Dynamics and Control work at NASA Armstrong

AUTONOMY

CONTROL OF FLEXIBLE STRUCTURES

STEVE JACOBSON, CHIEF, DYNAMICS AND CONTROL BRANCH
Dynamics & Controls (AFRC – RC)

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

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

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

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)

Education
- Bachelors
- Masters
- PhDs

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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

**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

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

- NASA’s Transformative Tools and Technologies (T³) 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 Research PA for future autonomy 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**
- Flight test
- Model
- Short-period
- First wing bending

**Wing Tip Accelerometer**
- Flight test
- Model
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)

- **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 Hz 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