Traveler
Trustworthy Autonomy

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Research Timeline

- **1980**: Automated Maneuvering Attack System (AMAS)
  - AFTI/F-16
    - Advanced Fighter Technology Integration
  - AFTI & ACAT/F-16
    - Automated Collision Avoidance Technology

- **2000**: Automated Collision Avoidance
  - Air
  - Integrated

- **2010**: Ground Collision Avoidance
  - Small UAS
  - GA
  - Quad-Rotor

- **2016**: Dedicated Safety Work
  - Platform Diversity

**SUAV/iGCAS/SR22**
- Improved Collision Avoidance System

**NASA**
Avoid Collisions
Do Not Impede the Pilot
Flight 18 event 6, 45 kts, 100' buffer
SR22 Hardware in the Loop Sim
The Challenge of Autonomy

• Verification & Certification of a Complex System
• A Possible Solution – Run-Time Assurance (RTA)
Safety Systems

- Predict Escape Trajectories
- Predict Future Threat State
- Determine Need to Evade & Threat Lethality
- Evade
- Notify

- Evasion Types
- Maneuvering Capability
- Evasion Trajectory Estimations
- Associated Uncertainties

- Evasion Trajectory Estimations
- Associated Uncertainties

- Scan/Track Pertinent Threat
- Simplify Threat Profile
- Associated Uncertainties

- Minimum Approach
- Integrity Check
- Time to Evade
- Command Evasion

- Intactness Check
- Execute Evasion

- Alert
- Record
- Recall

- Sense Own-State & Atmospherics
  - Sufficient to support trajectory estimation

- Sense Collision Threat
  - Terrain
  - Aircraft
  - Weather
  - Missiles

- Common Interface
- Autopilot Coupler

- Pilot Controls
  - Mode Selection
  - Interface
Multi-Monitor RTA
FAA/ASTM Collaboration

• ASTM Committee WK53403
  • Develop a standard practice that safely bounds the flight behavior of autonomous UAS.
  • Originated from our collaboration with them regarding Auto GCAS and integrity management work on early autonomy concepts
  • FAA has asked up to support the ASTM by sharing our techniques, practices and lessons learned as we develop EVAA

• Dec 16 Draft for Public Review
• Feb 17 Published
Multi-Monitor RTA Framework
Multi-Monitor RTA Framework

UNTRUSTED Systems

Sensors

Integrity Monitor

Recovery Control

Switch

Decider

SP Monitor

Flight Control System

SP Eyes

SP Controller
Behavioral Control Level
- Controllers
  - Avoidance Maneuvers
    - Rate/Att. Capture
    - Waypoint Following
    - Altitude Capture
  - Aircraft Lighting

Mission Interoperability Control Level
- Controllers
  - ATC
  - UTM

Aviate Control Level
- Controllers
  - Avoidance Maneuvers
    - Rate/Att. Capture
    - Waypoint Following
    - Altitude Capture

Emergency / Degraded Control Level
- Controllers
  - Forced Landing
    - Where to Land
  - LoC Prevention
  - LoC Recovery

Outer-Loop Control Level
- Controllers
  - Pitch Autopilot
  - Roll Autopilot
  - Speed Autopilot

Inner-Loop Control Level
- Controllers
  - Stability & Control
  - Structural Limiting
  - Envelope Protection

Communicate
- Controllers
  - ATC
  - UTM

Monitors
- Well Clear
  - Rules of flight

Aviate & Navigate
- Monitors
  - Communications

Monitors
- Collision Avoidance
  - Ground
  - Obstacle
  - Air Traffic
  - People & Property
  - Weather Avoidance
  - Person Avoidance
  - Population Avoidance

Monitors
- LOC
- Power Plant

Monitors
- OLIV
  - A/C State
  - Dynamic Consistency
  - Is this OLIV?

Monitors
- Sensors
  - Air Data
  - Accelerometers
  - Gyros
  - Angle of Attack
  - Sideslip
  - FCS
    - Watchdog Timer
    - Output Crosscheck
    - Control Surfaces

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Still in Work
Interlinked RTA Control Framework

Mission Interoperability

Behavioral

Aviate

Outer Loop

Inner Loop

Emergency / Degraded
I'm thinking the behavioral level is a lesser set of the aviate
Multi-Monitor/Multi-Layered Comprehensive RTA

Phase 1 – All data base driven

Communicate
Mission Interoperability Control Level
- Emergency Procedures
- ATC
- UTM
- Squad/Flight

Aviate & Navigate
Aviate Control Level
- Decider
- Higher-Order Mission Guidance
  - Collision Avoidance
    - Ground
    - Obstacle
  - Atmo
  - People
  - Property
- Weather Avoidance
- Population Avoidance

Emergency / Degraded Control Level
- Decider
- Forced Landing
- Where to Land
- LoC Prevention
- LoC Recovery

Thrust
- Controllers – Surfaces, Power-Plant & Thrust Vectoring
  - Structural Limit
  - Regression Modes
  - Stability & Control

Link
Communications

Behavioral Control Level
- Avoidance Maneuvers
- Lighting

Airspace Boundaries
- Well Clear
  - Well CtrlSep, Asmc.
  - Rules of Flight
- Personal Space
- Privacy Rights
- Property Rights

I'm thinking the behavioral level is a lesser set of the aviate.
The Big Picture - Traveler

Trustworthy Autonomy

Certification
- Developing research findings to inform standards development for certifiable autonomy
- Collaborating with ASTM Working Group on autonomy certification guidelines
- FAA Collaboration and Interest

Expandable Variable-Autonomy Architecture (EVAA)
- Stretching the paradigm of autonomy
  - Determinist Rulesets Bounding Autonomous Behavior
  - Risk-Based Decision Making
- A process enabling certification
  - Software Architecture/Framework
  - Test Approach
- Scalable autonomy
  - Pilot-in-the-Loop to “Fully Autonomous”

Low Altitude Small UAS Test Ranges (LASUTR)
- A tool for certification
- High-risk integrated research
Expandable Variable Autonomy Architecture (EVAA)

- A Software Framework
  - A Federated Architecture
    - Safety Systems
    - 1
    - 2
    - 3...
    - Flight Executive
  - Software Structure & Techniques

- Classical & Non-Classical Verification Methods

- Safety Evaluation of the Technology
  - Targeted at Flight Demonstrations
  - Social Interaction
Armstrong’s Traveler Effort

• **Goal:** Trustworthy Autonomy
  - BVLOS to and from uncontrolled areas
  - 400 feet to Surface
  - Any Number of Aircraft per Operator

• **NASA Funded Effort**
  - Leverages a 30 year development of autonomy from DoD & NASA
  - TRL 3 to 5
  - Local Armstrong Directed Objectives
  - Supporting formulation of TACP Autonomous Systems start in 2018

• **Primarily Software Approach and Process Development**
  - Platform ~Agnostic
  - Mission ~Agnostic
  - Sensor ~Agnostic

• **Flight Development and Evaluation in Support of ASTM Regulatory Development**
  - Target Demos to Make an Airworthiness Case to
  - Possible High-Visibility Demo in Spring of 2017
  - Second Demo possible in 2018
How is LASUTR different from FAA Test Sites?

Agile/Flexible
• No COA allows for rapid changes based on evolving requirements

Interoperability
• Ability to test multiple aircraft/concept in an integrated manner

High-Risk Testing for New Concepts
• BVLOS
• Autonomy
• Night operations
• Controlled “risk” including controlled “crashes” without FAA accident notification requirements
LASUTR and FAA Test Site Collaboration Flow

- High-risk research conducted at LASUTR
- This generates research findings to help formulate testing requirements
- Research findings are shared with community of interest (FAA, Test Sites, industry, academia)
- FAA generates testing requirements for Test Sites (and other entities)
NASA South – Range for High-Risk Research

- **Terrain**
  - Flat
  - Virtual Cliff
  - Virtual Hill
  - 4 mile loop
    - Much longer at other LASUTR sites

- **Obstacles**
  - Cell Tower
  - Shuttle Hangar
  - Light Poles
  - Power Lines
  - Virtual High-Tension Power Line
  - Virtual Power Lines
  - Virtual Antenna with Guy Lines
  - Trees
Command, Control & Monitoring Architecture

During Test & Evaluation

Infotainment System
A/C vector / Map & LRO

Monitoring Only

System Control

Traveler GCS

Test-C2 Test Only

Safety Pilot-C2 Emergencies Only

COTS-C2 COTS GCS

Test Director & Safety Officer

RC Controller

Safety Pilot

Cellular

Blue text & lines indicate the core autonomous system.
Orange text & lines indicate flight test only components.

POCs

UTM

LASUTR TSPi

Lighting & Sound
Phase 1
Integrated Testing

Traveler System

A/C & Flight Control System
- WP Navigation
- Roll & Vz Capture
- Autopilots
- Core Flight Controls
- GPS/INS

Test Resources
- LASUTR
- Traveler GCS
- COTS GCS
- RT Monitors
- Chase Vehicle
- RC Controller
- CIT

EVAA
- Mission Manager
- Flight Executive
- Coupler
- Decider
- Health Monitor

Map Manager
- Terrain Map
- Feature Map
- Risk Map

Trajectory Generator
- AC1
- AC2
- ACn

Population Avoidance
- GCAS
- GeoFence

Mission System
- Route Follower
- Route Planner
- Terrain Following
- Ops Manager
- Social Interface

Flight Test
- FLS
- Flight Executive

Legend
- RTA Functions
- Untrusted Controllers
- Baseline Aircraft
- Sensors
EVAA Phase 2 Aircraft

• VTOL & Forward Flight Capable
• Payload Capacity for Sensors & EVAA
  • EVAA Processors, Wiring & Interfaces
    • 1 - oDroid XU4 0.16 lbs.
    • 2 – Adrino Processors
    • Speaker
    • Lights 0.35 lbs.
  • Sensors
    • 4 - Stereo-Vision Camera Pairs and Processors
    • ADS-B 0.07 lbs.
    • UTM Wireless Interface
    • Flight Test TSPI, etc. 0.57 lbs.
• 50 to 75 MPH Flight Speed
• 50 to 75 Mile Range
• Easy Break-Down & Assembly for Transportation to and from Test Sites
EVAA RTA Framework

Phase 1

RTA Framework

542 IP

542 Evaluates & Models Sensors

RTA Input Manager

Mission System

OLIV

FLS

GeoFence

GCAS Monitor

542 IP

542 Implements, Evaluates & Models Autopilot Recoveries

Vehicle Management System

542 IP

542 Airworthiness Certification

542 Systems Certification

542 Evaluates & Models Sensors