APPROACH FOR STRUCTURALLY CLEARING AN ADAPTIVE COMPLIANT TRAILING EDGE FLAP FOR FLIGHT

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SFTE 46nd Annual Symposium - September 2015

Outline

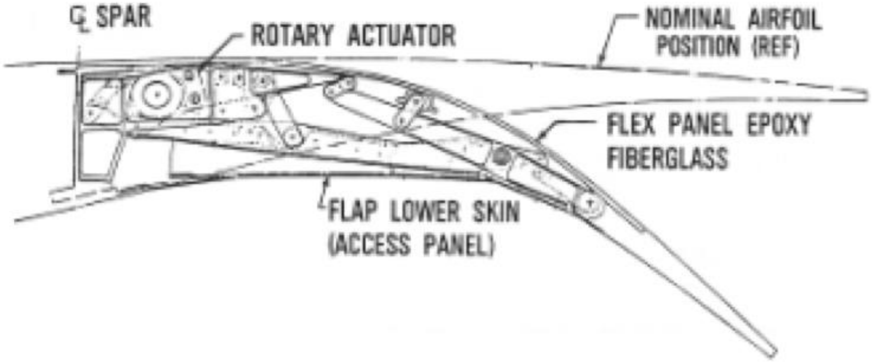
- **Project overview**
- **Historical perspective AFTI/F-111 MAW**
- **Compliant mechanisms overview**
- **Tailored structures airworthiness approach for ACTE**
  - Developed structural requirements
  - Completed structural design and analysis
  - Validated structural strength using building block testing approach
  - Installed instrumentation for monitoring structural loads and strains
  - Monitored structural health during envelope expansion with instrumentation and inspections
- **Conclusions**

ACTE Project Overview

- **Project objective: Flight demonstrate a compliant structure that replaces a large control surface**
- **Partnership between: NASA, AFRL, and FlexSys Inc.**
- **Safely cleared -2deg to +30deg ACTE flight envelopes**
  - Max Mach: 0.75, max altitude: 40kft
  - Max speed: 340 knots, max load factor: 2.0
- **ACTE potential performance benefits:**
  - Cruise drag reduction, wing weight reduction through structural load alleviation, and noise reduction during approach & landing
- **Project is providing structural and aerodynamic data to advance and assess the ACTE technology for future flight applications**

Historical Perspective - AFTI/F-111 Mission Adaptive Wing

- **Mission Adaptive Wing was a joint USAF/NASA/Boeing demonstration program**
- **Variable camber leading and trailing edge surfaces were installed on a F-111 testbed using mechanical rigid linkages**
- **The AFTI/F-111 MAW system had 59 flights from 1985 through 1988**
- **The flight test data showed a drag reduction of around 7 percent at the wing design cruise point to over 20 percent at an off-design condition**
- **Mechanical actuation system weight penalties and system complexity hindered the acceptance of the technology**

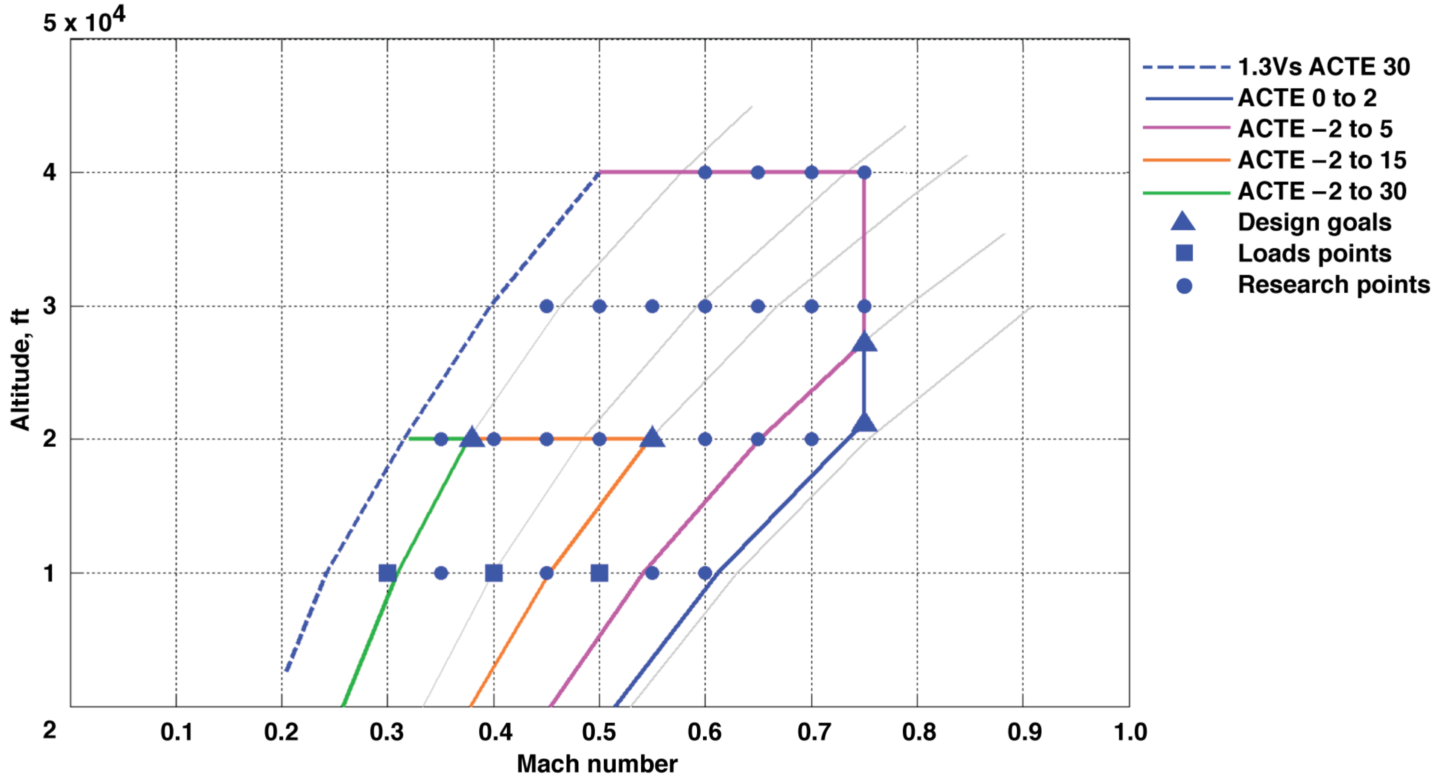


Compliant Mechanisms Overview

- Compliant design embraces elasticity, rather than avoiding it, to create one-piece kinematic machines, or joint-less mechanisms, that are strong and flexible (for shape adaptation)
- Large deformations can be achieved by subjecting every section of the material to contribute equally to the (shape morphing) objective while all components share the loads
- Every section of the material undergoes only very small linear elastic strain with very low stress and hence the structure can undergo large deformations with high fatigue life

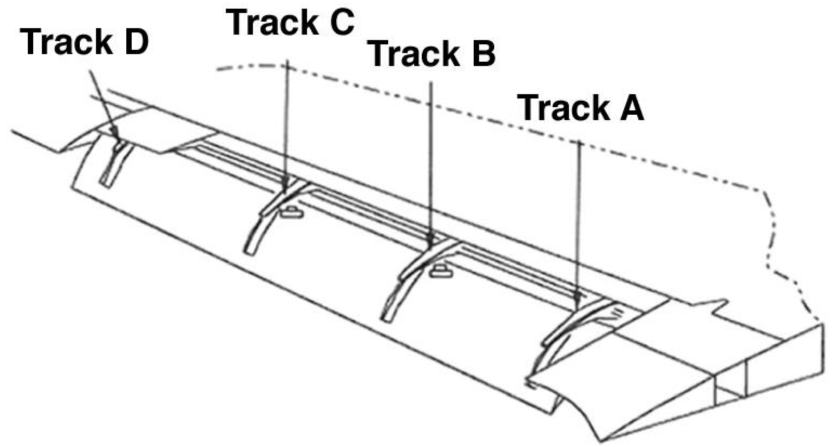
Structural Demonstration Objectives

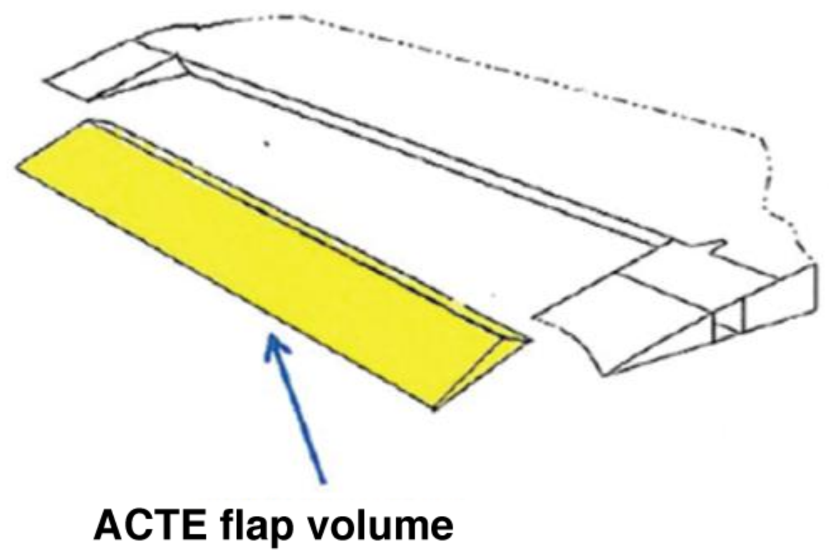
GIII Fowler flap position	ACTE flap position	Airspeed operational limit	Design airspeeds (+15 knot gust)
degrees	degrees	knots	knots
0	2	340	355
0	5	300	315
10	15	250	265
39	30	170	185



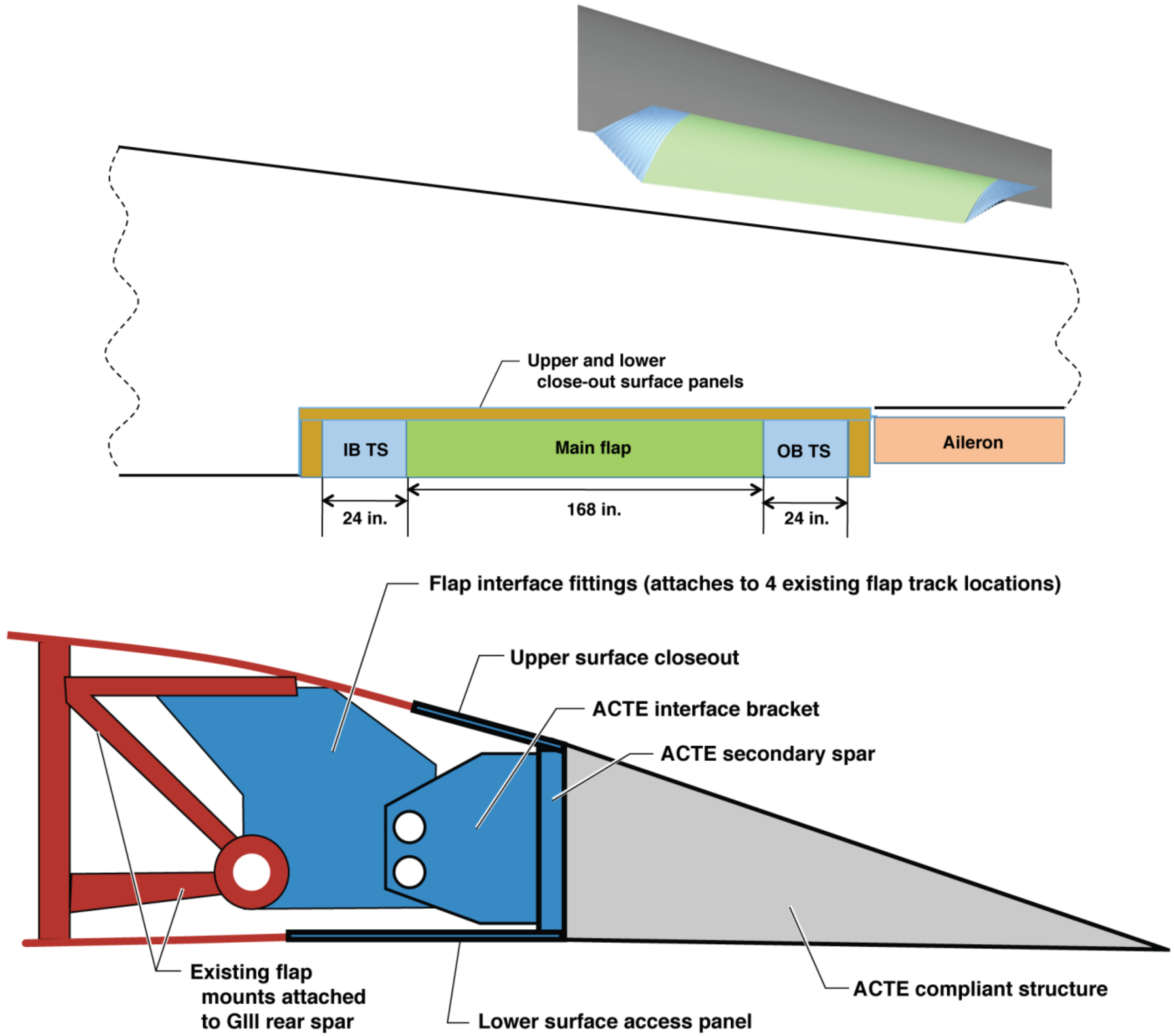
Interface Geometry Definition

- **The goal of the ACTE integration was to**
  - Match the shape of the existing Fowler flap in its zero-degree flap deflection fully retracted state
  - Integrate the ACTE onto the GIII with as little modification to the GIII as possible
- **The integration of the ACTE on to the GIII required removal of the Fowler flap, flap tracks, flap actuators and flight and ground spoilers**
- **The ACTE was attached to the rear spar using existing Fowler flap track fitting attachment points**
- **The lateral loads on the original Fowler flap were reacted out at track D which is adjacent to the aileron**



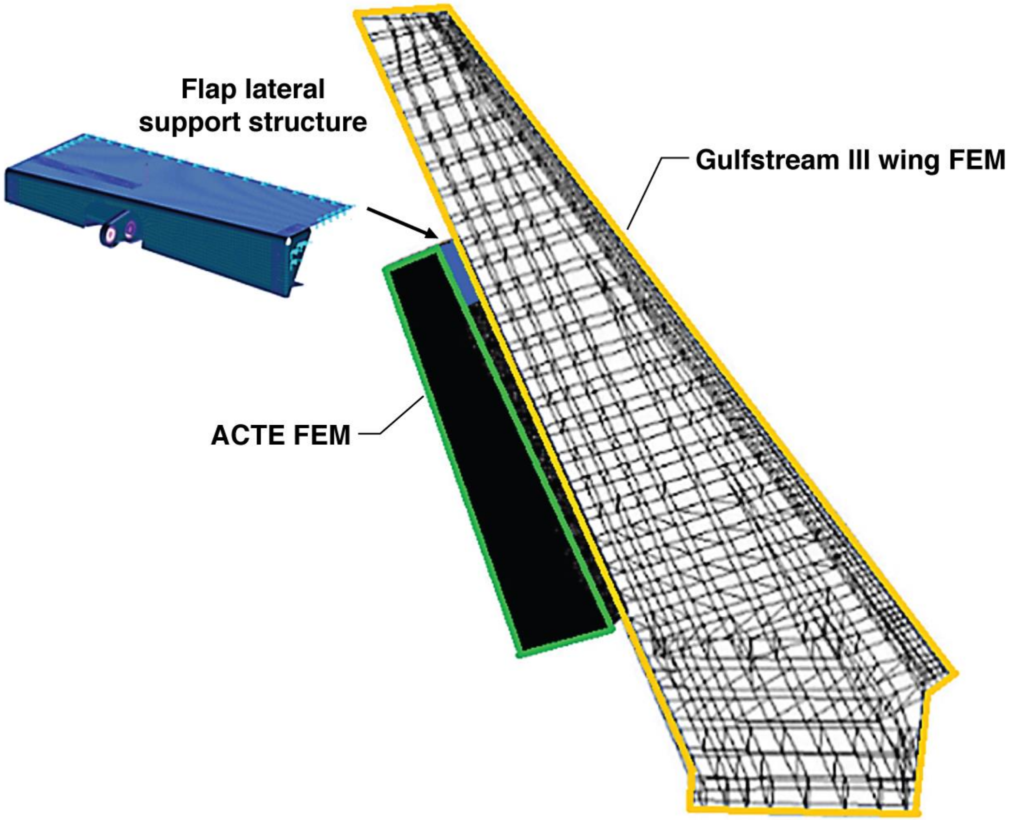


ACTE Structure Definition



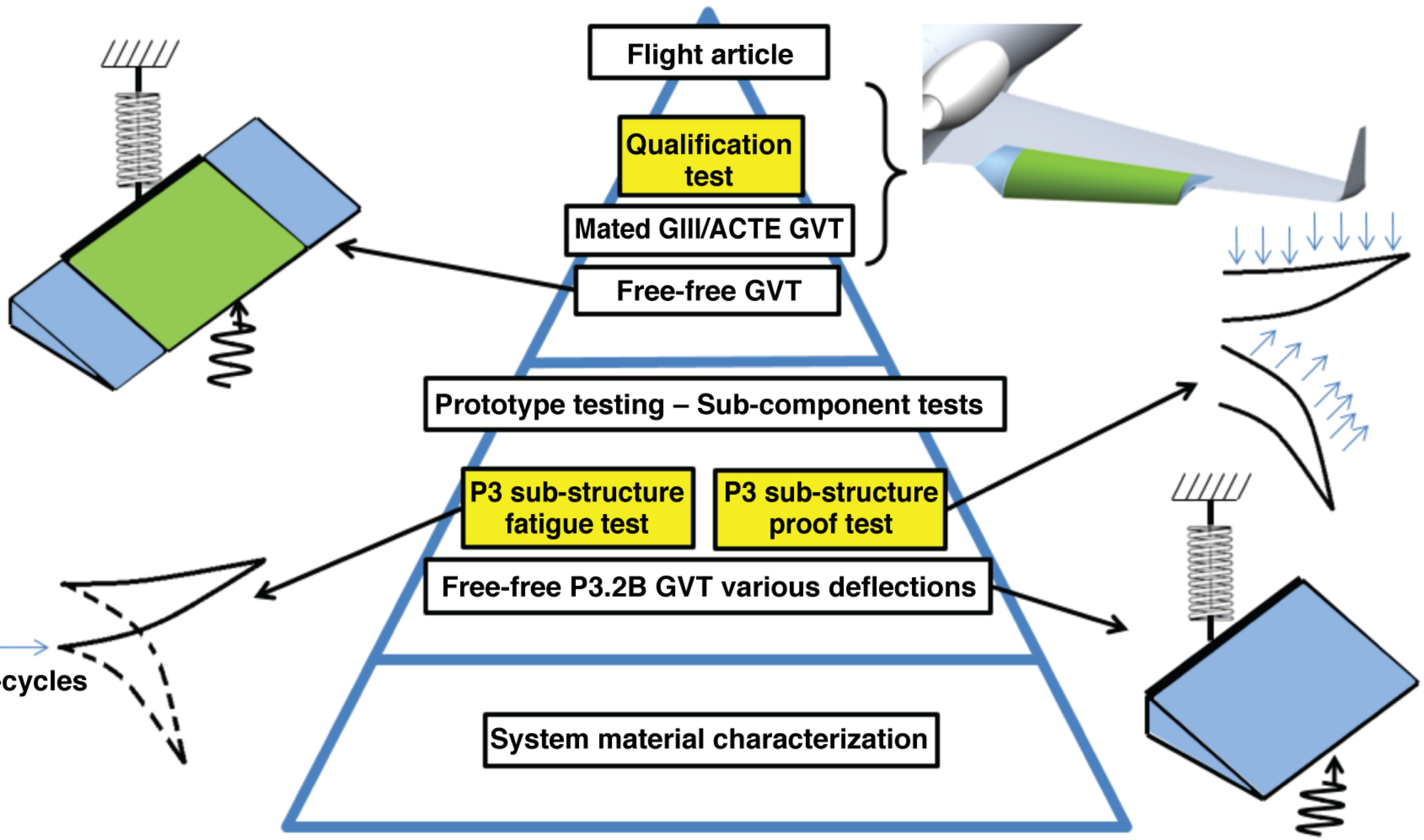
Structure Analysis Overview

- **External loads and stress analysis approach**
  - NASA provided external load cases to Flexsys, Flexsys completed the structural analysis with AFRC review
- **Inertial loads: 0g to 2.0gs (same as fowler flap)**
  - Targeted 1.5 to 1.7gs in flight
  - Maneuver loads were a smaller load driver than airspeed
- **Analysis design factors of safety**
  - 2.25 for interface design:
  - 2.0 for compliant mechanism:
  - 3.0 for actuation:
  - Strength vs stiffness design requirements and abuse loads are important things to assess during the design phase



ACTE Ground Testing Overview

- **Ground testing**
  - Building block approach: characterization -> prototype -> flight article checkout
- **Ground flight article checkout testing was very beneficial for getting a feel for the flap characteristics and working out kinks in the instrumentation**



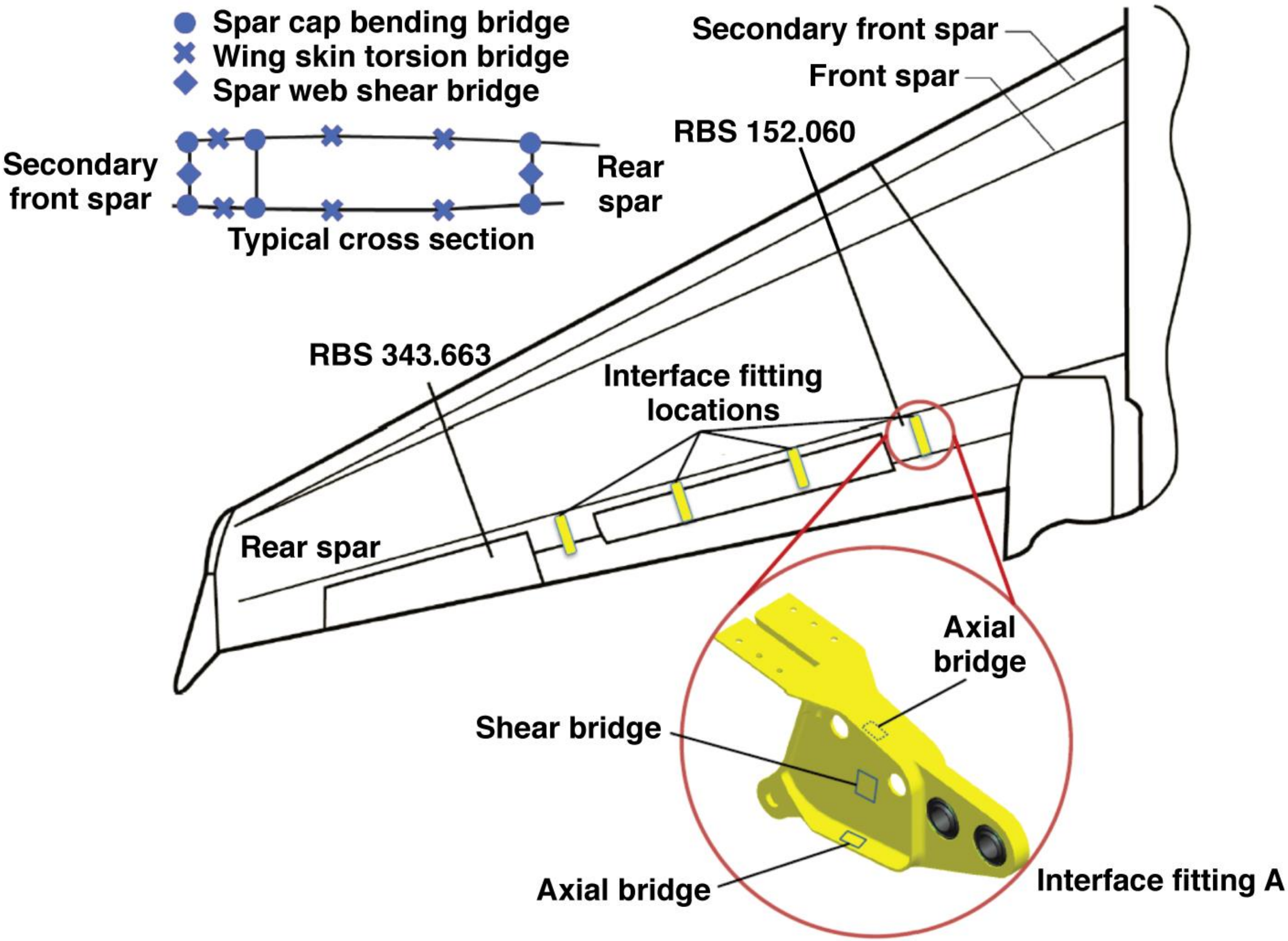
ACTE Structures Instrumentation Parameters

Structures parameters	Number of sensors	Equation errors
Wing loads	32	RBS 152: 2% RBS 343: 5%
Interface normal force and bending moment loads	21	Normal force: 10% Bending moment: 5%
Cartridge side load	4	5%
Metallic load/strain sensors located on ACTE	43	1%
Cartridge strain (fiber)	6000	NA
Vertical tail force	Derived from airspeed, aircraft sideslip angle, and rudder position	NA
Temperature	8	NA

Accomplishment:

- No strain gage failures during ACTE project execution

Flap Load Geometry

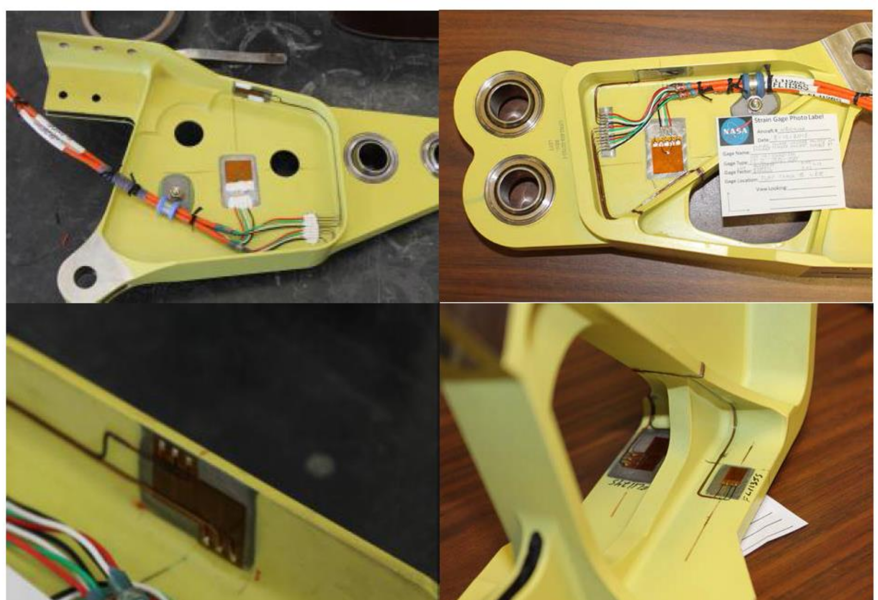


Wing Load Monitoring Overview

- **Two wing stations with the lowest margins were instrumented with strain gages and calibrated for monitoring normal, bending, and torque loads in flight**
  - Highest loads during ACTE flights were on the order of 50% of design limit loads
- **Load calibration tests provided valuable insight into the structure**
  - Load equations were derived based on load calibration data
  - Test data was used to validate the GIII wing FEM model
  - Insight into wing flex was observed based on test data
- **Testing provided confidence in ACTE analysis and clearance approach**

Interface Fitting Load Monitoring Overview

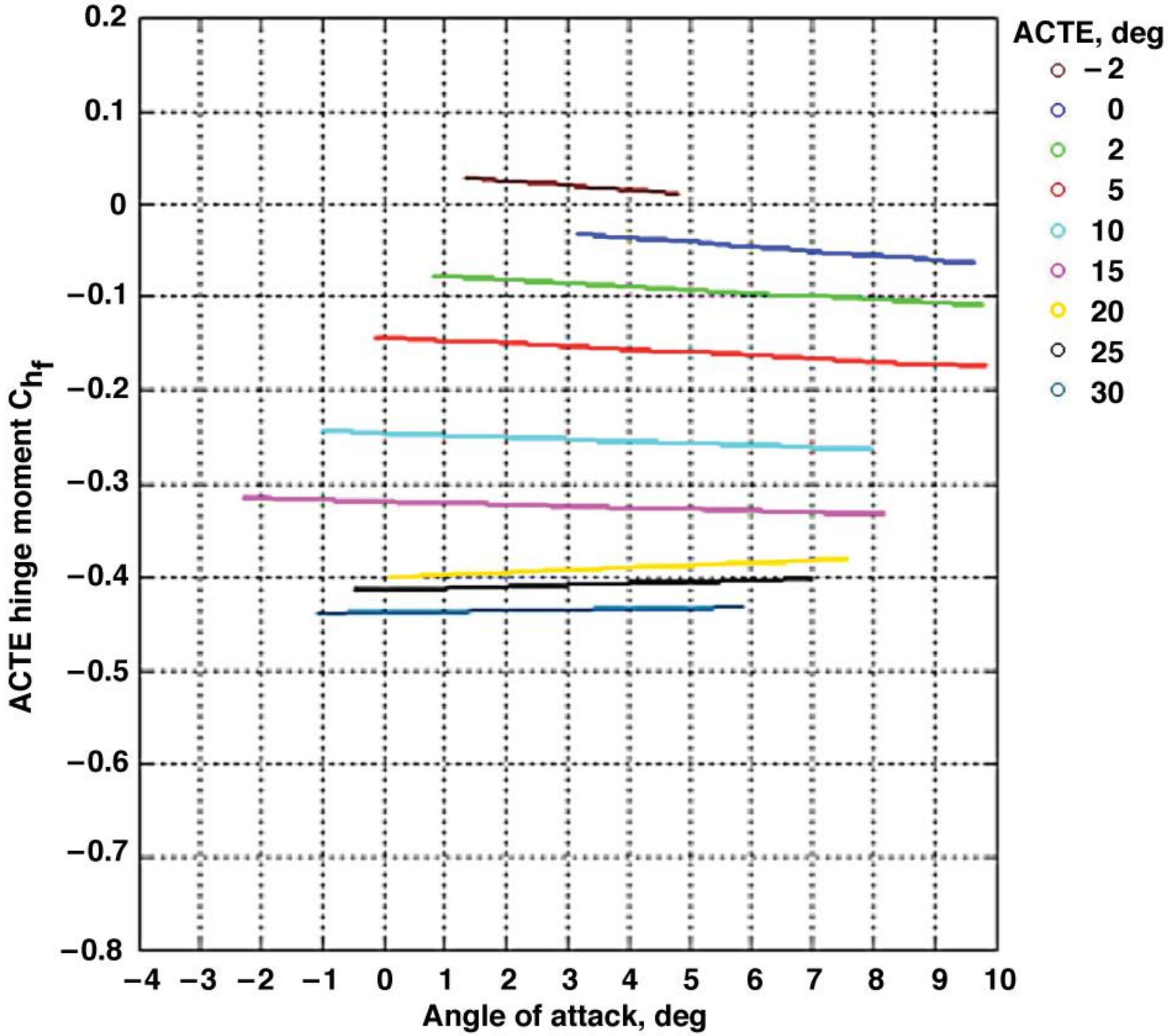
- **Objective: Monitor the loads in the ACTE/Wing Box interface during ACTE flights**
  - Envelope clearance
  - Model validation
- **All eight flap interface fittings were instrumented and calibrated using known loads for monitoring the loads real time in flight**
- **The calibration effort achieved errors on the order of 5% or less for bending and 10% or less for normal force**
- **Flap interface normal force and hinge moment loads were recorded for various flap deflections and flight conditions**



ACTE Flight Phase

- **Envelope expansion plan**
  - Laser scanning of the flap was used for symmetrically positioning the left and right flaps preflight
  - Start at zero degrees and work up in flap deflection
  - Interesting structural items did not show up until about 5 degrees (took about 7 flights)
  - Wind-up turn and pushover-pullup maneuvers were beneficial for assessing interface interactions
- **Control room monitoring**
  - Two main displays were used for monitoring structural health of the flap
  - Loads and strains were assessed pre, during, and post flight for monitoring health of the structure
  - Team had a pretty good feel for things after walking out of the control room
- **Health monitoring**
  - Strain gages on the flap were used to verify that the loads and strains returned to the pre-flight condition
    - Any anomaly with the structure should show up as an offset in the loads and strain sensors
  - The project also visually inspected the flap for cracks, wear, and loose fasteners post flight

ACTE Interface Hinge Moment Loads



Wing Deflection Measurement System

- **The wing deflection and twist were measured during the ACTE flights using a single camera located in the GIII cabin**
- **Targets were located on the wing forward spar, aft spar, and the 40% chord line at five wing span stations**
- **The camera captured one photograph every second**
- **Average error magnitudes are less than 0.112 inches**

Conclusions

- The ACTE technology was flight-tested on a GIII airplane for flap deflections of -2° up and +30° down.
- The structures airworthiness approach required a tailored approach that included structural analysis, ground testing, instrumentation monitoring, and periodic inspections
- A good deal of success can be attributed to all of the folks who supported the project along the way
- Good lessons learned from ACTE can be applied to future projects
- Looking forward to follow on phase for Mach extension and flap twist flights

Backup Slides

AFRC Aircraft Structural Safety of Flight Guidelines