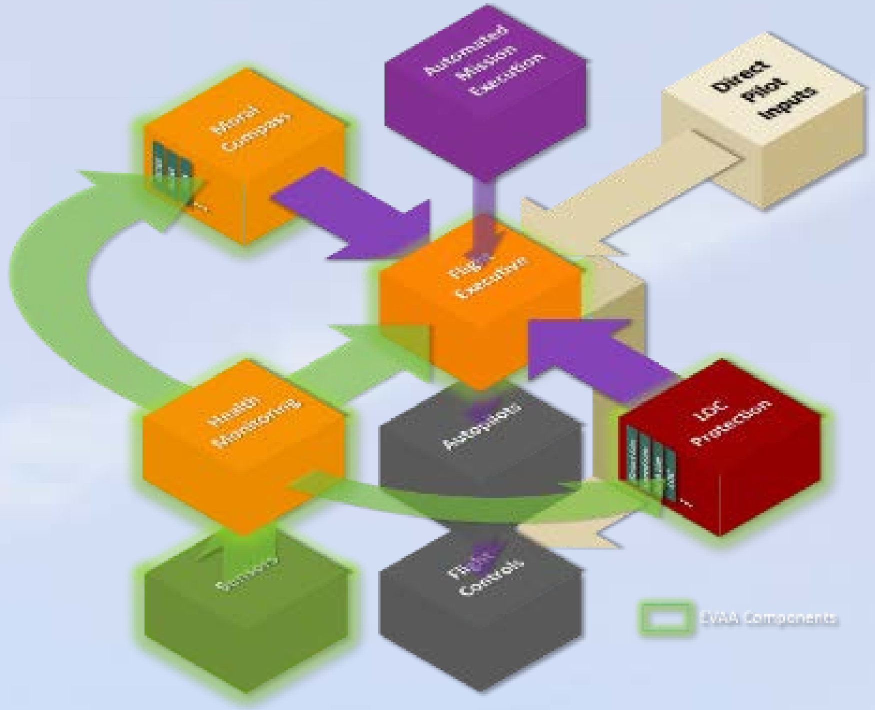
Multi-Monitor Run-Time Assurance

MM-RTA Framework

This Work is Unique to AFRC



Expandable Variable Autonomy Architecture (EVAA)



Software Research Testbed for MM-RTA

- Modular software architecture
- Add and replace software components as needed for developing research findings in a relevant environment

RTA Switch and Decider

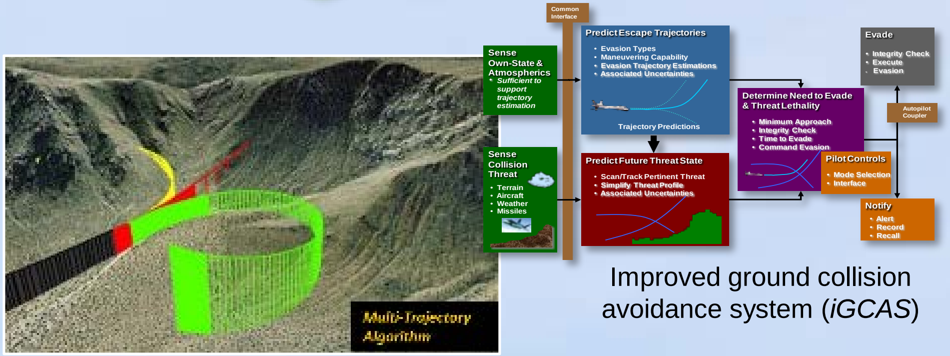
- Selects what function should be controlling the aircraft at any instance in time
- Risk-based decision making

Monitors

- Ground collision avoidance with obstacle awareness
- GeoFence – precisely staying within approved airspace
- Forced landing system – contingency management mitigating the consequences of the aircraft's actions
- Social interface functions – autonomy expressing Intent

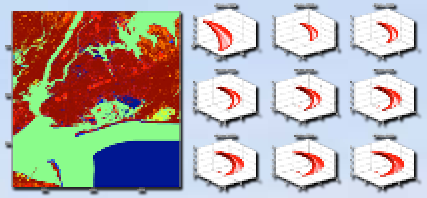
Controllers

- Conventional autopilot functions available on most aircraft and all UAVs



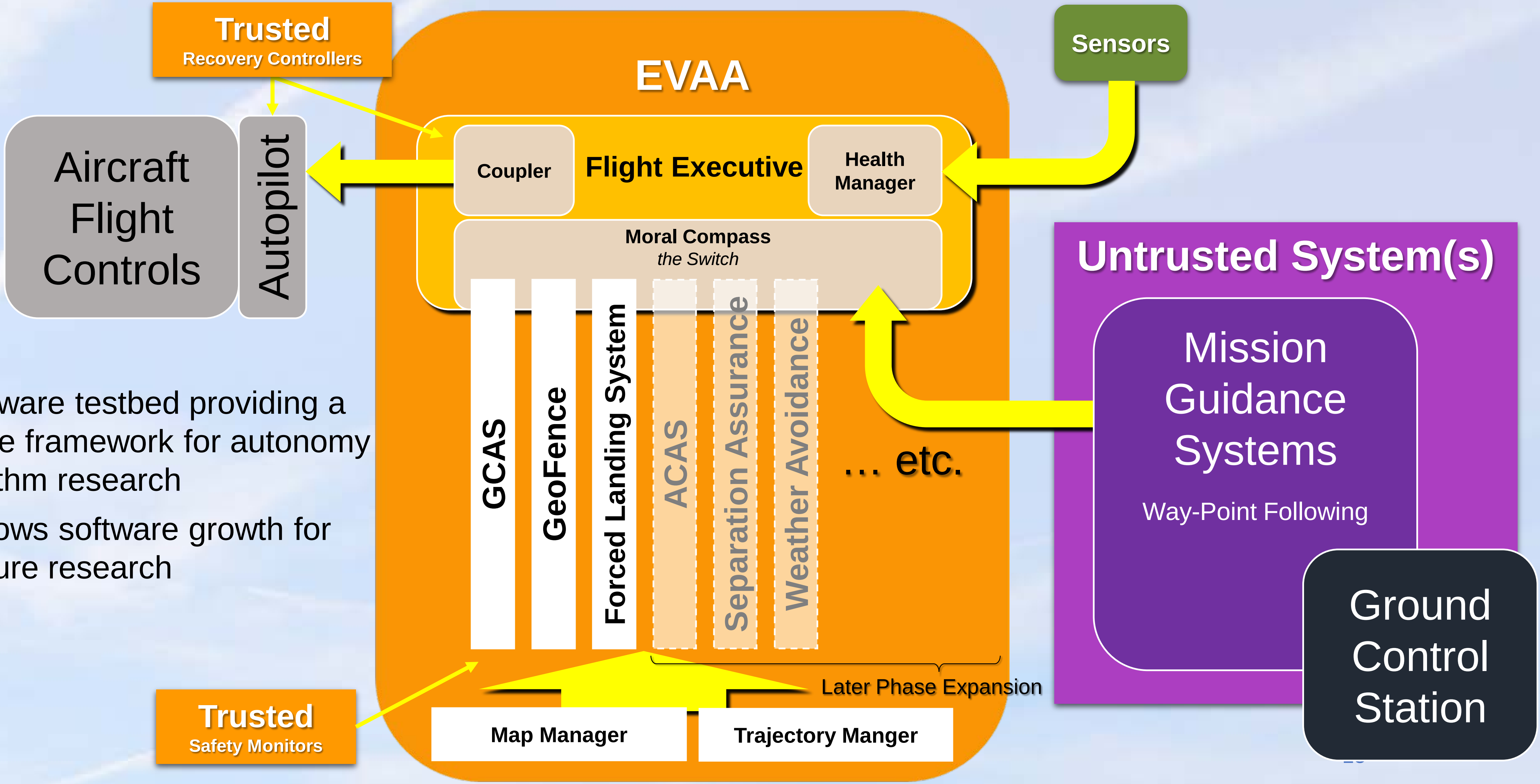
Improved ground collision avoidance system (*iGCAS*)

Brown text: Standard RTA components
Black text: Unique research components



Forced landing system

Expandable Part of EVAA

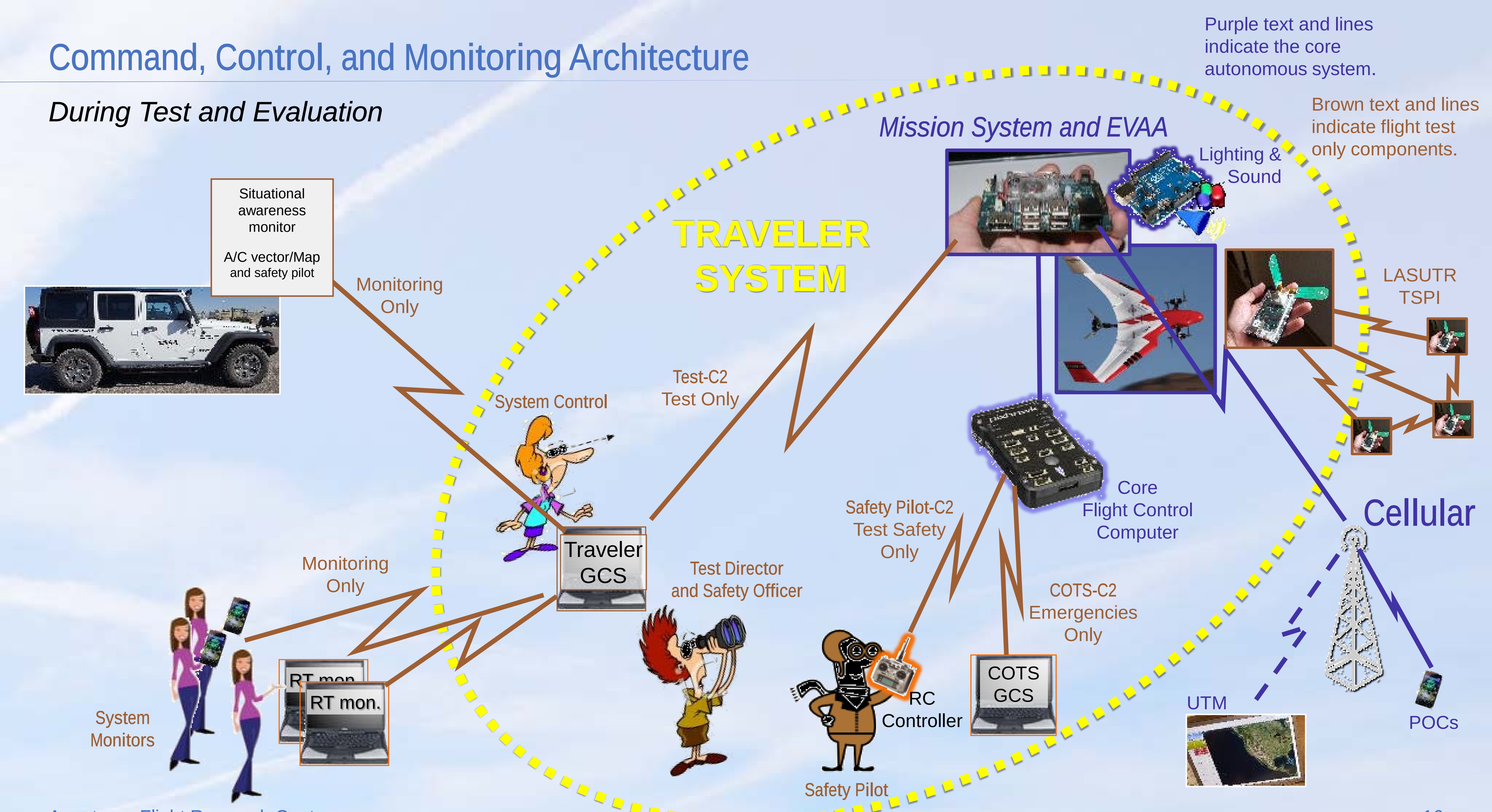


A software testbed providing a flexible framework for autonomy algorithm research

- Allows software growth for future research

Command, Control, and Monitoring Architecture

During Test and Evaluation



MM-RTA: Key EVAA Accomplishments

Aircraft/Testbed Modifications

- Research processor integrated January 17
- Sound and lighting system installed May 17

Research System

- Functional requirements completed November 16
- Design completed February 17
- Coding completed March 17
- Patent for GCAS monitor issued May 17

V&V

- Hardware in the loop sim completed Mar 17
- Integrated V&V completed May 17

Flight Test

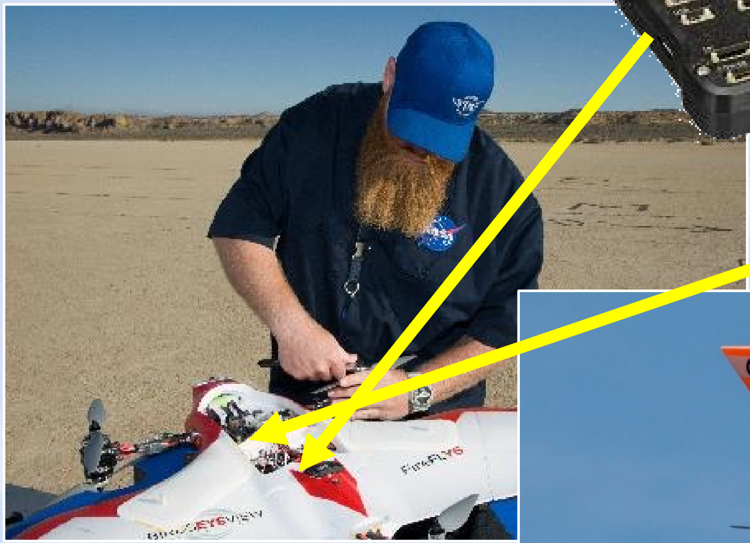
- Aircraft characterization test completed March 17
- EVAA flight test began May 17

Reporting

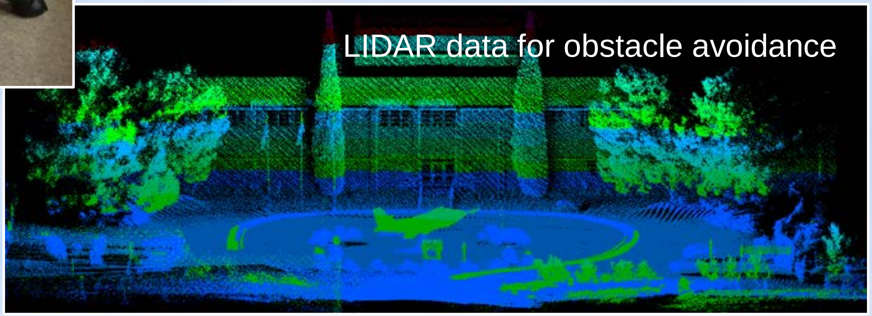
- Update to FAA and ASTM May 17


Flight Controls


Research Processor




Development Environment HITLS

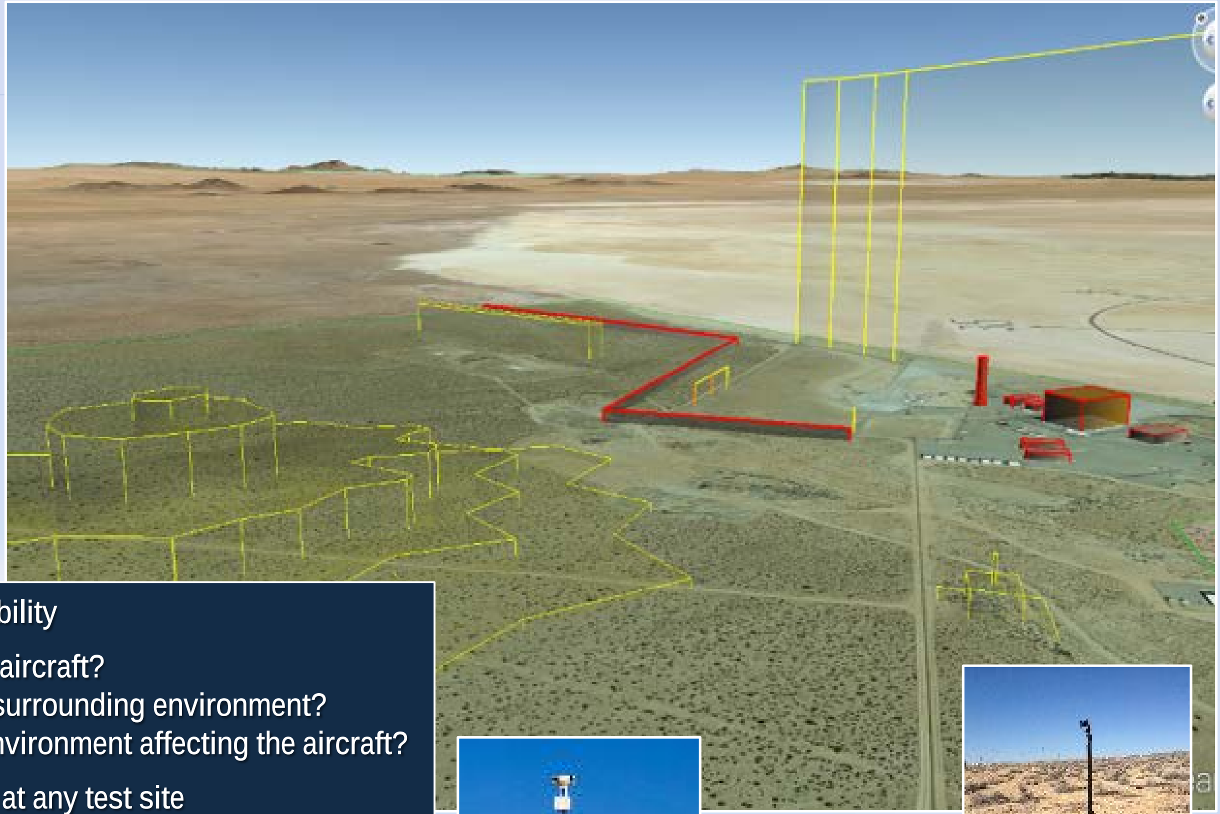


Generating Artifacts for Airworthiness

What is LASUTR?

What is LASUTR?

- A variety of environmental settings
  - **Buildings:** Large to small
  - **Obstacles:** Cell-tower, power lines, etc.
  - **Routes for flight/mission conduct:** Up to 25-mile loop
  - **Terrain variations**
    - Smooth, hills, mountains
    - 2,000 to 14,000 mean sea level (MSL) elevations
  - **Access:** Most assets are within a few 100 yards of office space
- Validated range instrumentation
  - **Tracking:** A validated independent position truth source with centimeter accuracy
  - **Weather:** Localized measurements
  - **Ground/obstacle mapping:** A validated dataset
  - Video documentation
  - Time-correlated



Vehicle controllability

1. Where is the aircraft?
2. Where is its surrounding environment?
3. How is the environment affecting the aircraft?

Easily replicated at any test site

1. No in-the-ground infrastructure
2. Solar/battery powered
3. Affordable

Tracking instrumentation

Ground mapping LIDAR

Long-range optics

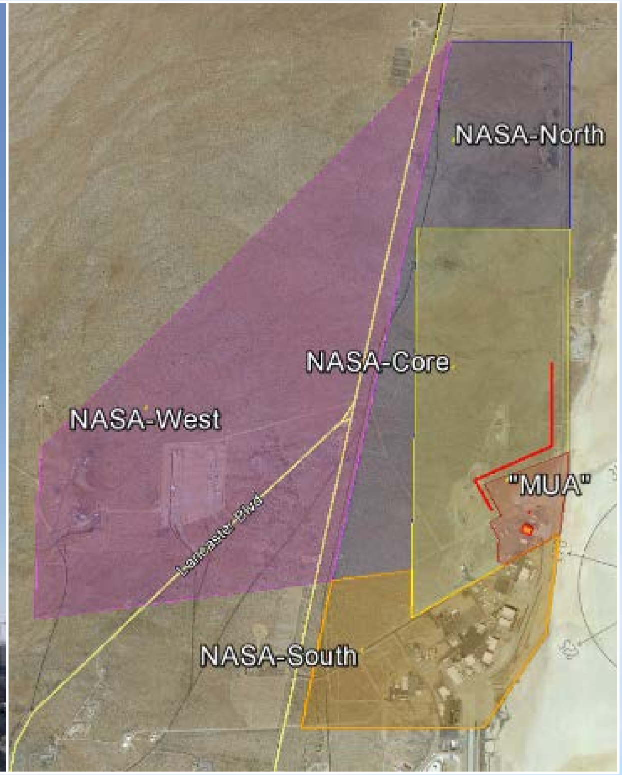
Spot wind instrumentation

LASUTR Areas

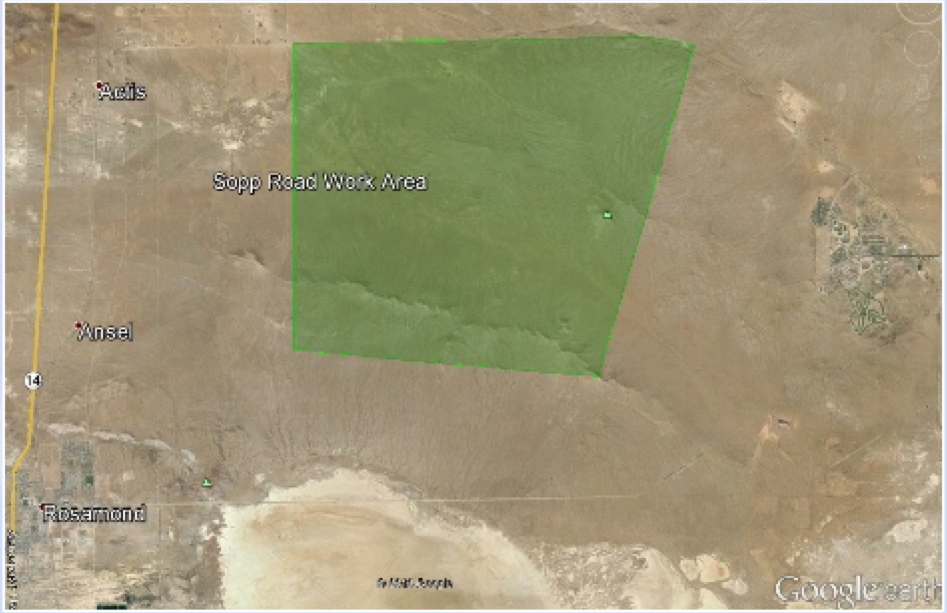
Three Areas

- North of NASA Armstrong (3.3 square miles)
- Northwest corner of Edwards Air Force Base (25 square miles)
- 10 miles east of Big Pine (50 square miles)

Forbes Areas



Sopp Road Area



Coyote Flats Area

Range Instrumentation

TSPI – Independent position data

Time-space positioning information (TSPI)

- Truth source for aircraft position
- < ½-pound add-on to aircraft
- Anticipated centimeter (cm) accuracy

Ground mapping Light Detection and Ranging (LIDAR)

- Geo-referenced truth for ground obstacles
- Anticipated cm accuracy

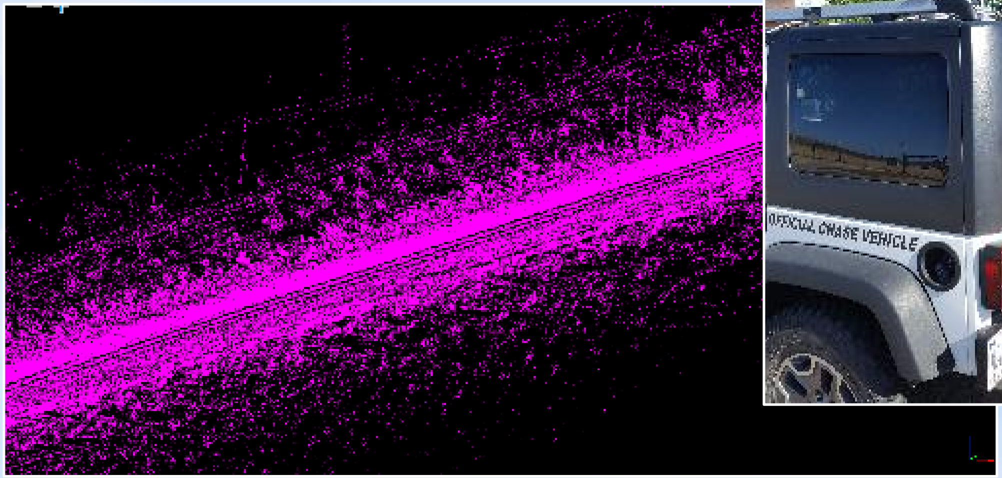
Long range optics tracking video

- Image-track
- Accuracy +/- 4 inches at 2,000 feet

Long-range optics (LRO)

Spot winds and video

Time-correlated



Geo-referenced ground mapping LIDAR data

Generating Artifacts – Accomplishments

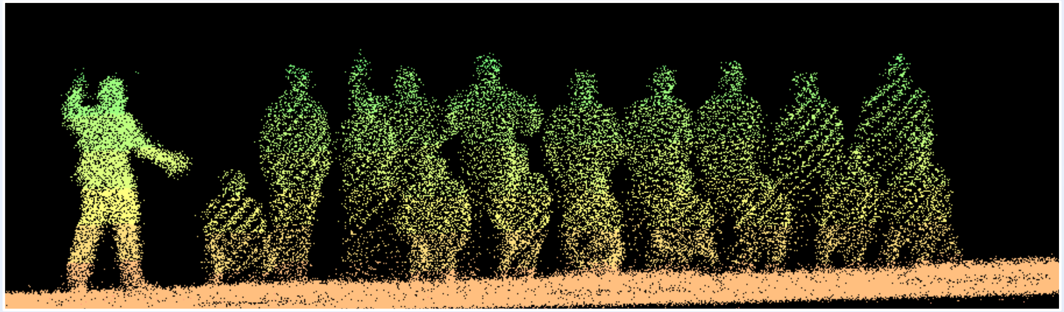
COMPLETE

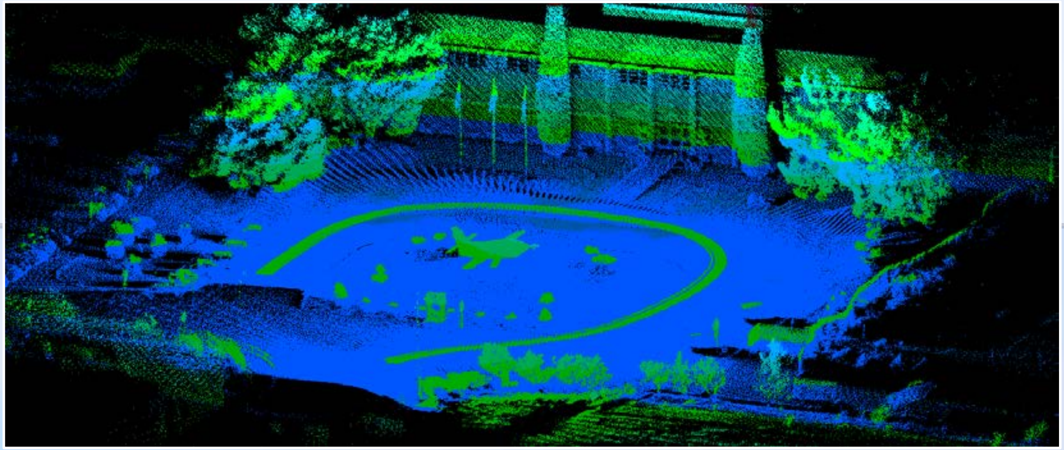
Flight Ranges

- Forbes range established and being used: Test obstacles ready for testing
- Sopp Road range established: Modest terrain variations ready for testing
- Coyote Flats test range established and being used: High-altitude testing and extreme terrain and foliage

Range Instrumentation

- Independent TSPI: Developed and functioning
- Ground mapping LIDAR for obstacle/feature data: Developed and functioning
- Spot weather instrumentation: Developed and functioning
- Long range tracking optics: Developed





Conclusion

Linkages to National Research Council (NRC) Autonomy Barriers

Autonomy Barriers	Traveler Response
Communications and data acquisition	Indirectly addressed
Cyber-physical security	Addressed
Decision making by adaptive/nondeterministic systems	Addressed
Diversity of aircraft	Addressed
Human-machine interface	Addressed
Sensing, perception and cognition	Partially addressed
System complexity and resilience	Addressed at vehicle level
Verification and validation	Addressed
Airspace access for unmanned aircraft	Indirectly and partially addressed
Certification process	Offers an approach
Equivalent level of safety	Addressed
Trust in adaptive/nondeterministic systems	Addressed
Legal issues	Partially addressed
Social issues	Partially addressed

Discussion

NASA

ASTM INTERNATIONAL
Standards Worldwide

FEDERAL AVIATION ADMINISTRATION

NASA