# NASA Dryden Status

**Aerospace Control & Guidance Sub-committee**
**Meeting 110**
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# Abstract

**NASA Dryden has been engaged in exciting work that will enable lighter weight and more fuel efficient vehicles through advanced control and dynamics technologies. The main areas of emphasis are "Enabling Light-weight Flexible Structures", real time control surface optimization for fuel efficiency and autonomous formation flight. This presentation provides a description of the current and upcoming work in these areas. Additionally, status is provided Dryden's work on HTV-2**

# Enabling Light Weight Flexible Structures

**Develop algorithms, sensors and architectures to enable static shape and dynamic control of light weight flexible aerostructures**

- **Multi-Utility Technology Testbed (MUTT)**
- **Advanced Sensors for controlling flexible structures**
- **Modeling, Simulation and Control**

# X-56A Multi-Utility Technology Testbed (MUTT)

- **NASA research interests**
  - Develop robustness criteria for active structural control
  - Integrate emerging sensor technology (i.e. FOSS, LESP)
  - Use MDAO and flight measurements to improve aeroservoelastic modeling and analysis
  - Demonstrate ability to derive onboard, in real time, shape and load information
  - Develop future research experiments (i.e. distributed conformal trailing edge flap control)

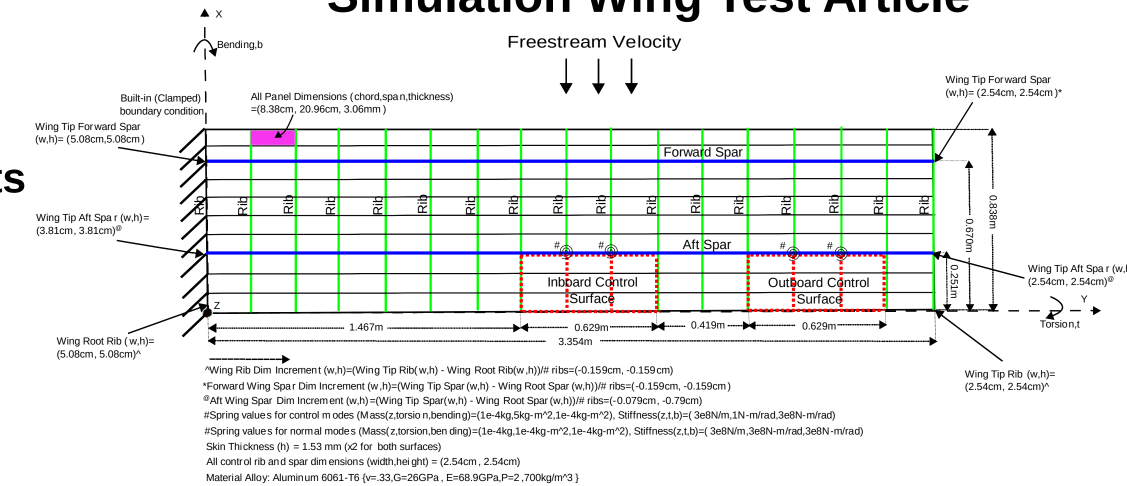
# X-56A Multi-Utility Technology Testbed (MUTT)

- Vehicle final assembly and system checkouts proceeding
- GVT will occur before end of calendar year
- First flight – Feb 2013
- Completion of AFRL / Lockheed flights – June 2013

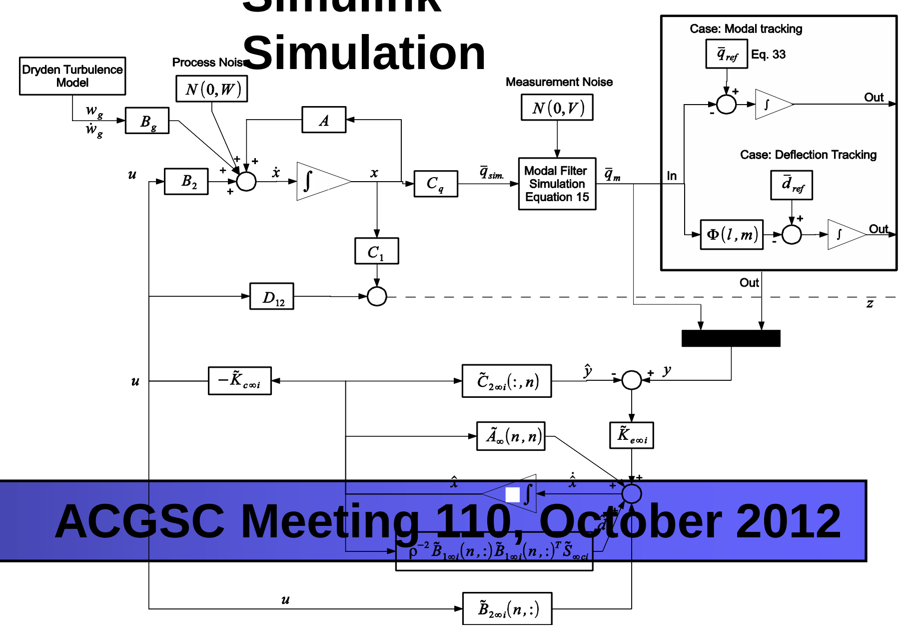
# Simulation Models for Wing Shape Control

- A simulation wing model was developed for testing control design with fiber input to control designs with accelerometer inputs
  - 2 control surfaces
  - Tapering spars/ribs to achieve more realistic tapered wing characteristics
  - 6061-T6 aluminum alloy used in many aircraft
- $n^{th}$ order $H_{infinity}$ controller simulation for tracking control
  - Controller inputs are fiber optics with modal filter simulation (transformation from simulation modal coordinates to physical coordinates and back to modal coordinates with multiplicative noise)
  - Process/measurement noise and turbulence was modeled only in tracking cases

## Simulation Wing Test Article



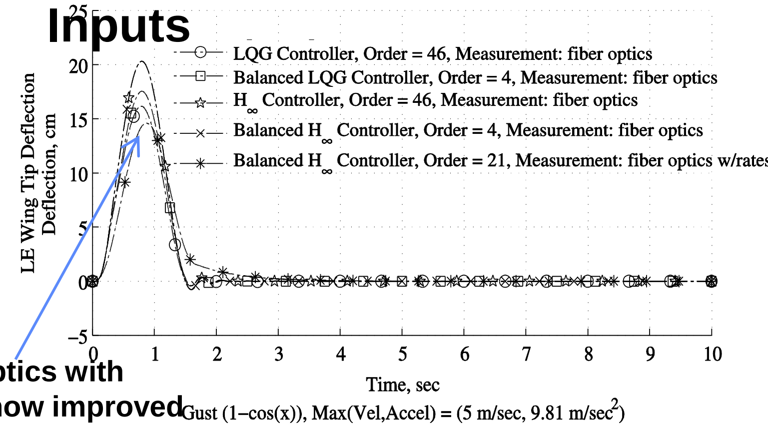

## Simulink Simulation



# Comparison of State-of-the-Art Accelerometers to Fiber Optics

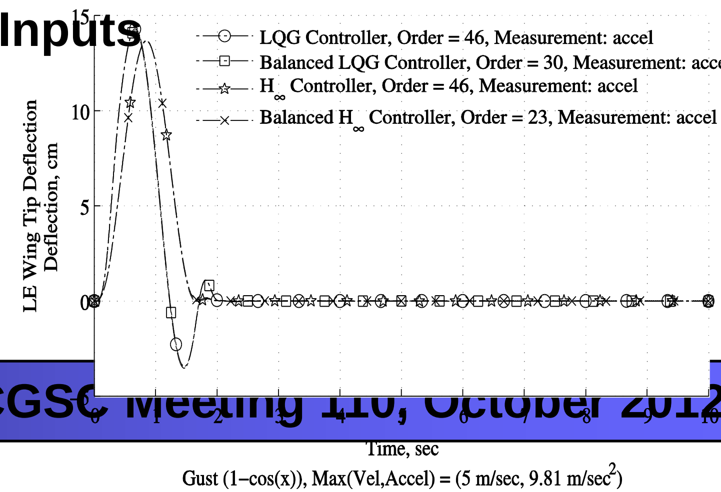
- **Where things stand in control design**
  - **Fiber optic benefits over state of the art**
    - **Reduced control order (46 to 4!)**
    - **Allows tracking control**
  - **Accelerometer advantages**
    - **Improved disturbance rejection (or gust load alleviation) properties**
- **If fiber optics measure rates, advantage of accelerometer control designs diminishes, but control order increases**
- **Flight condition is *open loop fluttering* in both systems**

**Control System with Fiber Optic Inputs**




**Fiber optics with rates show improved disturbance rejection**

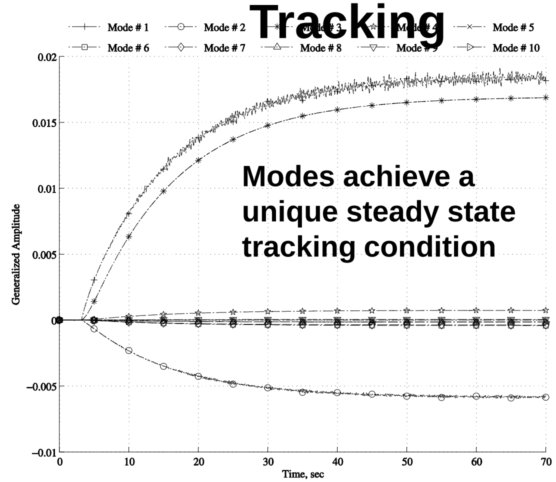
**Control System with Accelerometer Inputs**



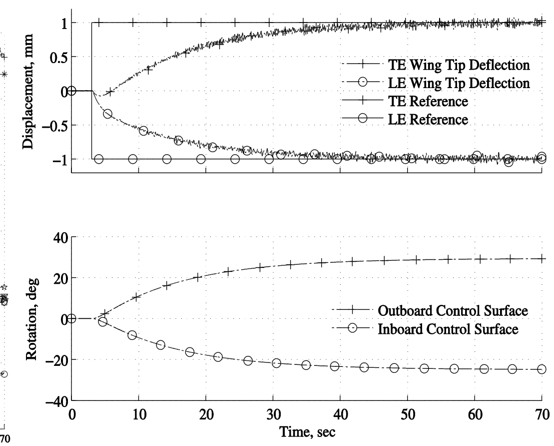
# Achievement of Wing Shape Tracking Control in Simulation with Fiber Optics

- **Perfect deflection tracking achieved in simulation**
  - Small deflections per control surface rotation due to reduced torsional flexibility in the simulation wing
  - Our research confirms flight condition, wing flexibility and control effector locations affect limitations of wing shape tracking control system

## Wing Tip Torsional Reference Tracking

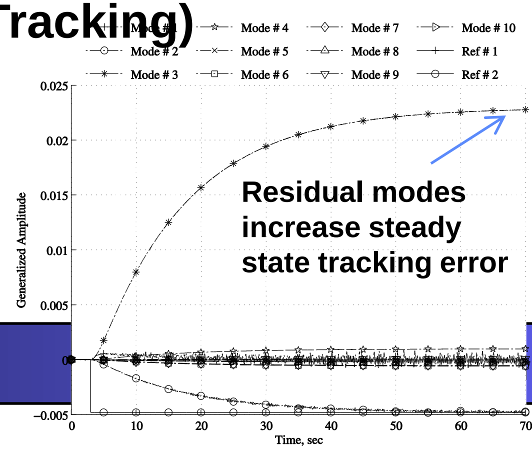



Modes achieve a unique steady state tracking condition

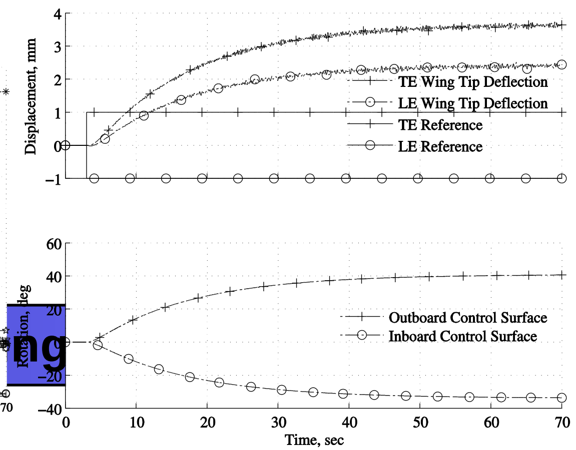



- **Perfect modal tracking achieved in simulation**
  - But residual modes must be suppressed with corresponding control effectors
    - » Demonstrates a need for conformal trailing edge surfaces (and leading edge) and/or smart actuators

## Wing Tip Torsional Reference Tracking (via Modal Tracking)

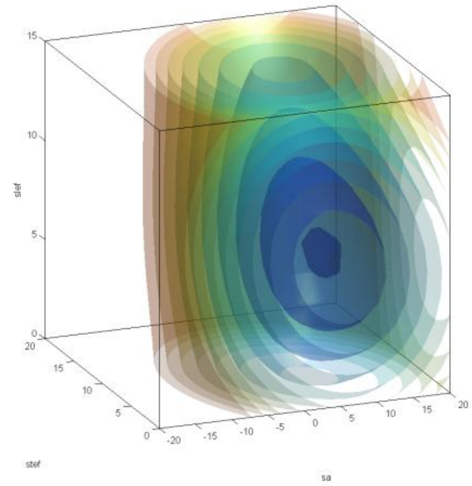


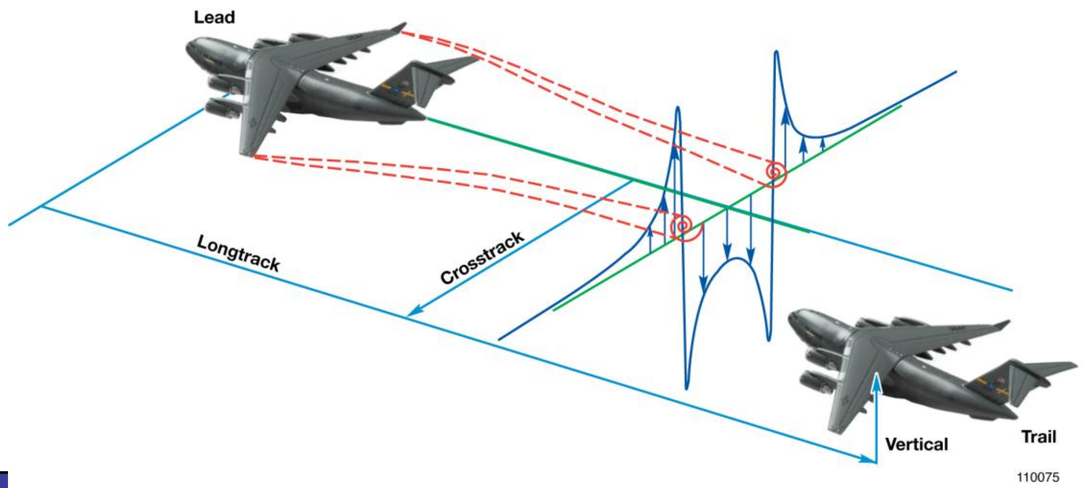

Residual modes increase steady state tracking error



# Fuel savings through optimization

•**Intelligent Control for Performance**



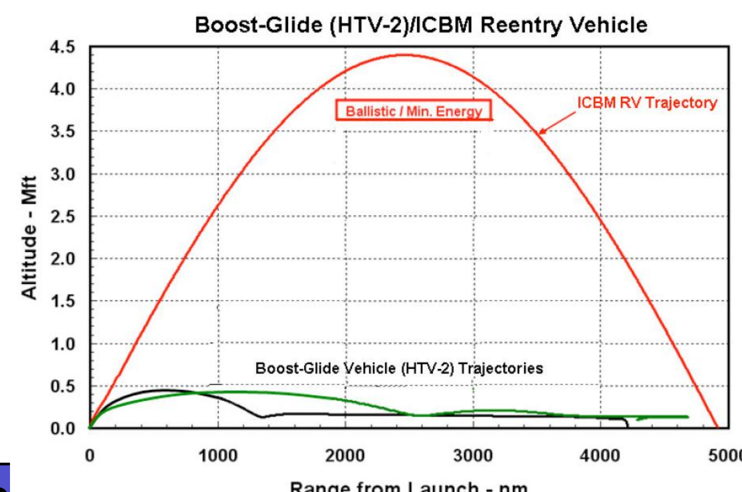



•**Formation Flight**

# Status on other work

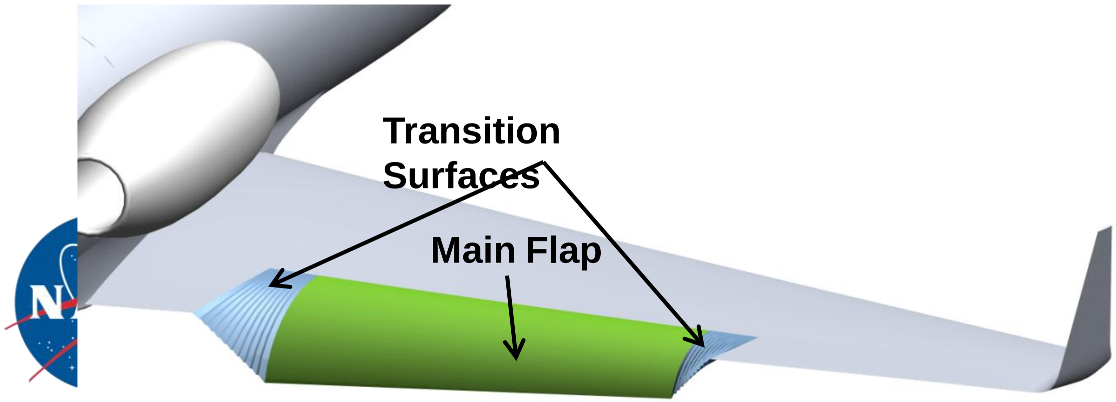
# HTV2 Background

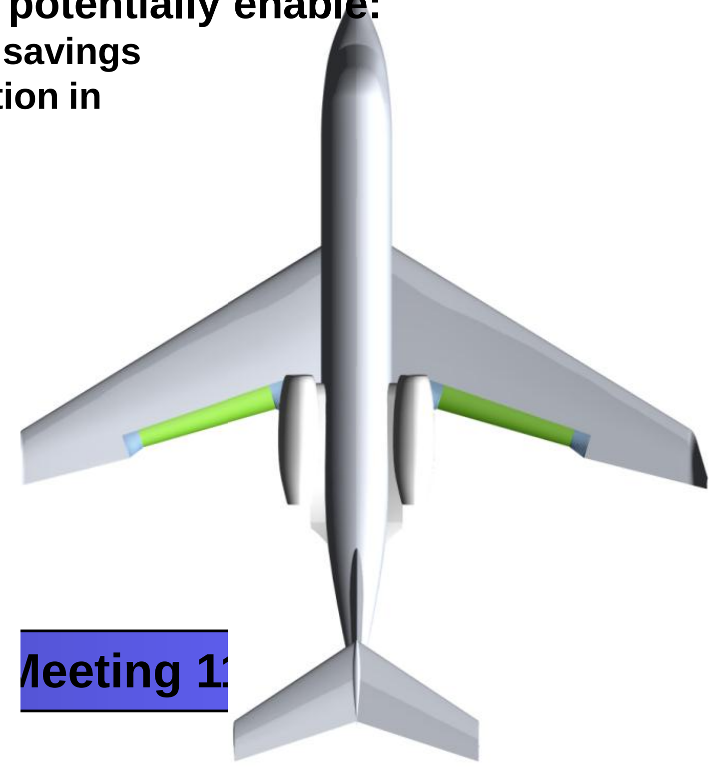
- **Hypersonic Technology Vehicle 2 (HTV-2)**
  - DARPA program to demonstrate:
    - » Boost-glide concept
    - » Hypersonic atmospheric flight technologies necessary for conventional prompt global strike (CPGS), classified
    - » 1500s hypersonic flight time
    - » Research objectives: aero-thermal, GNC, Aerodynamics
  - Flight 1 (April 2010) premature termination
    - » "…applied that data in flight test two, which ultimately led to stable aerodynamically controlled flight"
  - Flight 2 (Aug 2011) premature termination
    - » Ended prematurely due to "unexpected aeroshell degradation"
- **Hypersonic flight is not new, still not easy, unanswered questions remain**
  - "Only actual flight data could have revealed this to us." – Post-flight 2 quote from Darpa PM Major Chris Schulz



# Adaptive Compliant Trailing Edge

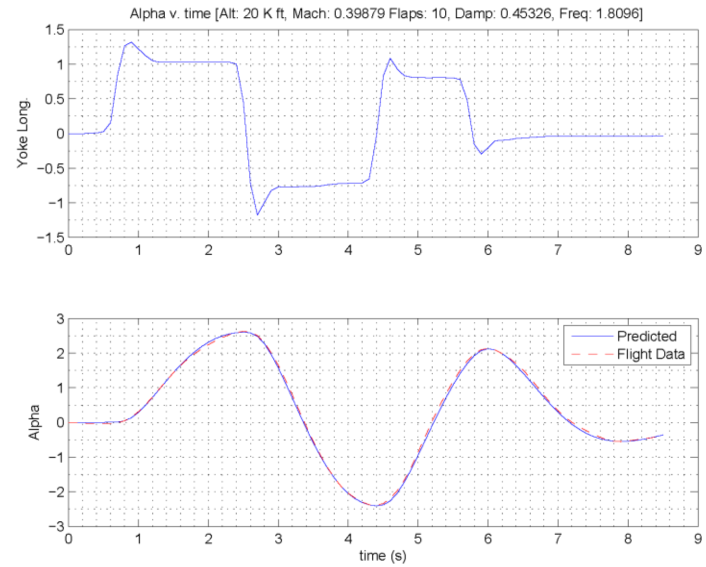
- AFRL is developing Adaptive Compliant Trailing Edge (ACTE) technology
  - Phase 3 SBIR with FlexSys, Inc. to develop a compliant flap for flight research
- Modifications to a Gulfstream III (G-III) are required for flight testing the compliant flap
  - Fowler (standard) flaps will be removed
  - Compliant flap will be installed on both the left and right wings, for aerodynamic symmetry
  - Flight/ground spoilers must be removed to make room for compliant flaps
- Advancing the TRL and integration readiness of compliant structures enables inclusion in the design of next generation aircraft
- Development of compliant structure technologies potentially enable:
  - 3-10% Cruise drag reduction and resulting fuel burn savings
  - 20% Wing weight reduction through a 20-30% reduction in wing root bending moment
  - 4-6 dB Noise reduction during approach & landing
  - Structural load alleviation
  - Increased control surface effectiveness

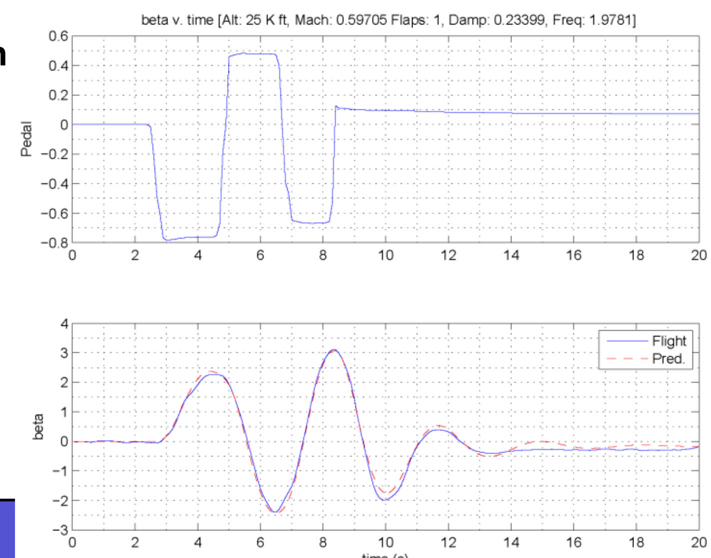


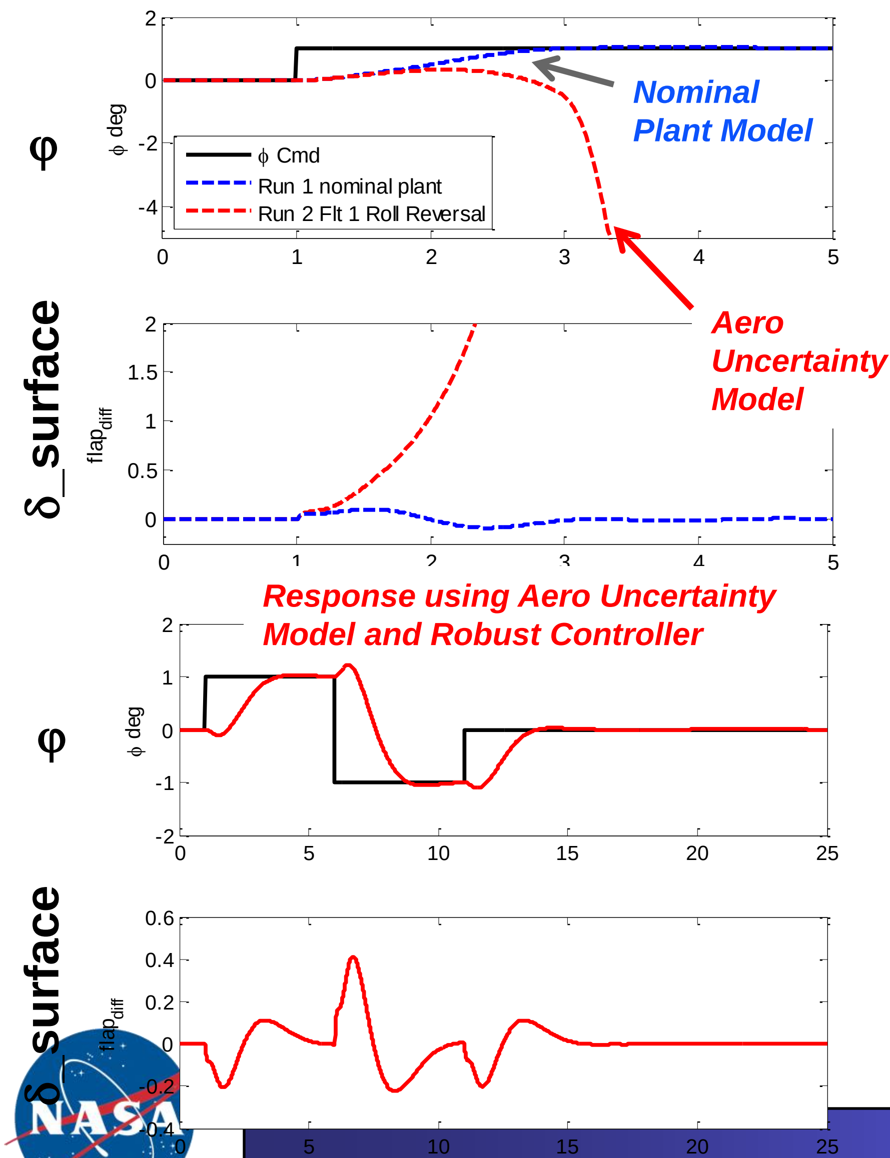
# ACTE Flight Preparations

- Removal of the flight spoilers reduces roll authority by ~50%
  - Approx. ½ of remaining the roll authority is required for nominal safe landing; gusts, ATC directions, etc.
  - Only leaves ½ of roll authority available for ACTE asymmetry, crosswind landings, engine-out control, etc.
- Flight safety assurance requires piloted simulation testing of G-III in the ACTE configuration
- Build-up flight testing and model development
  - Flight testing will be conducted in with an un-modified G-III and a modified G-III with flight spoilers inoperable
  - Baseline and no-spoiler system identification through lower order equivalent systems modeling
  - Baseline and no-spoiler aerodynamic modeling through parameter identification methods
  - ACTE aerodynamic modeling through CFD analysis
- Piloted simulation development progress
  - Hardware has been completed
  - Characterization data has been collected for the un-modified G-III configuration
  - Data reduction and analysis is well underway
  - Initial ACTE aerodynamic model has been developed



# DFRC Role on HTV2




- **Develop non-linear, 6-DOF vehicle simulation capability**
  - **Independent pre-flight GNC assessment (e.g. Monte Carlo)**
  - **3-Dof trajectory validation**
  - **Incorporate thermal model**
    - » **0D and 1D**
    - » **Ablation effects included**
    - » **Thermal stress in structure**
- **Support flight data analysis**
  - **Aerodynamic PID**
    - » **Total forces and moments**
    - » **Stability and control derivatives**
  - **Simulation reconstruction of flight events**
  - **Aero-thermal analysis**
- **Research objectives**
  - **Develop adaptive or robust controller to handle wide range of aerodynamic uncertainty**
  - **Develop real-time, adaptive guidance algorithm to handle thermal and aerodynamic constraints**

# To Fly What Others Imagine …