Strain Gage Load Calibration of the Wing Interface Fittings for the Adaptive Compliant Trailing Edge Flap Flight Test

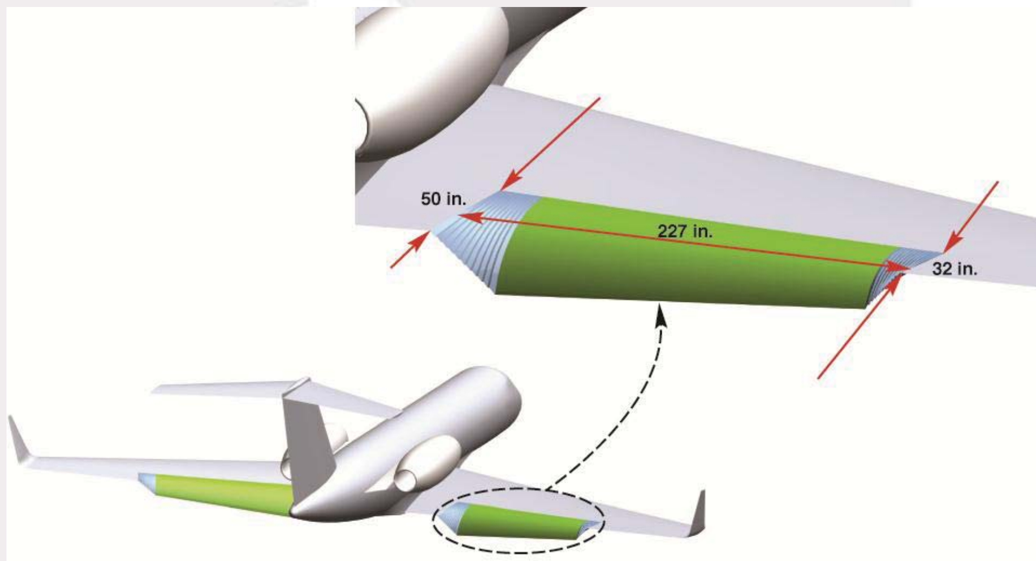
Eric J. Miller, Andrew C. Holguin, Josue Cruz, and William A. Lokos
NASA Dryden Flight Research Center, Edwards, California, 93523
SCITECH 2014, 13 - 17 January 2014, National Harbor, Maryland

Outline

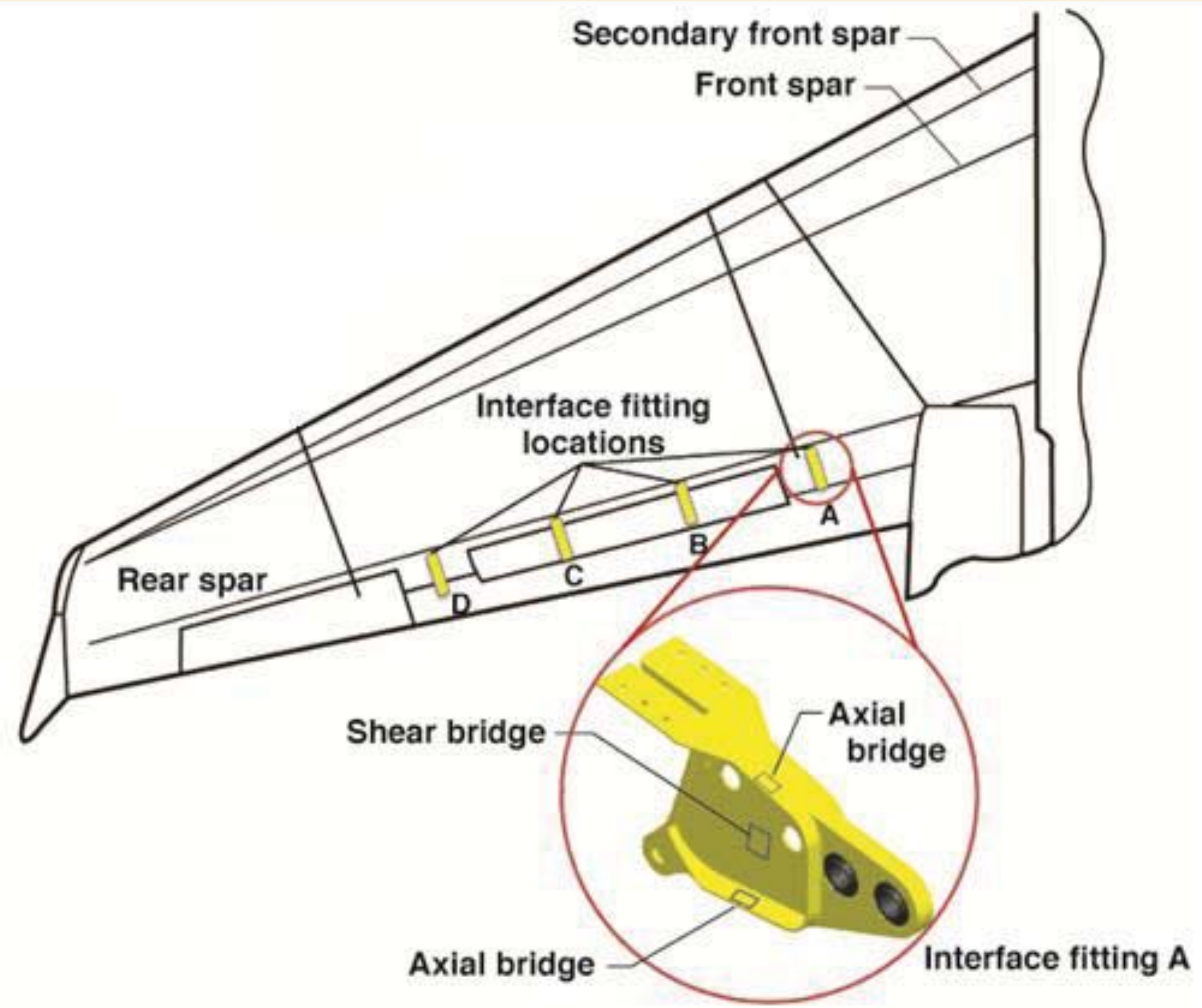
- ACTE Project Overview
- ACTE Real Time Load Monitoring
- Flight Loads Lab Overview
- Interface Structural Design
- Instrumentation Design
- Test Setup Design
- Calibration Load Cases
- Load Equation Derivation and Validation
- Conclusions

ACTE Project Overview

- NASA DFRC is partnering with the Air Force Research Laboratory (AFRL) and FlexSys Inc. (Ann Arbor, Michigan) to flight-test the Adaptive Compliant Trailing Edge (ACTE) experiment
- Does not translate like a Fowler flap
- Smoothly curling and seamless structure
- Planned ACTE flight envelope extends outside cleared Fowler flap envelope
- Possible strength exceedances of the wing box and interface structure warrant real time monitoring of the loads



ACTE Real Time Load Monitoring



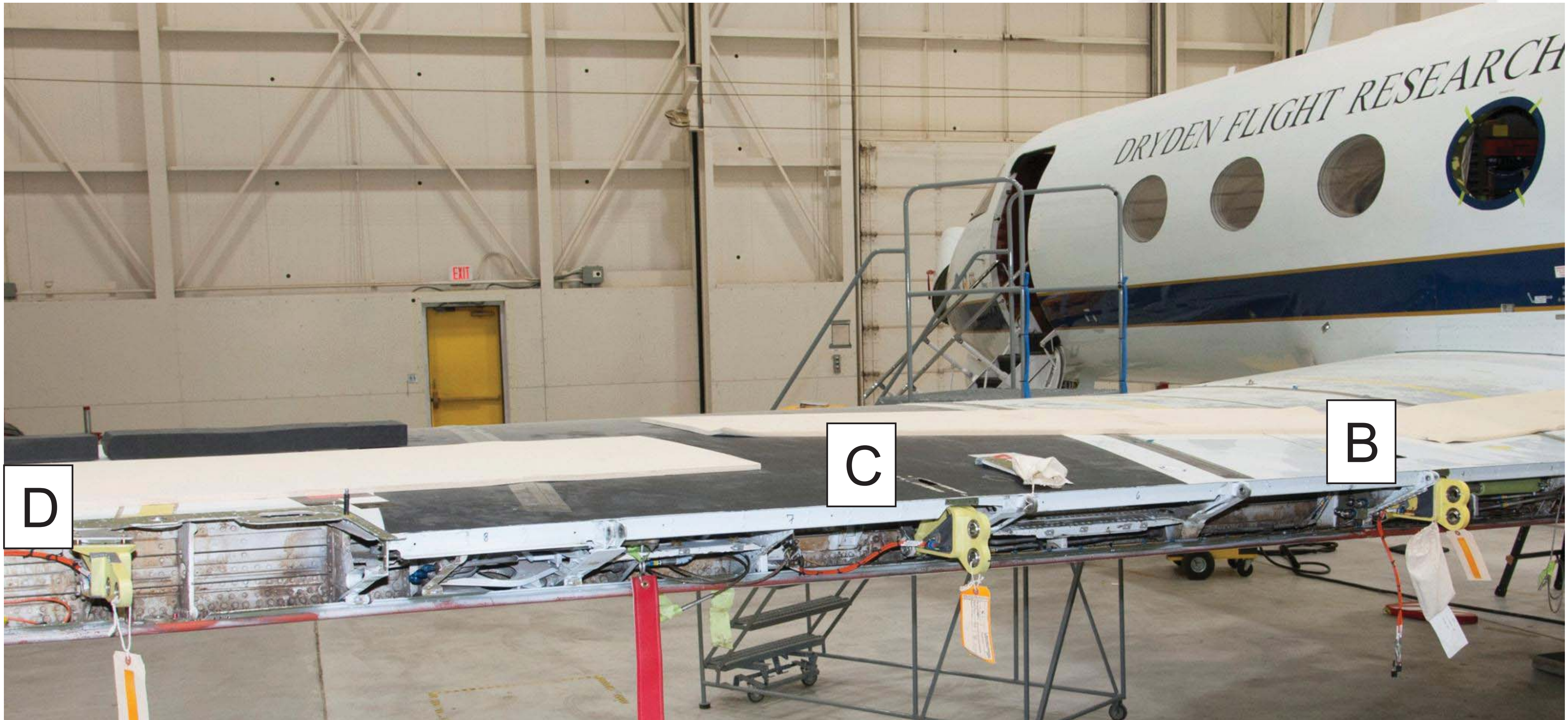
Flight Loads Laboratory Overview

- Single facility capable of conducting mechanical, thermal, and structural dynamics research and testing
  - Wide range of projects supported from X–15 to crew exploration vehicle (CEV)
- MOOG Hydraulic Load Controller can support up 80 channels for hydraulic load testing of single components up to full scale aircraft
- Advanced strain gauge instrumentation capability
- Supported G-III Load Calibration Testing

Interface Fitting Load Calibration Overview

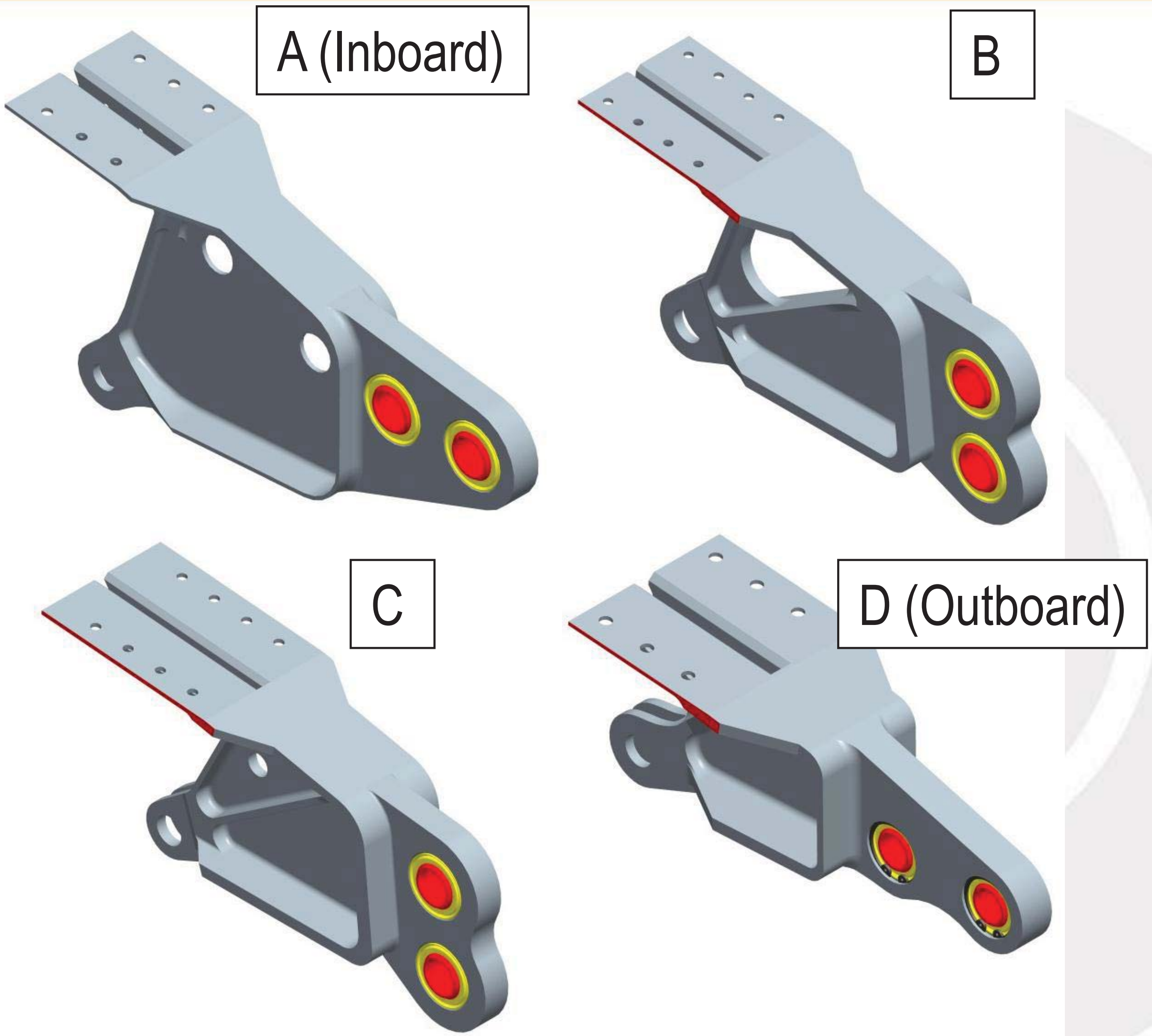
- Objective: Monitor the loads in the ACTE/Wing Box interface during ACTE flights
  - Envelope Clearance
  - Model Validation
- Plan: Instrument and calibrate all eight modified flap track fittings for monitoring the loads real time in flight
- The calibration effort aspired to achieve errors on the order of 5% or less for bending and 10% or less for shear
  - Benefits of having instrumentation diminish with larger errors

Interface Structural Design

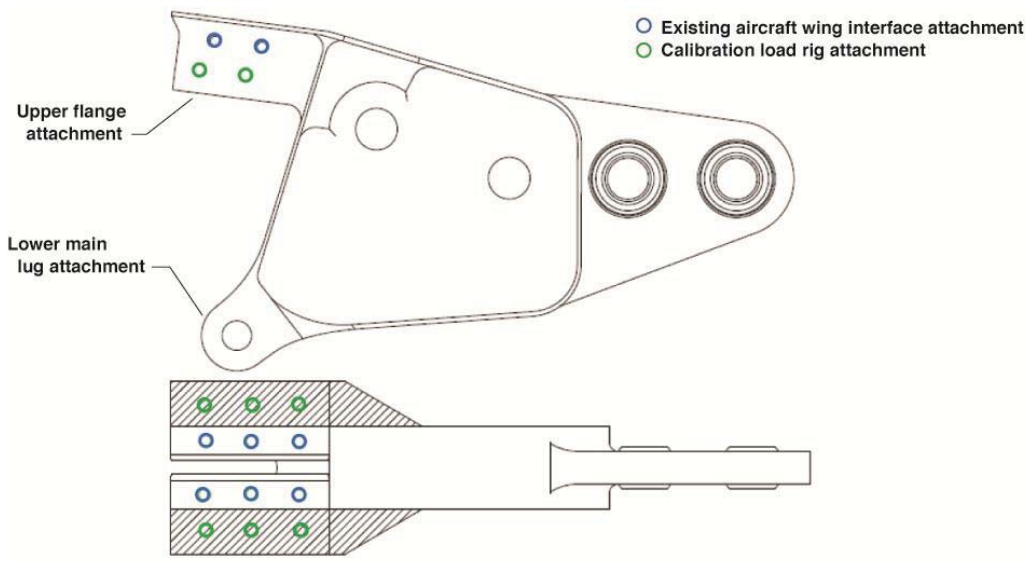


A is not Shown

Interface Structural Design

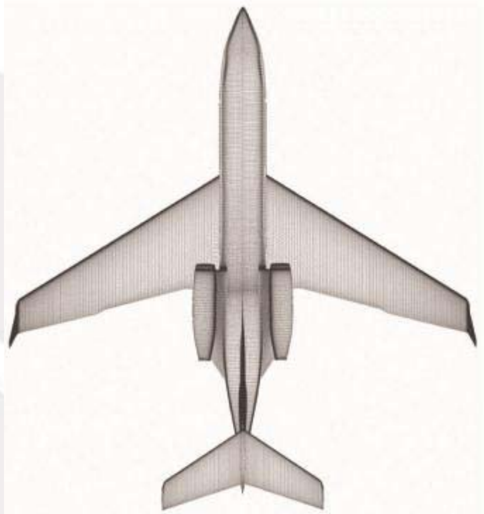


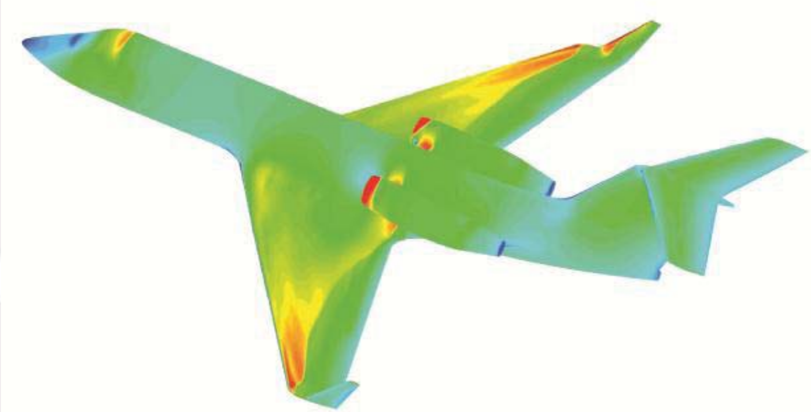
Interface Structural Design



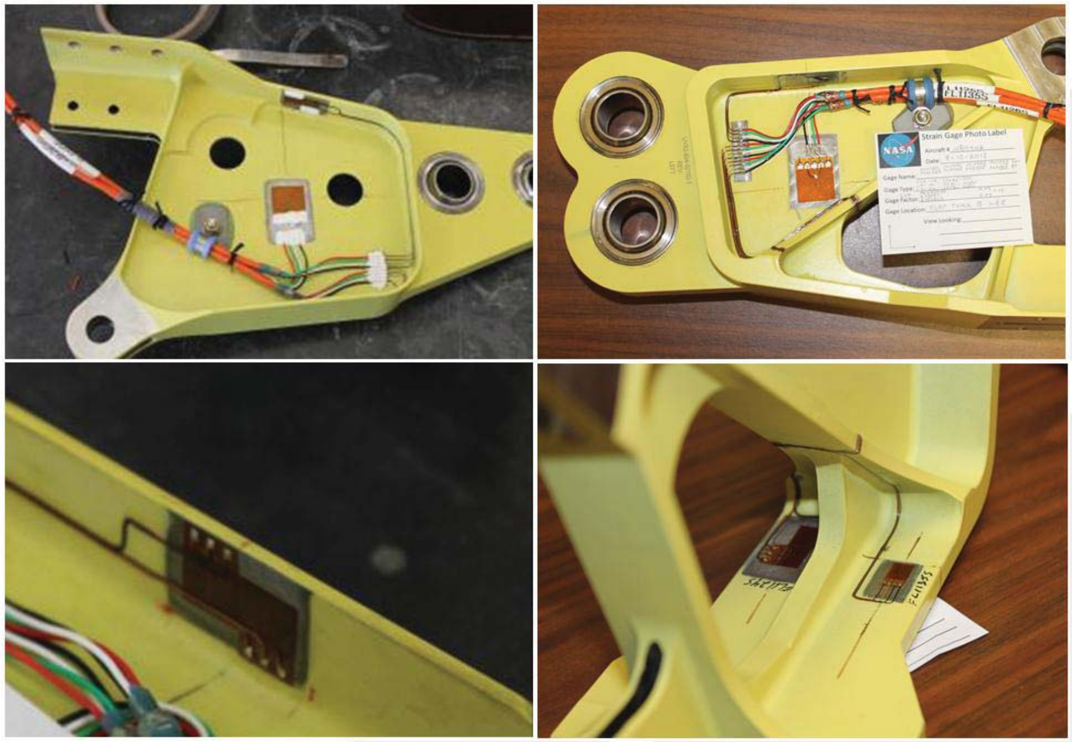
Interface Fitting Load Prediction

- External loads analysis was performed on the wing and ACTE cartridge
- All credible worst-case loading conditions for the GIII airplane were taken into account
- The resulting pressure loads for each flap deflection were applied to the ACTE finite element method (FEM) model to determine the interface loads



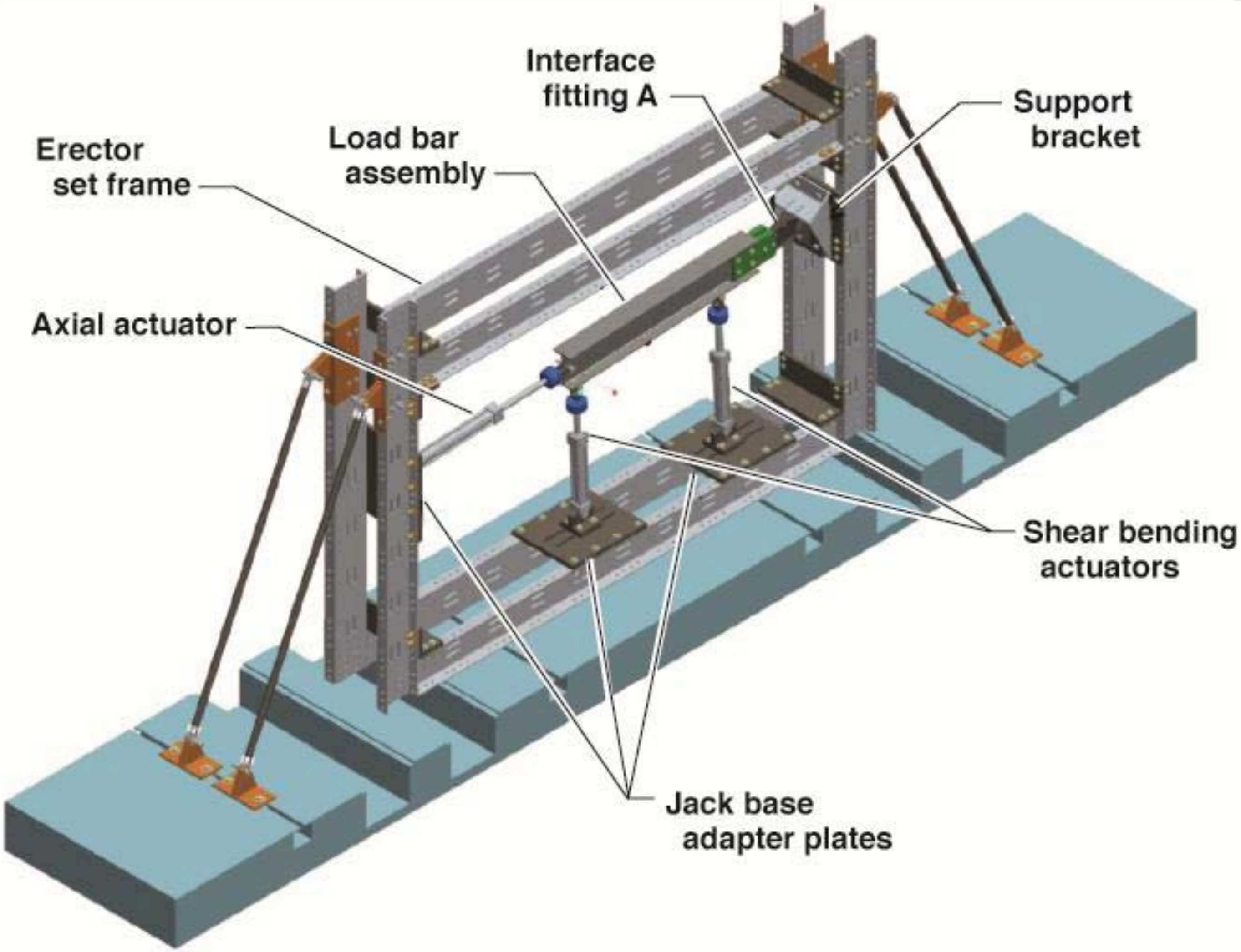


Instrumentation Design



Strain gage response variable	Gage response description
rAF1	Top flange axial bridge response
rAF2	Bottom flange axial bridge response
rNF	Shear bridge response
rPM	Pitching moment response (rAF2 - rAF1)
rAF	Axial force response (rAF2 + rAF1)
rBND	Bending bridge response (added to interface fittings B and C)

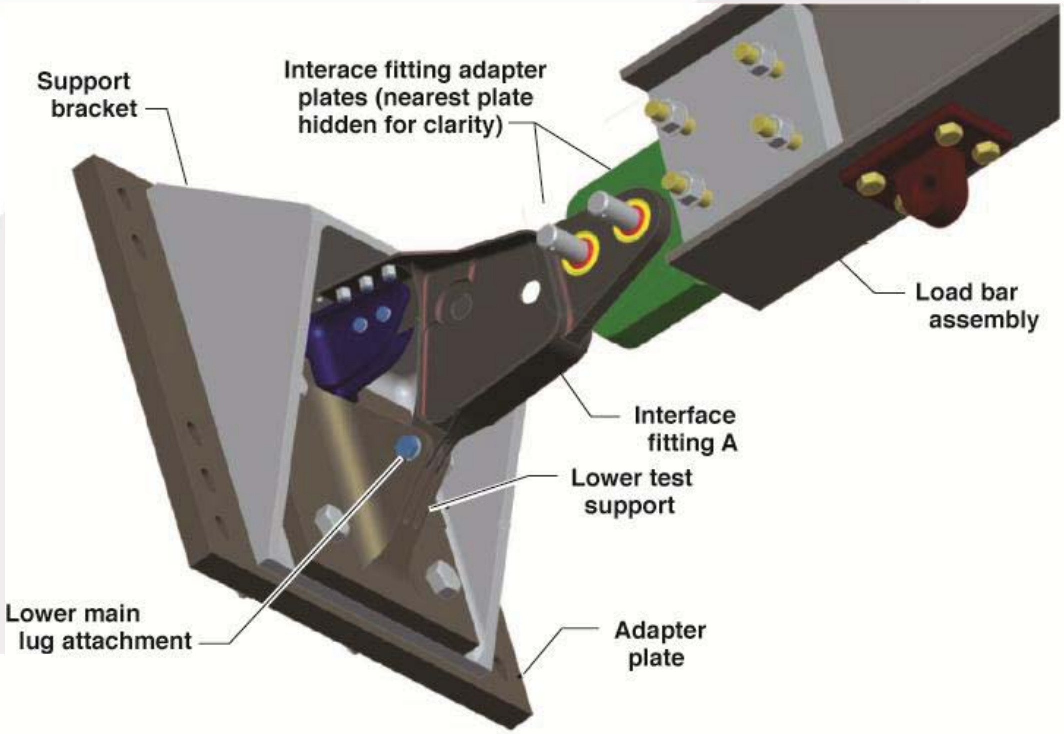
Test Setup Design

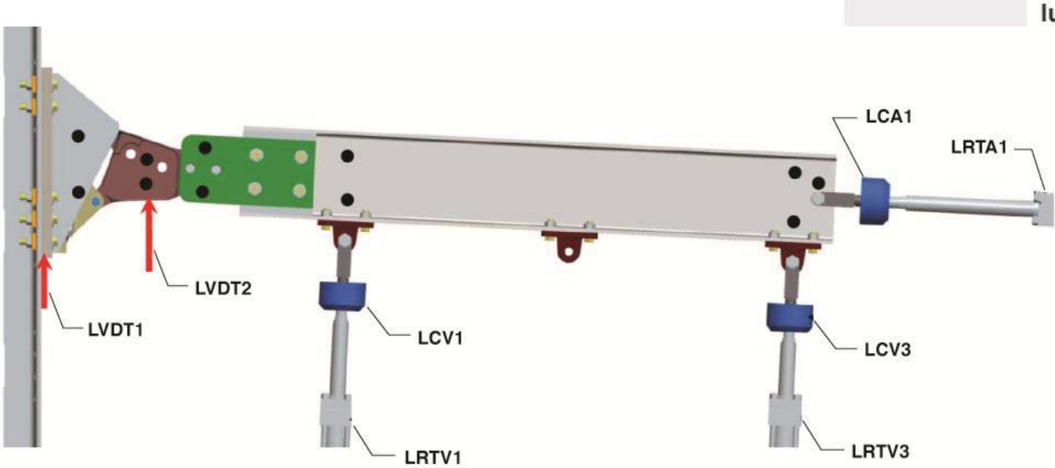


Test Setup Design

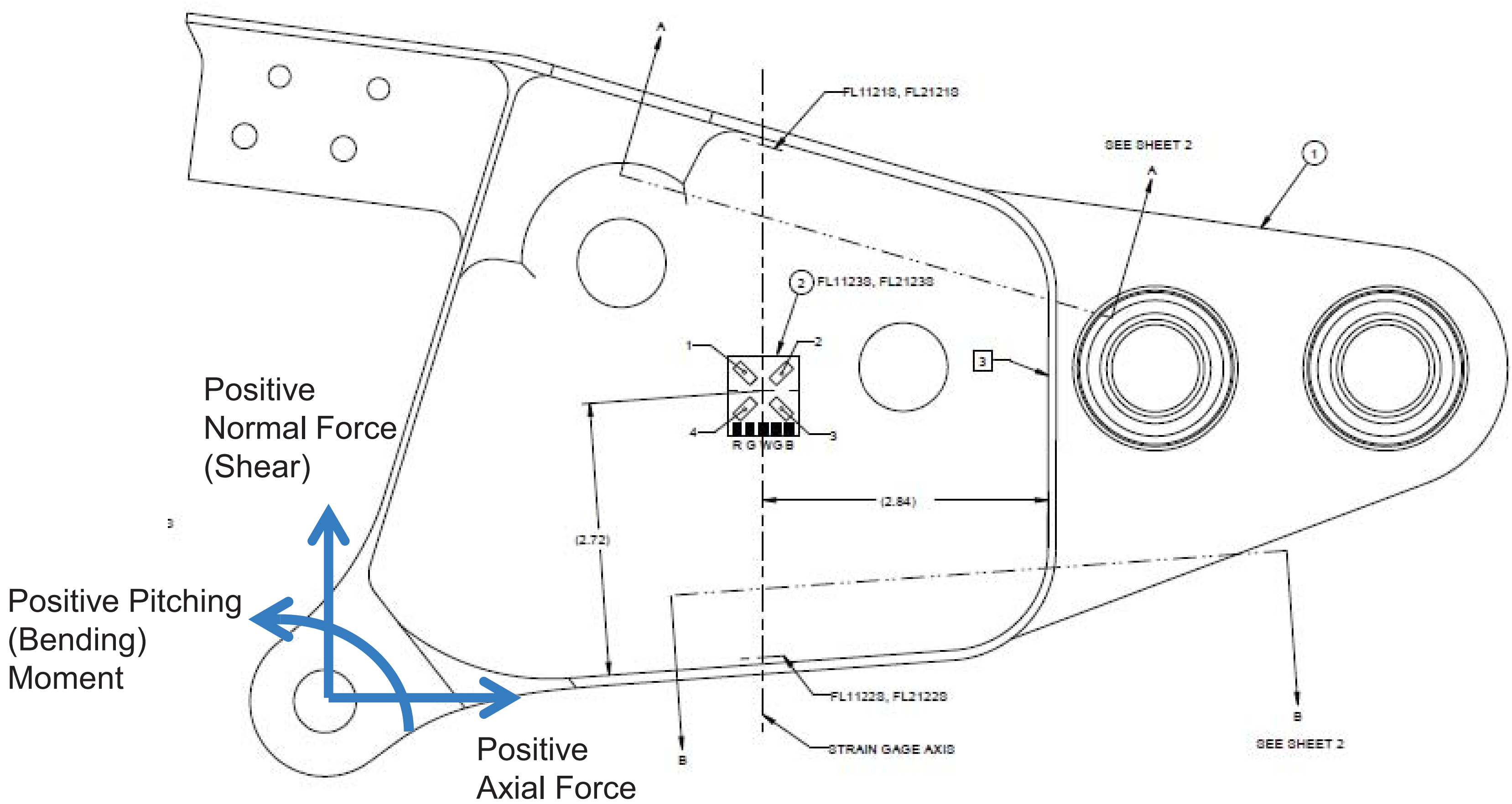
- Support hardware was designed to accommodate all four unique interface fitting pairs

- Strain Bridges, Load Cells, LRTs, LVDTs and Photogrammetry were recorded during the test

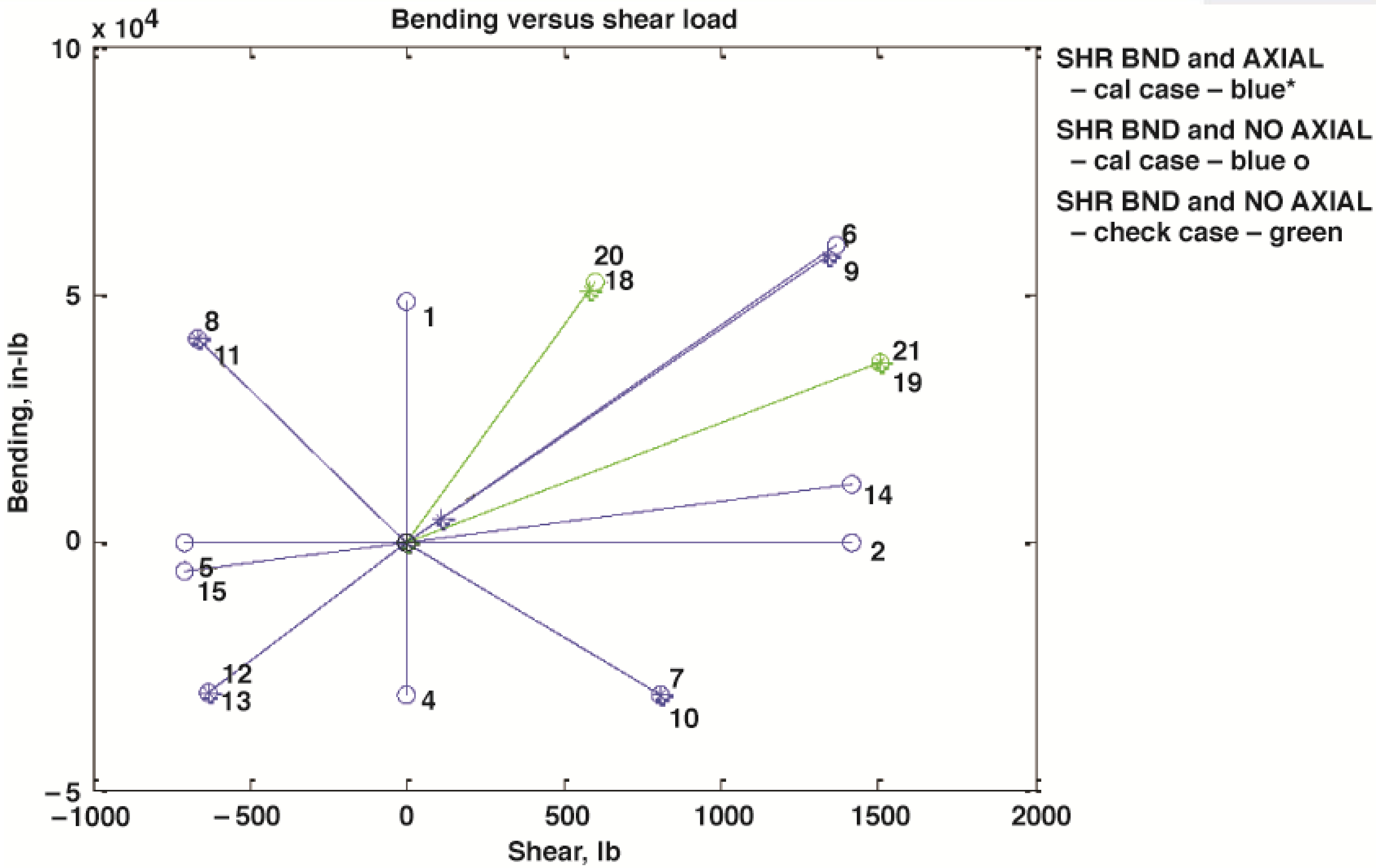




Derived Load Equation Coordinate System



Calibration Load Cases

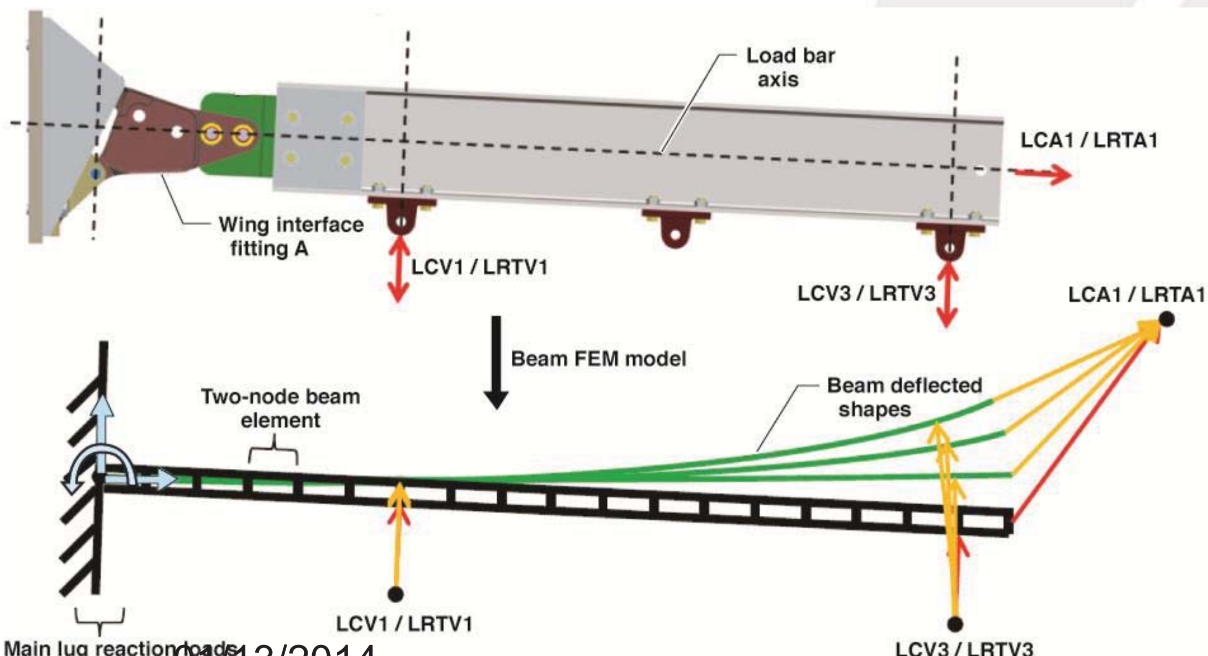


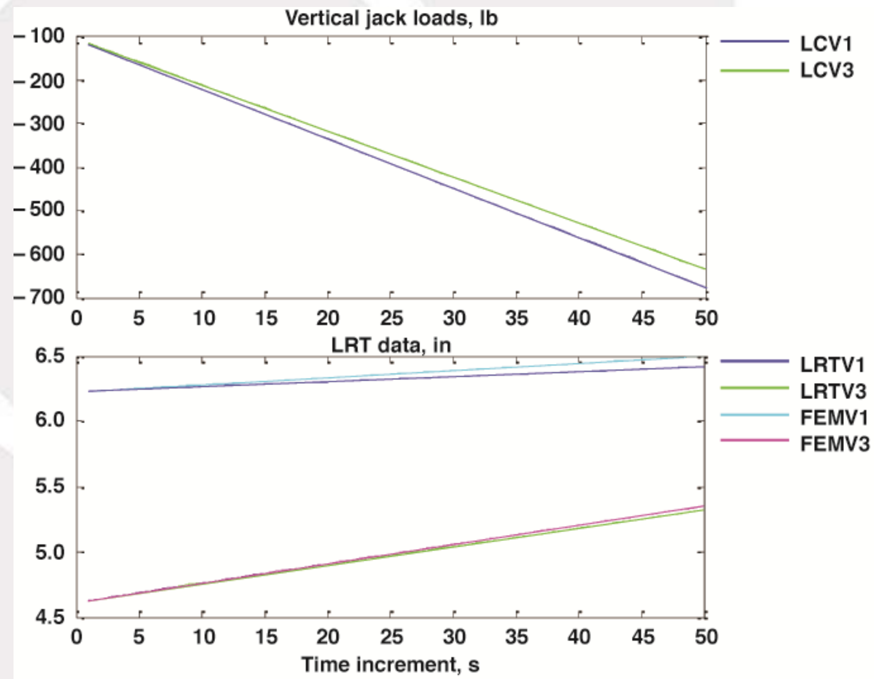
Load Equation Derivation Process

- Raw data analysis
- Correction of applied reaction loads
- Load case selection
- Mathematical model selection
- Linear regression analysis

Load Equation Derivation Process

- Correction of Applied Shear Bending and Axial Loads using Beam Finite Element Method (FEM) Model
  - The reaction loads are calculated as the shape of the interface fitting and load bar deflect during loading to best approximate the applied load components
  - The beam model is validated against the displacement transducers
  - The most error occurs in the bending reaction load during application of the axial jack (Error is on the order of 2%)





Mathematical Model Selection

- The calibration model for calculation of the component loads F is related to the gage responses R by a linear function

$$F = a_o + \sum_{i=1}^{n} b_i R_i + \sum_{i=1}^{n} c_i |R_i|$$

- n is the number of strain gage response variables (n = 3 for fittings A and D; and n = 4 for fittings B and C).
- The *a*, *b*, and *c* terms represent the calibration coefficients determined by multiple linear regression.

Interface Fitting A and D

Regression Math Model	Intercept	rNF	rPM	rAF	rBND	|rNF|	|rPM|	|rAF|	|rBND|
FittingA_Shear_RMM1	1	1							
FittingA_Shear_RMM2	1	1	1						
FittingA_Shear_RMM3	1	1	1	1					
FittingA_Shear_RMM4	1	1	1			1	1		
FittingA_Bending_RMM1	1		1						
FittingA_Bending_RMM2	1	1	1						
FittingA_Bending_RMM3	1	1	1	1					
FittingA_Bending_RMM4	1	1	1			1	1		
FittingA_Axial_RMM1	1			1					
FittingA_Axial_RMM2	1		1	1					
FittingA_Axial_RMM3	1	1	1	1					

Interface Fitting B and C

Regression Math Model	Intercept	rNF	rPM	rAF	rBND	|rNF|	|rPM|	|rAF|	|rBND|
FittingB_Shear_RMM1	1	1							
FittingB_Shear_RMM2	1	1	1						
FittingB_Shear_RMM3	1	1			1				
FittingB_Shear_RMM4	1	1		1	1				
FittingB_Shear_RMM5	1	1	1			1	1		
FittingB_Shear_RMM6	1	1			1	1			1
FittingB_Bending_RMM1	1				1				
FittingB_Bending_RMM2	1			1	1				
FittingB_Bending_RMM3	1	1			1				
FittingB_Bending_RMM4	1	1	1						
FittingB_Bending_RMM5	1	1		1	1				
FittingB_Bending_RMM6	1	1	1			1	1		
FittingB_Bending_RMM7	1	1			1	1			1
FittingB_Axial_RMM1	1			1					
FittingB_Axial_RMM2	1			1	1				
FittingB_Axial_RMM3	1	1		1	1				

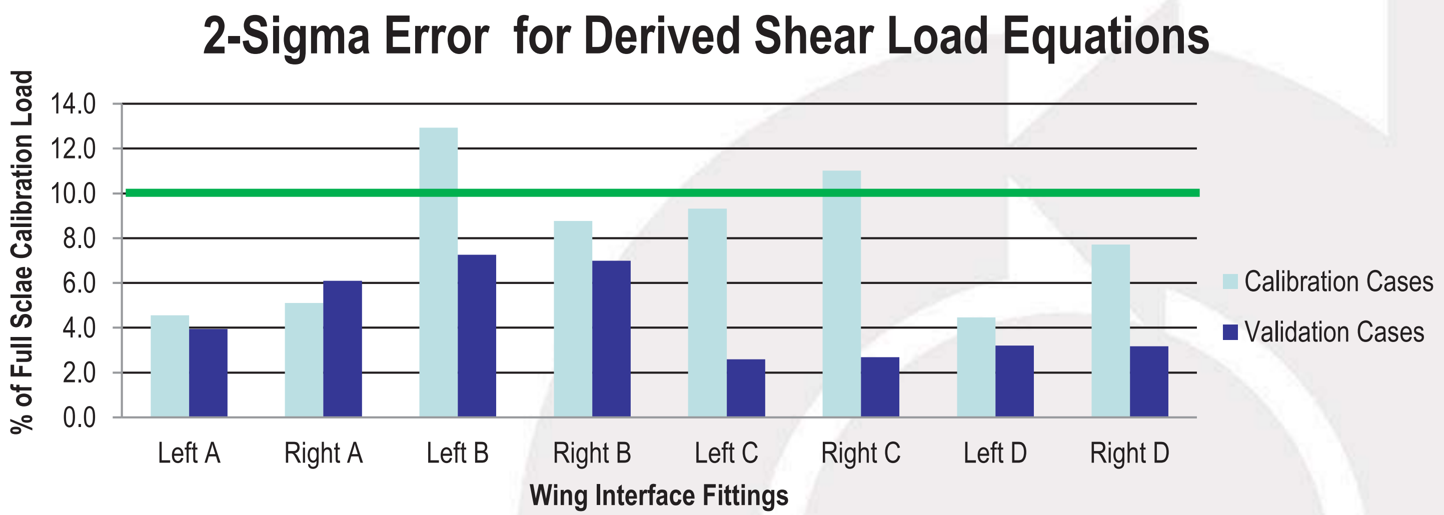
Load Equation Validation

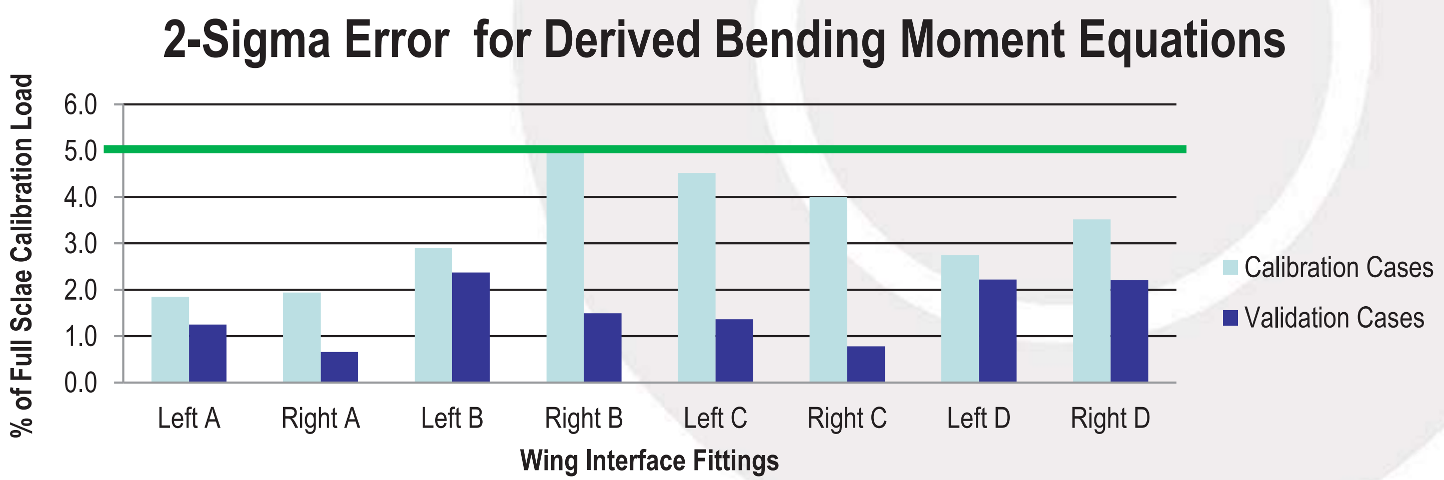
- Calibration Load Schedule
  - Applied loads cover the flight operational envelope
- Maximum of Variance Inflation Factor (VIF)
  - VIF is a measure of the multicollinearity between the variables in the linear regression analysis
  - VIF should be less than 10
  - VIF larger than 10 may indicate flaws in the load case design
- Standard Deviation of Load Residuals
  - 2σ values are shown as percent of full scale calibration load value
- Root Mean Square (RMS) Error
  - x_i is the measured value, x'_i is the derived value, and n is the number of measurements

$$e = 100 * \sqrt{\frac{\sum_{i=1}^{n}(x'_i - x_i)^2}{\sum_{i=1}^{n} x_i{}^2}}$$

- Validation Check Case
  - A quality check case is one that represents realistic flight loads but is not contained in the original calibration load set.

Load Equation Validation





Conclusions

- The interface fittings in general do not lend themselves to ample bridge response given the large design factors of safety and short, stubby nature of the flight articles

- The preloading of the interface fitting at the beginning of each load cycle made a considerable difference in obtaining acceptable data and is recommended when multiple interfaces are involved that induce hysteresis effects

- The test rig deflection should also be sufficiently investigated before testing, to minimize off-axis loading effects
  - Finite Element Methods were used to correct the loads for off axis effects

Conclusions

- The Primary load equations were selected based on multiple calibration metrics
- An independent set of validation cases were used to validate each derived equation
- The 2σ residual errors for shear load validation cases are less than 8% of full scale calibration load (Desired 10% or better) and the 2σ residual errors for bending moment load validation cases are less than 3% of full scale calibration load (Desired 5% or better)

The World's Forum for Aerospace Leadership