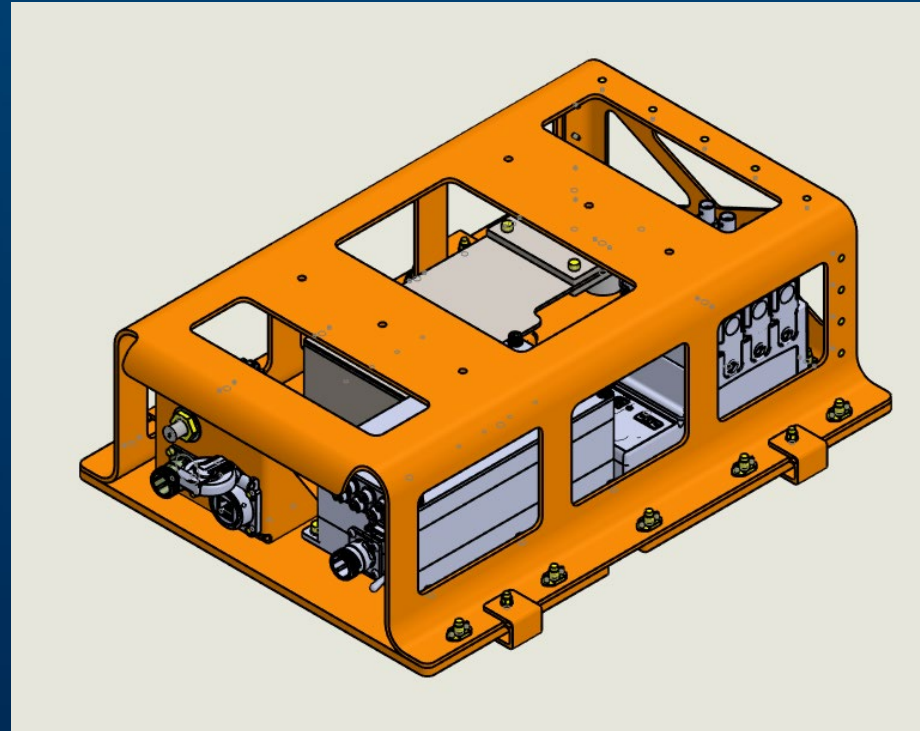


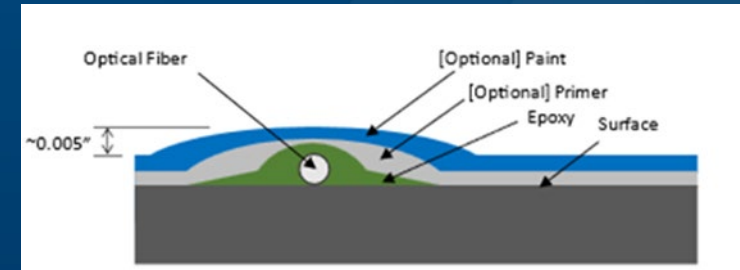
T-34 FOSS Flight Test



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Fiber Optic Sensor System: FOSS

- What is FOSS?
 - Lightweight Fiber-Optic fibers embedded with Fiber Brag Gratings
 - FBGs placed in discrete locations acting as “sensors” can be used for strain, temperature, or shape sensing.

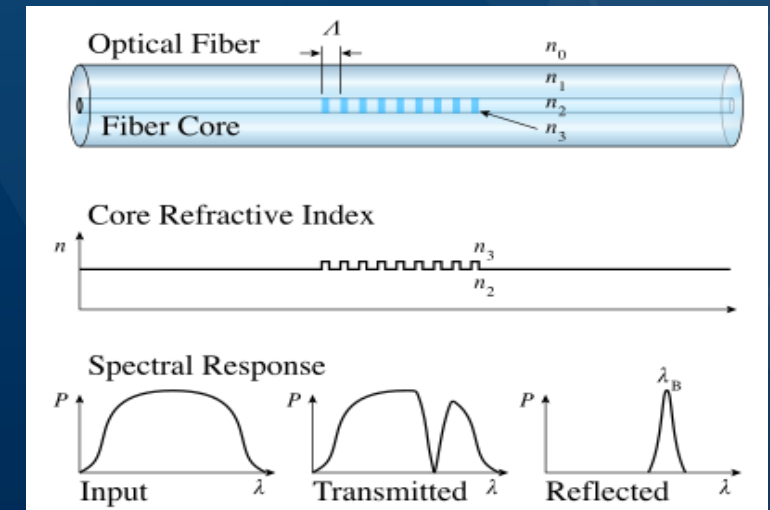


Bonded onto surface similar to strain gauges

Multiple Fiber Bragg Gratings (FBGs) can be embedded within fiberoptic cable with each FBG acting as a strain gauge (Not to scale, actual width about a human hair)



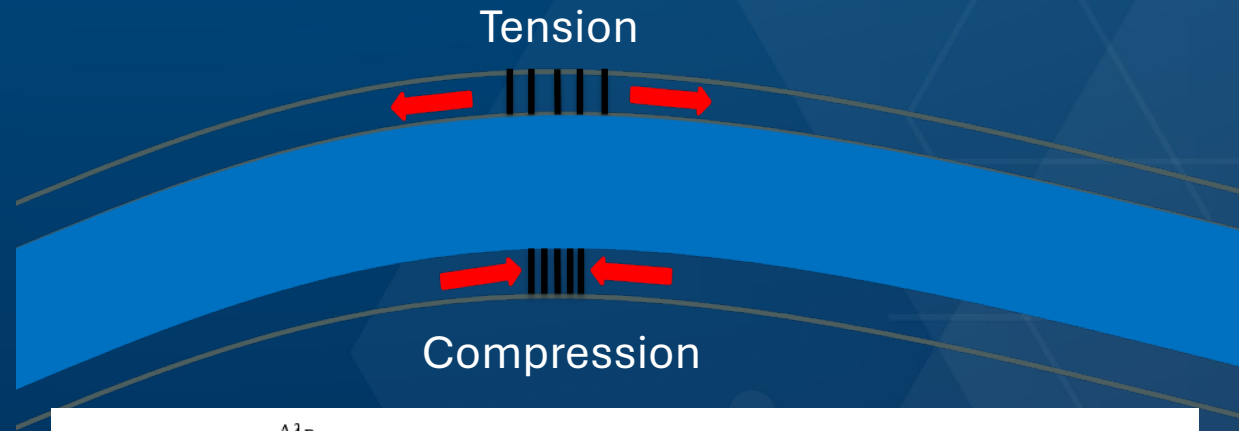
FBG



“Fiber Bragg Grating” by Sakurambo. Creative Commons share alike 3.0 license

How does it work?

- Δ Wavelength
- As the fiber flexes the tension and compression causes the spacing within the FBGs to change causing a change in the wavelength reflected



$$\frac{\Delta\lambda_B}{\lambda_{B0}} = (1 - p_e)\epsilon + (\alpha_A + \alpha_n)\Delta T \quad (1)$$

ϵ = strain

$\Delta\lambda_B$ = Change in wavelength of FBG

λ_{B0} = Average initial wavelegnth

$p_e = 0.167$ at 25°C Strain optics coefficient

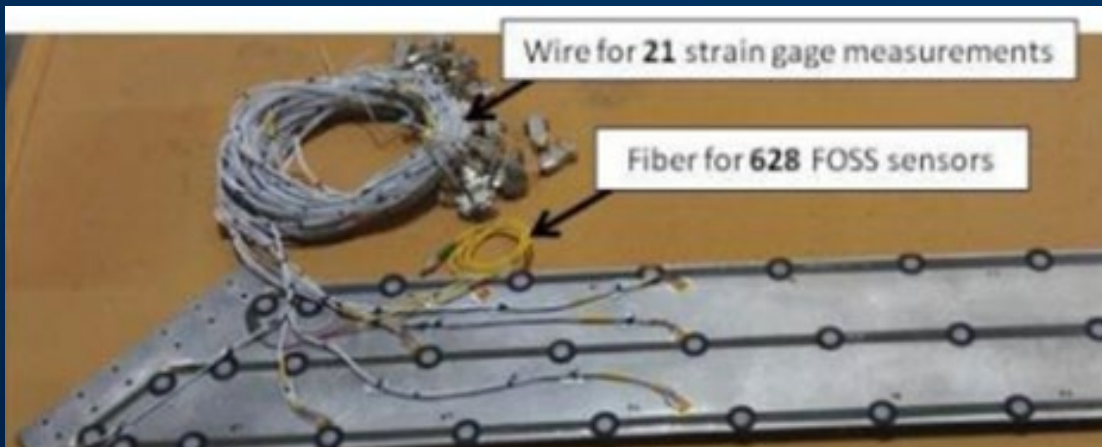
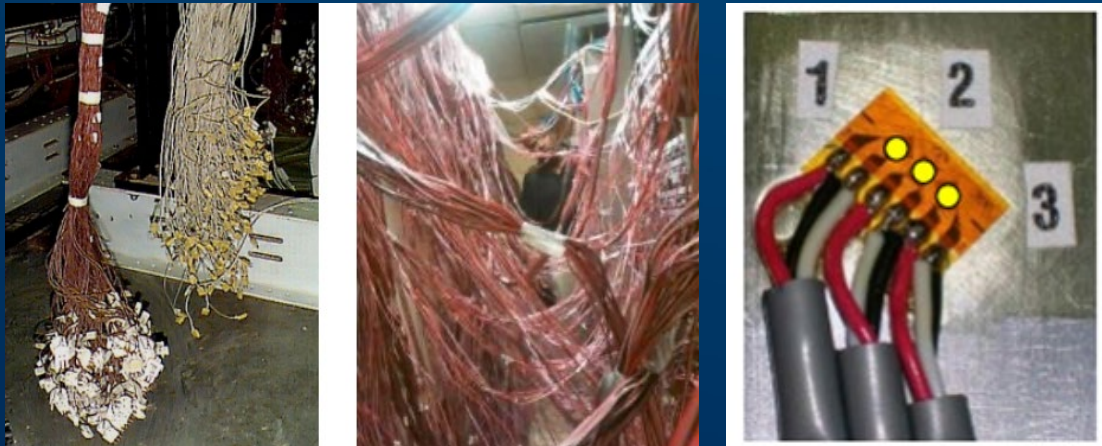
ΔT = Change in temperature

$\alpha_A = 0.55 \times 10^{-6}$ Coefficient of thermal expansion (CTE) of the optical fiber at 25°C

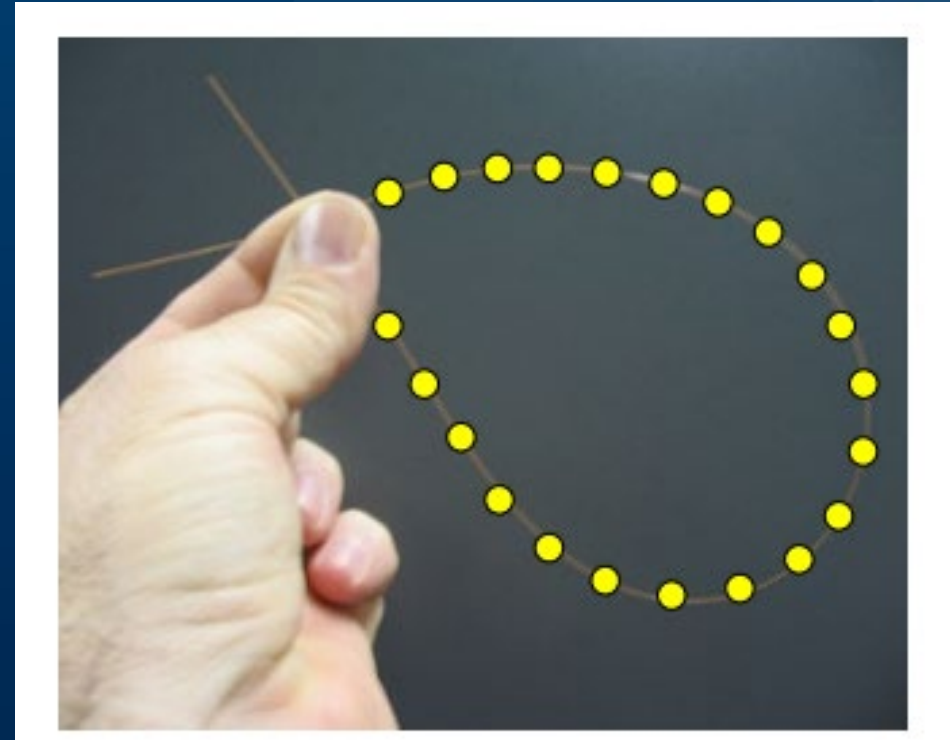
$\alpha_n = 8.2 \times \frac{10^{-6}}{^{\circ}\text{C}}$ at 25°C Thermo optics coefficient

Why FOSS?

Traditional



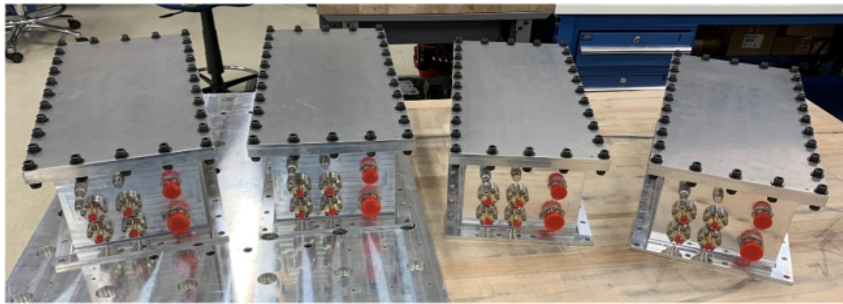
- FOSS Benefits:
 - Lighter weight
 - Less wiring
 - Easier to install
 - Not susceptible to EMI



FOSS VERSIONS: WDM Flown at Holloman and AFRC for this demonstration

FOSS (OFDR version)

- Use weak FBGs (0.01% reflectivity) with identical wavelength
- Use external FPGA to conduct FFT algorithm to calculate sensor strain/temperature
- Use a mechanical swept-source laser
- Can be tuned to work as a WDM system



Launch Capable FOSS Specifications

Parameters	Units
Fiber channel count	4
Max sensing fiber length	40 ft
Max patch cable length from system	≈100 ft
Fiber type	Single-mode fiber (SMF)-28
Max no. of sensors/fibers	2,000
Max Sample rate	50 Hz
Onboard storage	32 GB
Interface	Gigabit Ethernet
User Interface Protocol	transmission control protocol (TCP)/internet protocol (IP)
Operational Communication Protocol	user datagram protocol (UDP)
Power	70 W at 28 VDC
Weight (including enclosure)	38 lbs
Size (application specific)	18.15 in by 8.625 in by 6.25 in

FOSS (WDM version)

- Use strong FBGs (50%+ reflectivity) with unique wavelength
- Use peak-detection to calculate sensor strain/temperature
- Use a semiconductor solid-state laser with no moving part
- Cannot be switched to OFDR mode.

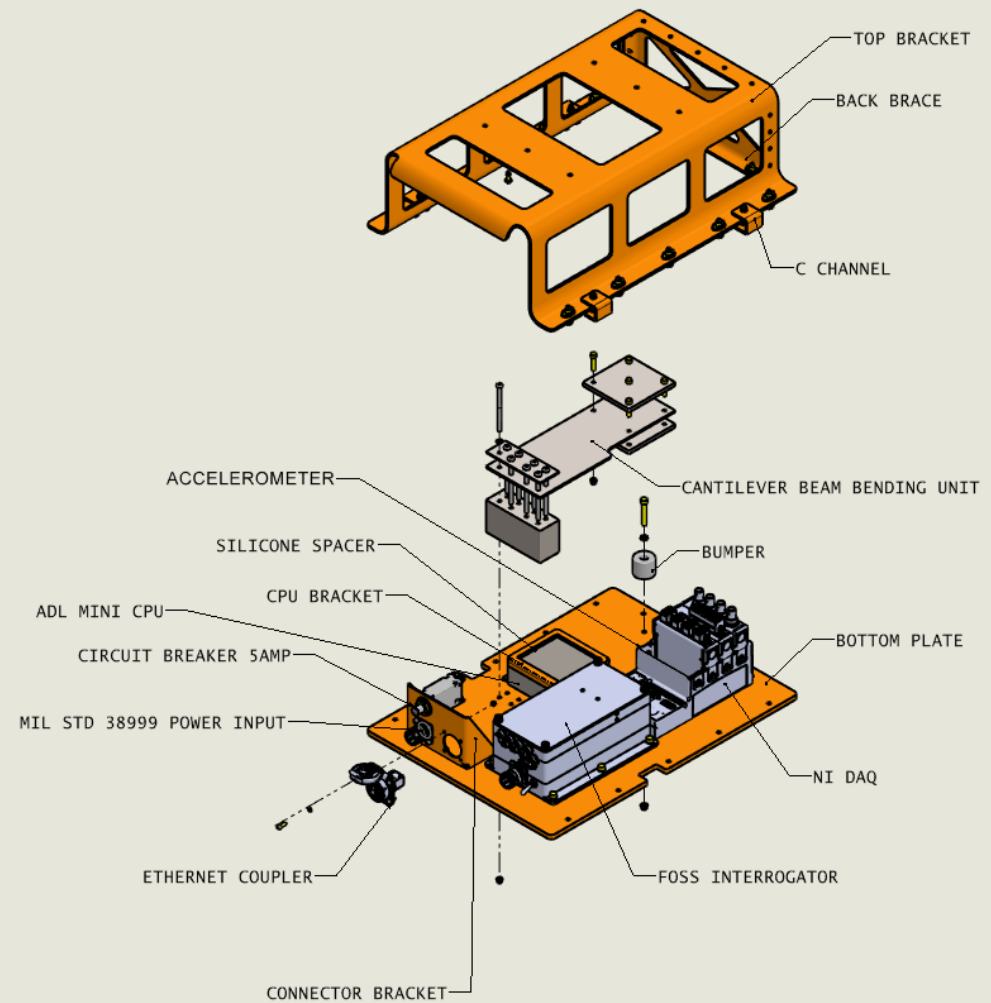


WDM FOSS Specifications

Parameters	Units
Fiber channel count	4
Max sensing fiber length	No limit
Max patch cable length from system	No limit
Fiber type	Single-mode fiber (SMF)-28
Max no. of sensors/fibers	32
Max Sample rate	400 Hz
Onboard storage	64 GB
Interface	Gigabit Ethernet
User Interface Protocol	transmission control protocol (TCP)/internet protocol (IP)
Operational Communication Protocol	user datagram protocol (UDP)
Power	11 W at 28 VDC
Weight (including enclosure)	3.72 lbs
Size (application specific)	3.4 in x 6.85 in x 2.78 in

The T-34 Project

- Cantilever beam on pallet
- WDM FBG on wing spars in wheel wells collocated with foil gauges and thermocouples
- Perform 4-point calibration before and after
 - Fuel tanks empty on landing gear
 - Fuel tanks empty on jacks
 - Fuel tanks full on landing gear
 - Fuel tanks full on jacks
- Fly 100 hours and compare drift before and after.
 - Do the traditional foil strain gauges and FOSS drift at the same rate?



End User Concerns

- DARPA, the NAVY and Boeing expressed concerns about FOSS (Fiber Optic Sensor System) Durability and Longevity
- AFRC Technology Transfer Office aims to
 - Conduct a long-term evaluation of FOSS strain
 - Stability
 - Robustness
 - Repeatability
 - Show that FOSS and conventional strain gauges trend closely
 - Provide real-world long-term aircraft flight test data



Early Testing History & TPS Involvement

- Initial testing with TPS/ 586th
 - FOSS T-38 payload duplicated to fly aboard T-34 865
- Evaluated early concept in realistic flight test conditions
 - Exposed integration, data flow, and operational anomalies
- Key outcomes:
 - Identified hardware integration issues
 - Revealed data synchronization problems





Lessons Learned from TPS Flights at Holloman AFB

- First: T-38C at Holloman was also integrating a new on-board data instrumentation suite for the test flight (KLAW)
- FOSS was not capable of obtaining onboard time from their system.
- In post process, time-sync is required to capture the take-off time, which involved looking at each flight-card and noting the “lack-of-strain” moment from the cantilever beam between the Jet taxiing (with a lot of low-strain vibration) and the actual take-off (g-loading) to determine and synchronize the event times.
- HAVE FOSSIL flight testing flown March of this year had an operational KLAW system
- We had time-synchronization and telemetered strain data real-time to a ground station



Lessons Learned from TPS Flights at Holloman AFB

- Second: We had not anticipated there would be a temperature gradient at various points inside the AgilePod.
- During flight, the temperature was cooler in the front of the Pod versus the back, which made the initial assumption of uniform temperature throughout the Pod invalid.
- This affected the accuracy of the strain measurements that were bonded onto the AgilePod itself, but didn't affect the cantilever beam measurements on the test article which had TCs on both sides.
- Post lab testing confirmed that the cantilever beam has uniform despite changing temperatures based on changing flight levels.
- HAVE FOSSIL testing had a dedicated FOSS temperature sensor on the test article to ensure temperature data was captured on the beam for compensation.

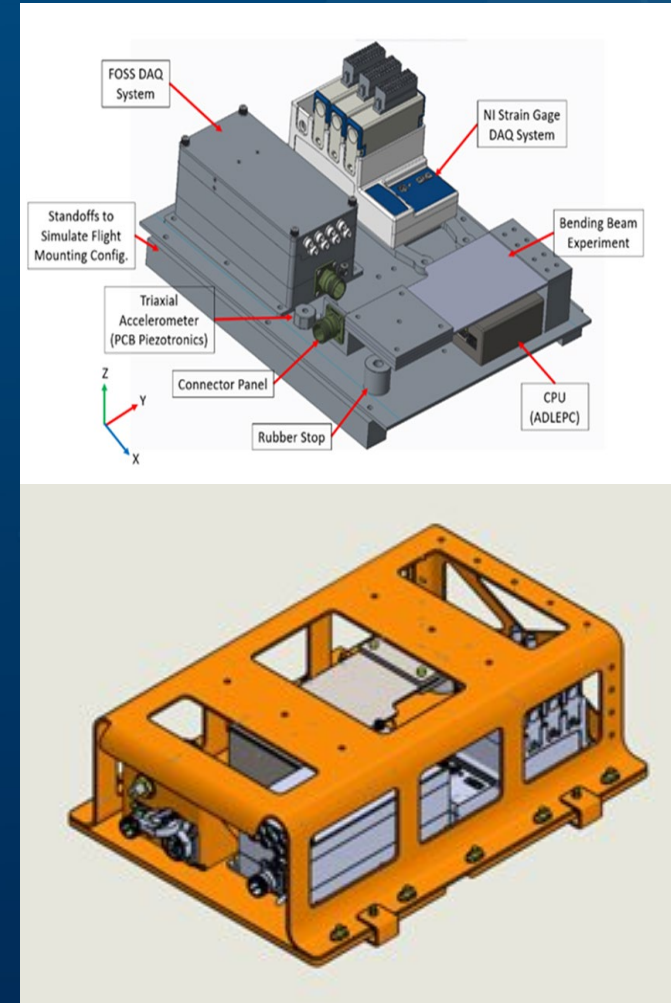


Lessons Learned from TPS Flights at Holloman AFB

- Third: During HAVE FOSSIL it was determined that one of the fusion splices was mounted at the fulcrum of the cantilever beam which caused it to separate during deflection
- This caused the data to drop out during high G maneuvers
- To remedy this issue the pallet was flipped to put the fusion splice in compression instead of tension during high G maneuvers.
- Moving forward it is recommended not to install fusion splices on fulcrum points or high movement areas.

Payload Adapted to T-34

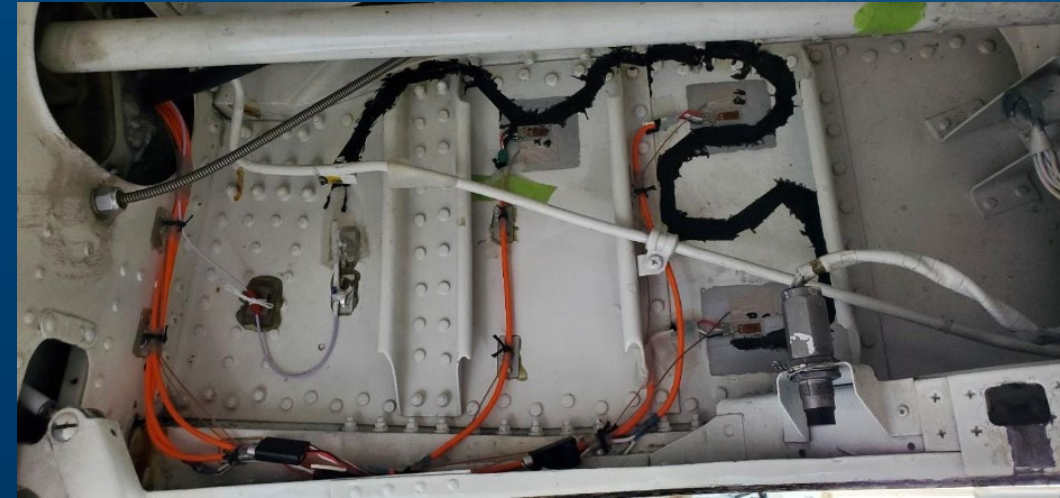
- Structural branch review:
 - Adapted to existing mounting structure in T-34 luggage compartment
 - Reviewed and modified to meet AFRC flight loads standards
- Electrical engineering reviews:
 - Wire load reviews
 - Routing and mounting conformance
- Sensor installation:
 - Due to staff loading, outside contractor sourced to install strain gauges.
 - NASA engineers with proper certification assembled equipment under the observation of tenured technicians and inspectors



Sensor Installation and Calibration

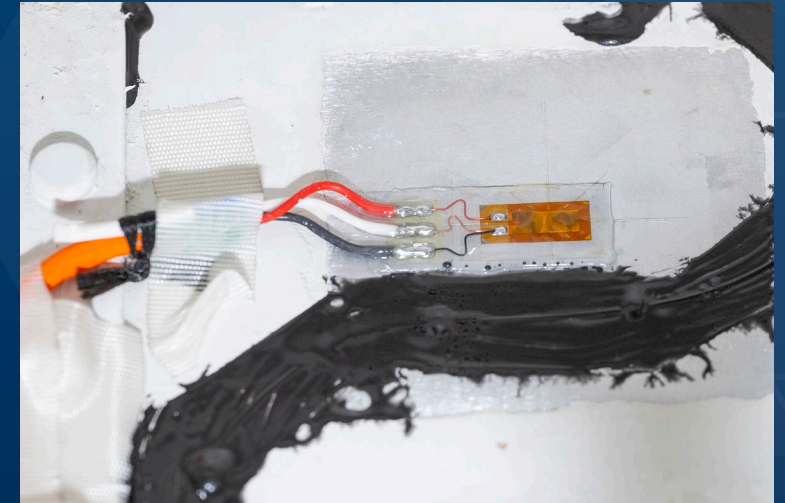
- Key steps:
 - Wing spars accessible via wheel wells
 - Conventional foil gauges, thermo-couples and FOSS FBG collocated three places on port and starboard wing spars
 - Foil gauges tested for resistance
 - FBGs tested for light conductivity
 - Final sensor operation verified via FOSS interrogator and NI DAQ

- Calibration set points:
 - Gauge readings captured at four set points.
 - Aircraft on gear or jacks giving two fulcrum points
 - Wing tanks full and drained for two load set points
 - Repeat these four points at the end of flight series.



Big Picture RD&E Development Process

- End-to-End flow:
 - Concept -> Bench Testing -> Ground Integration -> Flight Readiness -> Flight Test -> Analysis -> Report
- Key elements:
 - Incremental risk reduction
 - Progressive capability growth
 - Continuous verification
- Integration into T-34:
 - Power, mounting, safety, data interfaces
 - Designed to be non-intrusive and rapidly configurable



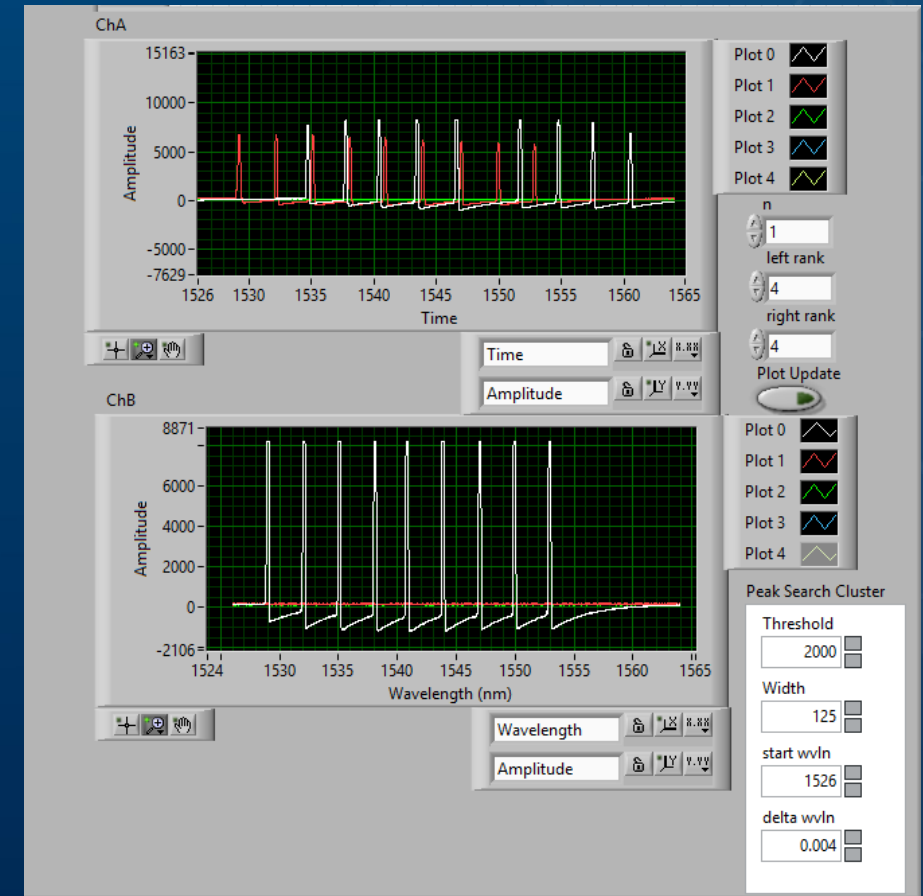
Flight Test Execution

- Test Objectives:
 - Validate system performances
 - Evaluate integration impacts
 - Verify data quality
- Key achievements:
 - Successful system operation in flight
 - Reliable data capture
 - Minimal aircraft impact



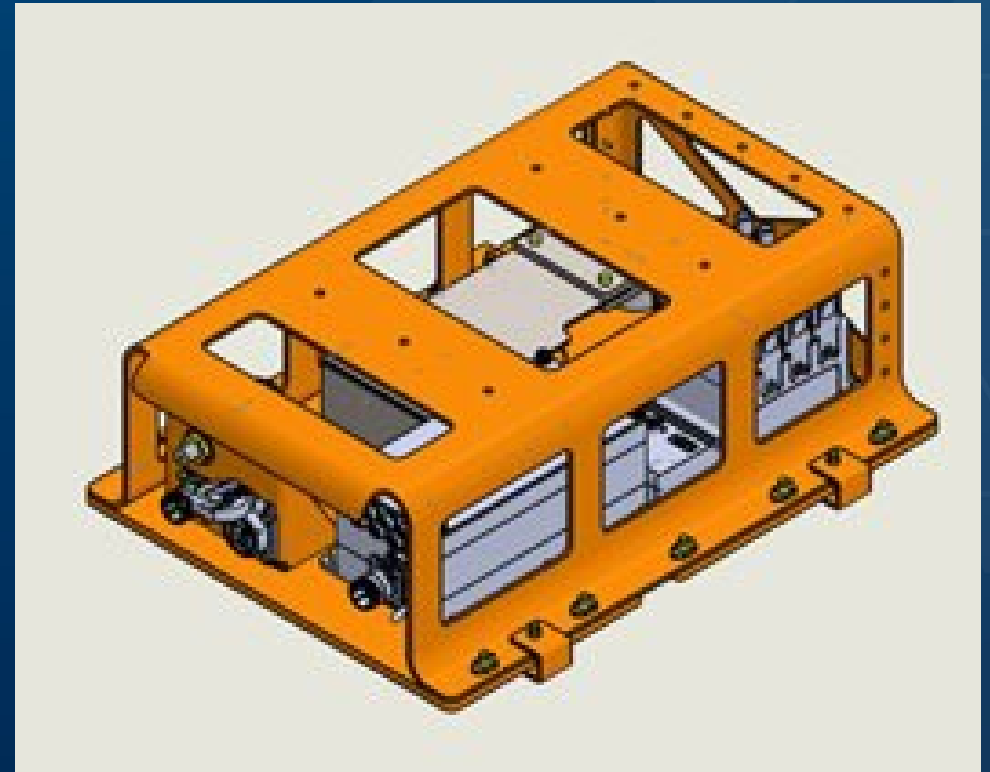
Analysis & Reporting

- Post-flight process:
 - Data validation
 - Performance assessment
 - Comparison to objectives
- Outputs:
 - Technical findings
 - System improvement recommendations
 - Lessons for next spiral



Lessons Learned & Path Forward

- Major lessons:
 - Early operational testing is essential
 - Spiral development reduces risk and cost
 - Integration simplicity drives usability
 - Continuous tester feedback improves system maturity
- Future Focus:
 - Expanded sensor integration
 - Improved automation
 - Broader RD&E application



Wrap Up

- Key Takeaways:
 - Early TPS testing defined real engineering problems
 - Spiral development matured FOSS efficiently
 - System is now a flight-worthy RD&E platform
 - Model can be applied to future research systems

