National Aeronautics and
Space Administration

NASA Armstrong
Flight Research Center
Dynamics and Control Branch

Steve Jacobson

Chief, Dynamics and Controls

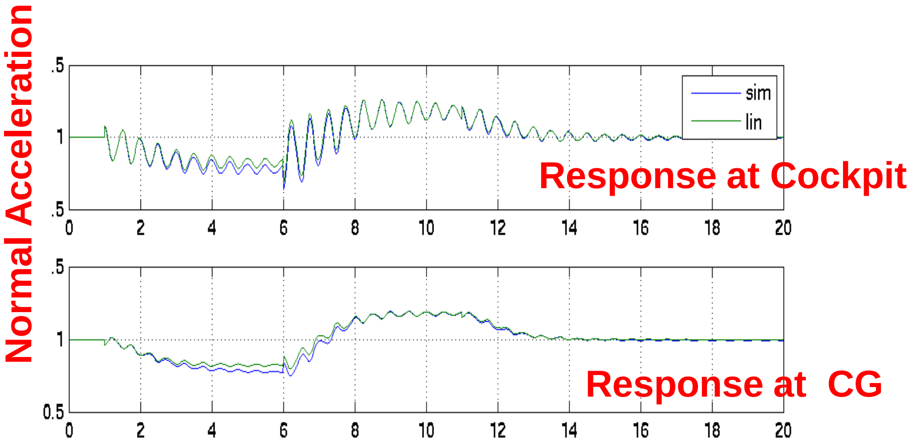
04 March 2015

Abstract

NASA Armstrong continues it's legacy of exciting work in the area of Dynamics and Control of advanced vehicle concepts. This presentation describes Armstrong's research in control of flexible structures, peak seeking control and adaptive control in the Spring of 2015.

Control of Flexible Structures: Supersonic aircraft

- **Integrated rigid / low frequency structural dynamics modeling for handling qualities, control law evaluation and development**
  - Integrated flexible-rigid state space matrices
    - aero effects due to structural deformation
    - structural deformation due to aero excitation
  - 6-DOF simulation modeling
  - Z-AERO generation of state-space matrices

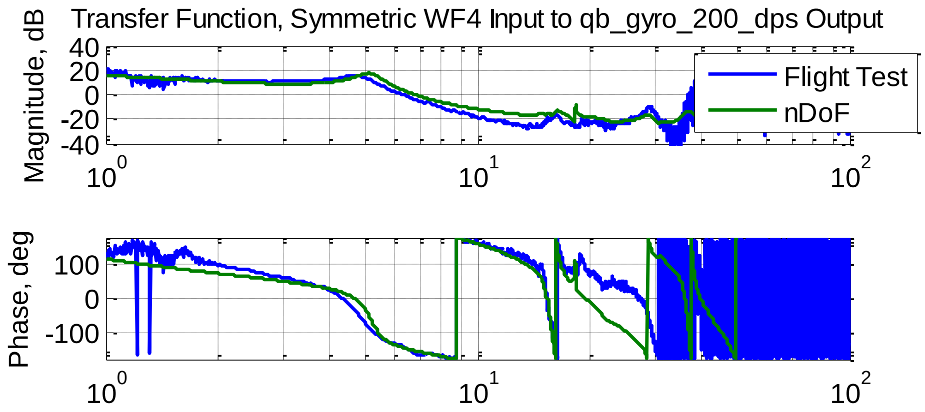


Dynamic structural models

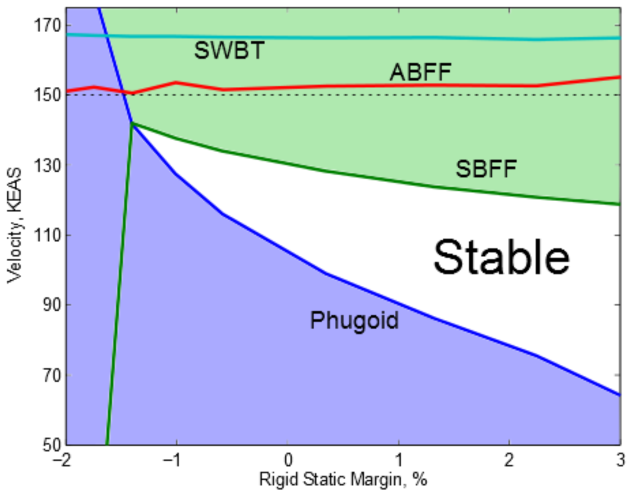
Modeling Approach

- Linear Structural Model
  - Mode Shapes
  - NASTRAN Finite Element Model
  - Correction for state consistency
- Unsteady Aerodynamic Model
  - ZAERO Panel Method
  - Transfer Function Approximation
- Sensor and Actuator Dynamics
- Models have 260 Total States

Stiff Wing Structural Dynamics



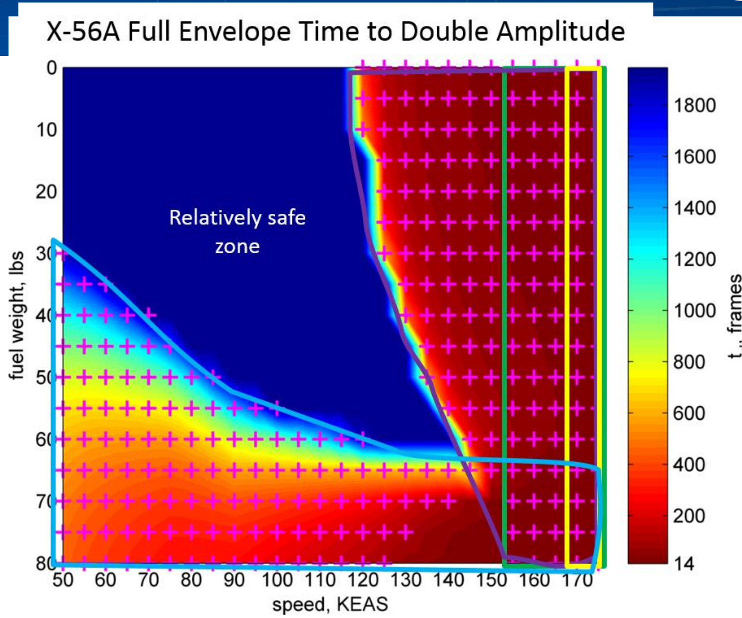
Flexible Wing Instabilities



Technical Challenges

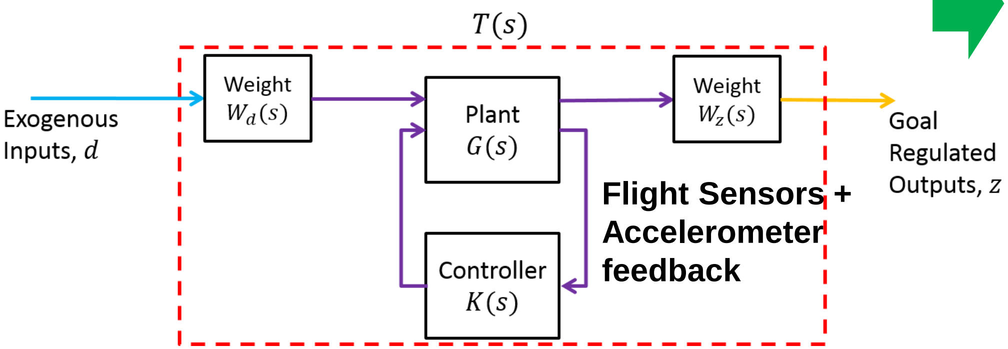
- Piloted Simulation
  - Real-time
  - Numerical Stability
- Verification & Validation
  - Too many parameters to identify
  - Which parameters are critical
- Free Play modeling
- System Uncertainty

The X-56A Flexible Wing Flutter Suppression Challenge

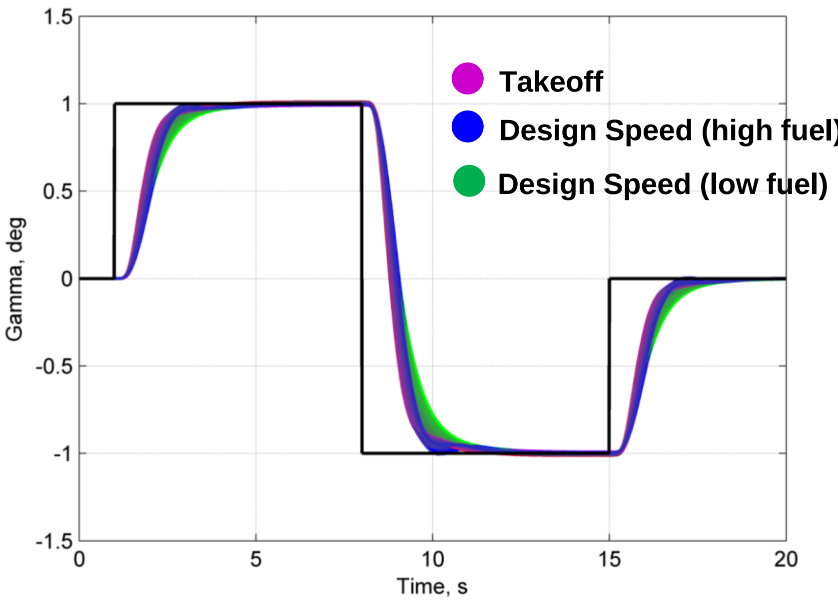


- **Most of envelope is unstable**
- **Using a frequency based MIMO control design method, performance objectives were met**
- **Accelerometers used in control system to suppress high frequency instabilities**

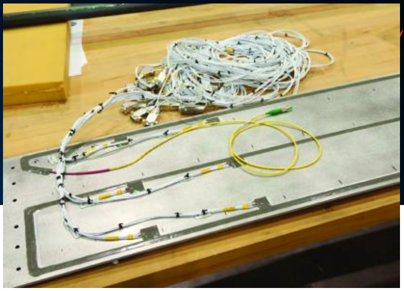
Control Design Architecture



Gamma Response to 1 Degree Command

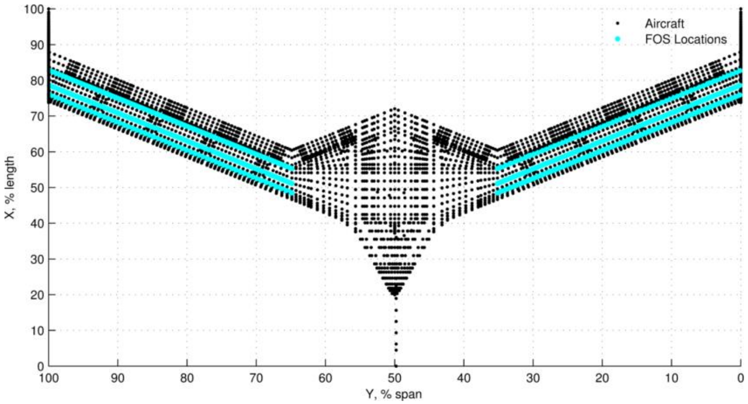


Sim of Flutter Suppression using FOSS

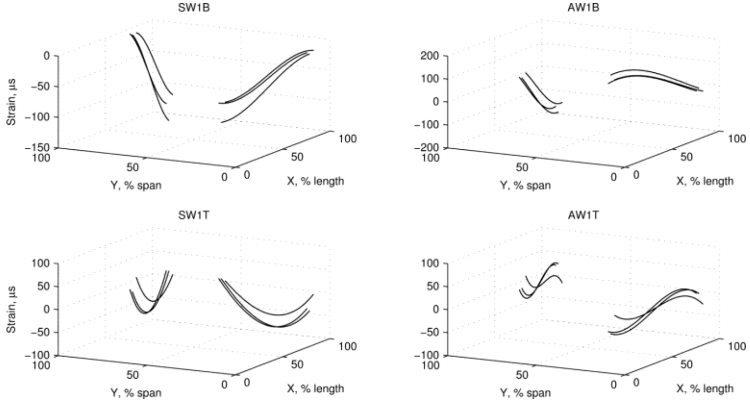


- Demonstrated Active Flutter Suppression on X-56A models with simulated strain feedback from thousands of sensors from fiber optic shape sensors (FOSS)

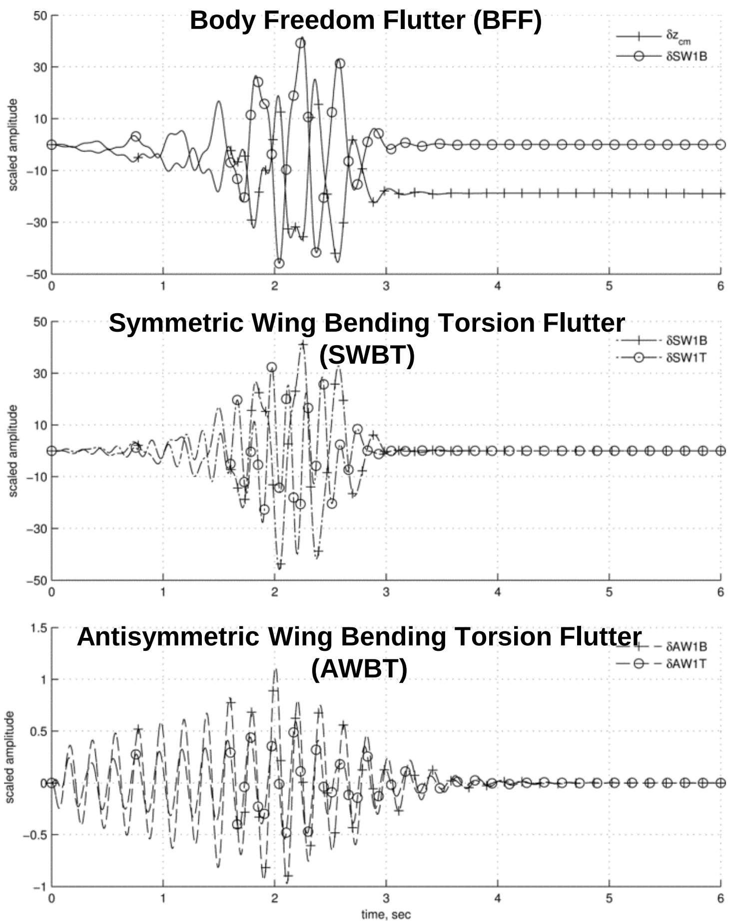
FOSS Mapping (6 fibers)



Strain Modes from NASTRAN



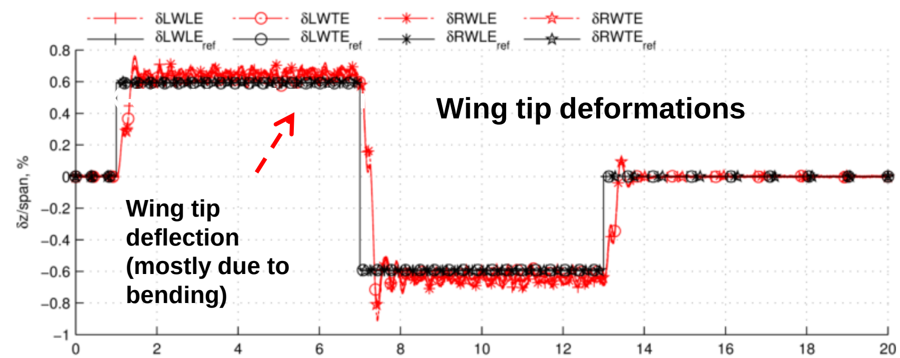
X-56A - Active Flutter Suppression Simulation using FOSS



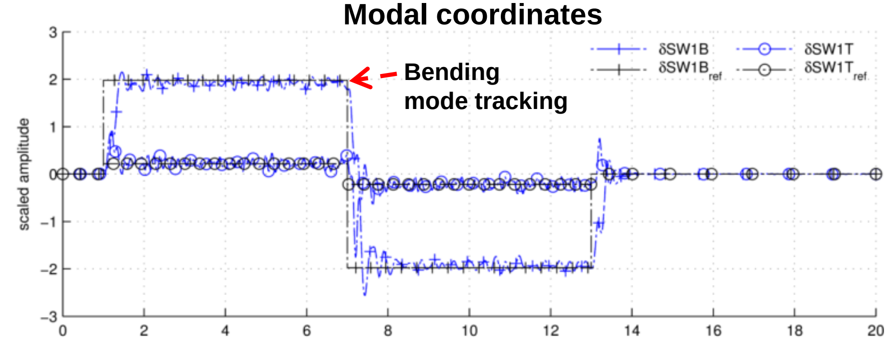
Simulation of Virtual Deformation Control using FOSS

- FOSS can support a shape tracking architecture through virtual deformation control or direct strain/deformation feedback

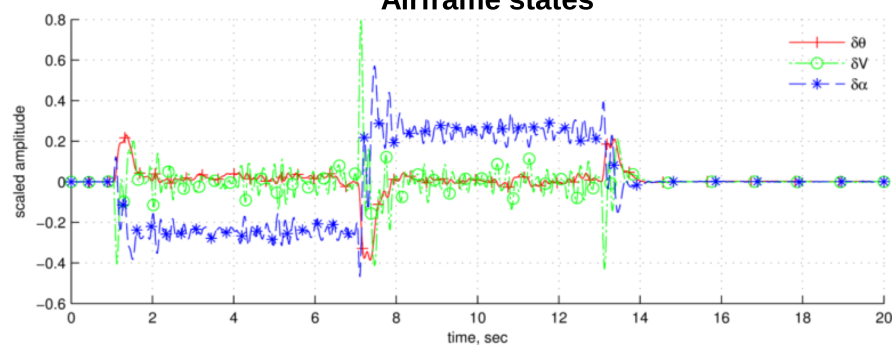
X-56A Virtual Deformation Control Using FOSS



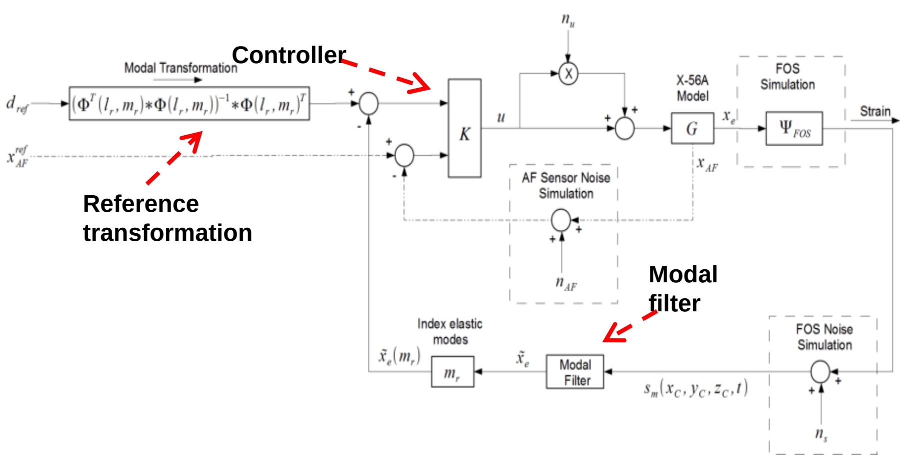
Modal coordinates



Airframe states



X-56A Virtual Deformation Control – Modal Reference Simulation



Automated Cooperative Trajectories

Cooperative Trajectory (CT) Concept

Proactive, collaborative approach to separation assurance and wake turbulence avoidance.

- Two or more aircraft
- Continuous data-link communication (such as ADS-B Out/In)
- Parallel, closely-spaced trajectories with reduced separation (0.5 – 2 NM)
- Automatic control to maintain separation
- Probabalistic vortex models combined with real-time, in situ measurements to estimate the location of the wake

The project goal is to demonstrate ACT using COTS technology (i.e. ADS-B datalink and modifications to existing autopilots)

Assured Autonomy for Aviation Transformation

ACT enables automated, distributed, multi-vehicle control.

- Distributed Knowledge of Aircraft and Wake Locations
- Integration of ADS-B Messages with Autopilot Systems

Safe, Efficient Growth in Global Aviation

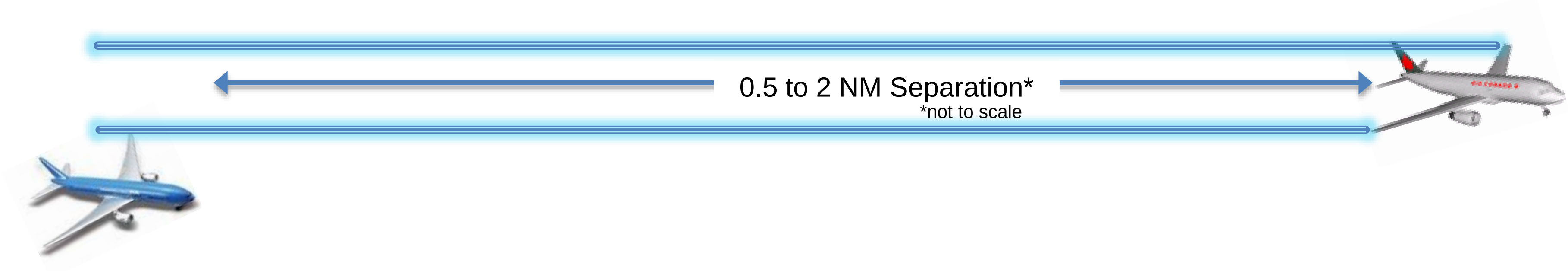
Operation as Meta-Aircraft using automated, multi-vehicle coordination for peer-to-peer separation assurance and wake avoidance.

- Reduced Airspace Congestion
- Improved ATC Workload

Ultra-Efficient Commercial Transports

Sustained, trimmed flight within the upwash portion of the lead aircraft's wake reduces the trailing aircraft's total drag by up to 15%.

- Lower Cost per Mile
- Reduced Particulate Emissions at Altitude



Hypersonics, Adaptive Control

- **Application of adaptive control to hypersonics, lifting bodies**
  - Lateral Control Divergence Parameter (LCDP) -> HTV-2, space shuttle, X-38, X-2
  - Insidious roll reversal nature of LCDP (stable roots, positive control derivative)
- **Adaptive controls**
  - HTV-2 6-DOF simulation of LCDP event
  - Control methodologies
    - Retrospective Cost Adaptive Control -> Dr. Dennis Bernstein, U of Michigan
  - Sysense, Inc – Dr. Jason Speyer
    - Modified Gain EKF to estimate system
    - Extended LQG to solve for feedback controller