F/A-18 Strain Gage Loads Calibration Test

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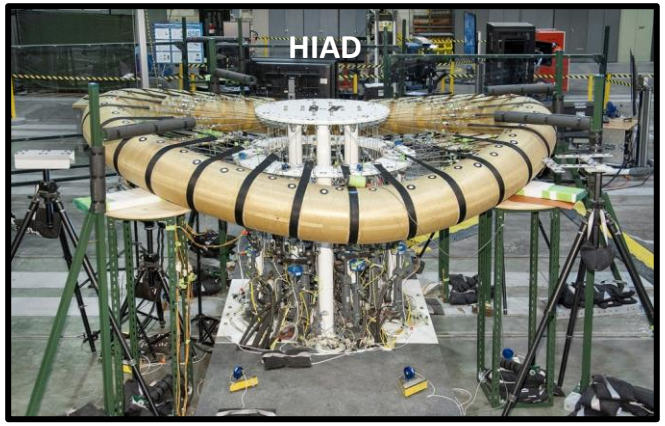
Outline

- Background
- Test Article
- Project Review Process
- Test Requirements
- Instrumentation
- Test Setup Design
- Load Pad Design
- Load Pad Bonding
- Overall Test Setup
- Test Execution
- Equation Derivation
- Summary and Conclusions

Background

- NAVAIR requested NASA Armstrong Flight Research Center to calibrate strain gages on an F/A-18E
  - Wings
  - Vertical Tails
  - Horizontal Tail Spindles
- Correlate known applied loads to strain gage output
- Provide real-time loads information during flight testing

AFRC Flight Loads Laboratory







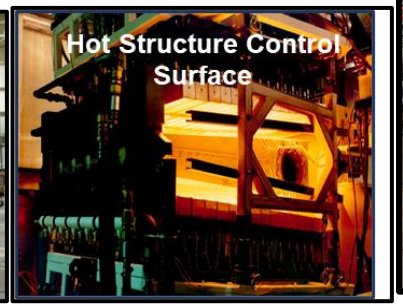


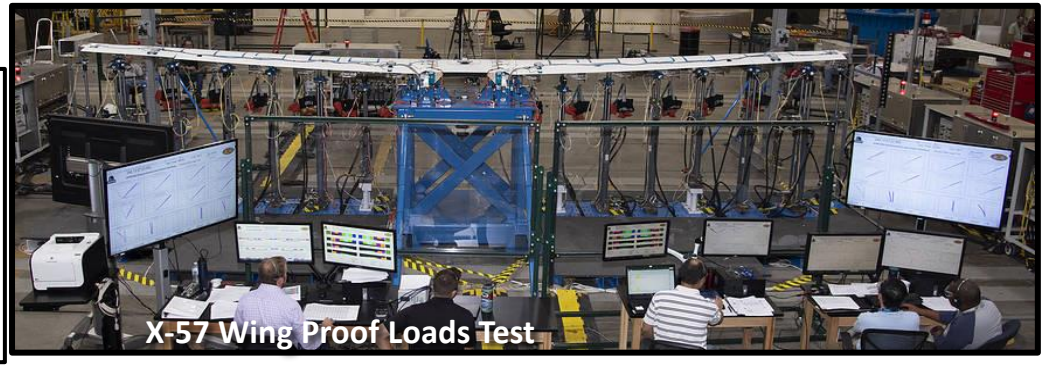














F/A-18E Test Article



Photo Source https://www.navair.navy.mil/product/FA-18EF-Super-Hornet

Flight Loads Lab Project Review Process

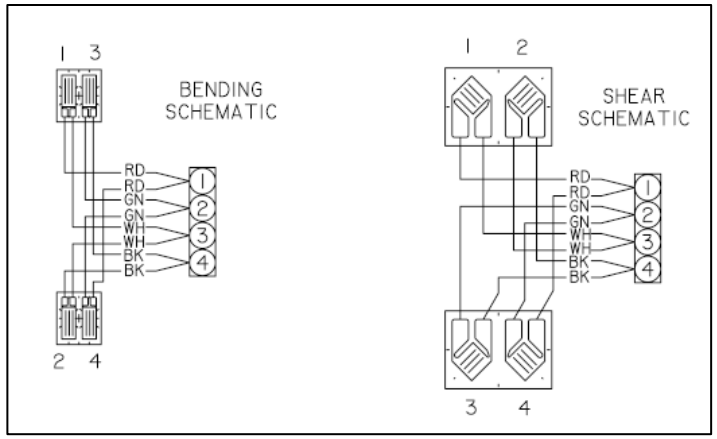
- Requirements Review
- Preliminary Design Review
  - Initial review of test setup and test approach
- Critical Design Review
  - Final review of test setup hardware design and analysis
  - Test approach review
- Test Readiness Review
  - Detailed review of test approach (test plan, checklist)
  - Hazard analysis
  - Test setup inspection

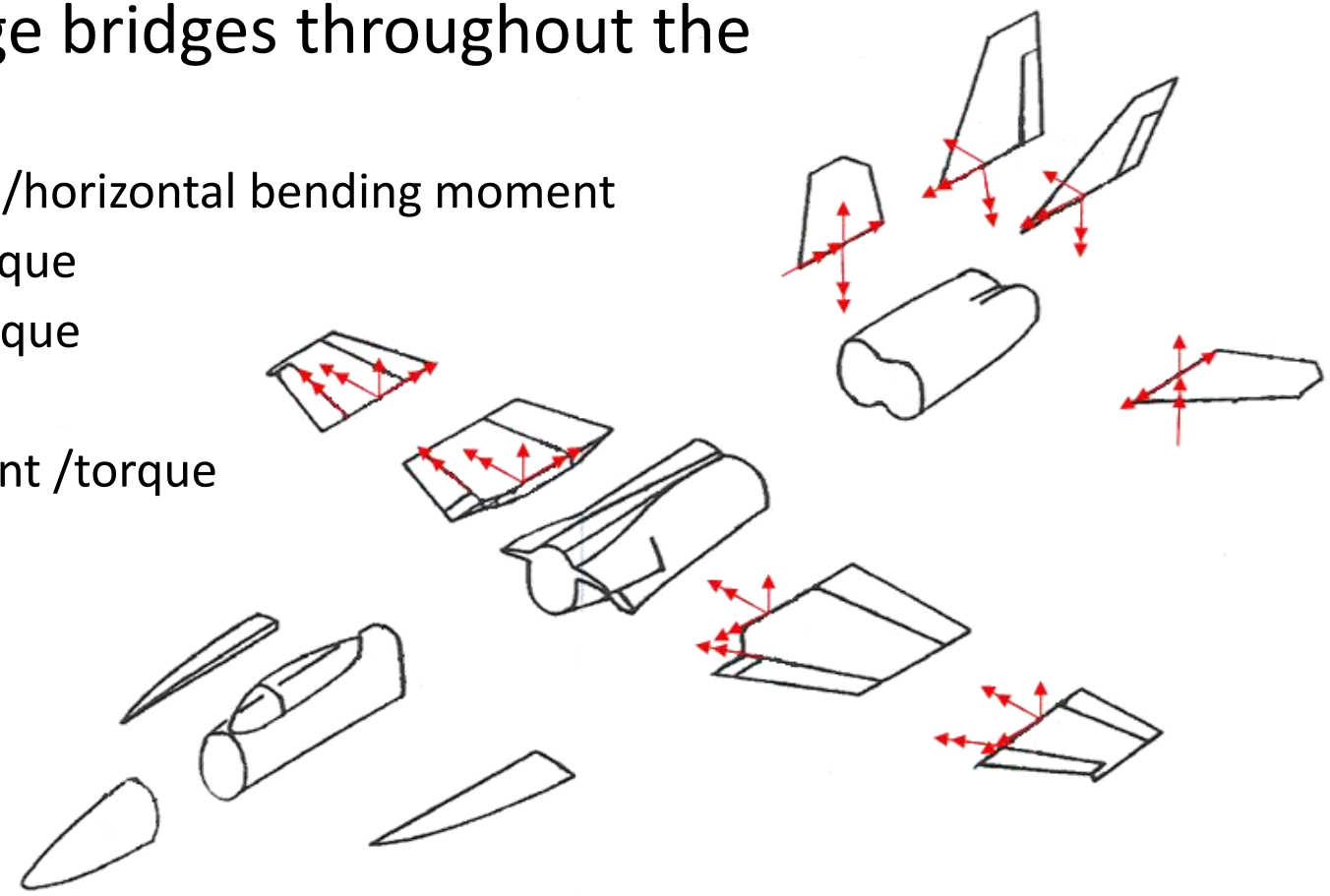
Test Requirements

- AFRC recommended test to 60% of airframe design limit load (DLL)
  - Adequate when
    - Strain gages are installed at proper locations
    - Sufficient number of load cases with varying loading direction/center of pressure
  - Tests above 60% DLL increases risk to test article with limited benefit
- Execute 87 load cases prescribed by NAVAIR
  - 11 spindle
  - 62 wing (wing box, control surfaces, pylon)
  - 14 vertical tail
  - Minimum of 2 cycles per load case
- Derive loads equations (spindle, wing, vertical tail)
- Deflection measurements for wings, vertical tails, and fuselage
- Measure reaction loads at aircraft restraining points

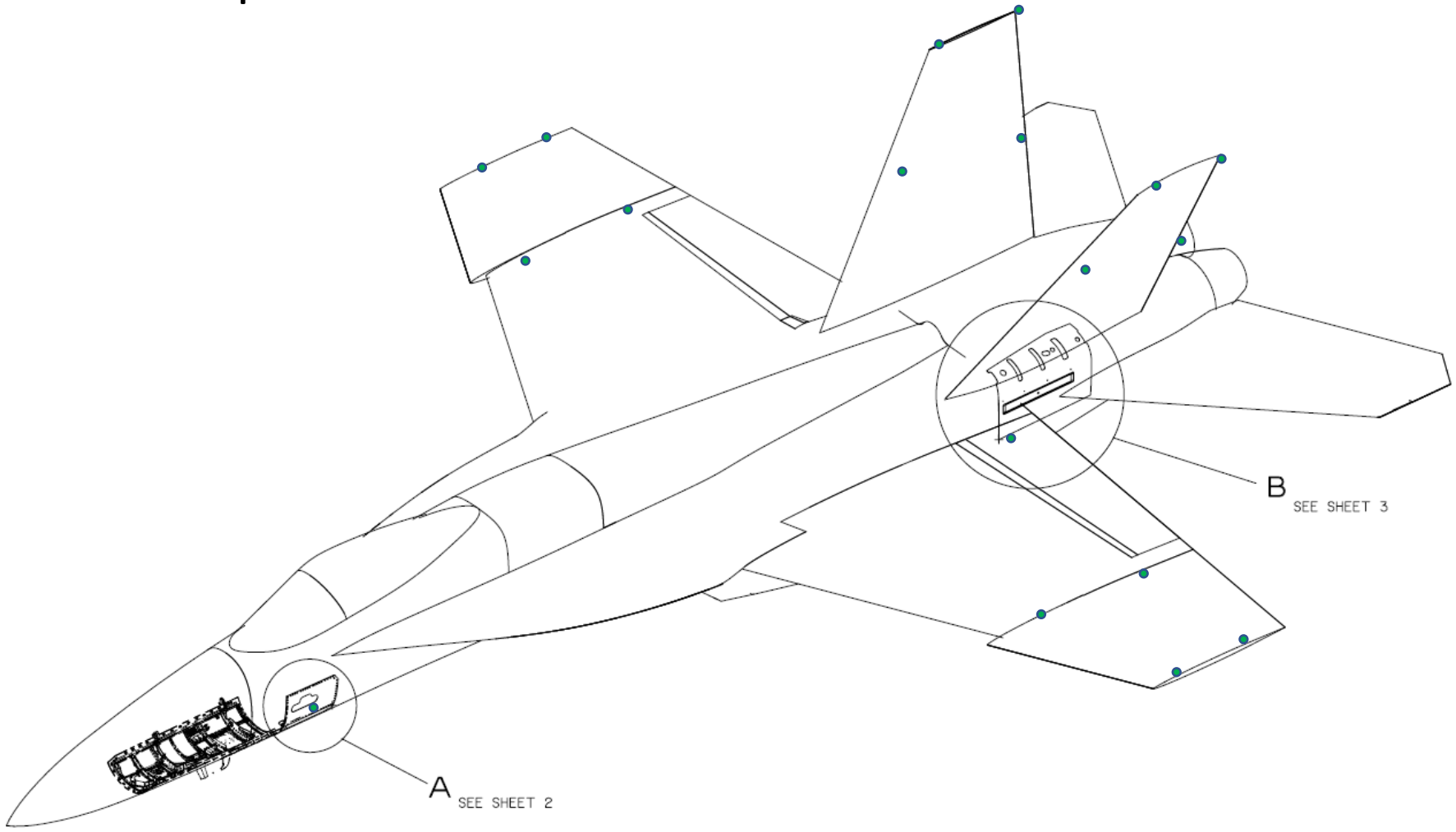
Instrumentation
Strain Gage Bridges

- NAVAIR pre-installed strain gage bridges throughout the aircraft
  - Horizontal tail fore/aft shear & vertical/horizontal bending moment
  - Wing root shear/bending moment/torque
  - Wing fold shear/bending moment /torque
  - Wing leading edge flap hinge moment
  - Vertical tail root shear/bending moment /torque



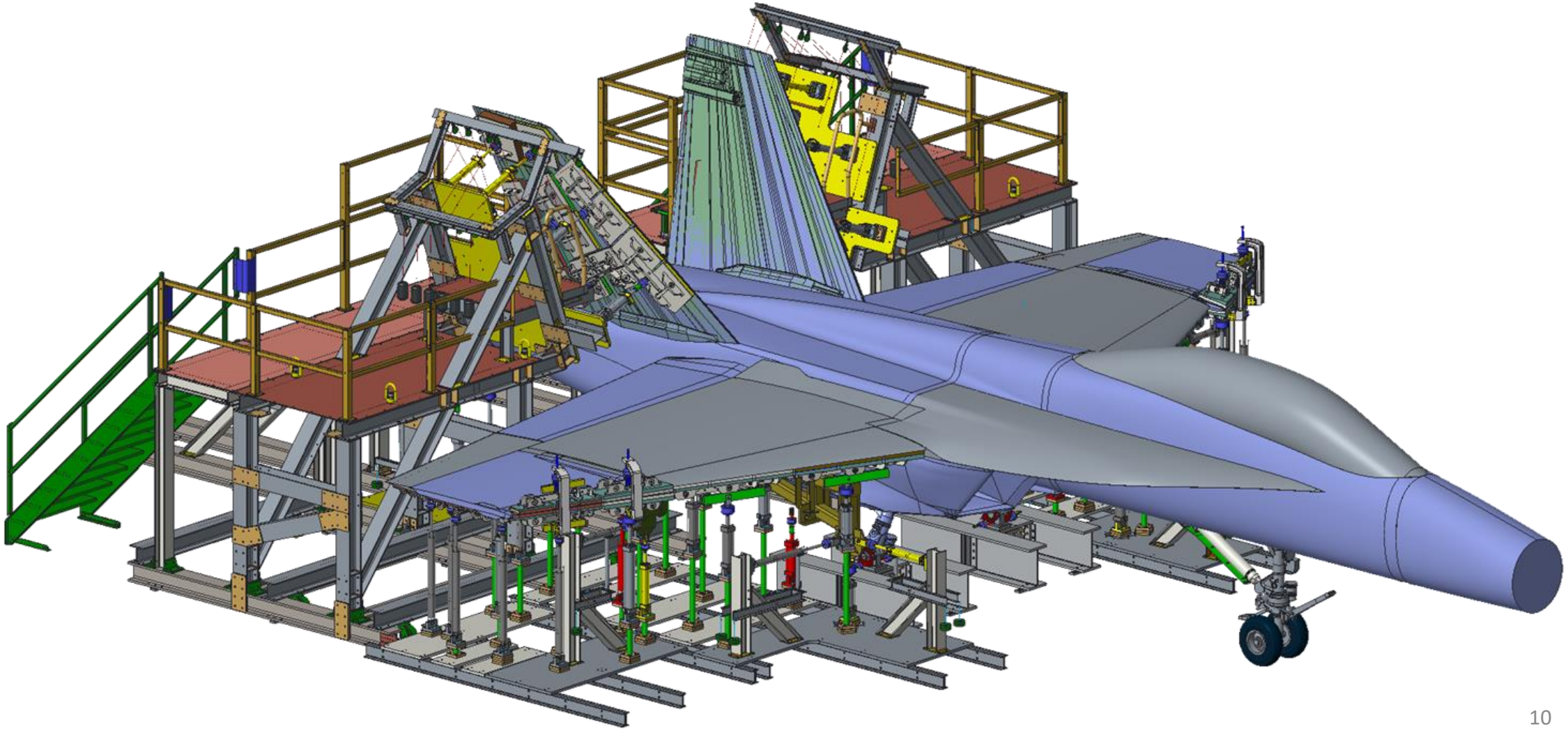


Instrumentation
Displacement Measurement Locations

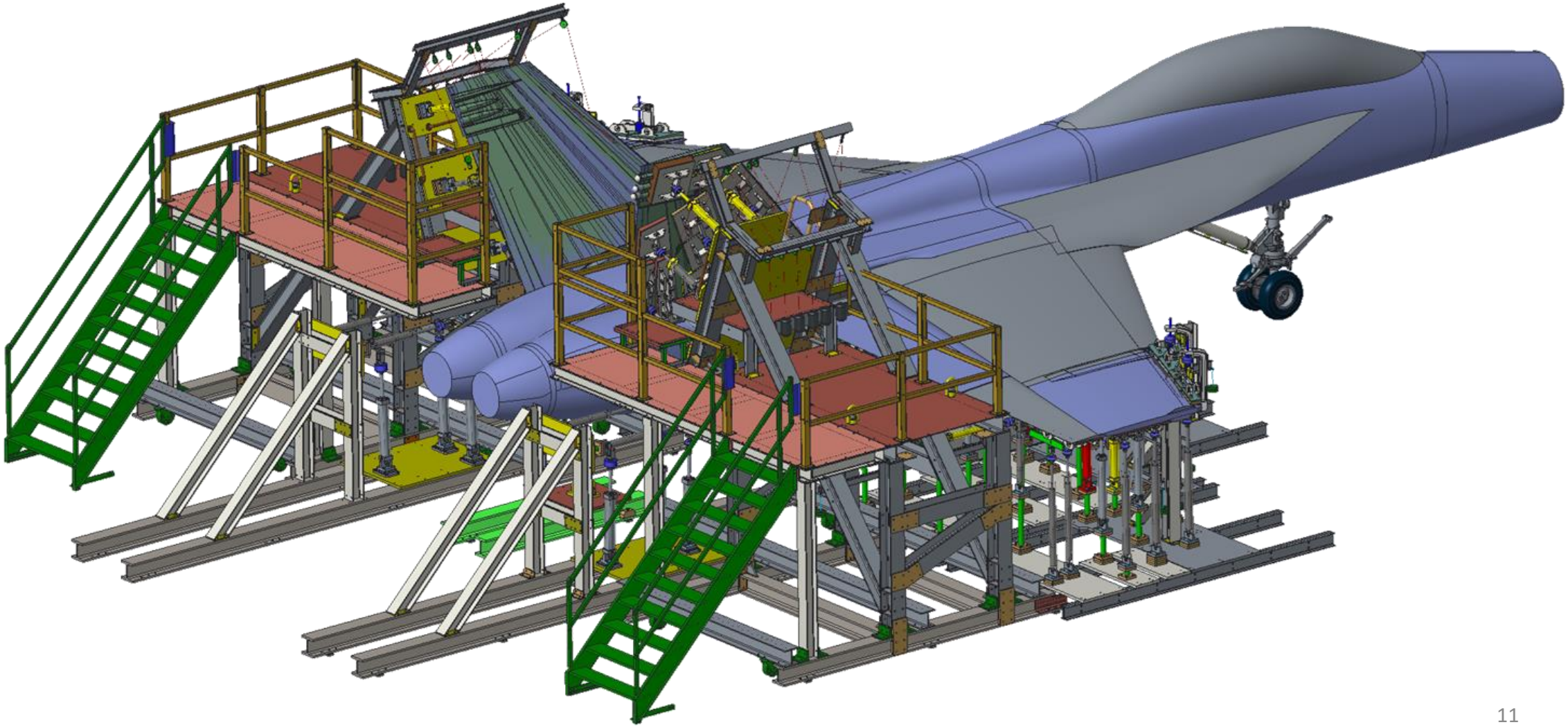


String Potentiometer Locations

Test Setup: Design



Test Setup: Design (cont.)

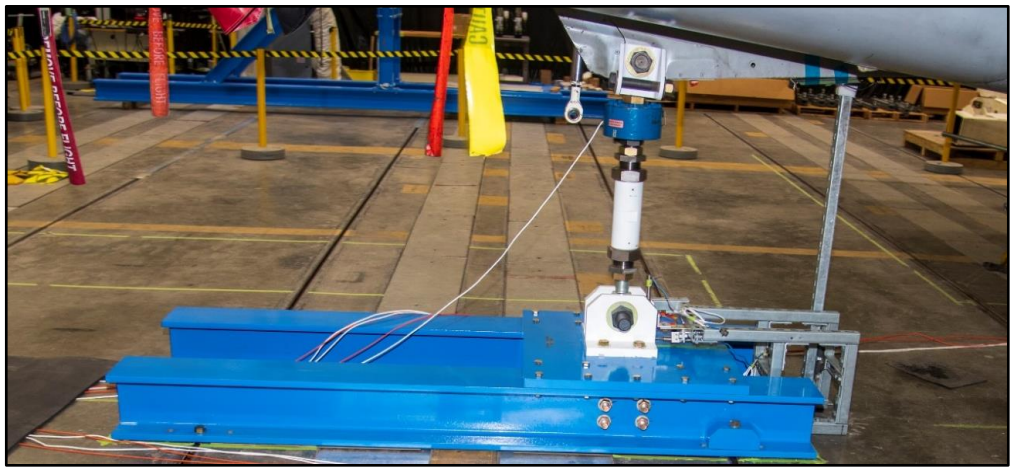


Test Setup: Restraining the Aircraft

- Applied loads exceeded aircraft weight
- Secured aircraft to floor tracks
- Attached to main landing gear trunnions and arresting hook fitting
- Restraining hardware
  - Designed to factor of safety of 3.0 against ultimate strength
  - Mild steel/Grade 8 bolts in most places
- Minimized constraints to allow aircraft to flex

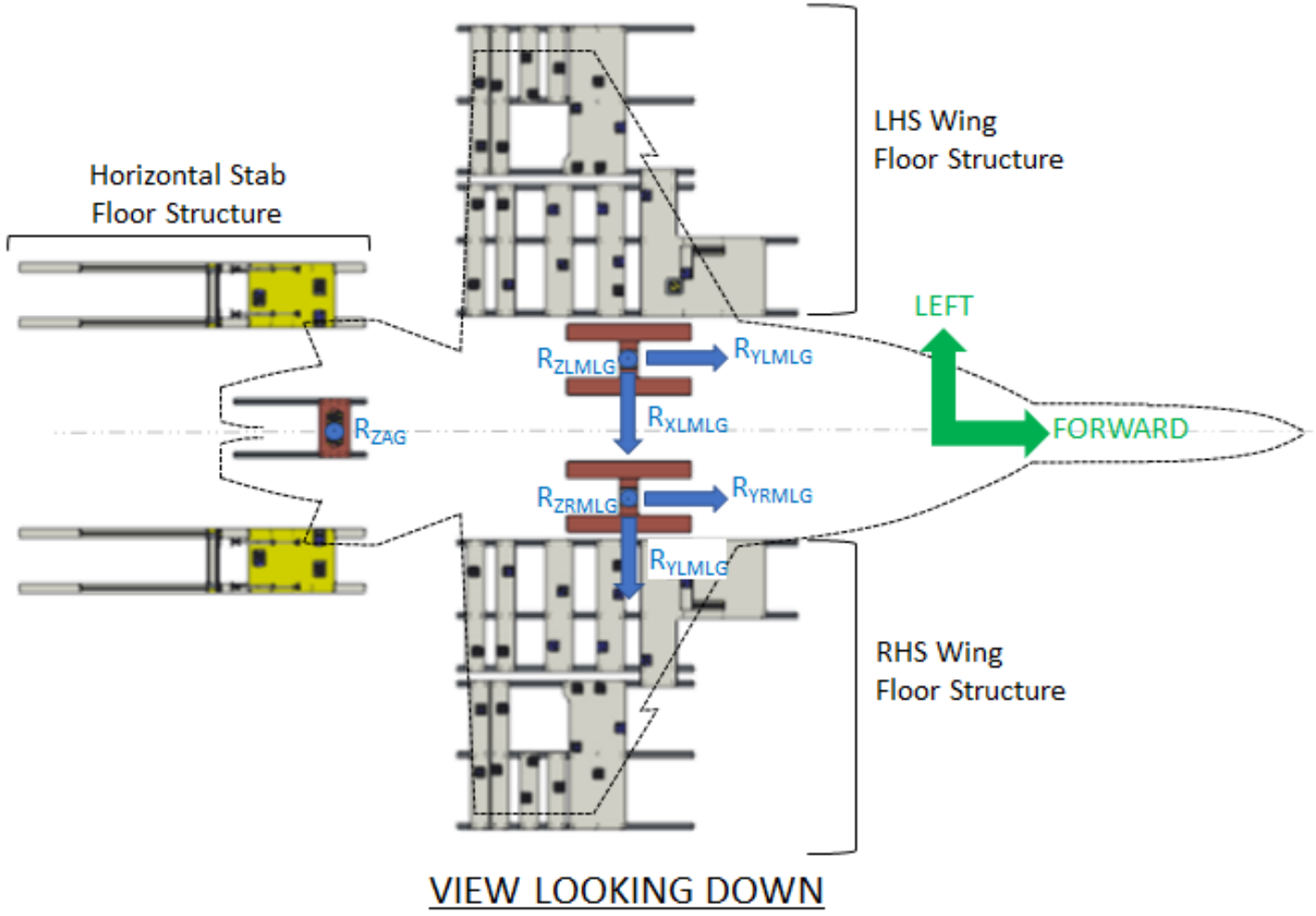


Restraint at Main Landing Gear
(AFRC2021-0098-013)



Restraint at Arresting Hook Fitting
(AFRC2021-0098-007)

Test Setup: Aircraft Constraints

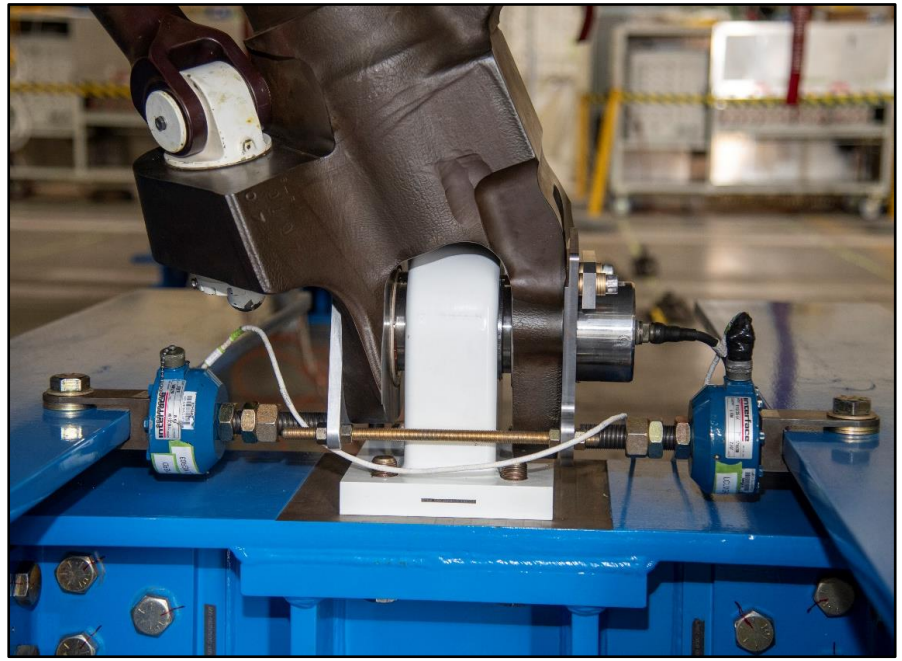




Floating Nose Gear with Loose Chains

Test Setup
Attaching Aircraft to Restraining Hardware

- Towed aircraft within 0.5” of designated location
- Restraining hardware marked and match drilled
- Lowered aircraft jacks to transfer aircraft weight to restraining hardware
- Tight tolerances to prevent shift during test
- Placed reaction load measuring instrumentation
  - Load cell for vertical load at arresting hook fitting
  - Load cells for side load at MLG
  - Dual axes load pin for vertical and longitudinal loads at MLG



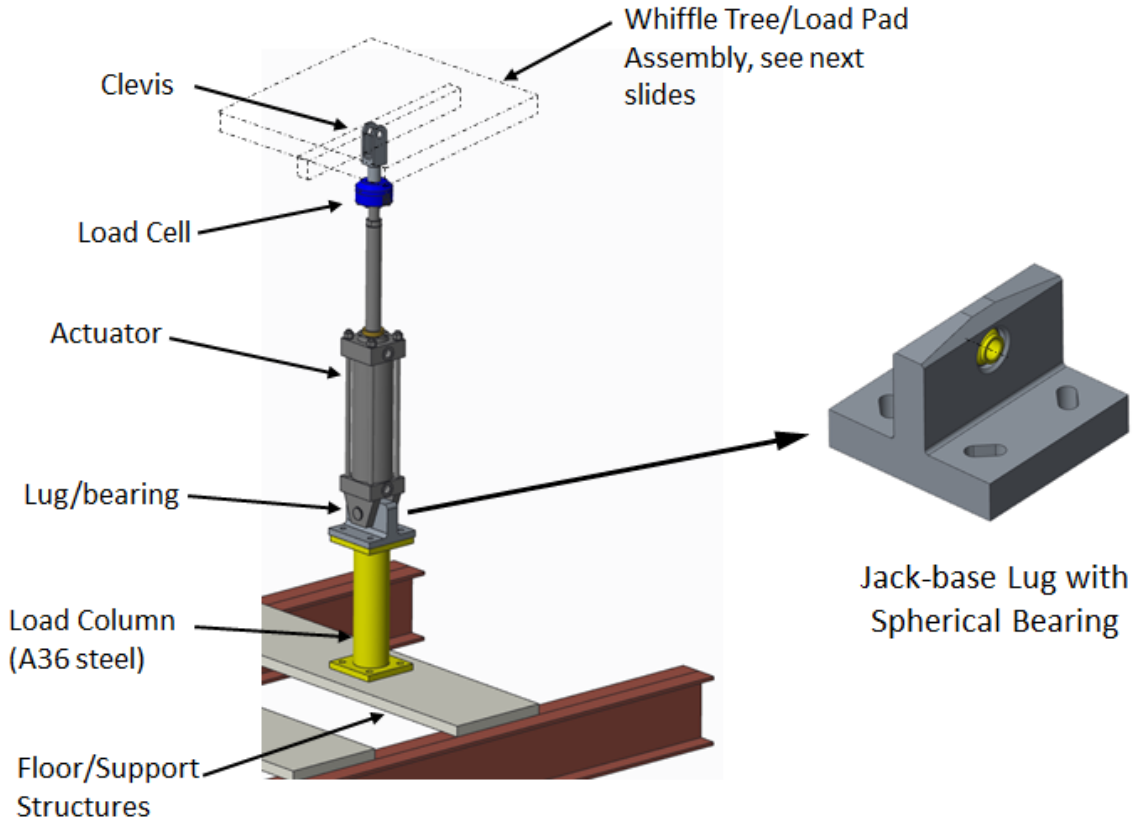
Instrumentation at Left Main Landing Gear Attachment (AFRC2021-0098-094)

Test Setup
Instrumentation for Situational Awareness

- String potentiometer at several locations
- Linear variable differential transformers on restraining hardware
- Cameras
  - Overall test setup
  - Focused on critical locations

Test Setup: Load Trains

- Load trains applied load to the test article
- Load trains fixed to ground hardware
- Load trains included a hydraulic actuator, a load cell, and various interface hardware to apply loads evenly onto the aircraft
  - Whiffle trees
  - Jack base
  - C-loader
- Actuator selection a balance between
  - Predicted deflection (required usable range)
  - Buckling strength
  - Diameter (required load)
  - Available hydraulic fluid in the reservoir

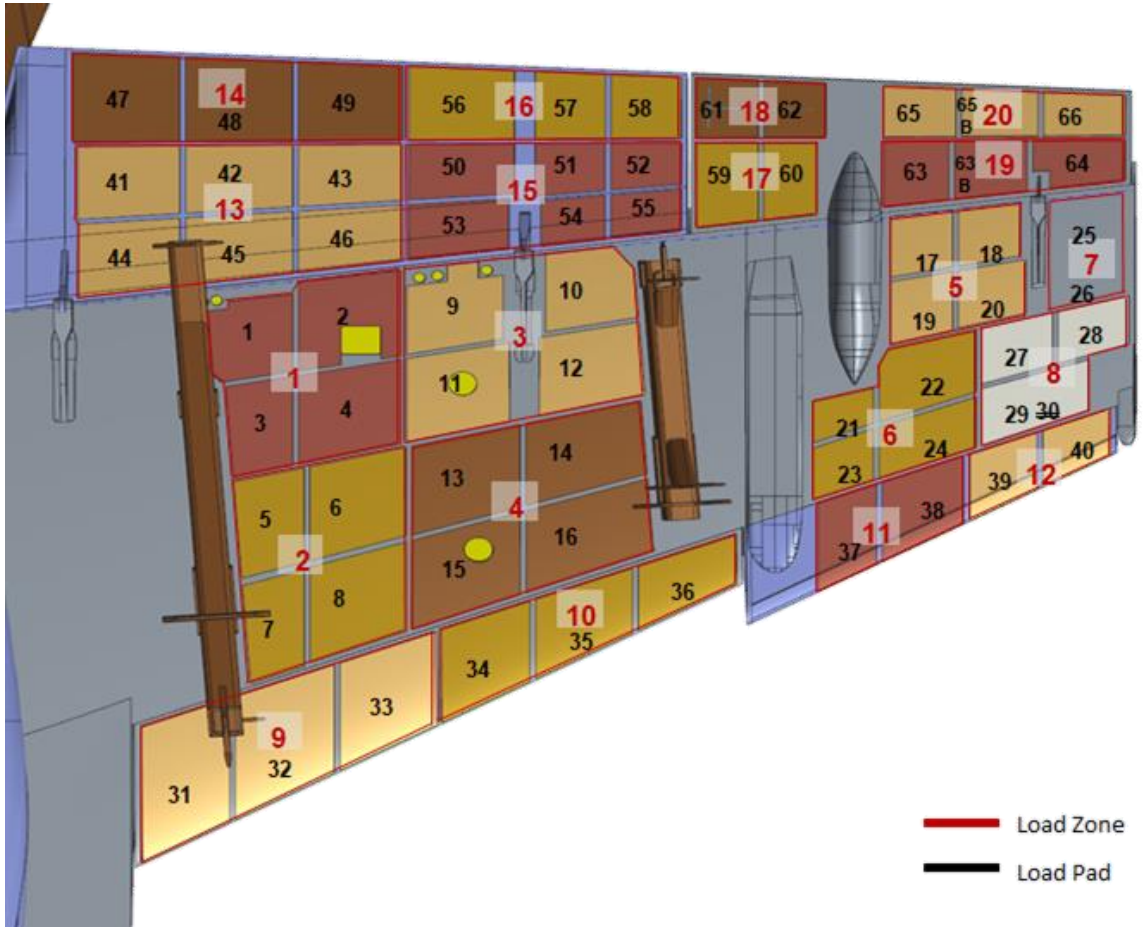


Load Train Components

Load Pad Design
Zone Layout

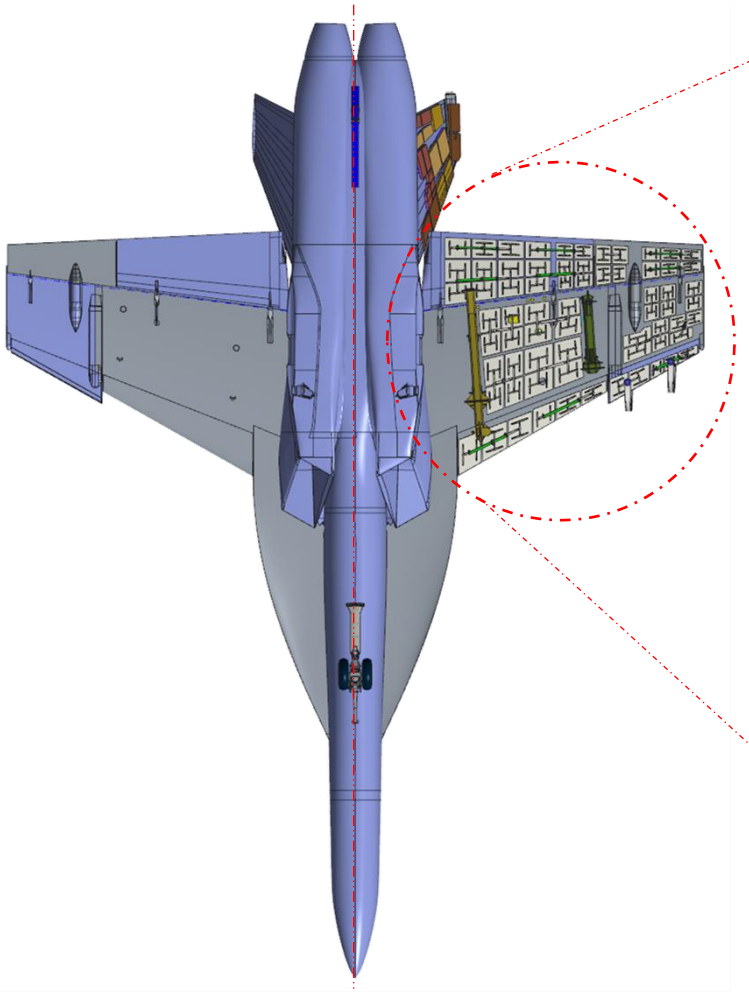


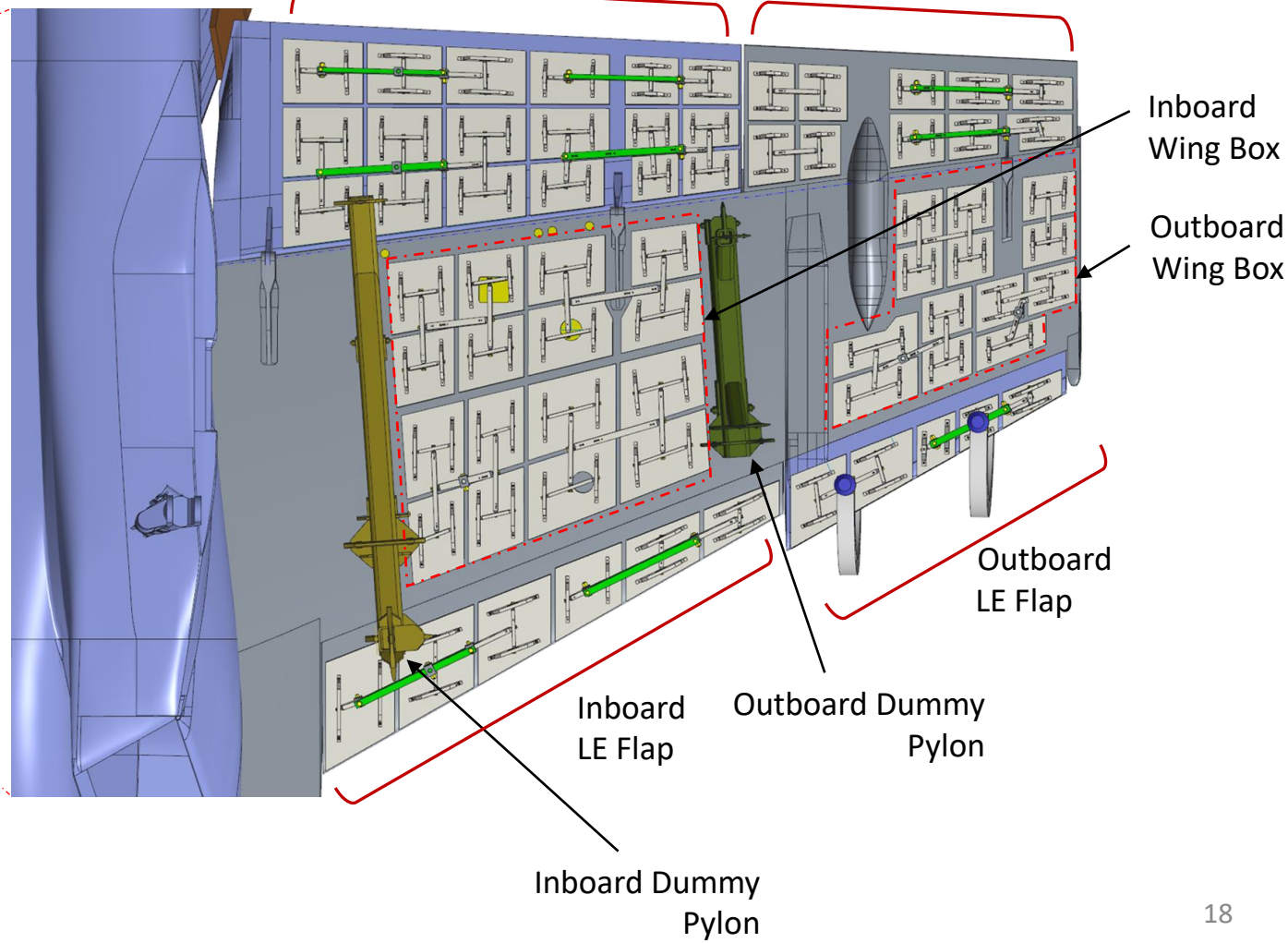
Load Zones for Right Vertical Tail



Load Zones for Right Wing

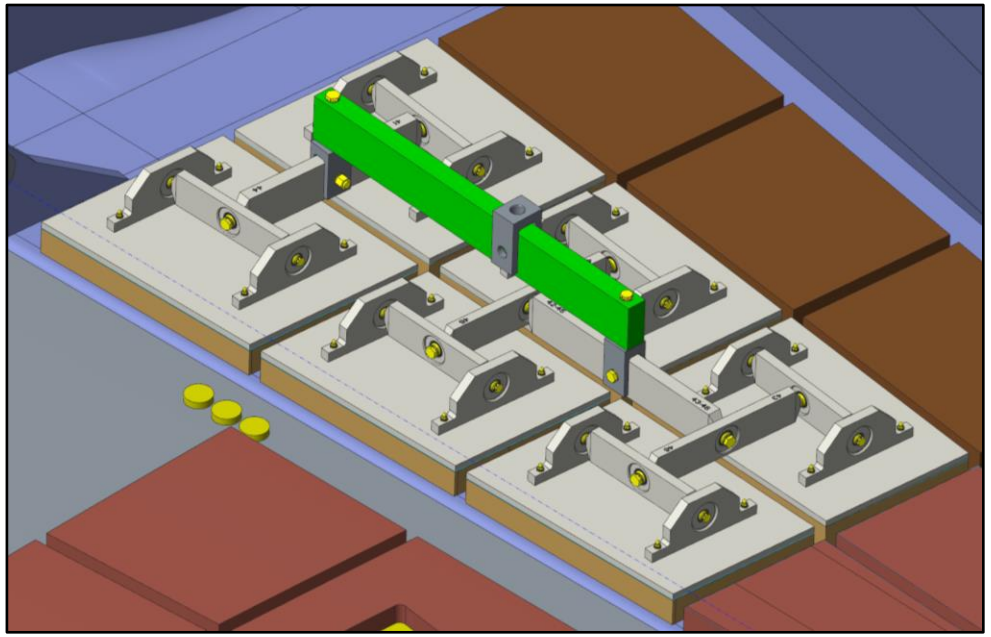
Load Pad Design
Whiffle Tree Layout

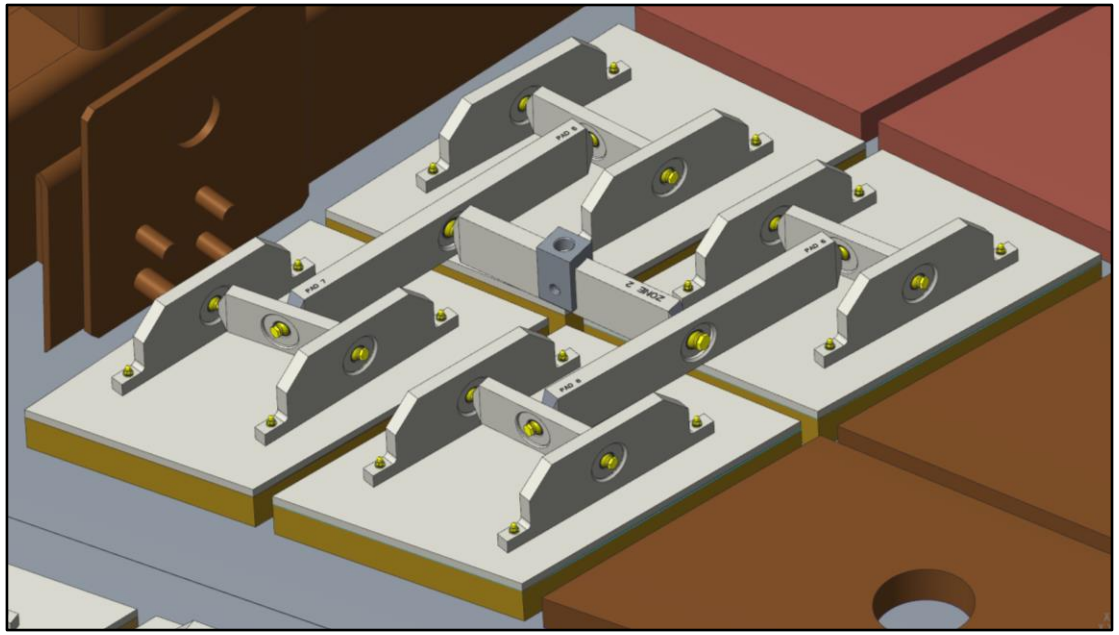




Load Pad Design
Whiffle Tree System (cont.)

- Load beams and plates for even distribution of actuator load to aircraft surface
- Pivot at joints to allow rotation

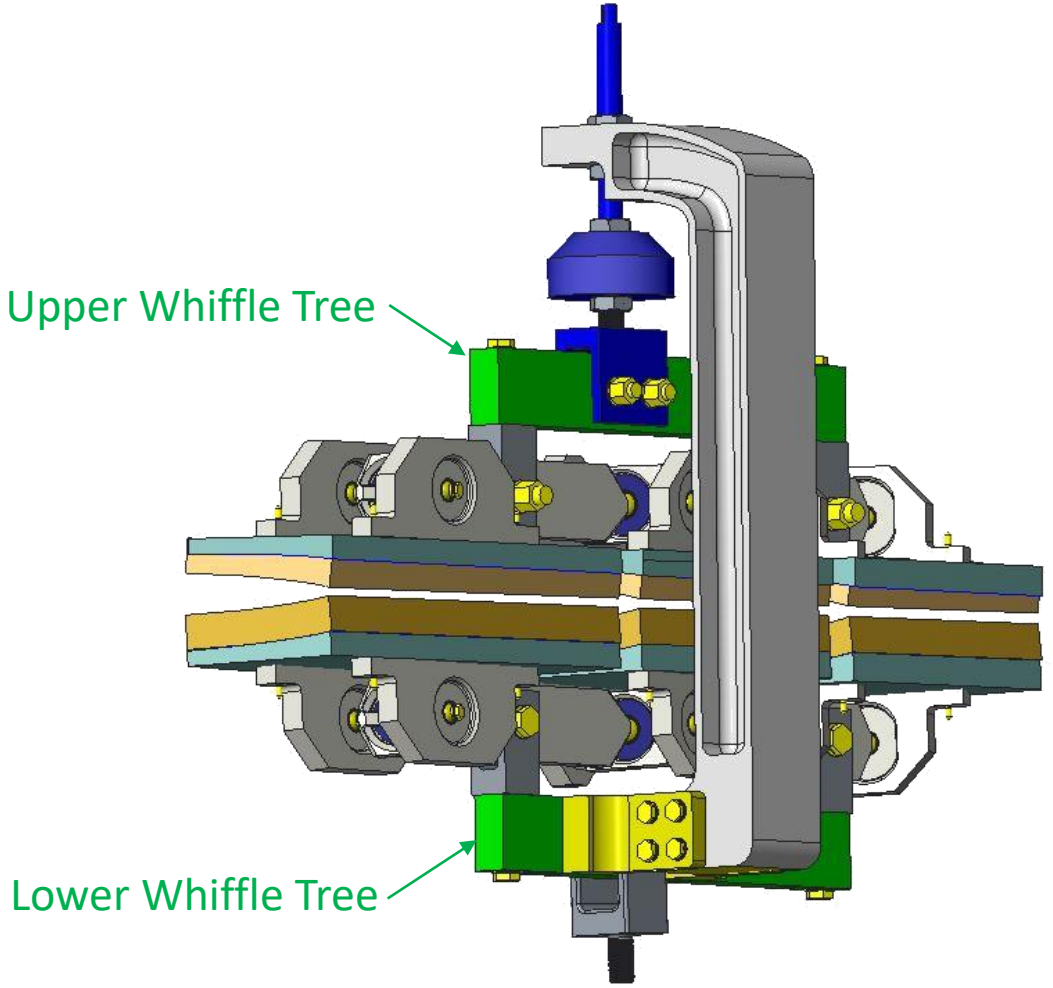




Load Pad Design

C-Loader at Wing Outboard Leading-Edge Flaps

- Distributed applied load to lower and upper surfaces to prevent exceedance of surface pressure limits
- Applied loads on both surfaces monitored during test



C-Loader Assembly

Load Pad Bonding
Marked Pad Locations



Load Zone Markings for Right Vertical Tail
(AFRC2021-0014-001)



Load Zone Markings for Right Wing Outboard Section
(AFRC2021-0014-010)

Load Pad Bonding
Vacuum Bag Process



Load Pad Installation



Load Pad Support for Adhesive Curing

Load Pad Bonding

Acceptance Testing: Load Pads

- Bonded pads for tensile and compression loads
- Proof tested in load frame
- Acceptance test performed on all wing lower surface pads
  - All pads passed test



Load Pad Testing In Test Machine

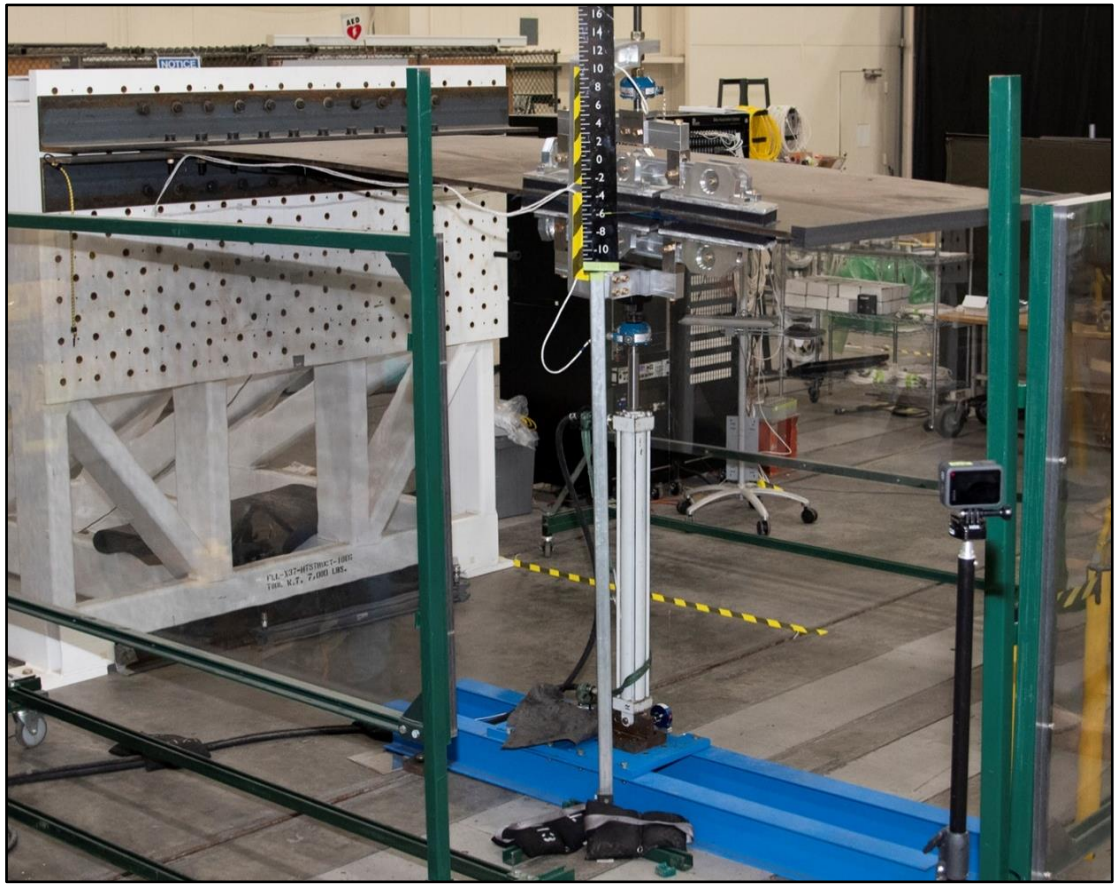


Load Pad Acceptance Test

Load Pad Bonding

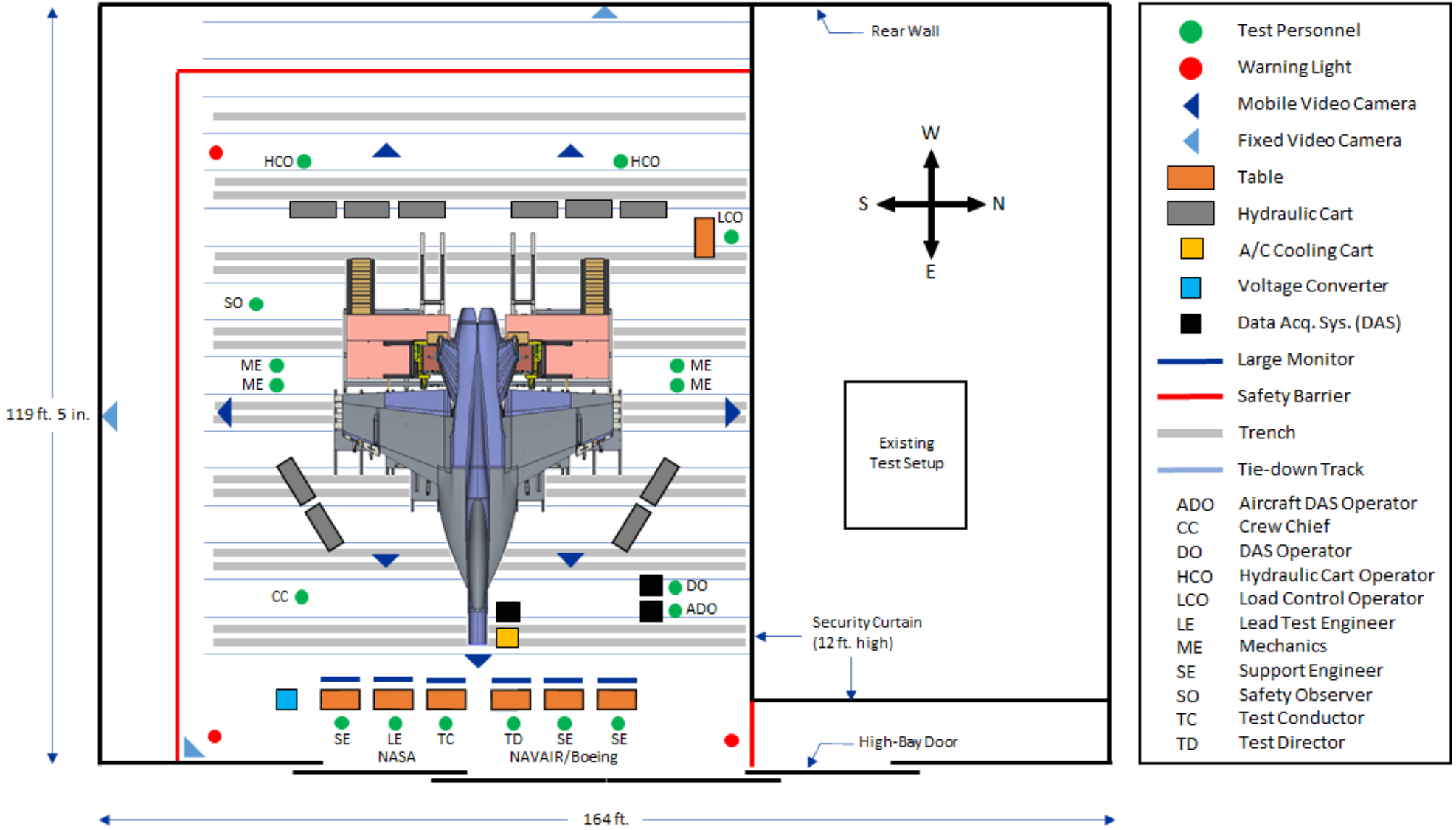
Acceptance Testing: C-Loader

- Set up a cantilever plate to simulate the wing
- Attached the C-Loader to the “outboard corner” of the plate (OLEF position)
- Applied tensile and compression loads
  - Verified system won’t bind or collapse
  - Measured load distribution between upper and lower whiffle trees



C-Loader Testing on Cantilevered Plate

Test Setup: Area Layout



Test Setup: Area Layout (cont.)



Test Setup: Spindle Test

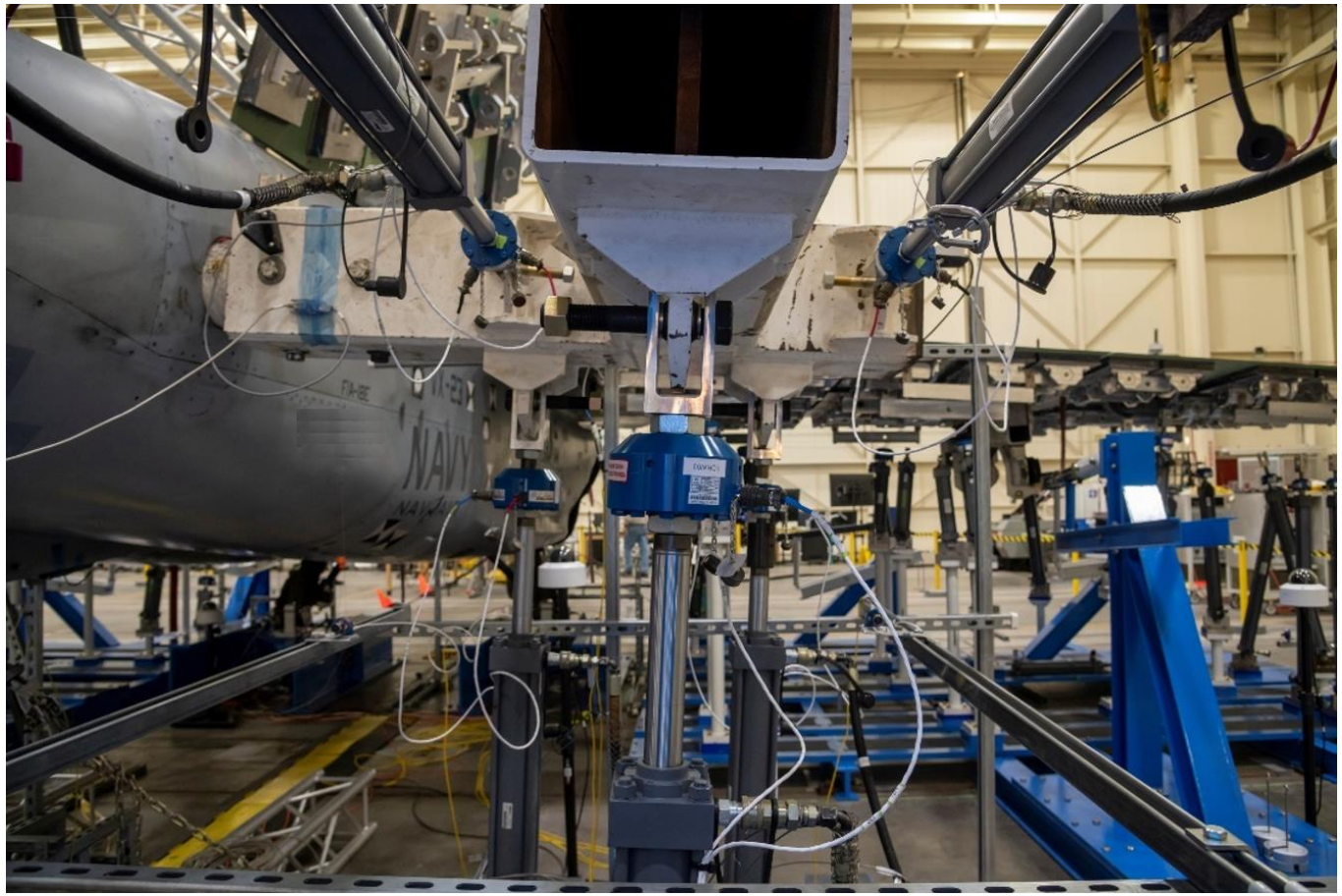
- Horizontal tail removed and replaced with dummy hardware for load introduction into the spindle
- 5 load trains per side
  - 3 vertical
  - 2 fore/aft



Spindle Testing – Side View
(AFRC2021-0132-15)

Test Setup: Spindle Test (cont.)

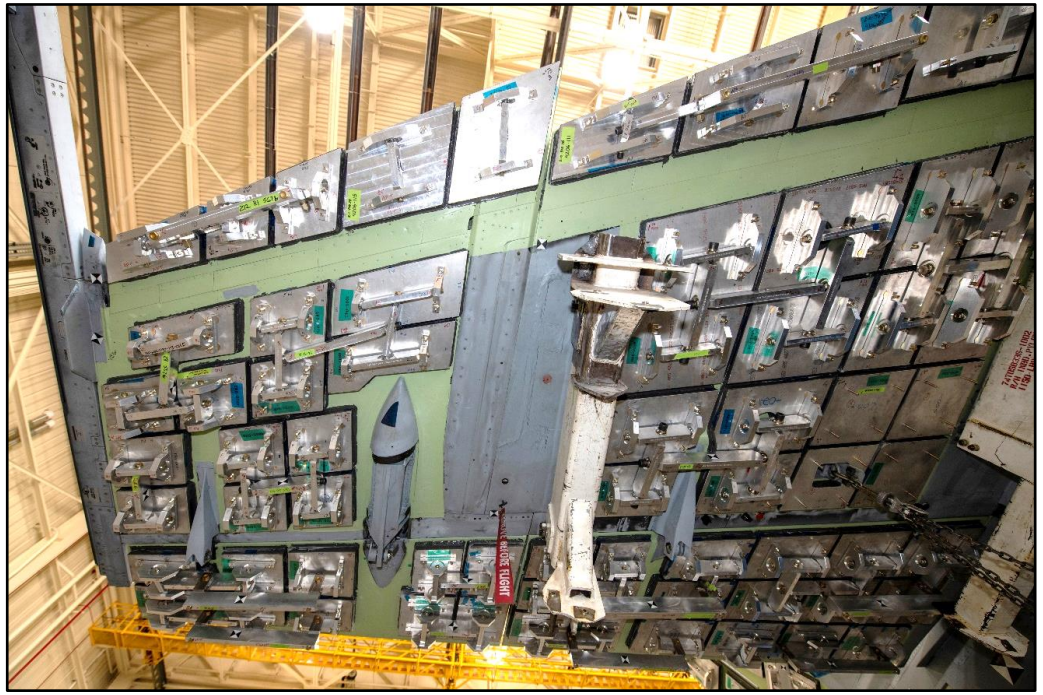
- Rotational freedom provided at both ends of the load train



Spindle Testing – Looking Forward
(AFRC2021-0132-52)

Test Setup: Wing Test

- Loaded both left and right wings symmetrically
- Wing lower surface mostly covered
- 56 actuators including 4 on each dummy pylon
  - Dummy pylons used to introduce pylon loads into the wings



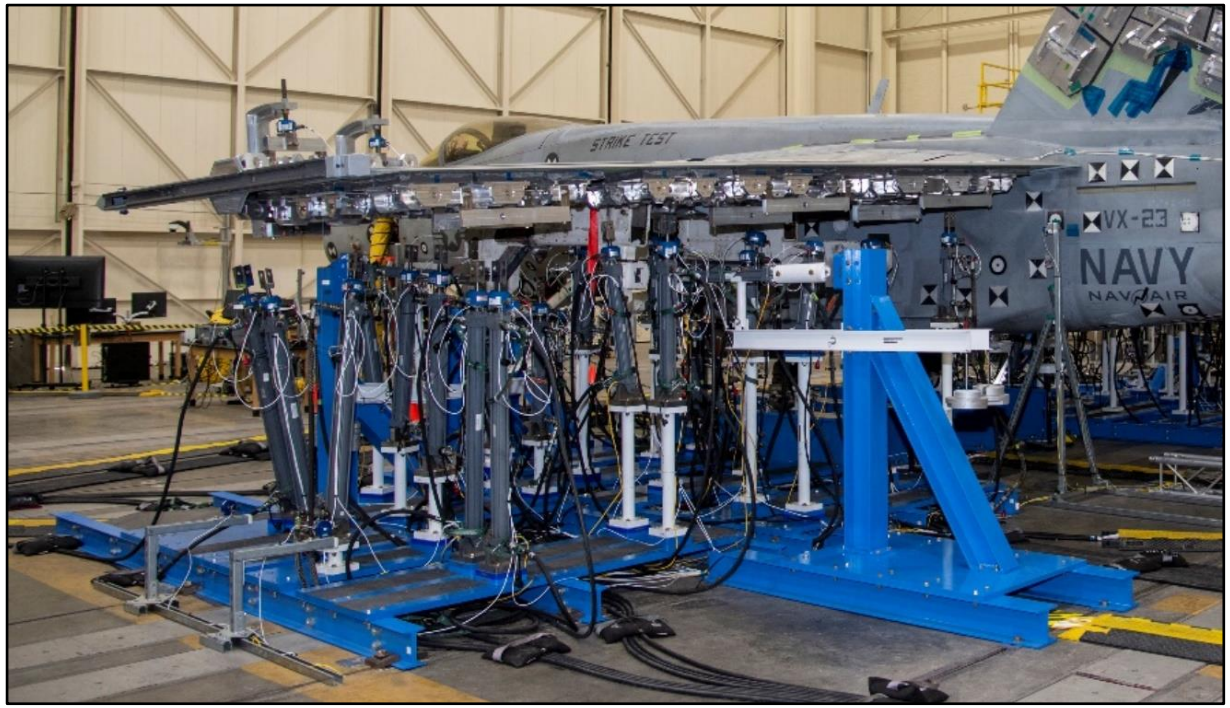
Right Wing Whiffle Tree Systems
(AFRC2021-0098-096)



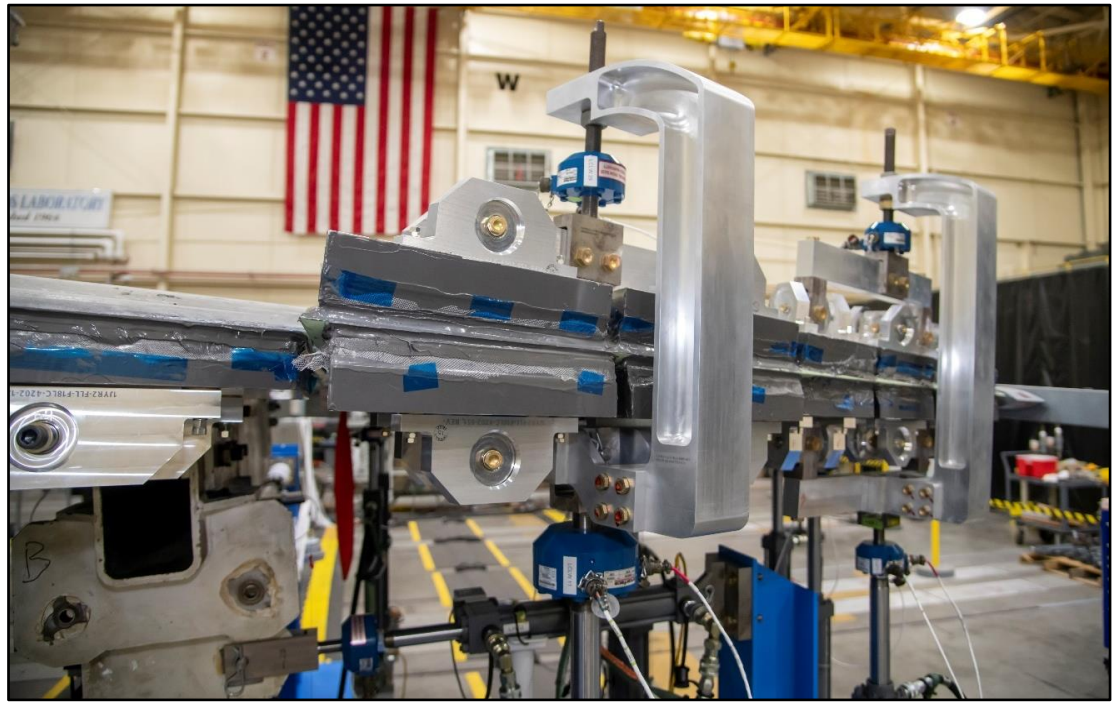
Wing Test Setup – Looking Aft
(AFRC2021-0025-126)

Test Setup: Wing Test (cont.)

- Underwing populated with hardware
- Counterweight system used to balance horizontally installed actuators



Wing Test Setup
(AFRC2021-0145-41)



C-Loader As Installed on Leading Edge Flap
(AFRC2022-0025-108)

Test Setup: Vertical Tail Test

- Loads applied to vertical tail from outboard surface and load structure



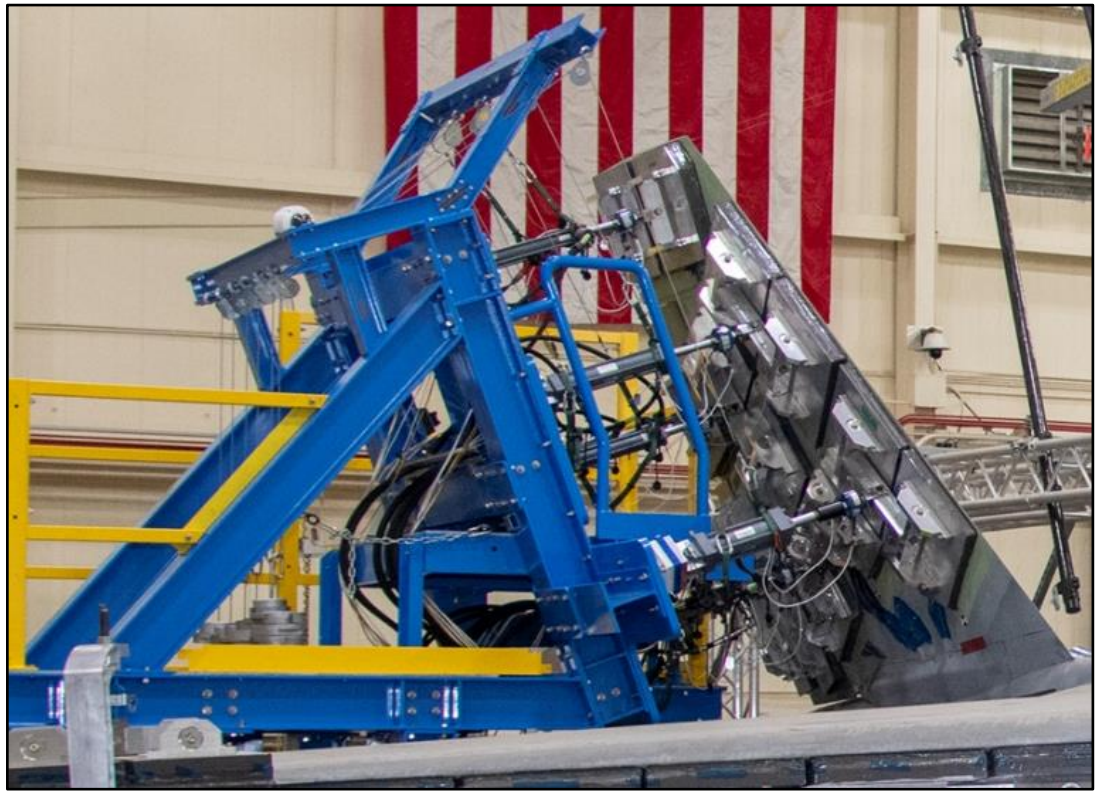
Vertical Tail Test Setup
(AFRC2022-063-27)



Vertical Tail Test Area Layout
(AFRC2022-063-29)

Test Setup: Vertical Tail Test (cont.)

- Counterweight system used to balance load train weight



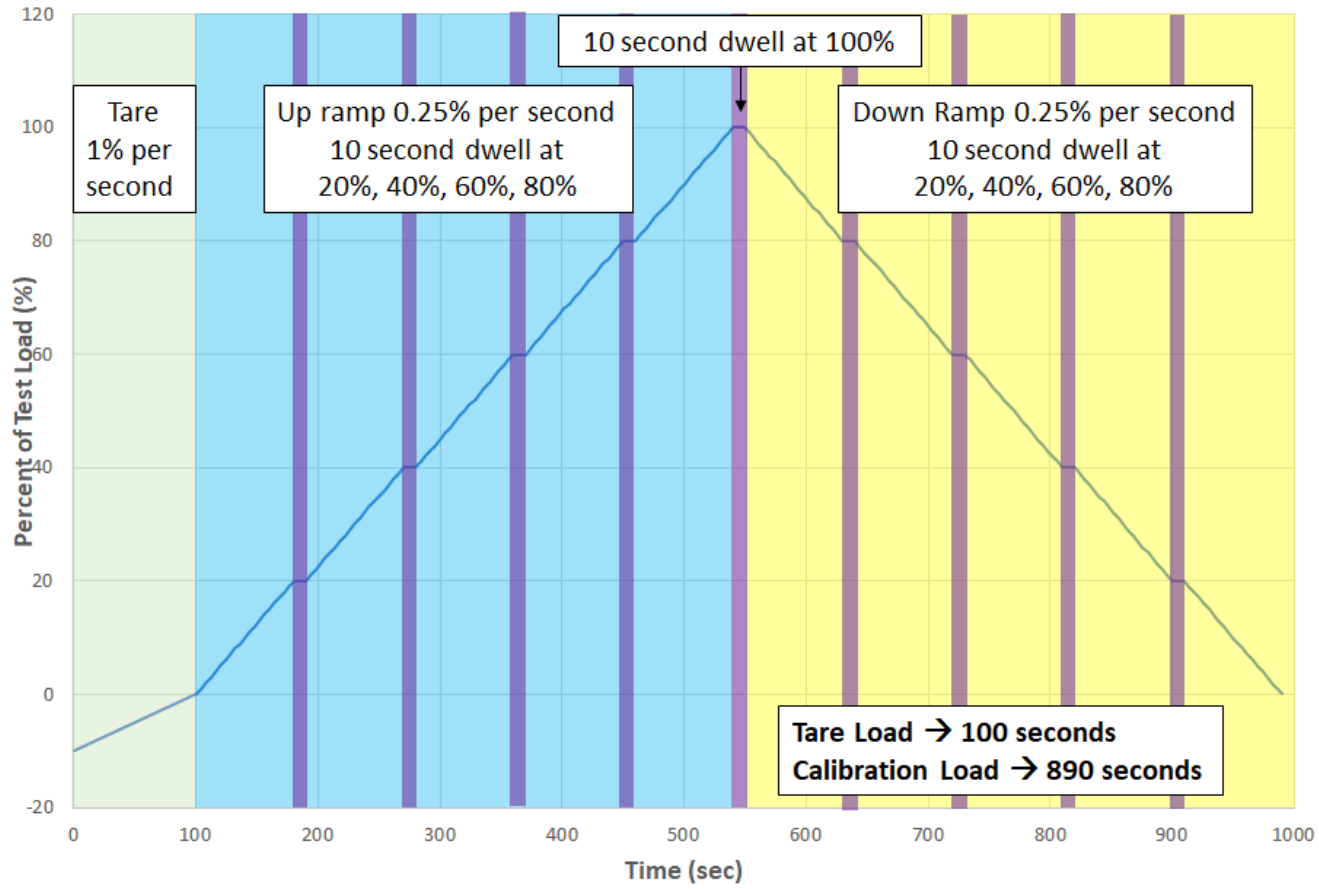
Vertical Tail Test Load Trains
(AFRC2022-052-103)



Vertical Tail Test Counterweight System
(AFRC2021-052-63)

Test Execution: Load Profile

- Started with tare load
- Dwelled every 20% for hydraulic actuators to balance
- 16.5 min per cycle



Test Execution: Data Management

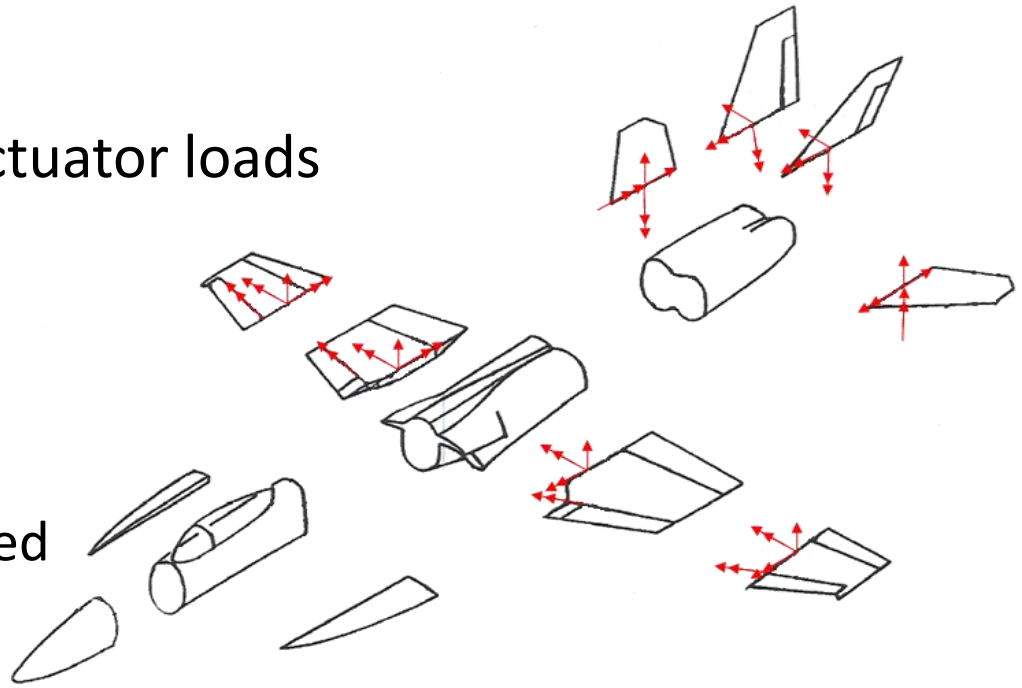
- Aircraft data acquisition system collected strain gage data
- Lab data acquisition system collected test equipment data
  - Load cell
  - Actuator stroke
  - Displacement
- Post test data synchronization used IRIG-B time

Test Execution: Data Monitoring

- Several displays used for data monitoring of all real-time data
- Carefully monitored data
  - Applied loads as percentage of test load (56 channels for wing test)
  - Strain gage response
    - Responsive and linear
  - String potentiometer for test article deflection
  - Linear variable differential transducer for test setup hardware movement
  - Actuator stroke for potential out-of-stroke event
- Video displays to help monitoring hardware contact or failure

Equation Derivations

- Strain gage loads equations for the various component loads derived using multi-variable least square method
- Example (3-gage equation)
  - Calculated applied component load using actuator loads
    - Used as-installed actuator center
  - Applied Component Load =
    SG1 x Coef1 + SG2 x Coef2 + SG3 x Coef3
    - SG are measured strain gage outputs
    - Coef are unknown coefficient to be calculated
  - Used data from multiple load cases
  - Coefficients were calculated



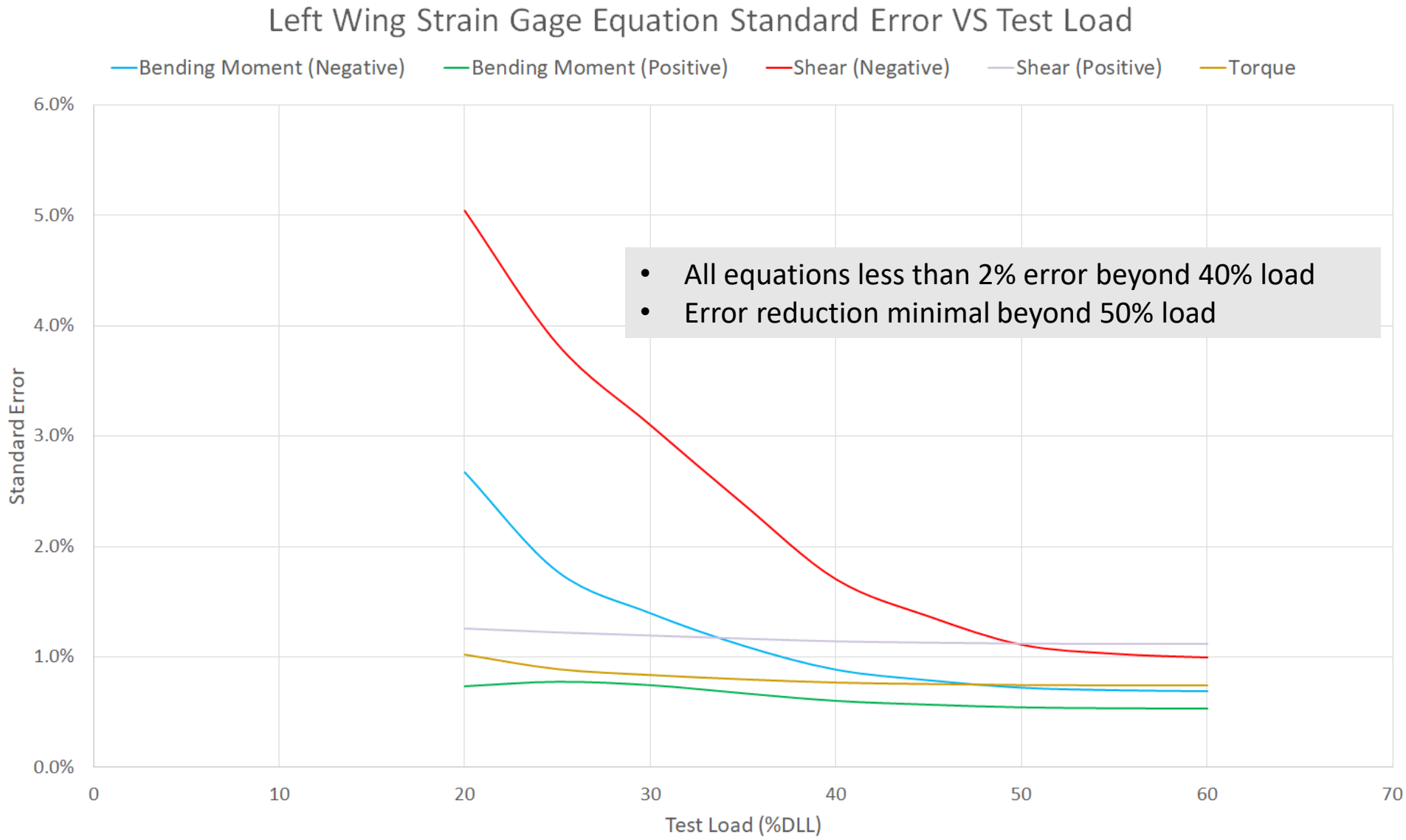
Equation Derivations
Test Load Level Parametric Study

- *What is the appropriate test load level for strain gage loads calibration of an F/A-18E type wing?*
  - Test to sufficient load level for extrapolation to 100% design limit load
  - There is a cost for testing to higher levels
    - Added risk
    - Added cost
- Typically, 2% error for loads equations is acceptable for flight testing

Equation Derivations
Parametric Study

- Left wing bending, shear, and torque equations studied
  - Used NAVAIR selected gages for equations
  - Positive and negative equations for bending moment and shear
  - Single equation for torque
  - 62 load cases
    - Mostly distributed load cases
    - 4 LEF/Aileron only loads cases
    - 15 pylon only load cases
  - Check cases selected from the 62 load cases
    - Selected max component load case as check case

Equation Derivations



Summary & Conclusions

- Successfully completed 87 planned load cases
- Successfully met test objectives
  - Calibrated strain gages (wings, vertical tails, & horizontal spindles)
  - Collected deflection data
- Test setup hardware successfully met the loading measurement requirements
- Focused monitoring on strain gage data and test instrumentation resulted in safe and successful test execution
- Test load level of ≈60% DLL produced high-quality equations