Dynamics and Control work at NASA Armstrong

AUTONOMY

CONTROL OF FLEXIBLE STRUCTURES

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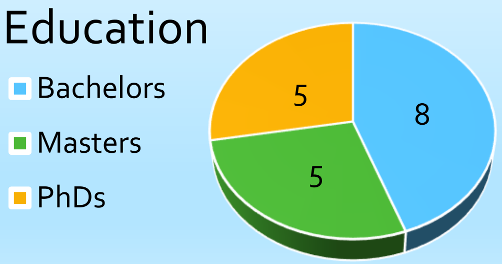
Dynamics & Controls (AFRC – RC)

Demographics

- 18 full time CS, 2 WYE, 1 Pathway
- Average age 39.8



Capabilities

- Flight control, estimation, and guidance
- Flight dynamics
- Flying qualities/handling qualities
- System integration, test, V&V
- Flight research, flight test techniques, data analysis
- Intelligent/adaptive/robust flight control
- Multi-vehicle control
- Autonomous/adaptive mission
- Precision trajectories

Research

- Control of Flexible Aerostructures
- Autonomy
  - Trustworthy autonomy
  - Multi-Monitor Run Time Assurance
  - Cooperative Trajectories
  - Where to land
- Dynamics and control of Hybrid Electric Vehicles

Current Projects

- Control of Flexible Structures on X-56A Multi-Utility Technology Testbed
- Automated Cooperative Trajectories (ACT)
- Adaptive Compliant Trailing Edge (ACTE)
- X-57 Scalable Convergent Electric Propulsion Technology and Operations Research (SCEPTOR)
- Trustworthy Autonomy (TRAVELER)
- Quiet Supersonic Technology (QueSST)

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AFRC Autonomy work

Trustworthy Autonomy

Development & Flight Demonstration

Run Time assurance

Advanced Cooperative Trajectories

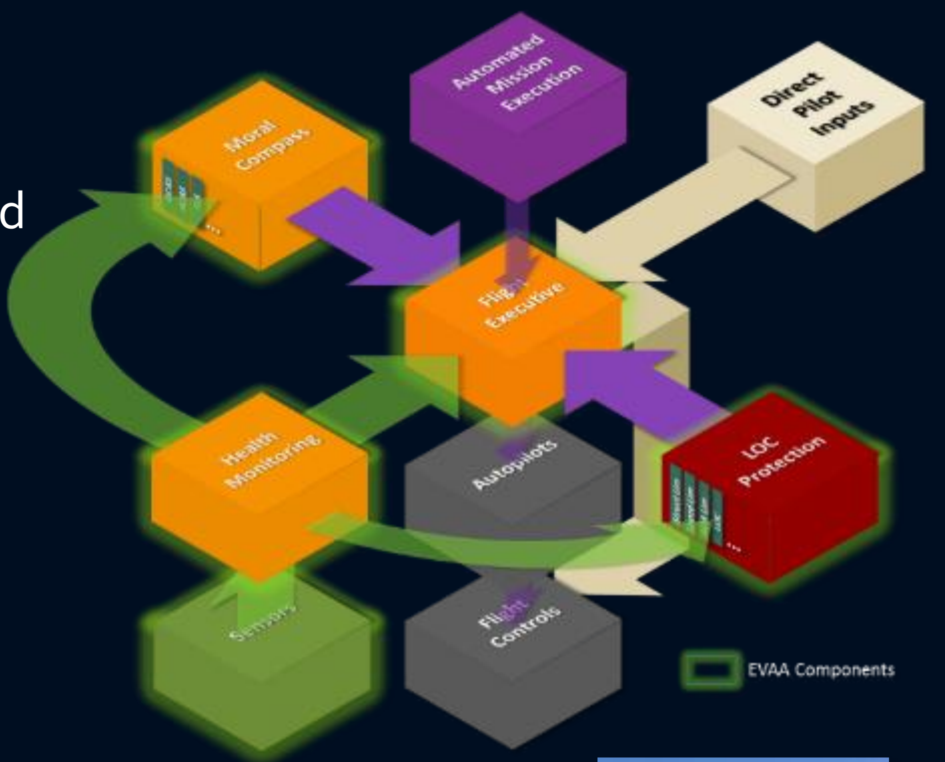
Multi-Monitor Run Time Assurance

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

1. **MM-RTA** research findings using Low Altitude Small UAS Test Range (LASUTR) and Expandable Variable Autonomy Architecture (EVAA) realistic environment capabilities

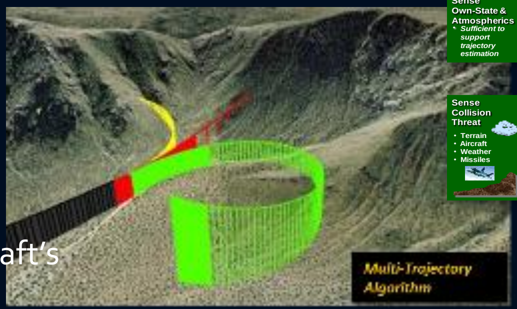
2. Develop a **methodology for generating the artifacts** necessary to develop **an airworthiness case** for unmanned and autonomous systems

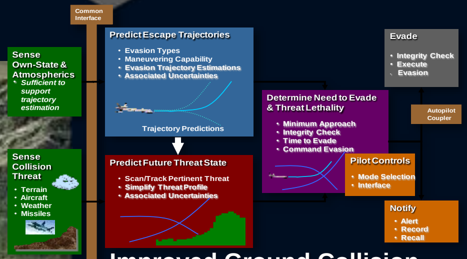
3. Use research findings to **inform standards** and best practices which will accelerate the certification of autonomous systems



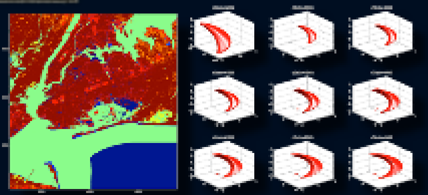
Expandable Variable-Autonomy Architecture (EVAA)

- A Software Research Testbed for MM-RTA
  - Modular Software Architecture
  - Add and Replace Software Components as needed for developing research findings in a relevant environment
- The RTA Switch & Moral Compass
  - Selects the appropriate function to control the aircraft at any instance in time
  - Moral Compass = Risk-Based Decision Making
- Monitors
  - EVAA Allows the Integration of Any Number of Monitors
  - 3 Being Implemented in Phase 1
    - 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
  - Addressing Trust through Transparency in Decision Making
    - Social Interface Functions – Autonomy Expressing Intent
- Controllers
  - Conventional autopilot functions available on most aircraft & all UAVs





Improved Ground Collision Avoidance System (*iGCAS*)



Forced Landing System

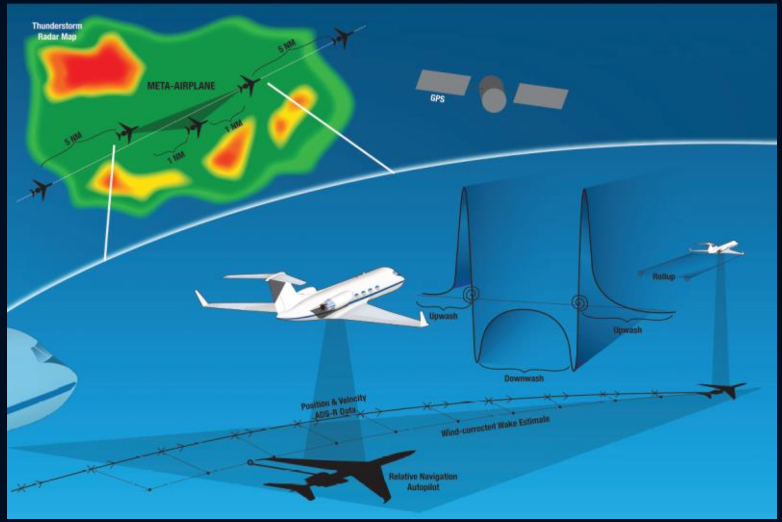
Blue text: Standard RTA components
White text: Unique research components

Automated Cooperative Trajectories

Project Overview

The NASA Automated Cooperative Trajectories (ACT) project is advancing ADS-B enabled autopilot capabilities to improve airspace throughput and vehicle efficiency.

- Meta-Aircraft Operations for safe, reduced separation and decreased air traffic control workload
- Formation Wake Surfing for fuel savings



Meta-Aircraft Concept

The ACT project is run out of the NASA Armstrong Flight Research Center in Edwards, CA

- NASA's Transformative Tools and Technologies (T^3) and Flight Demonstrations and Concepts (FDC) Projects
- 2016: Completed single-ship (C-20A) system integration checkout flights of a Research Programmable Autopilot (PA) with ADS-B In capability.
- 2017: Due to heavy use of the C-20A for Science Missions, ACT is looking to transition to another NASA G-III and update the Reseach PA for future Auonomy applications.

Control of Flexible Aerostructures

DYNAMICS AND CONTROL AS APPLIED TO LIGHT WEIGHT AEROSTRUCTURES

- LIGHTER AIRCRAFT
- FUEL SAVINGS
- SHAPE CONTROL

ADVANCED MODELING
ADVANCED SENSING
ADVANCED CONTROL

Advanced Aerostructure Modeling

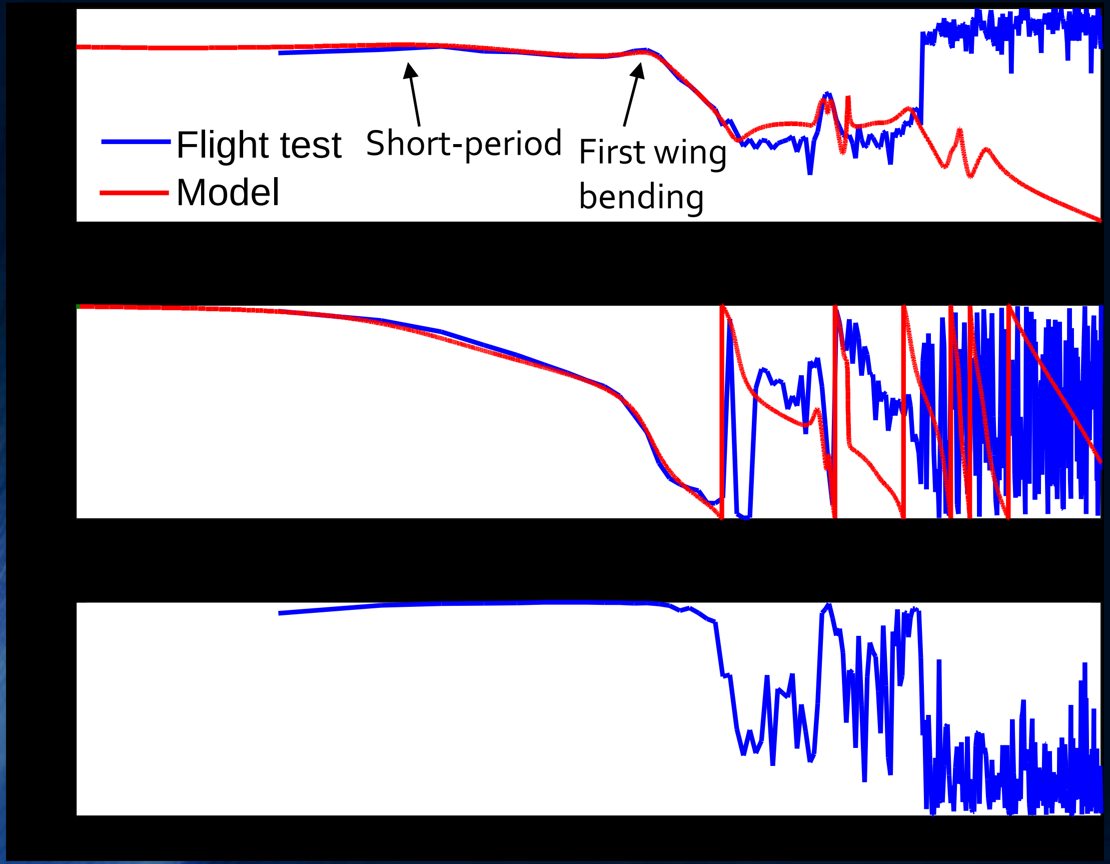
- Challenges
  - Frequency separation rigid and flex no longer valid
  - State consistency between mass and flight conditions . Modes change, sign inconsistency , state ordering
  - Gravitational and velocity changes can't be ignored
  - Time domain unsteady aero insufficient

- New approach
  - Model interaction between rigid body and flex modes simultaneously.
  - Assumed modes approach for state consistency. Same mode shapes for all conditions
  - Include the complete mass matrix form the finite element model and assume large velocity variations
  - Frequency domain transformation of unsteady aero.

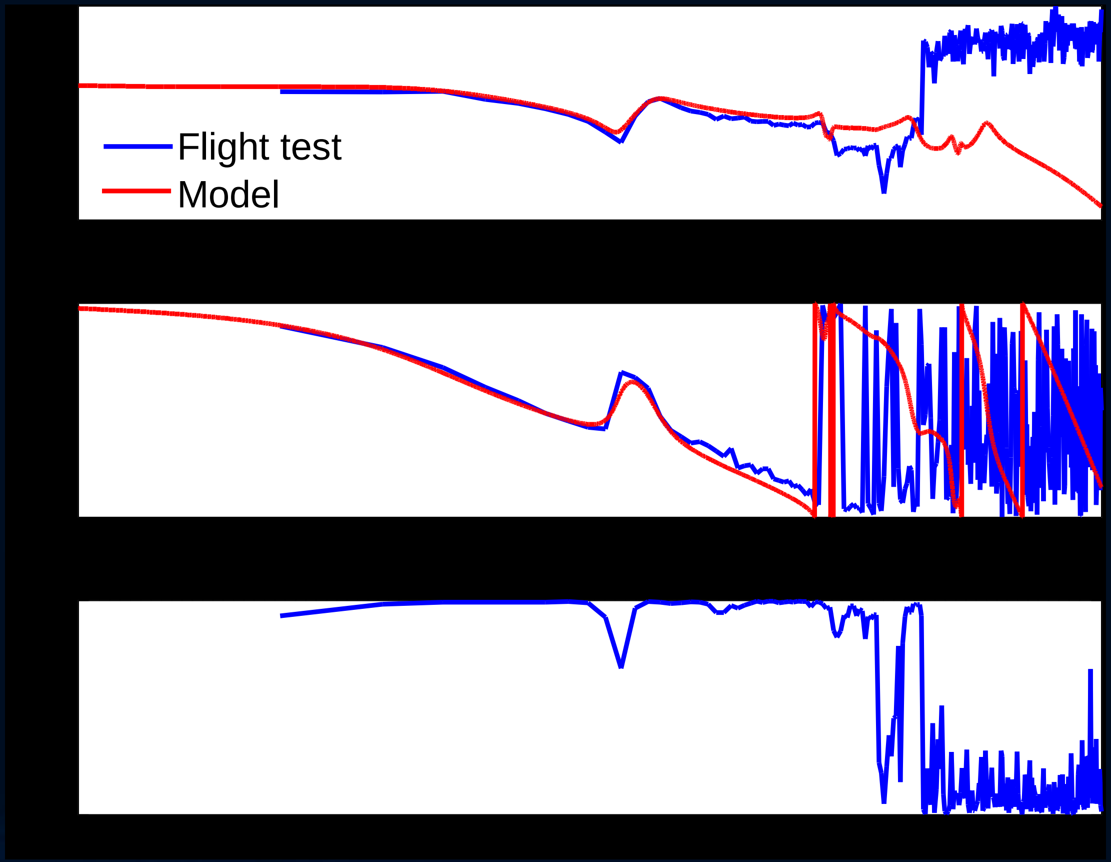
Advanced techniques are complex and showing good correlation with flight data.

X-56 Flight Data Comparison: Pitch response, low fuel, high speed

PITCH RATE

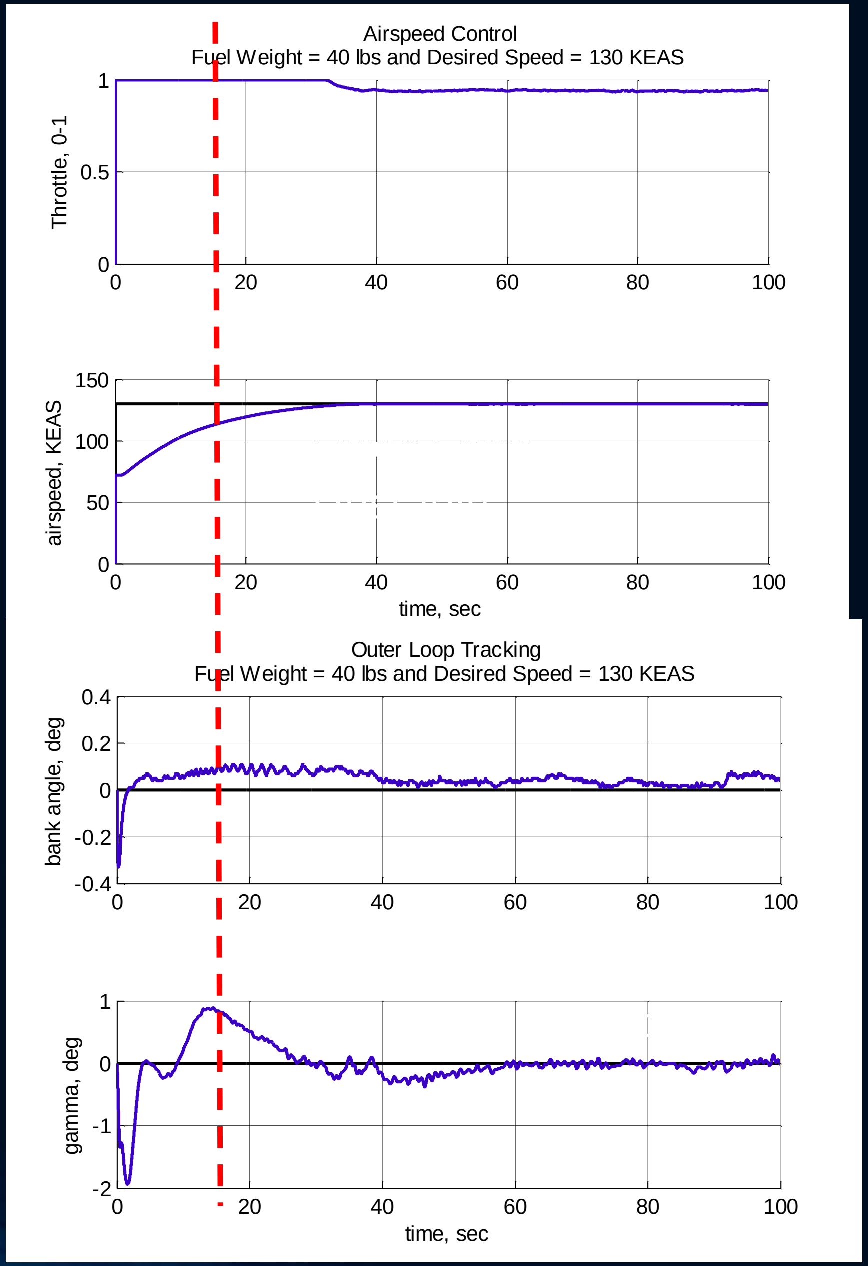


WING TIP ACCELEROMETER



Nonlinear Simulation of X-56A Flex Wing Flutter Control

- The nonlinear simulation has been updated with flexible modes to exhibit flutter behavior
- An airspeed maneuver was completed from 75 kts to 130 kts
  - Flutter speed is at 115 kts
- System exhibited stable characteristics with controller in loop
  - Suggests the linear models are at least representative of our nonlinear flutter models
- Further comparisons between linear and nonlinear systems are in progress



X-56A

- Flex wing status
  - New landing gear, design/build/install (Jan-Aug 2016)
  - GVT completed (Aug 2016)
  - MOI test completed (Sept 2016)
  - FRR completed (Nov 2016)
  - Low Speed Taxi completed (Dec 2016)
  - Medium Speed Taxi (in progress)

X-56A – Flex Wing GVT

- Future Flight Tests:
  - Phase 0: Low speed flex wing flights (as soon as the lakebed dries, expected April 2017)
    - Retuned stiff wing controller for flex wings at low speeds (classical PID controller)
    - Check out takeoff and landing dynamics with the new landing gear
  - Phase 1: High speed flex wing flights (expected June-Aug 2017)
    - Engage H2 flutter suppression controller (w/ accel feedback) and expand airspeed out past flutter by 25%
    - Collect data to validate aeroelastic modeling approach
  - Phase 2: Shape control (early 2018)
    - Use FOSS in the feedback loop to control the shape of the wing