Trustworthy Autonomy Development and Flight Demonstration

Multi-Monitor Run Time Assurance Research Update

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Summary Description

Trustworthy Autonomy Development and Flight Demonstration

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

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<tr>
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<tbody>
<tr>
<td>Automated Maneuvering Attack System (AMAS)</td>
<td><strong>Automation Research</strong></td>
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<tr>
<td>AFTI and Automated Collision Avoidance Technology (ACAT)/F-16</td>
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<tr>
<td>Small Unmanned Air Vehicle (sUAV)/Improved Ground Collision Avoidance System (iGCAS)/SR22</td>
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**DEDICATED SAFETY WORK**

- **Ground**
- **AIR**
- **Integrated**

**PLATFORM DIVERSITY**

- sUAS
- General Aviation
- Quad-rotor

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The Challenge of Autonomy

- Verification and certification of a complex system
- Possible solution: run-time assurance (RTA)
Multi-Monitor Run-Time Assurance (MM-RTA)

With Risk-Based Decision Making
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 **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
## Informing Standards – Accomplishments

### 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)
- 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

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

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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

Mission System and EVAA

TRAVELER SYSTEM

Test-C2
Test Only

Safety Pilot-C2
Emergencies Only

COTS-C2
COTS Only

Lighting & Sound

LASUTR
TSPI

Cellular

POCs

Core Flight Control Computer

System Control

Test Director

Safety Pilot

RC Controller

GCS

A/C vector/Map

Situational awareness monitor

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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

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Generating Artifacts for Airworthiness
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**
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)
Range Instrumentation

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

Spot winds and video

Time-correlated

Geo-referenced ground mapping LIDAR data

TSPI – Independent position data
Generating Artifacts – Accomplishments

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

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