

X-57 Mod II Ground Vibration Test using LAN-XI Hardware

SAMSON TRUONG, NATALIE SPIVEY, & ROGER TRUAX

NASA ARMSTRONG FLIGHT RESEARCH CENTER – STRUCTURAL DYNAMICS GROUP

Agenda

1. Introduction
2. X-57 Background
3. X-57 Mod II GVT
4. Summary
5. Closing

NASA Armstrong, Edwards Air Force Base, CA



▲ NASA's premier aeronautical research center for flight testing located at Edwards Air Force Base \approx 1.5 hours drive north of Los Angeles

- Year-round flying weather
- Remote location
- Varied topography
- Extensive range airspace
- 29,000ft (8,840m) of concrete runways
- 68 miles (110km) of lakebed runways
- 301,000 acres (1,220km²)
- Supersonic corridor
- US Air Force Alliance



What Does NASA Armstrong Do?

Advancing technology & science through flight

- **Aviation:** Perform flight research & technology integration to revolutionize aviation and pioneer aerospace technology
- **Spaceflight:** Validate space exploration concepts
- **Earth Science:** Conduct airborne remote sensing and science observations



X-57



X-59, Low-Boom Flight Demonstrator



Gulfstream, G-III



F-15



X-56



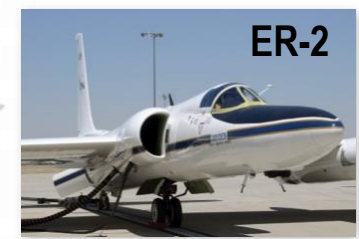
Orion PA-1 Launch Abort System



DC-8



SOFIA



ER-2

Armstrong's Capabilities



Core Competencies

- Flight operations & engineering staff
 - Back shops
- Atmospheric flight research & test
 - Flight safety & risk management
 - Flight project & mission management
 - Flight research technology
 - Flight test operations
 - Experimental aircraft (piloted & unmanned)

Facility Capability

- Experimental & testbed aircraft
 - Self-certification process
- Unmanned aircraft systems
- Airborne science platforms
- Range & aircraft test facilities
 - Dryden Aeronautical Test Range: Control Rooms
 - Research Aircraft Integration Facility: Simulations
 - **Flight Loads Laboratory: Structural Testing**
 - Building 703: Science Aircraft Facility



What is the Flight Loads Laboratory?

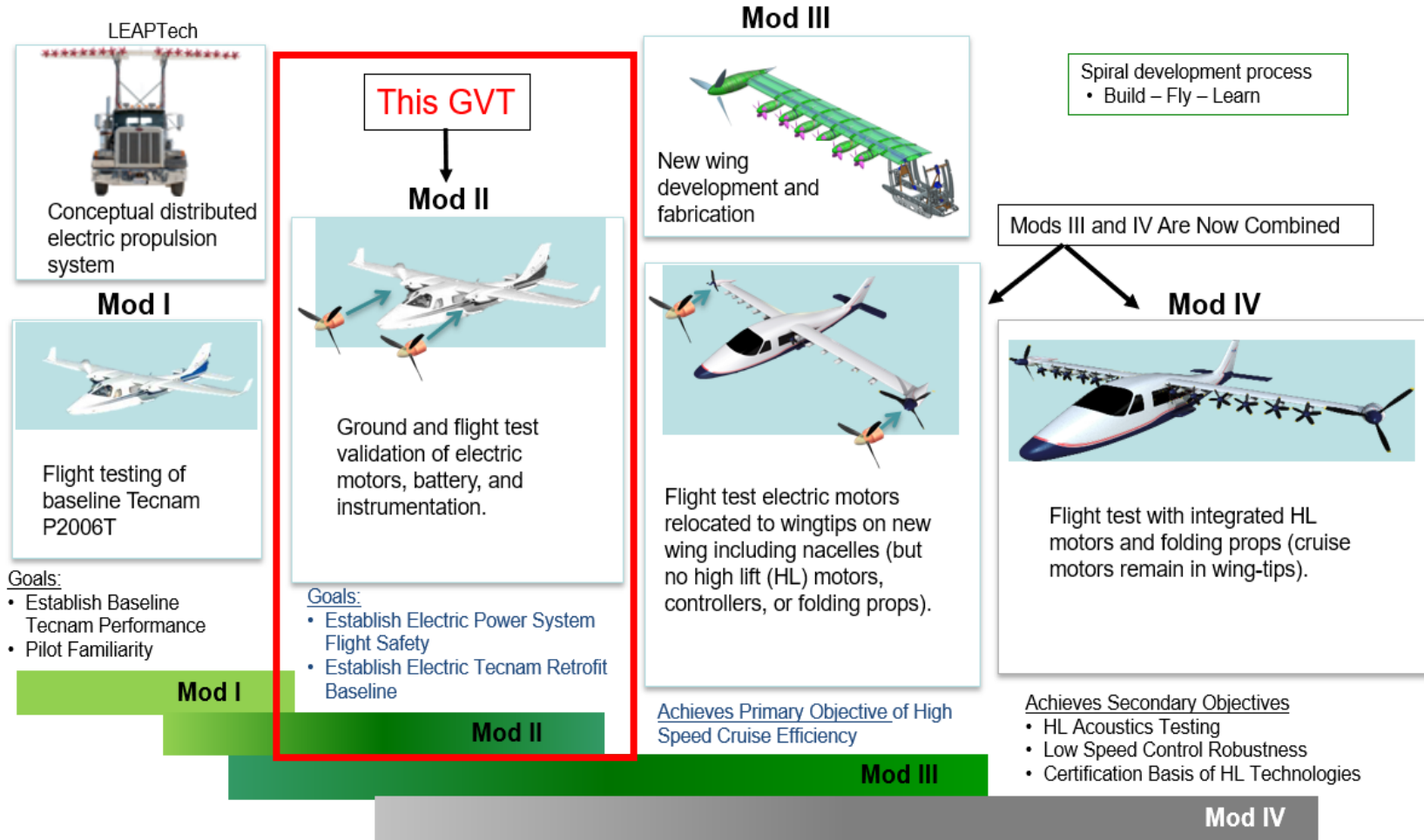
- ▲ Where structures, dynamics & thermal component & airframe qualification/airworthiness & research happens
- ▲ High-bay test area with flight line access for large-scale structural & thermal testing of aerospace structures
 - Floor tie-down tracks, Strongbacks, Test fixture development
 - Structural Instrumentation & Data Acquisition
- ▲ Test Capabilities
 - **Loads:** Proof loading, load calibrations, deflection tests, control surface proof of operations, loads flight test
 - **Dynamics:** Modal test, flutter test, ASE test, freeplay test, mass property test
 - **Thermal:** Thermal and thermal-mechanical test, TPS development and test, pyrometry, SMAs, elastomer aerospace applications, frangible joint evaluations
 - **Sensors:** Conventional, high temperature & advanced instrumentation





X-57 Background

- Ultimate goal of the final X-57 modification is to demonstrate a 500% increase in high-speed cruise efficiency, zero in-flight carbon emissions, and 15 dB reduction in noise levels

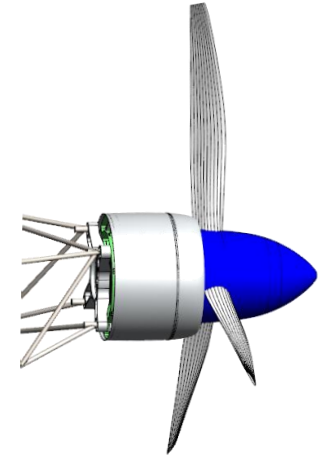




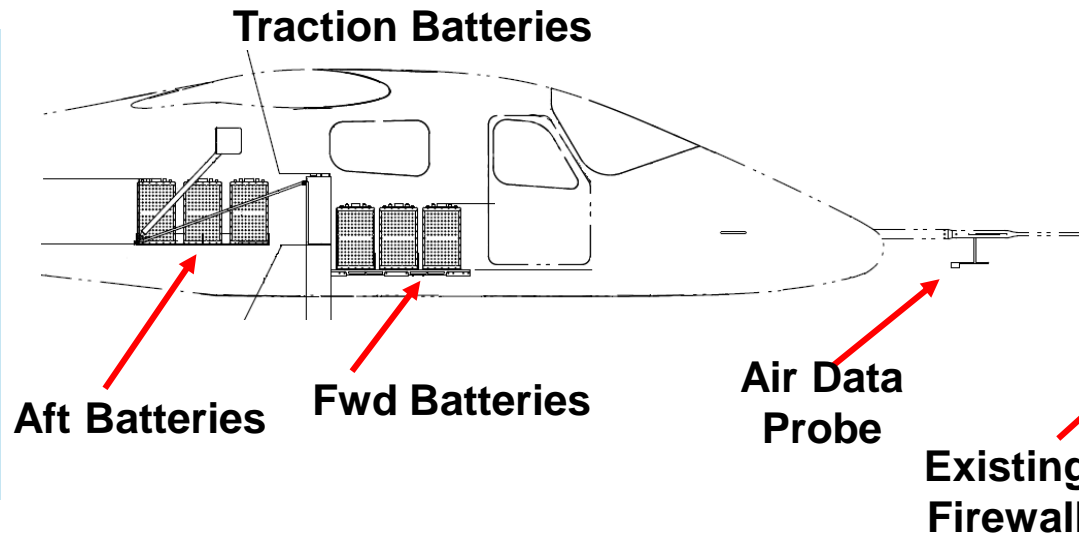
X-57 Mod II Background

- ▲ X-57 Mod II aircraft is the Mod I baseline Tecnam P2006T aircraft redesigned with two electric motors powered by traction batteries
- ▲ Mod II Modifications
 - Added: Cruise Motors/Mounts (adapters, trusses), Propellers/Hubs, Cruise Motor Controllers (CMCs) Traction Batteries and Air Data Probe
 - Electric motors mounted onto motor adapters and truss which has the new CMCs and then mounted onto the existing firewall

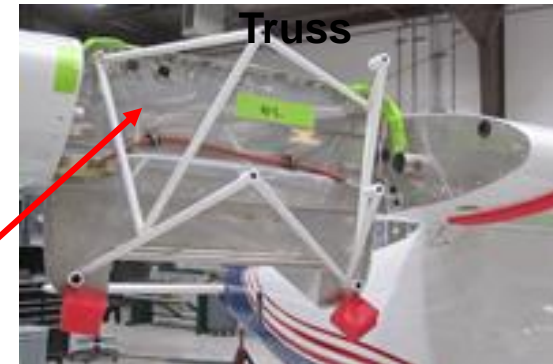
CAD of Motor Mount Truss, Adapter, Motor, Hub, Props & Spinner



X-57 Mod II Aircraft \approx 2,780 lbs



Motor Mount Truss





X-57 Mod II Ground Vibration Test

- ▲ X-57 Mod II Ground Vibration Test (GVT) conducted at NASA Armstrong from Nov – Dec 2019
 - Goal: Gather modal data of a near flight ready configuration to correlate and validate the Mod II aircraft beam finite element model (FEM) to the GVT results
 - Two boundary conditions were tested:
 - **Free-Free:** Aircraft on soft support system to simulate free flight conditions
 - **On-Tires:** Aircraft on-tires to characterize on-ground modes for future aircraft ground motor testing safety clearance and taxi tests

X-57 Mod II GVT, Conducted at NASA Armstrong Fall 2019



Right Electric Cruise Motor





X-57 Mod II GVT – Test Objectives

- ▲ Primary Objective: Capture modes that are part of the aircraft predicted flutter & whirl flutter mechanism

Primary Objective	Reasoning
<ul style="list-style-type: none">▪ Stabilator Rotation▪ Fuselage 1st Vertical Bending (F1VB)	<ul style="list-style-type: none">▪ Modes predicted in pre-test FEM that were part of Classical Flutter Mechanism
<ul style="list-style-type: none">▪ Motor Assembly Vertical Bending▪ Motor Assembly Lateral Bending	<ul style="list-style-type: none">▪ Modes predicted in pre-test FEM that were part of Whirl Flutter Mechanism
<ul style="list-style-type: none">▪ Aircraft Rigid Body Modes	<ul style="list-style-type: none">▪ To characterize soft support system effectiveness

- ▲ Secondary Objective: Capture fuselage lateral bending & torsion modes, wing modes, and landing gear modes
- ▲ Tertiary Objective: Capture higher order wing modes and control surface modes



X-57 Mod II GVT – Test Setup Overview

X-57 Mod II GVT Test Setup on Soft Supports



Nose Gear
Bulkhead Soft
Support

Lt Wing Shaker

A-Frame for Nose Gear Soft
Support

Lt MLG Soft
Support



X-57 Mod II GVT – GVT Equipment

▲ Accelerometers (100 mV/g)

- PCB T356A16 triaxial accels
- PCB T333B32 uniaxial accels
- PCB T333B uniaxial accels

PCB T356A16
Triaxial Accel



PCB T333B32
Uniaxial Accel



PCB T333B
Uniaxial Accel



▲ Excitation System

- Shaker: MB Dynamics Electromagnetic Modal 110, 3 qty

MB Modal 110 Shaker



▲ Data Acquisition: Brüel & Kjær LAN-XI DAQ

- Mainframes – Daisy chained together thru network switch
 - LAN-XI 11-slot Main frame, 2 qty
 - LAN-XI 5-slot Main frame, 2 qty
- Modules - Capable of recording 344 channels
 - LAN-XI 4-ch Input + 2-ch Output 3160 Modules, 2 qty
 - LAN-XI 12-ch 3053 Modules, 27 qty
 - LAN-XI 6-ch 3060 Modules, 2 qty



B&K LAN-XI Main Frame



LAN-XI Module

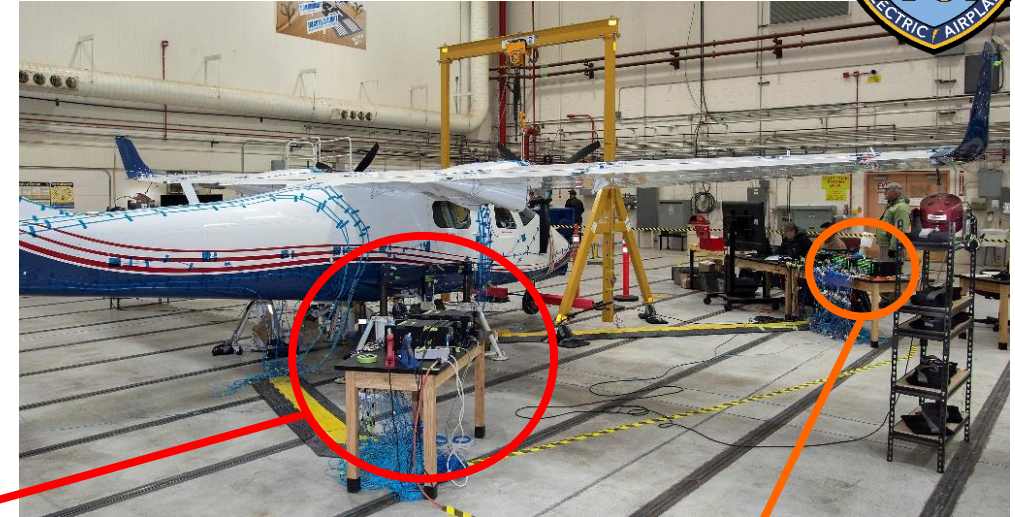
▲ GVT Software: BK Connect



X-57 Mod II GVT – LAN-XI DAQ Setup

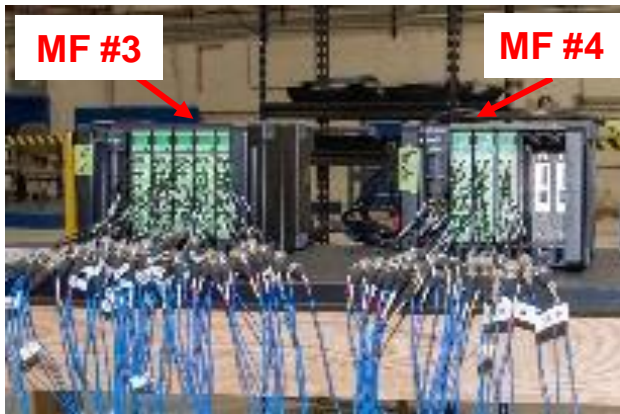
LAN-XI DAQ frontend setup: Four mainframes (two 11-slot & two 5-slot) capable of driving 4 shakers & recording 344 channels with network switch daisy chaining modules

- Fwd aircraft setup
 - MF#1: two source module (3160) & nine 12-channel input module (3053)
 - MF#2: eleven 12-channel input module (3053)
- Aft aircraft setup
 - MF#3: five 12-channel input modules (3053)
 - MF#4: three 12-channel input modules (3053)

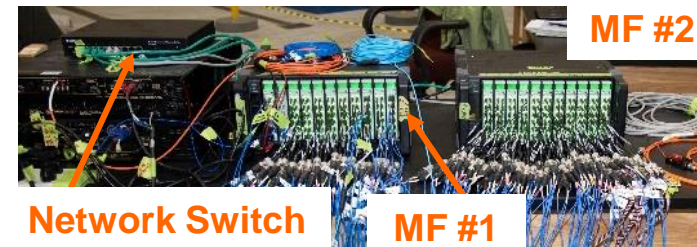


LAN-XI DAQ Aft Aircraft Setup

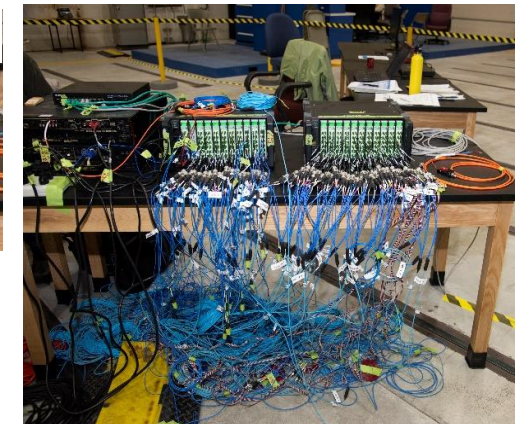
LAN-XI DAQ Fwd Aircraft Setup



For MLG soft support & aft aircraft accels



For fwd aircraft accels & A-frame





X-57 Mod II GVT – Shaker Setup



Motor Prop Hub



Aft Fuselage



Right Wingtip



Vertical Tail



Main Landing Gear



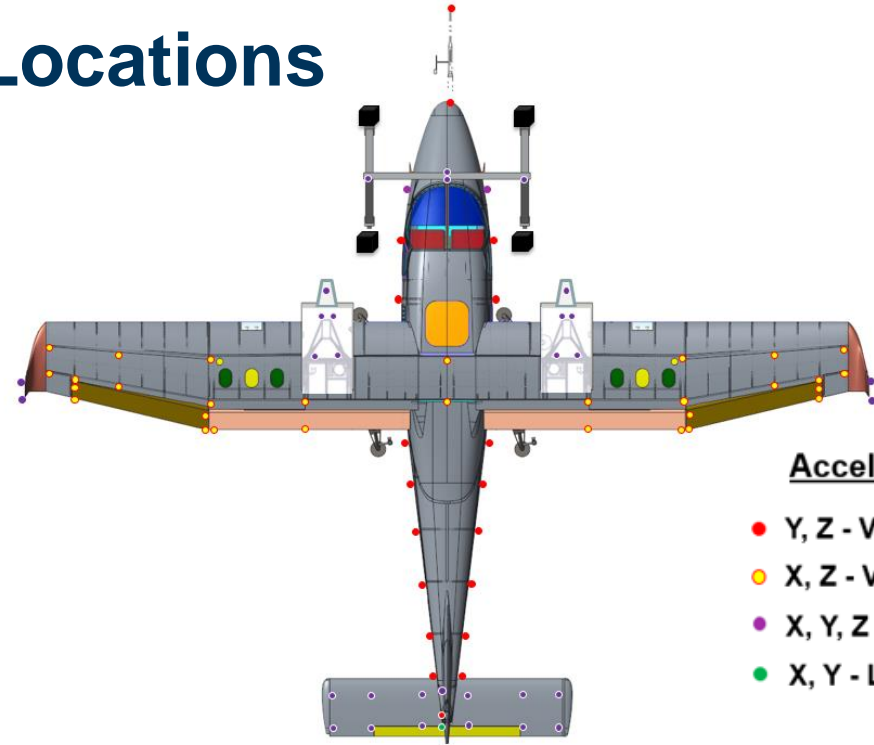
X-57 Mod II GVT – Accelerometer Locations

Free-Free

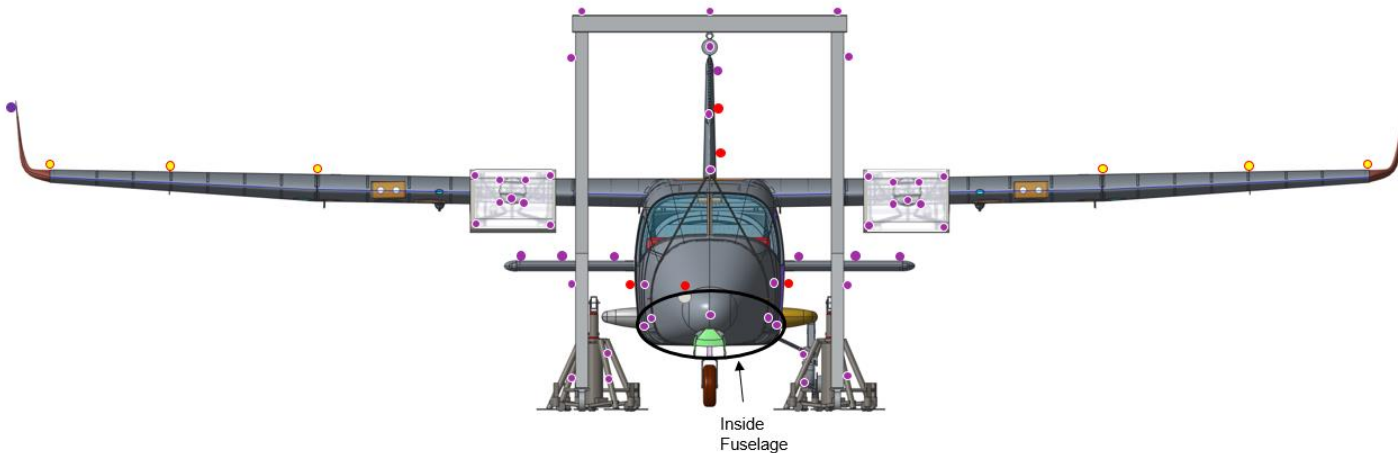
- 127 accelerometer locations measuring 318 degrees of freedom (DOF)

On-Tires

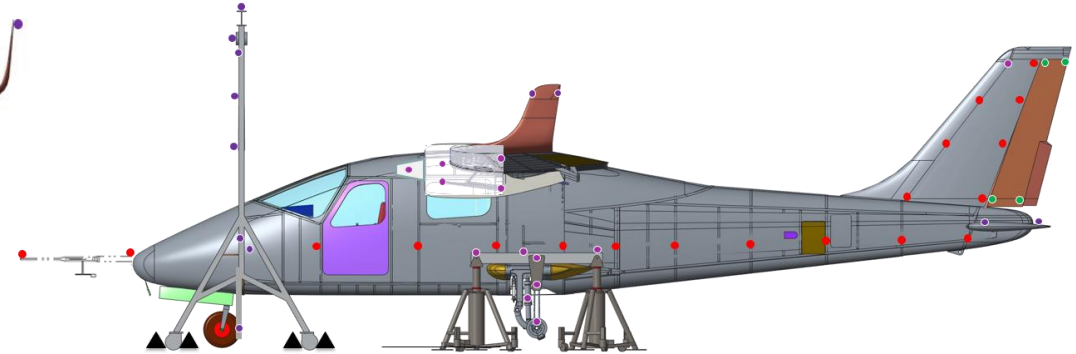
- Soft support accelerometers removed
- 113 accelerometer locations measuring 276 DOF



X-57 Mod II GVT Accel Locations (Top View)



X-57 Mod II GVT Accel Locations (Front View)



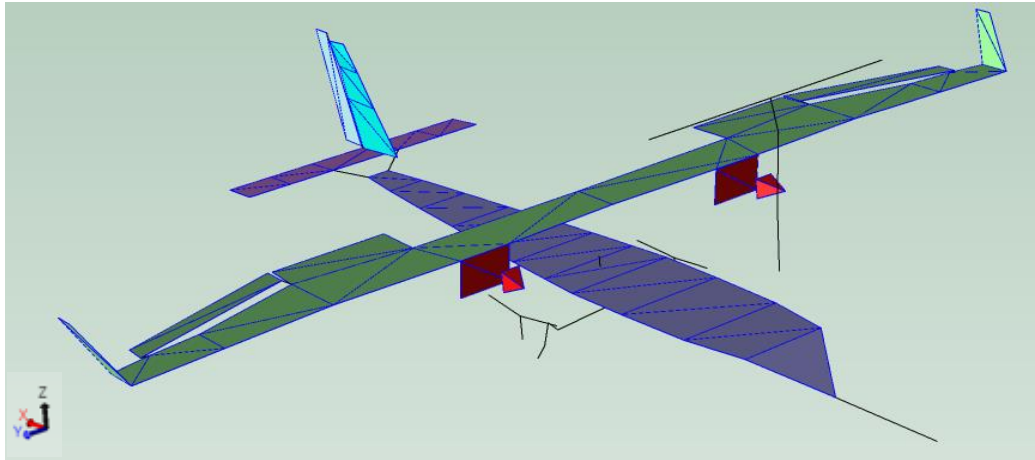
X-57 Mod II GVT Accel Locations (Lt Side View)



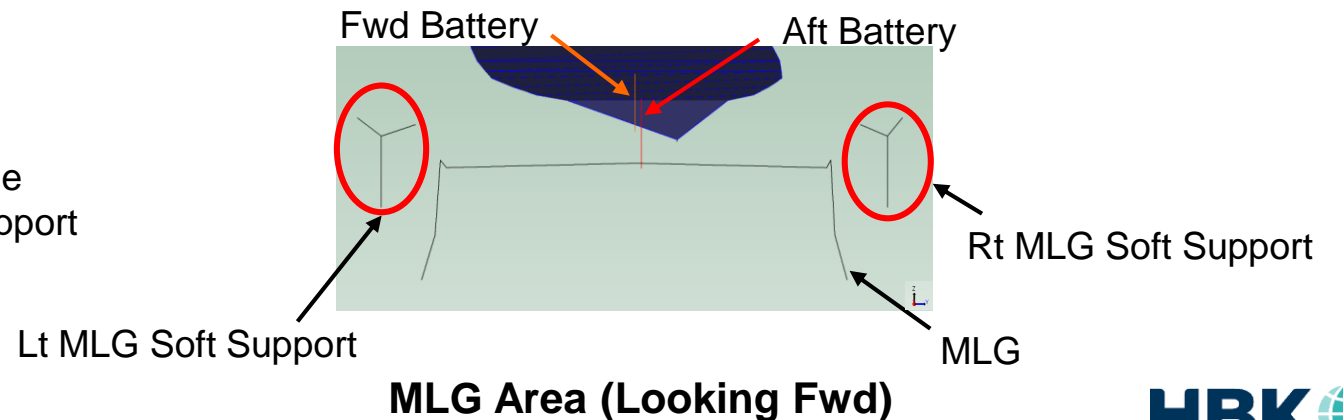
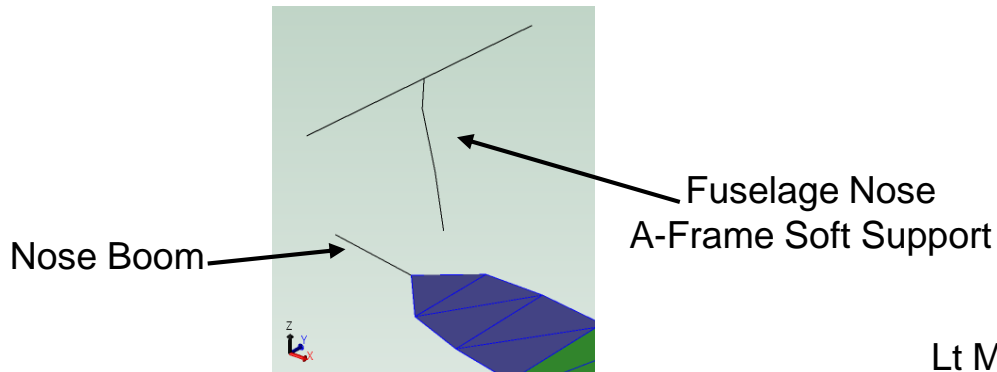
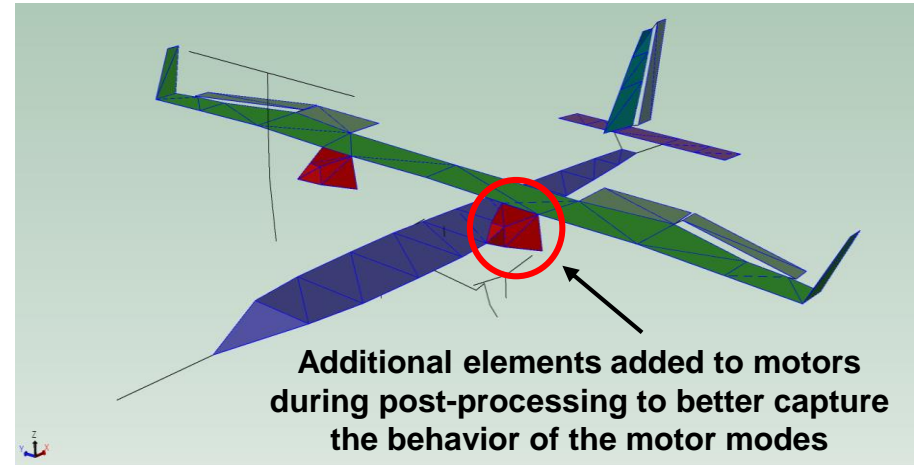
X-57 Mod II GVT – Test Display Model

- Test Display Model (TDM) was created in BK Connect using a combination of quad & triangular elements and trace lines for Nose Boom, MLG, Fwd/Aft Batteries & A-Frame

X-57 Mod II Aircraft GVT Model

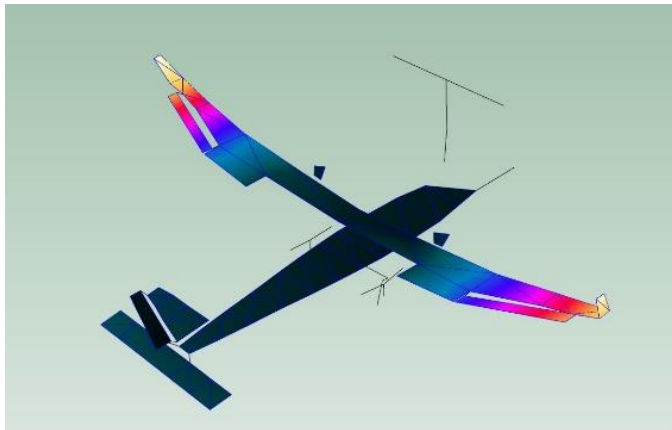


Motor Model Modified Post-Test

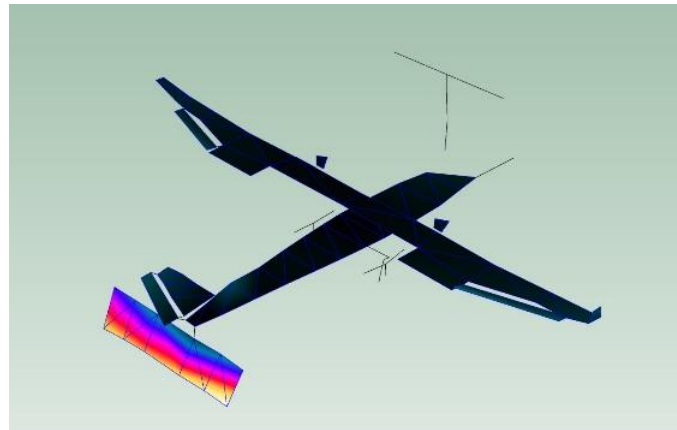


X-57 Mod II GVT – Post-Processing Results Summary

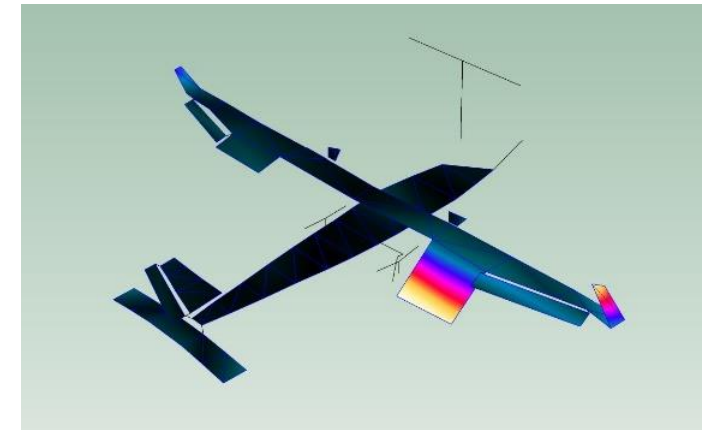
- ▲ GVT results processed in BK Connect with different parameter estimation techniques
- ▲ Asymmetries were seen between the left and right sides of the vehicle, particularly in the control surfaces, and were seen in all of the test configurations
- ▲ GVT modes for On-Tires setup do not necessarily follow the order in the Free-Free setup, with several of them not observed or missing
- ▲ Several modes from the Free-Free setup are coupled together in the On-Tires setup case



Sym Wing 1st Bending (SW1B)



Stabilator Rotation



Sym Flap Rotation



X-57 Mod II GVT – Hardware & Software Summary

Challenge

- BK Connect software
 - Learning how to use software effectively & efficiently
 - Stability issues with software
 - Ability to handle large channel counts (300+) & large quantities of data efficiently
 - NASA's required weekly IT computer updates cause can unexpect issues with software

Solution

- Need for BK Connect to be able to manage and handle multiple large test data runs with high accelerometer channel count

Benefit

- LAN-XI hardware
 - LAN-XI DAQ setup is extremely fast & more reliable compared to other GVT DAQ systems
 - Flexibility of using of how to use the LAN-XI modules and/or mainframes daisy chained through network switches
 - Front panel lighting feature allows for quick assessments of channel status
- BK Connect software
 - BK Connect user-friendly interface allows for quick data quality check & visualization of mode shapes between test runs
 - Hardware browser is helpful and allows quick visual insight



Thank You!



Thank You

<https://www.nasa.gov/centers/armstrong/home/index.html>