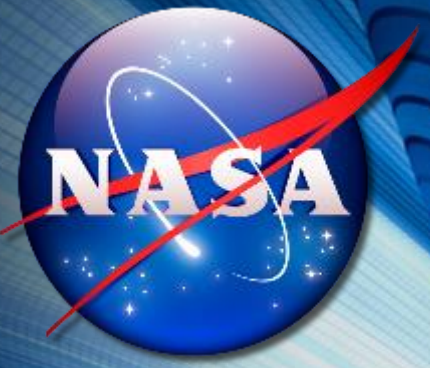


Trustworthy Autonomy Development & Flight Demonstration

Multi-Monitor Run Time Assurance Research Update

Mark Skoog
Armstrong Flight Research Center

Research Timeline

1980 2000 2010 2017

Automated Maneuvering Attack System (AMAS)

Automation Research

AFTI/F-16
Advanced Fighter Technology Integration

AFTI & ACAT/F-16
Automated Collision Avoidance Technology

Automated Collision Avoidance

Air

Ground

Integrated

Dedicated Safety Work for Fighters

Ground Collision Avoidance

Quad-Rotor *Transition*

GA

Small UAS

Platform Diversity

SUAV/iGCAS/SR22
Improved Collision Avoidance System

Ground Collision Avoidance System (GCAS)

Common Functional Architecture

Common Interface

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

Sense Collision Threat
- Terrain
- Aircraft
- Weather
- Missiles

Predict Escape Trajectories
- Evasion Types
- Maneuvering Capability
- Evasion Trajectory Estimations
- Associated Uncertainties

Trajectory Predictions

Predict Future Threat State
- Scan/Track Pertinent Threat
- Simplify Threat Profile
- Associated Uncertainties

Determine Need to Evade & Threat Lethality
- Minimum Approach
- Integrity Check
- Time to Evade
- Command Evasion

Pilot Controls
- Mode Selection
- Interface

Evade
- Integrity Check
- Execute
- Evasion

Autopilot Coupler

Notify
- Alert
- Record
- Recall

Avoid Collisions

Do Not Impede the Pilot

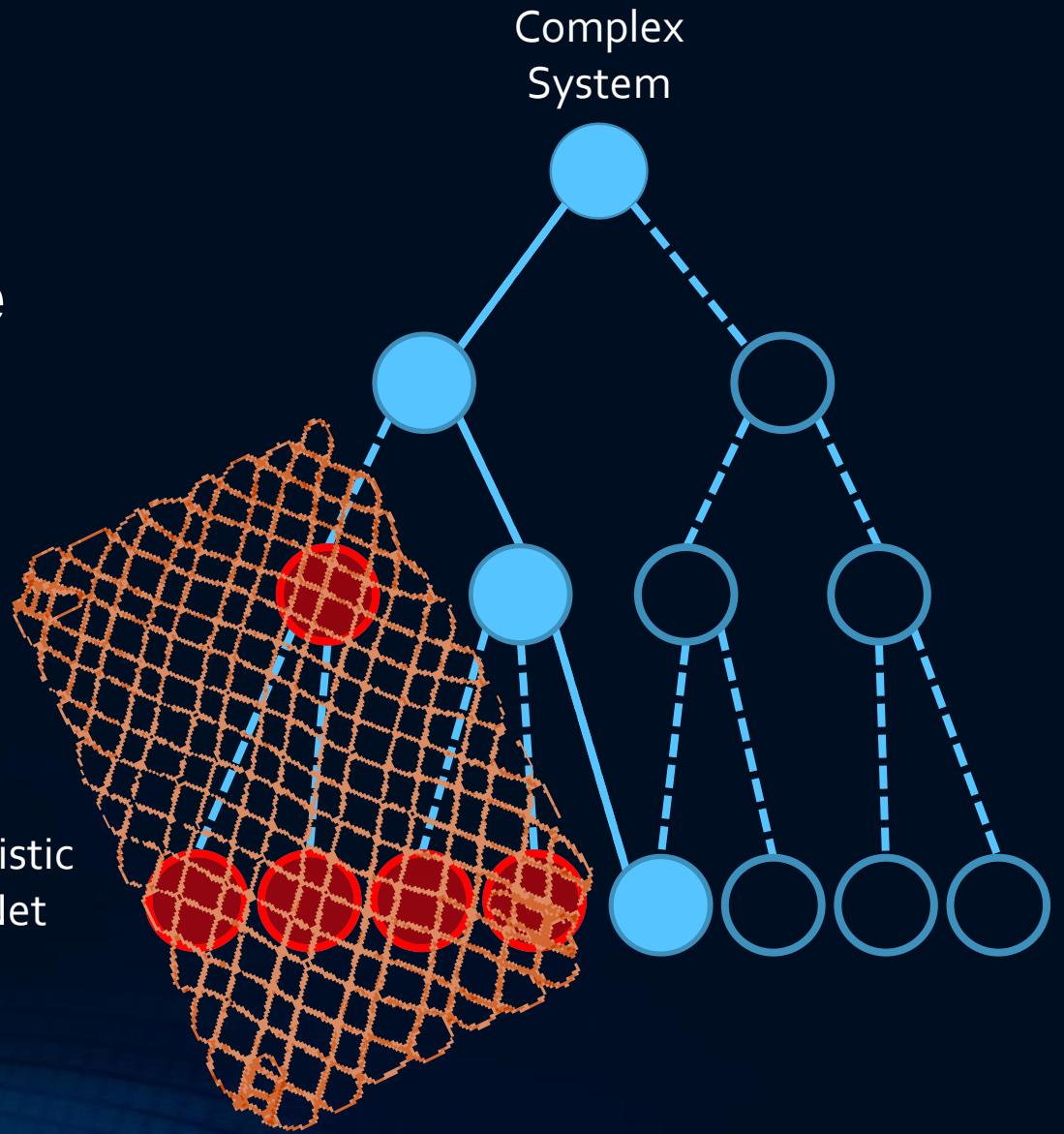
sUAV

Automatic Air Collision Avoidance System (Auto ACAS)

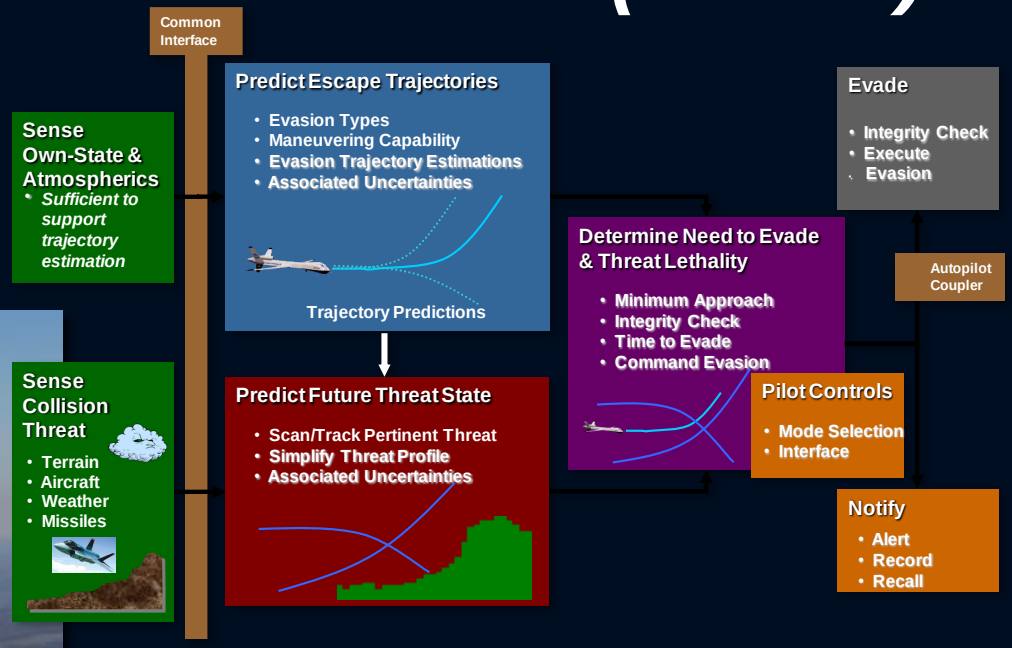
Automatic Integrated Collision Avoidance System (Auto ICAS) - Air & Ground Multi-Ship

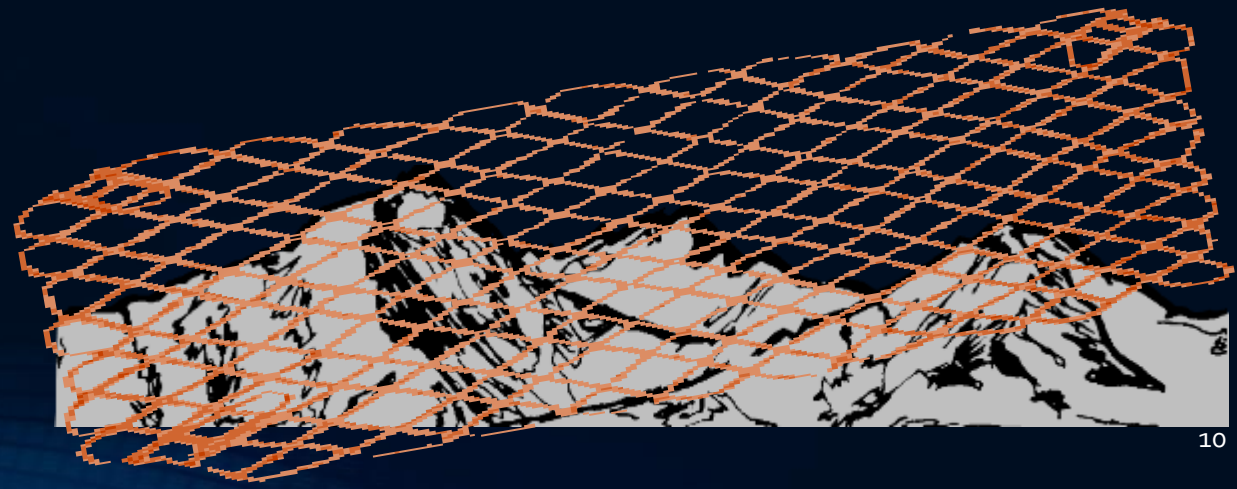
The Challenge of Autonomy

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

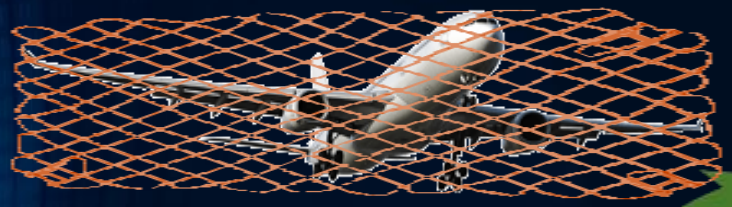


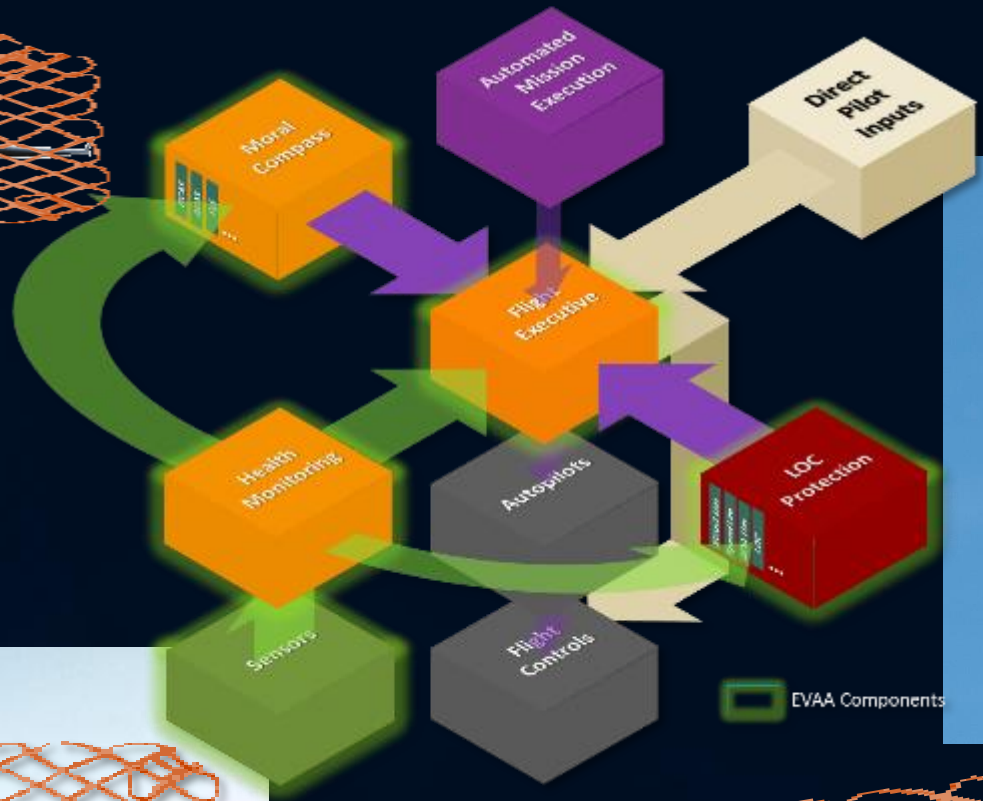
Ground Collision Avoidance System (GCAS)

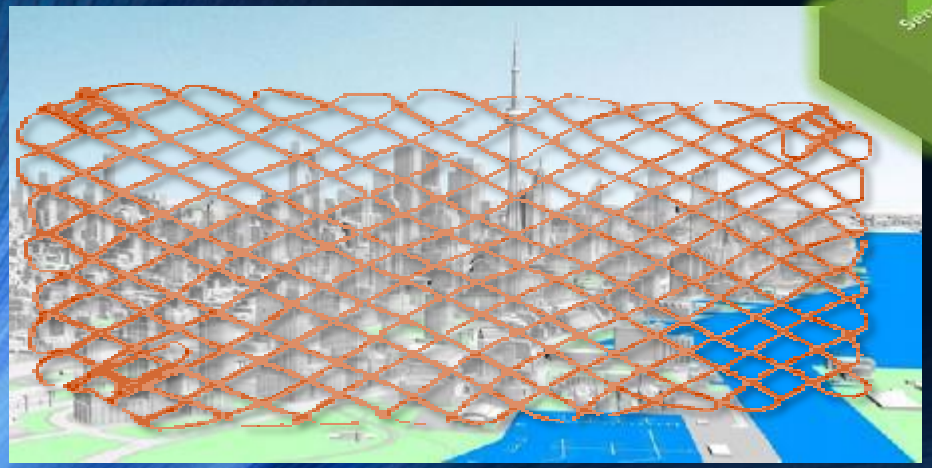


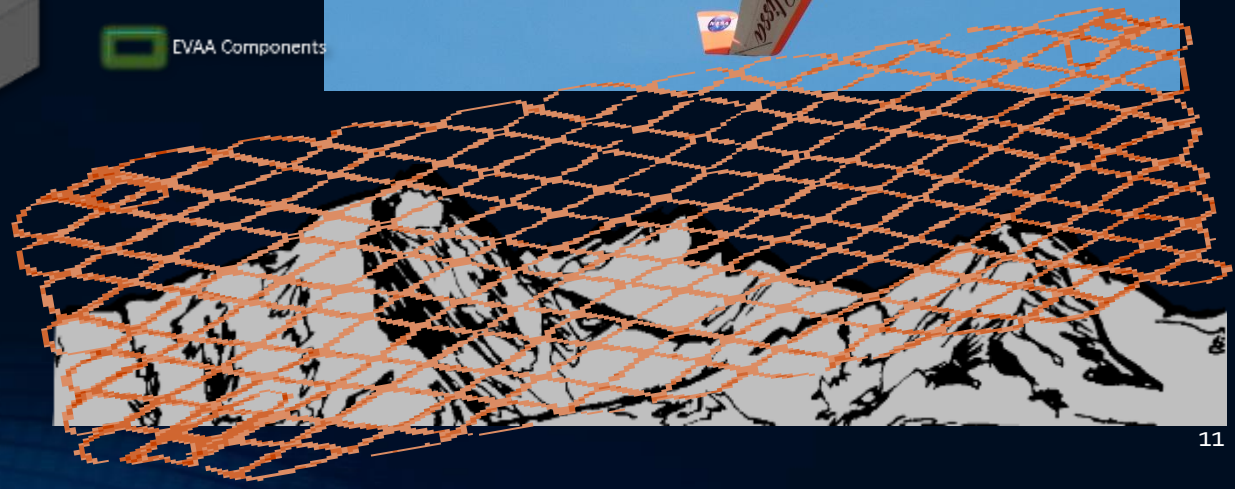


Multi-Monitor RTA (MM-RTA)
with Risk-Based Decision Making







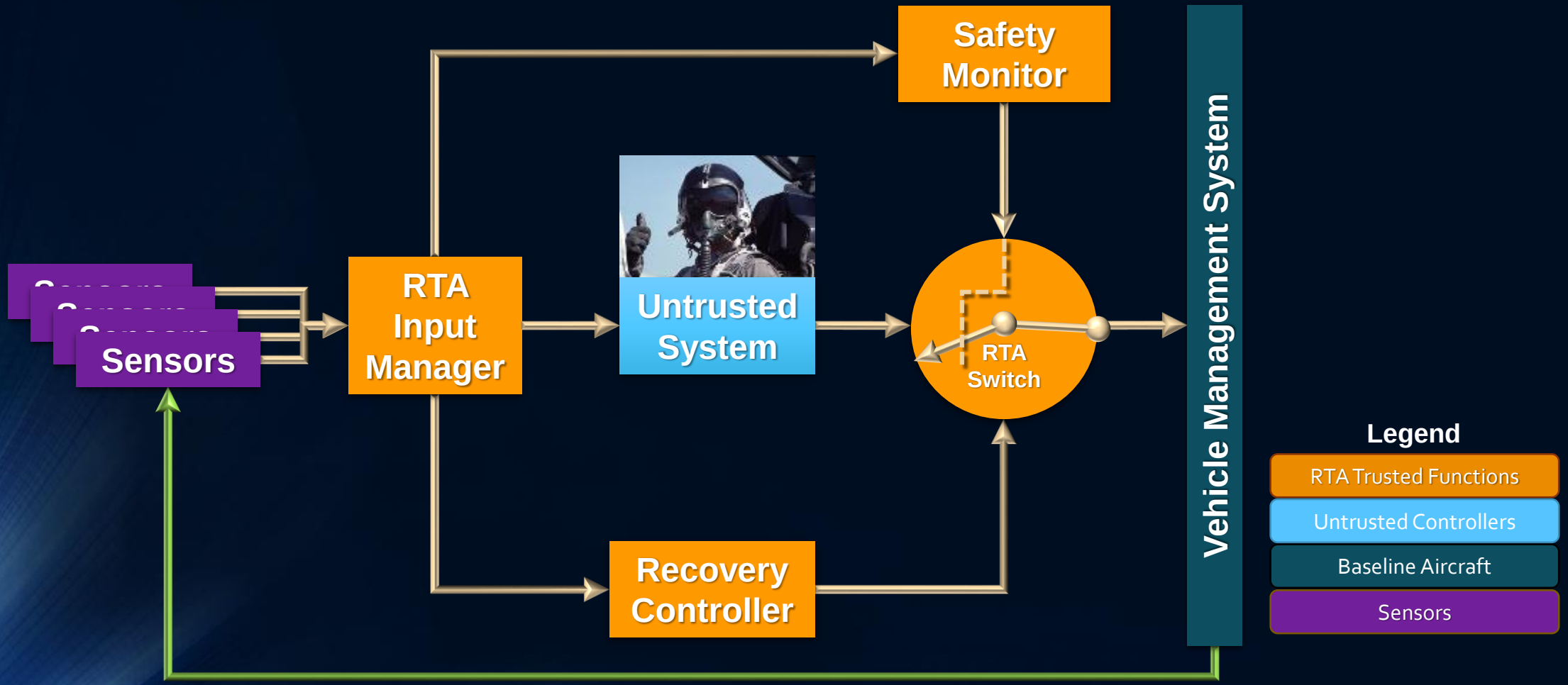


Informing the Standards Community

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

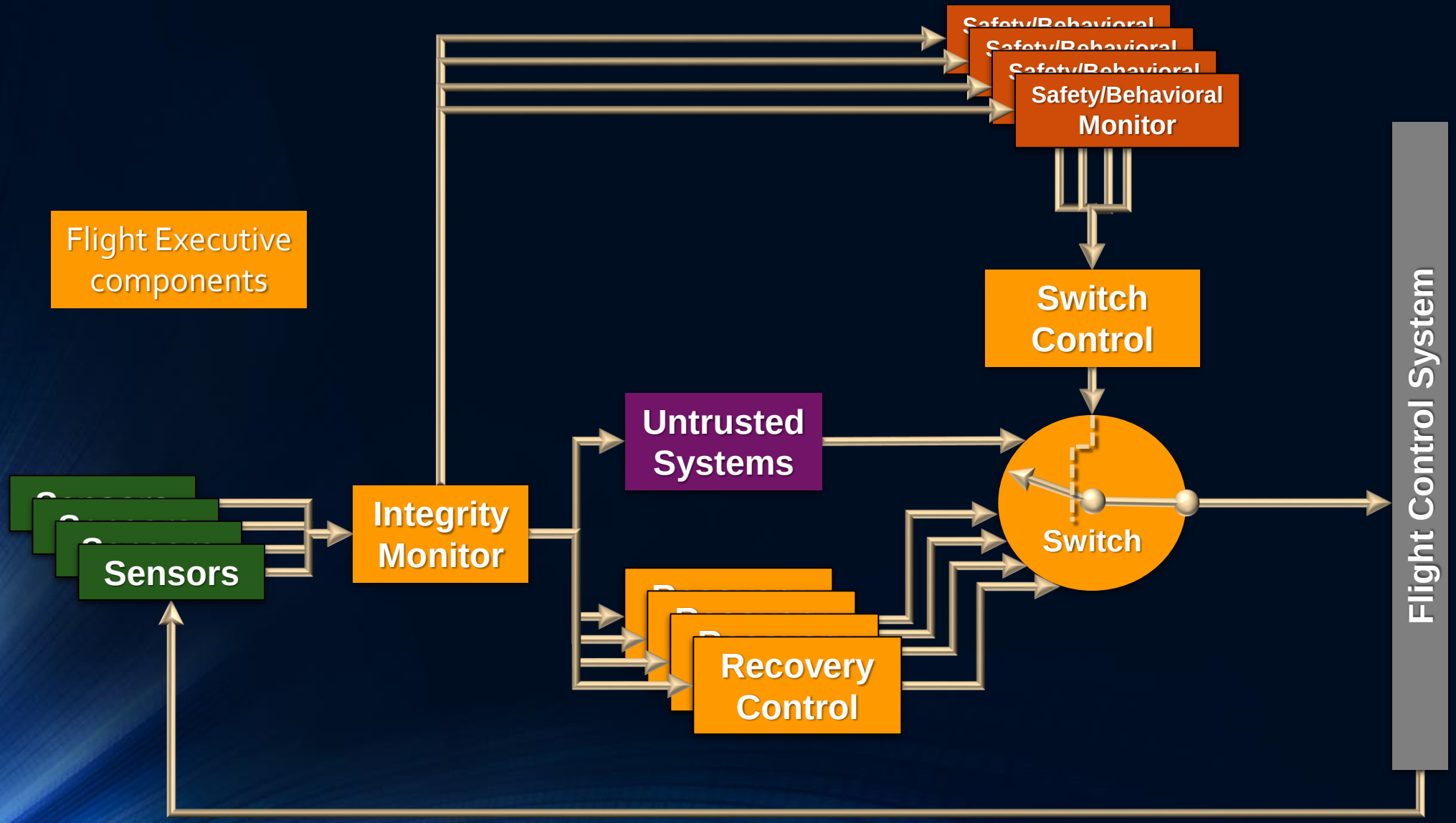
- WK53403 Goal: Develop a standard practice that safely bounds the flight behavior of autonomous UAS
- Involvement originated from AFRC collaboration with FAA regarding Auto GCAS and integrity management work on early autonomy concepts
- Published Industry Standard Practice in Oct 2017

Traditional RTA Framework



MM-RTA Framework

This Work is Unique to AFRC



Traveler
Phase 1 EVAA Development

Objective

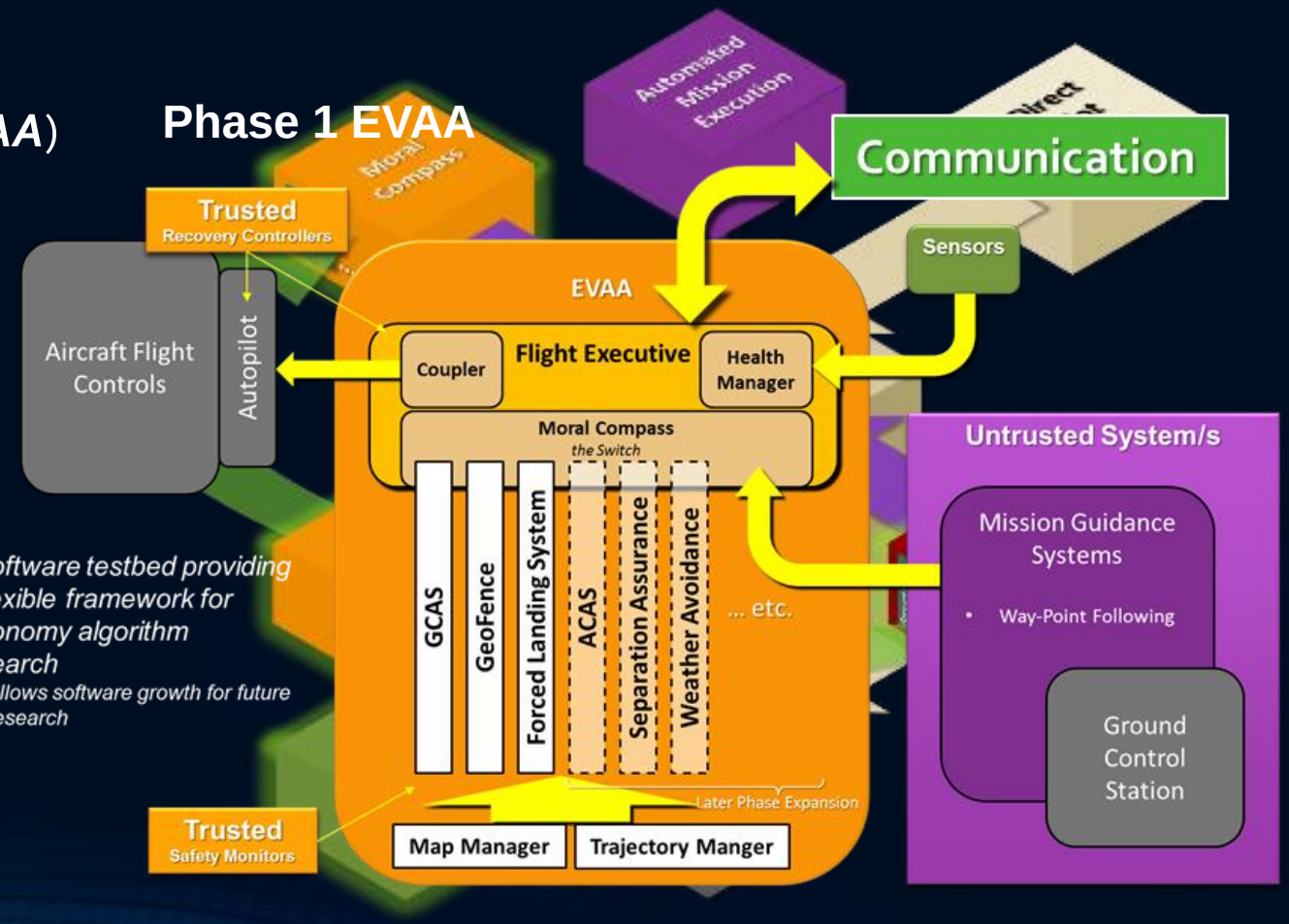
- Develop research findings to inform standards development for certifiable autonomy
- Evaluate the dynamic interaction of an MM-RTA with no integration between monitors

Expandable Variable-Autonomy Architecture (***EVAA***)

- Stretching the paradigm of autonomy
  - Deterministic Rulesets Bounding Autonomous Behavior
    - Functionally Partitioned Monitors
  - Risk-Based Decision Making
- A process enabling certification
  - Software Architecture/Framework
  - Test Approach
- Scalable autonomy
  - Pilot-in-the-Loop to "Fully Autonomous"

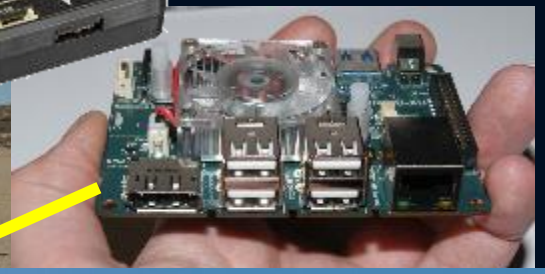
Low Altitude Small UAS Test Ranges (***LASUTR***)

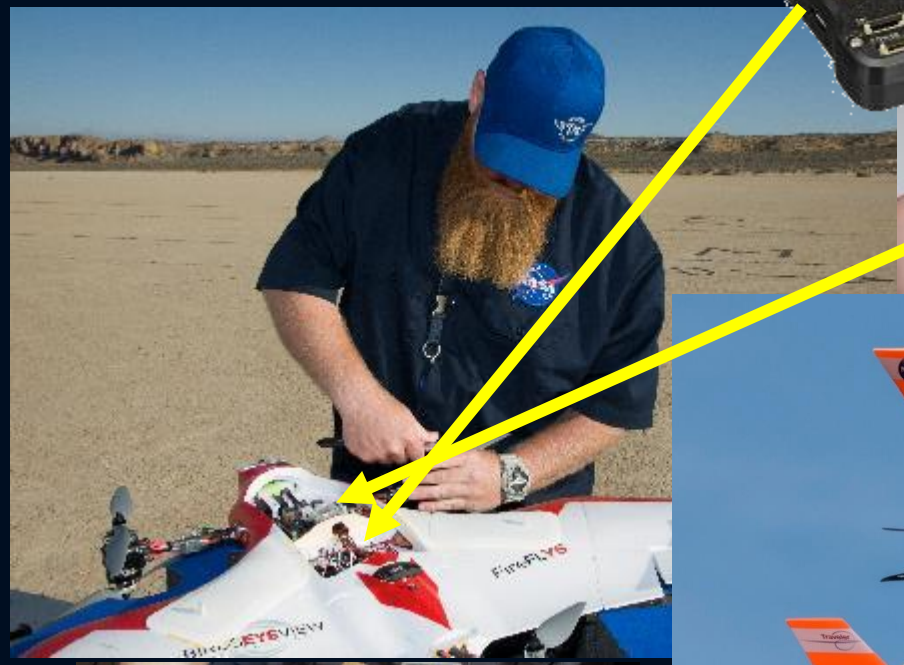
- A tool for certification
- High-risk integrated research

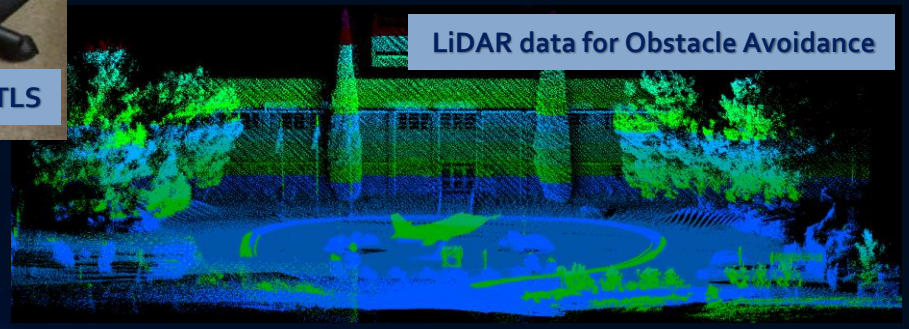


MM-RTA: Key EVAA Accomplishments

- **Aircraft/Testbed Modifications**
  - Research Processor Integrated Jan 17
  - Sound & Lighting System Installed May 17
- **Research System**
  - Functional Requirements Completed Nov 16
  - Design Completed Feb 17
  - Coding Completed Mar 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 Mar 17
  - EVAA Flight Test Began May 17
- **Reporting**
  - Update to FAA & ASTM May 17

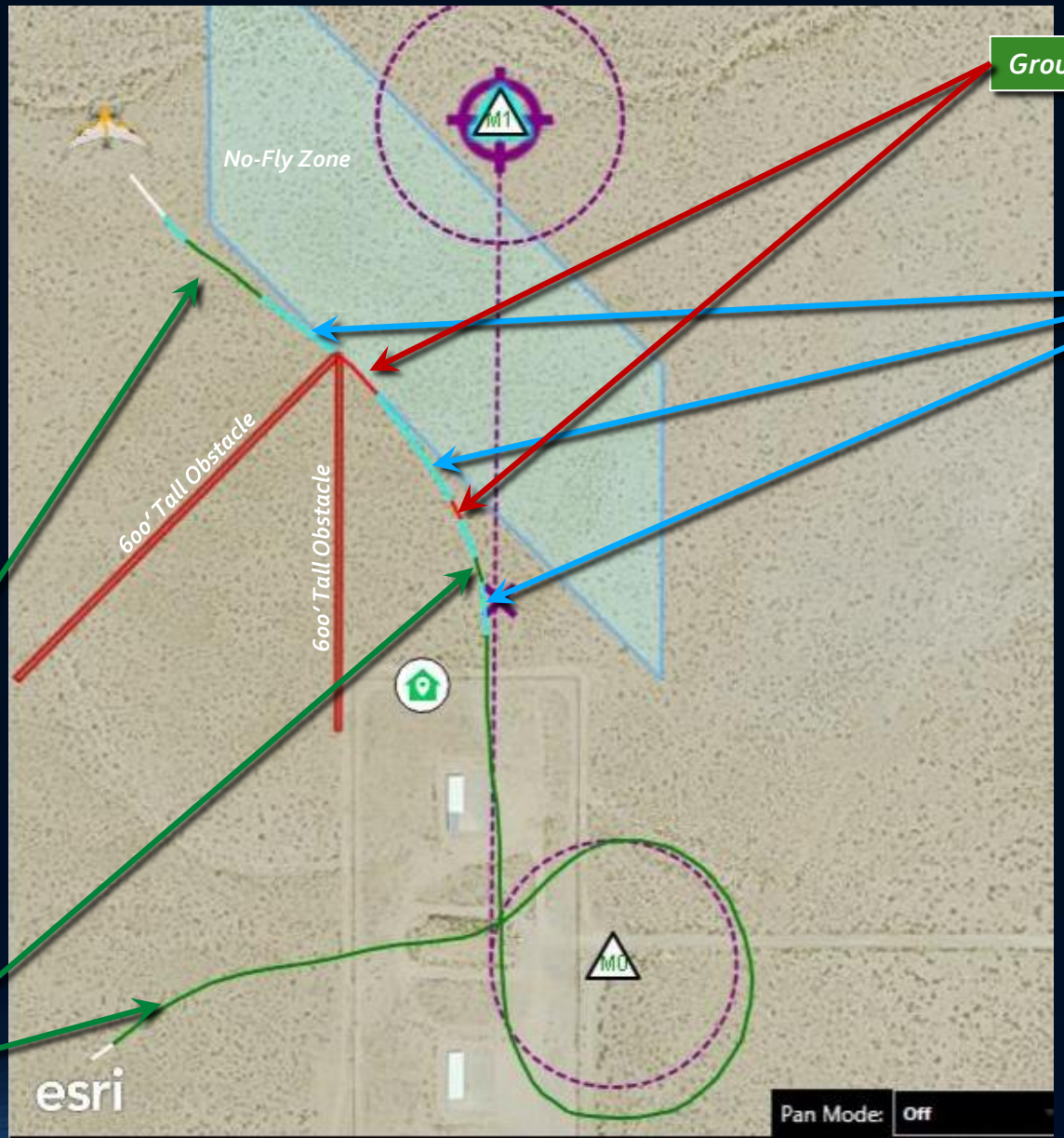






Flight Test Accomplishments

EVAA Command Delegation with Conflicting Multi-Monitor Resolution



Ground Collision Avoidance Control

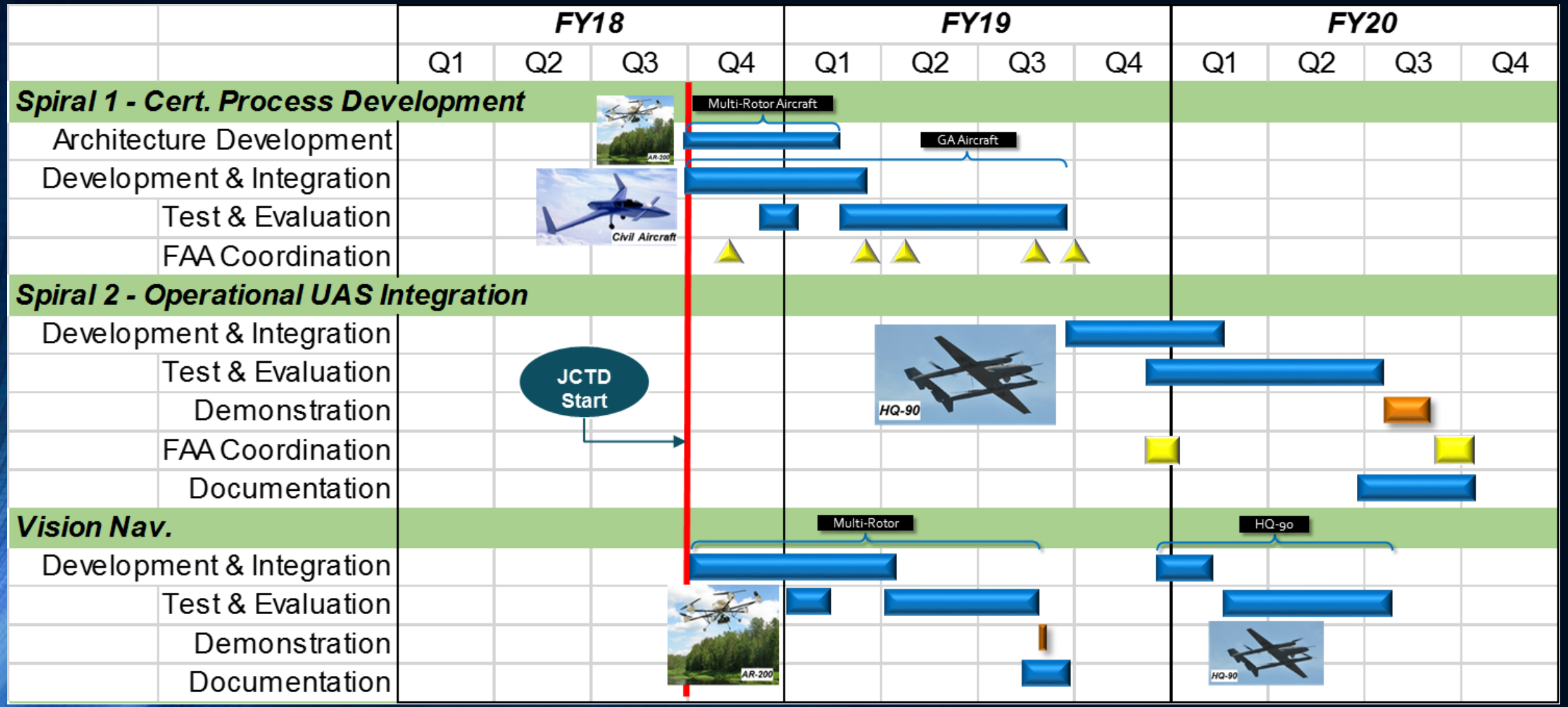
GeoFence Control

Waypoint Following Control

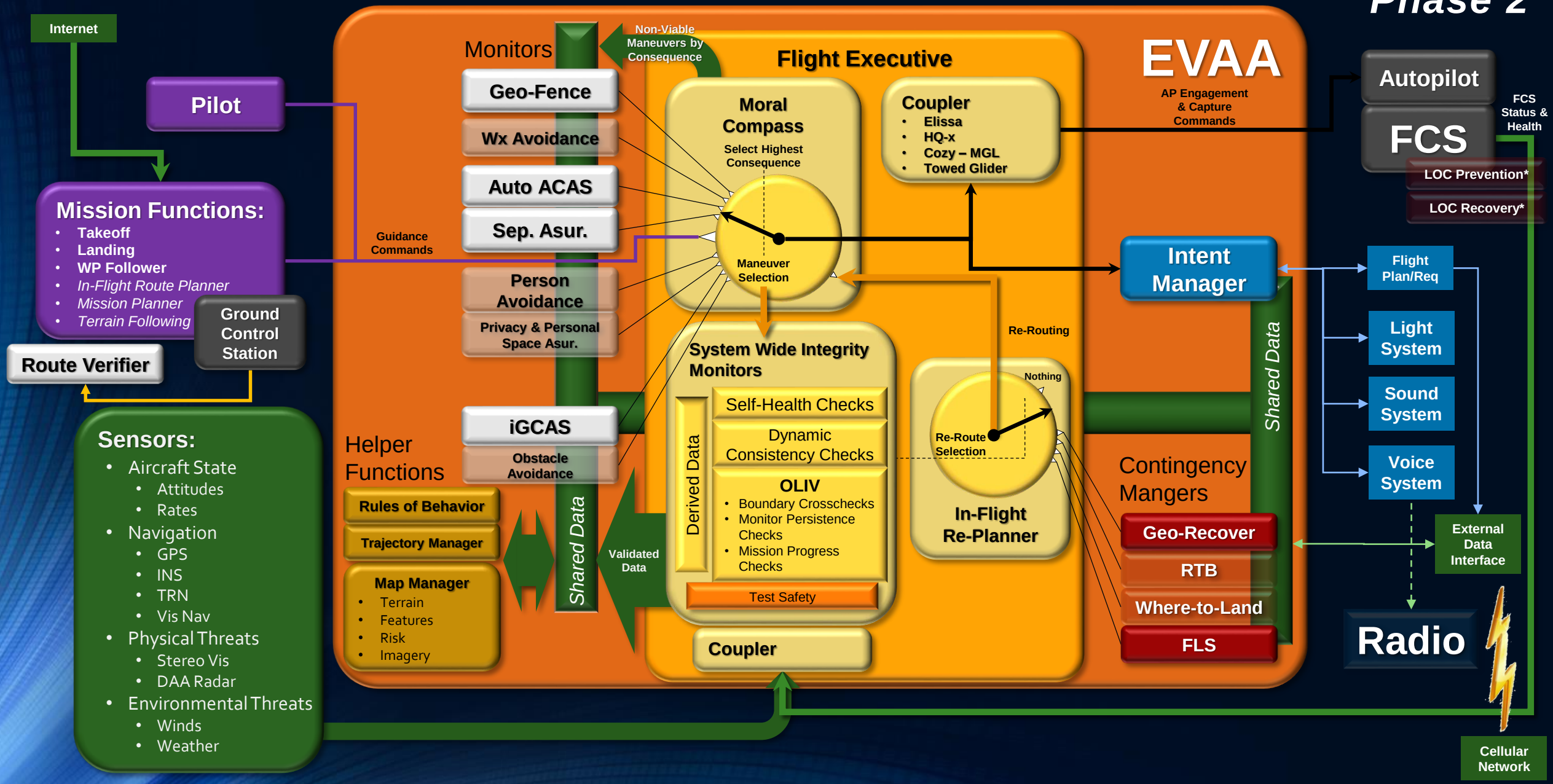
EVAA Phase 2

EVAA Phase 2 Development

OSD's JCTD Resilient Autonomy Project



Expandable Variable-Autonomy Architecture (EVAA) Phase 2



OSD Resilient Autonomy

Cooperative & Non-Cooperative Targets

Automatic Well-Clear & Air Collision-Avoidance

ADS-B & DAA Radar

HQ-90

Cellular or Other Link

Non-Safety Critical Link

EVAA Processor

Automatic Airspace Boundaries & Safe-Ditch Contingency Management

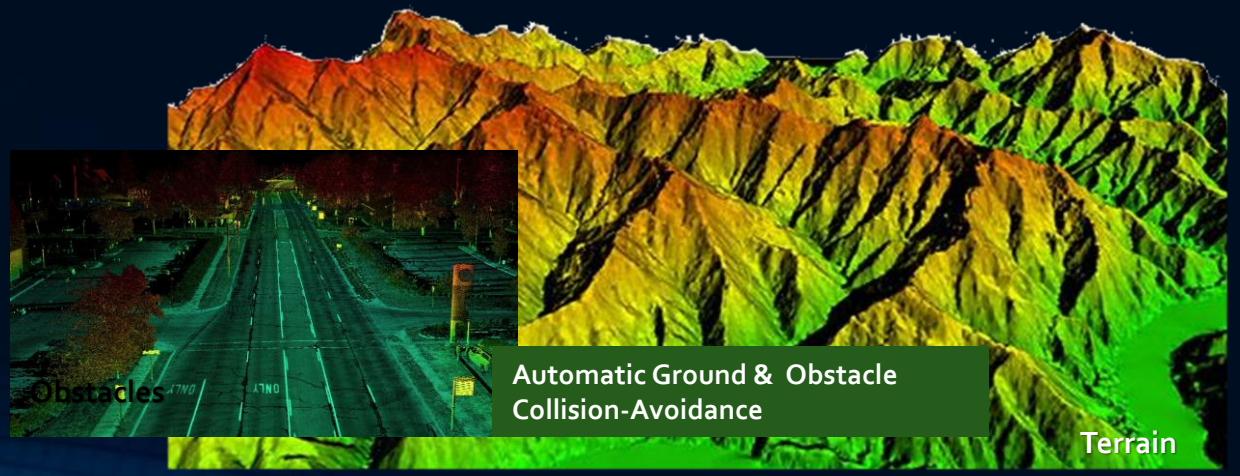
EVAA
- Certifiable Autonomy
- Safe Pilotless BLOS Ops
- Risk-Based Decision Logic
- Easily Tailored to any Vehicle & Mission

Visual-Nav System – transient operation in GPS denied or degraded environment

Big Data

Non-Safety Critical Link

GCS Features
- Mission Plan Verification
- Situational Awareness Displays

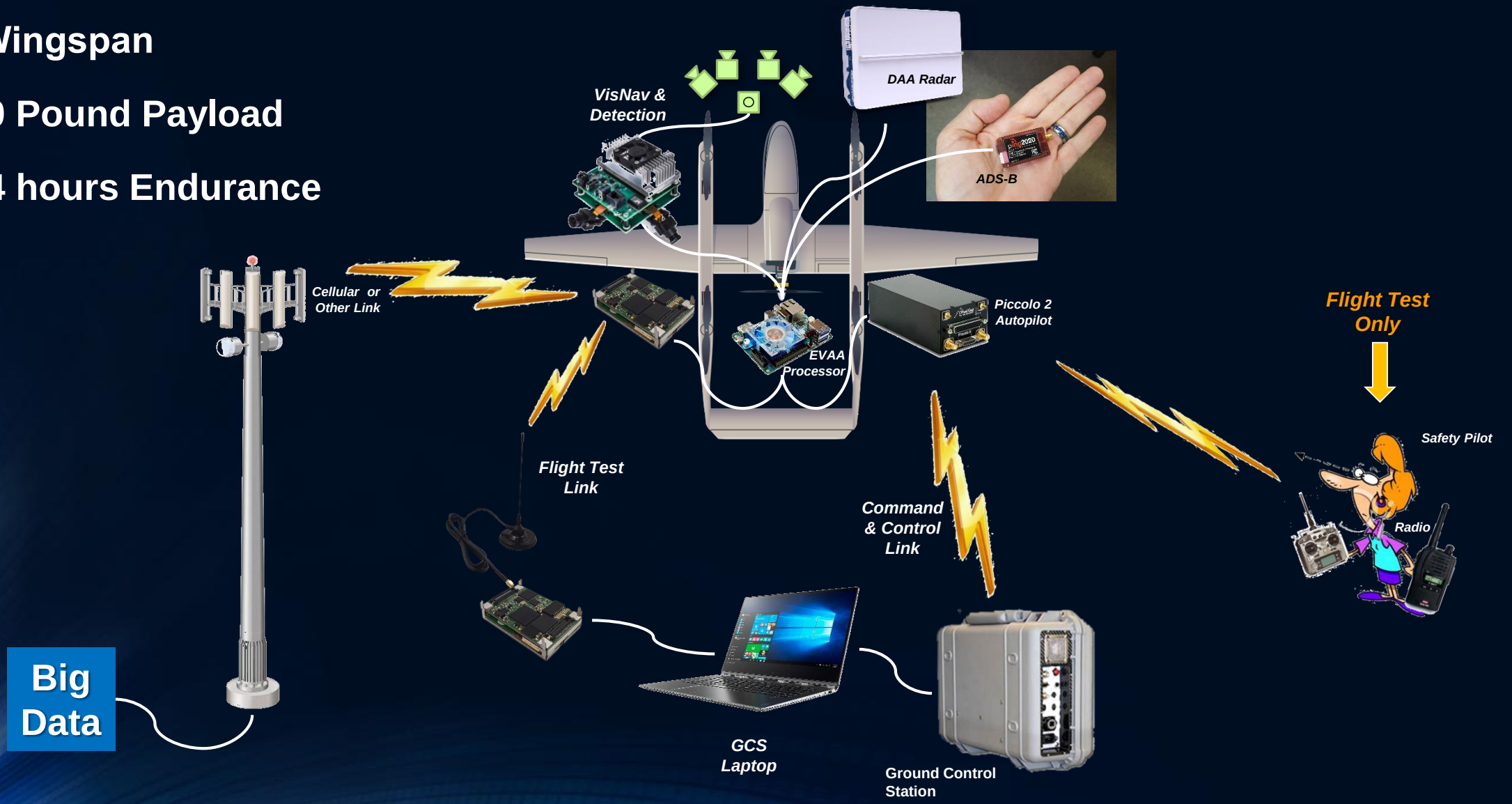


Automatic Ground & Obstacle Collision-Avoidance

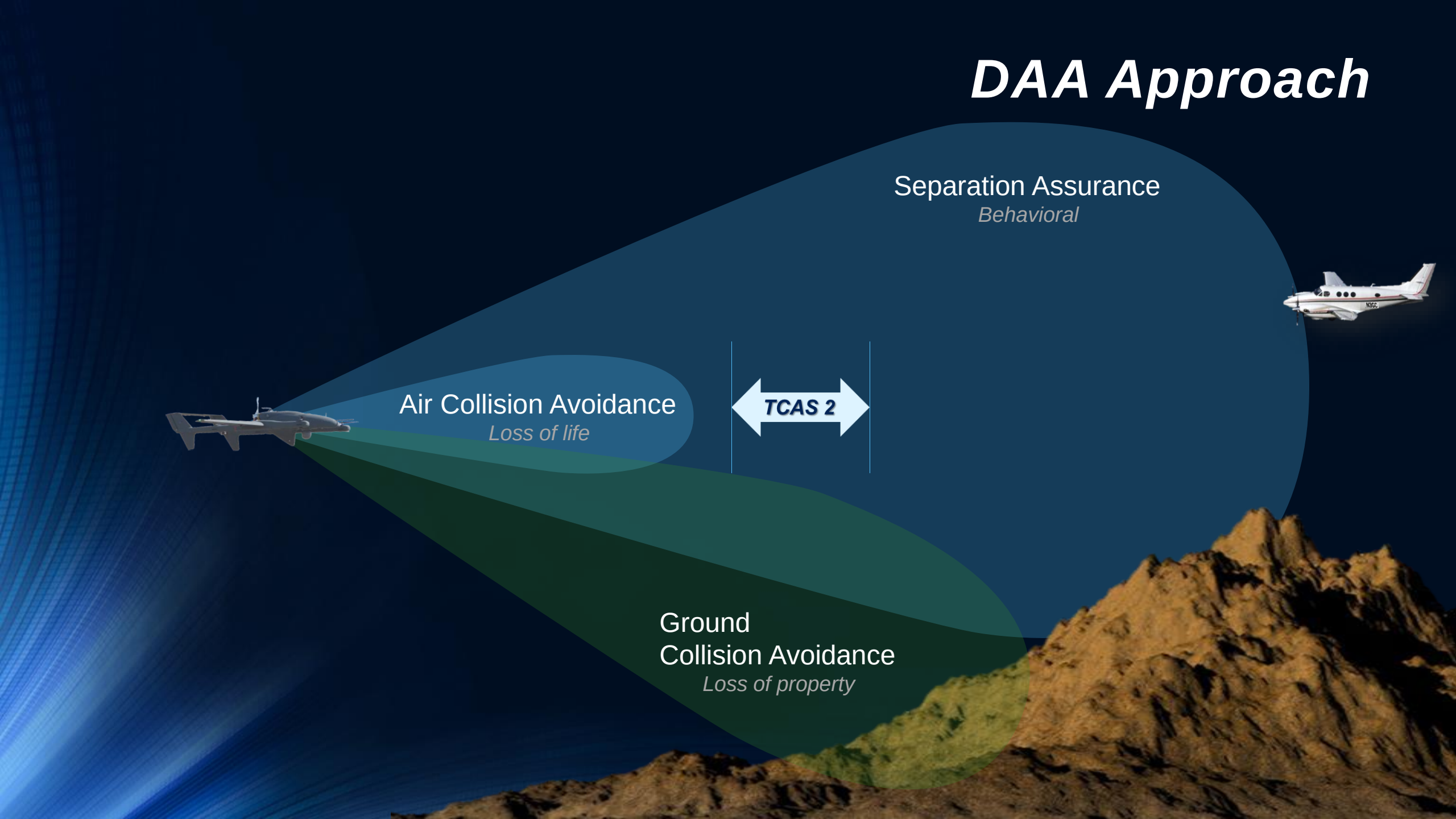
Terrain

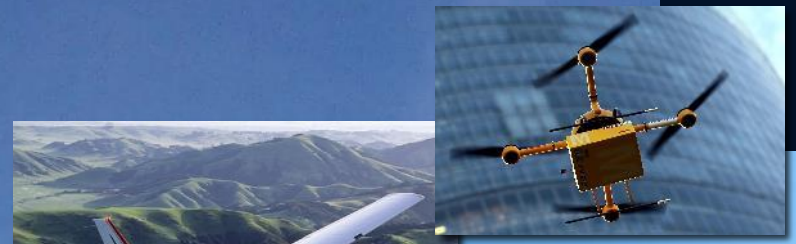
HQ-90 Testbed

- 103 Lbs. Max Gross Takeoff Weight
- 14’ 8” Wingspan
- 20 to 30 Pound Payload
- 12 to 24 hours Endurance



DAA Approach





Questions