Rotating Balance Design and Production, GRC-419R

Kenneth Toro, Devin Burns, Peter Parker, and Jonathan Ponder

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Collaborators

- **Langley Research Center**
  - Devin Burns
  - Peter Parker
  - Sean Commo
  - Donny Harper
- **Glenn Research Center:**
  - Mark Woike (retired)
  - Jonathon Ponder
  - Tony Shook
  - Joe Dussling
  - Jim Buckley
  - Scott Metzger
- **Modern Machine & Tool**
  - Dennis Yates
  - Yousuf Mohammad
  - Kevin Bloxom
  - Mark Roth
  - Howard Walls
- **And Others**

Project Overview

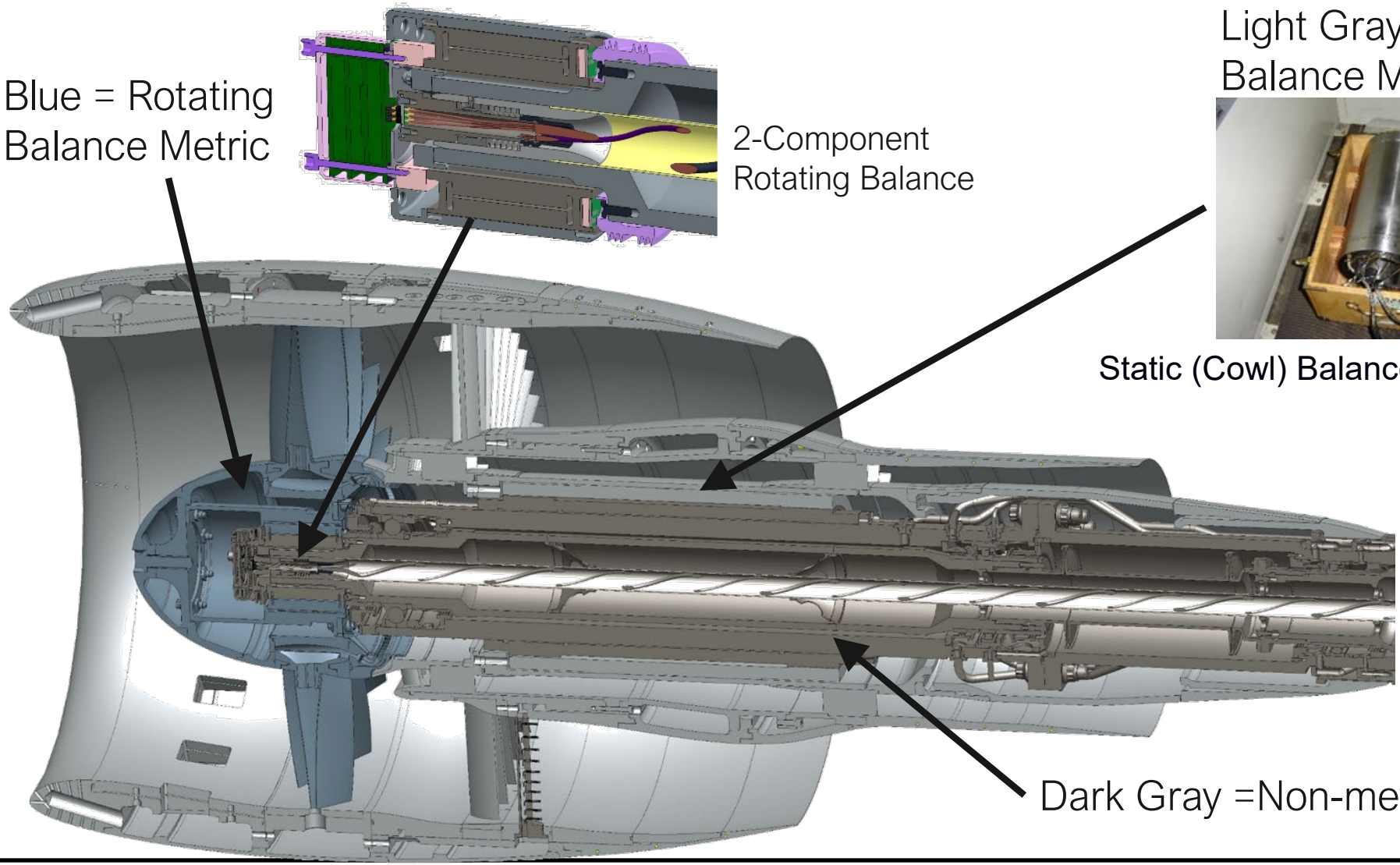
Four (x4) new rotating balances are in various stages of design and production

- **(x2) Two-component small form factor rotating balances, GRC-517R-A&B for advanced turbofan testing at NASA Glenn Research Center**
- **(x1) Two-component rotating balance GRC-419R for boundary layer ingestion testing at NASA Glenn Research Center**
- **(x1) Two-component reduced diameter balance for tail cone thruster testing at NASA Ames Research Center**
- **(x1) Six-component balance Unducted Single Fan, USF at NASA Glenn Research Center**

Motivation

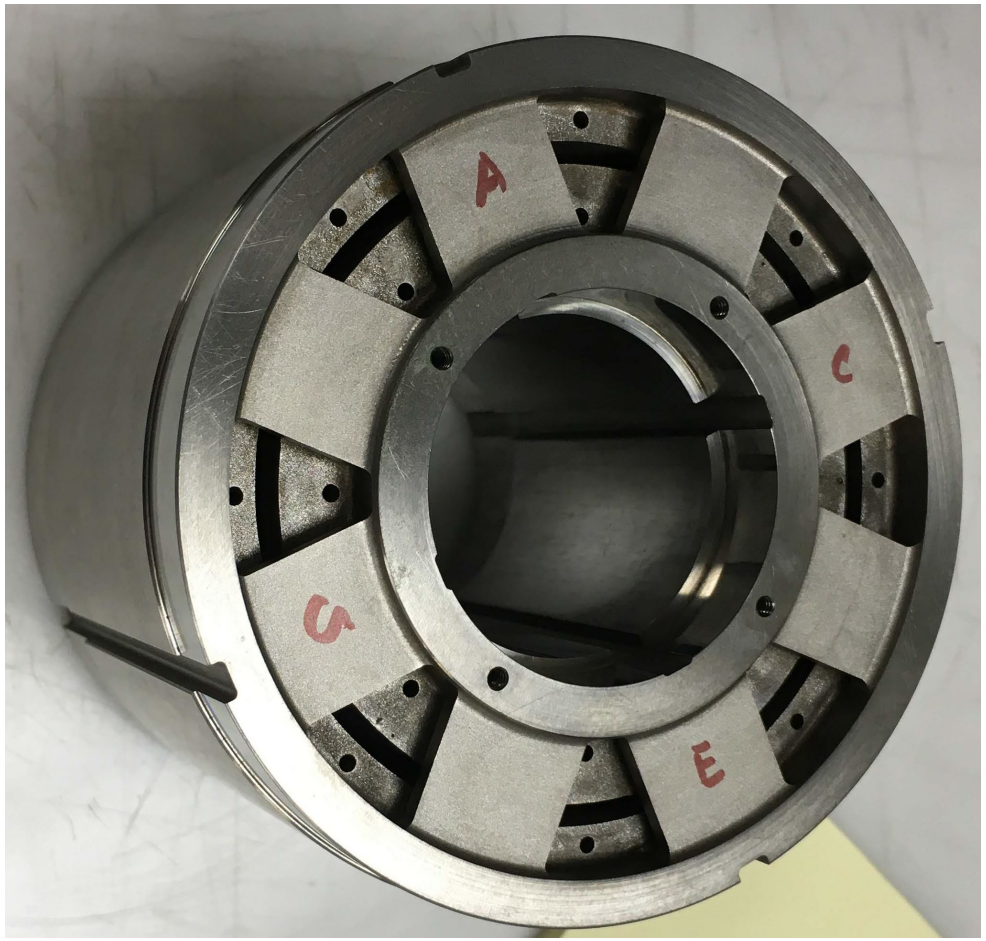
- **Force balances provide a measure of propulsion performance independent from flow field measurements.**
  - System performance (net thrust – drag) is only measured with force balances.
  - Fan efficiency measurements based on rotor torque are more accurate than pressure/temperature-based measurements.
- **New two-component rotating balances are being required for the testing of fan concepts being developed under several NASA Aeronautical Research Mission Directorate (ARMD) and Advanced Air Transport Technology (AATT) Projects**
  - Higher bypass ratio fans with smaller engine cores (GRC-517Rs)
  - **Boundary layer ingestion tolerant fans (GRC-419R)**
  - Hybrid electric propulsion concepts (tail cone thruster, etc.)
  - Unducted single fan (GRC-222R)
- **Need to interface to new state-of-the-art FPGA telemetry systems that have been developed for fan testing at NASA GRC**

Current Need



Rotating Balance Design Overview

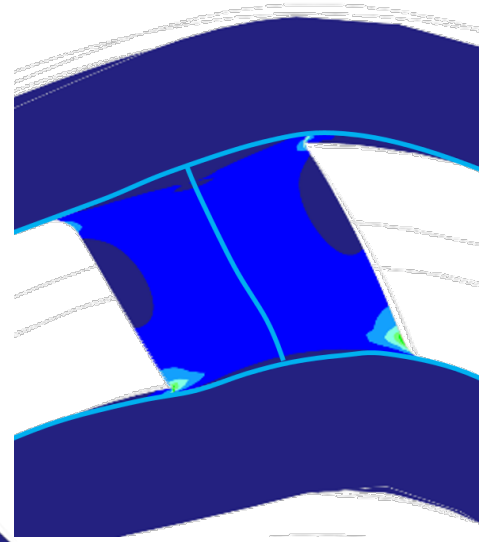
- **Spoke wheel design, with both forward and aft beam groups**
- **Two measurement components:**
  - Torque and Thrust
- **Thick “bulkhead” behind beams**
- **Keyways to transmit torque loads**

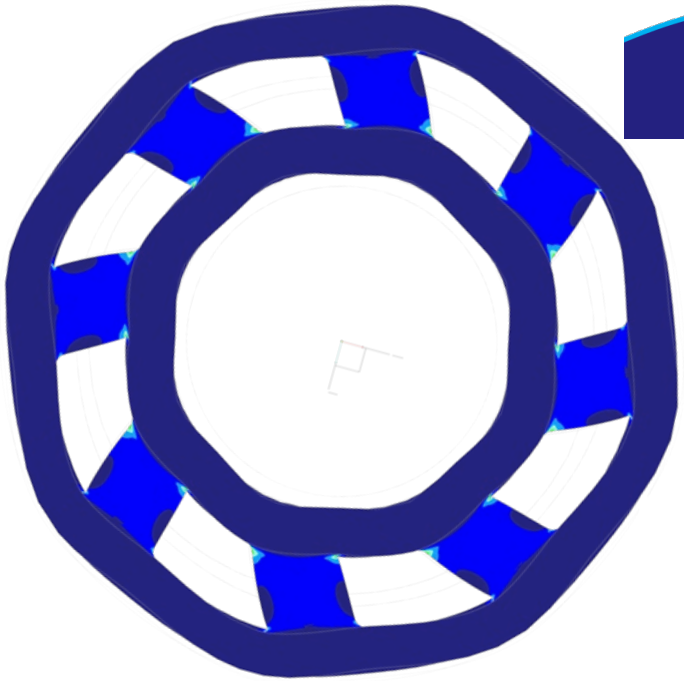


Finite Element Analysis Observations

- **Double bending behavior was initially expected due to torque load**

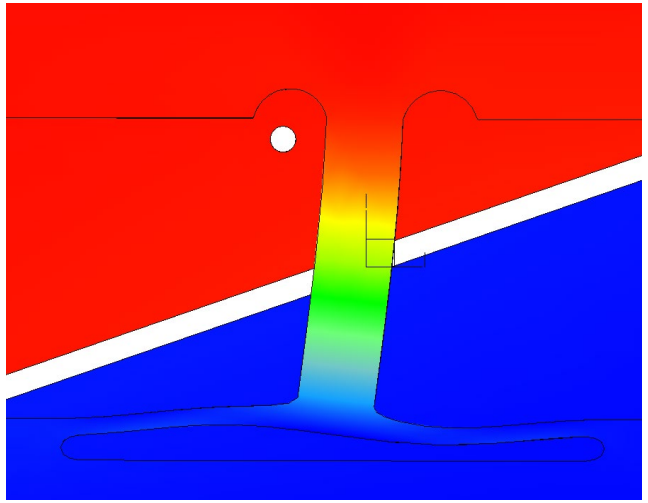
- **FEA revealed warping behavior of the outer and inner diameters**
  - Warping of outer diameter reduces double bending behavior of beams

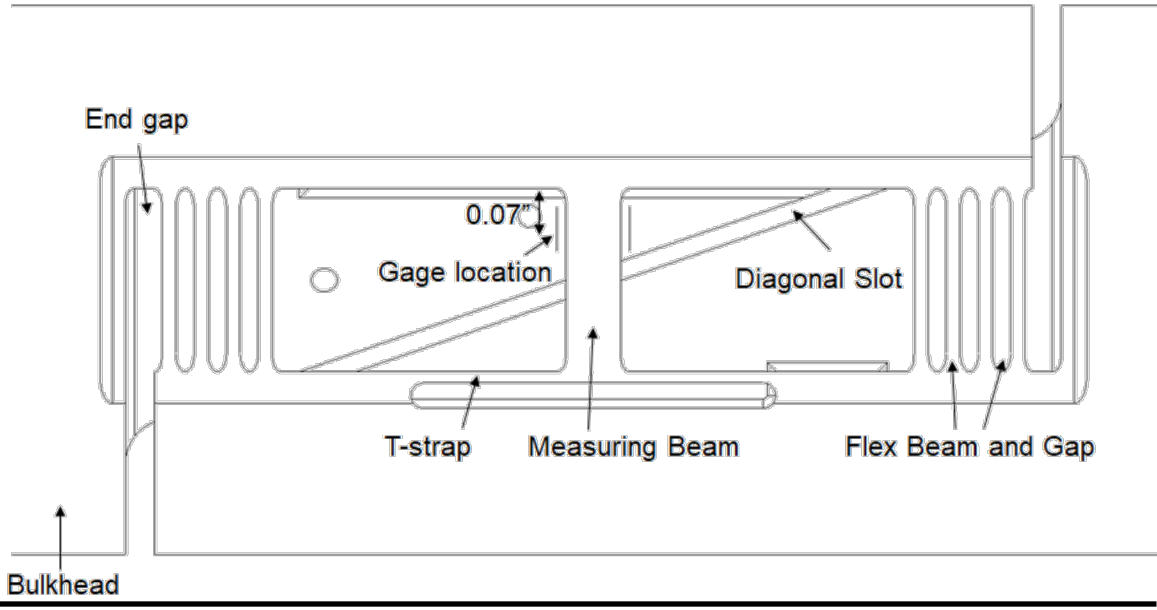




Analytical Model – T-Strap

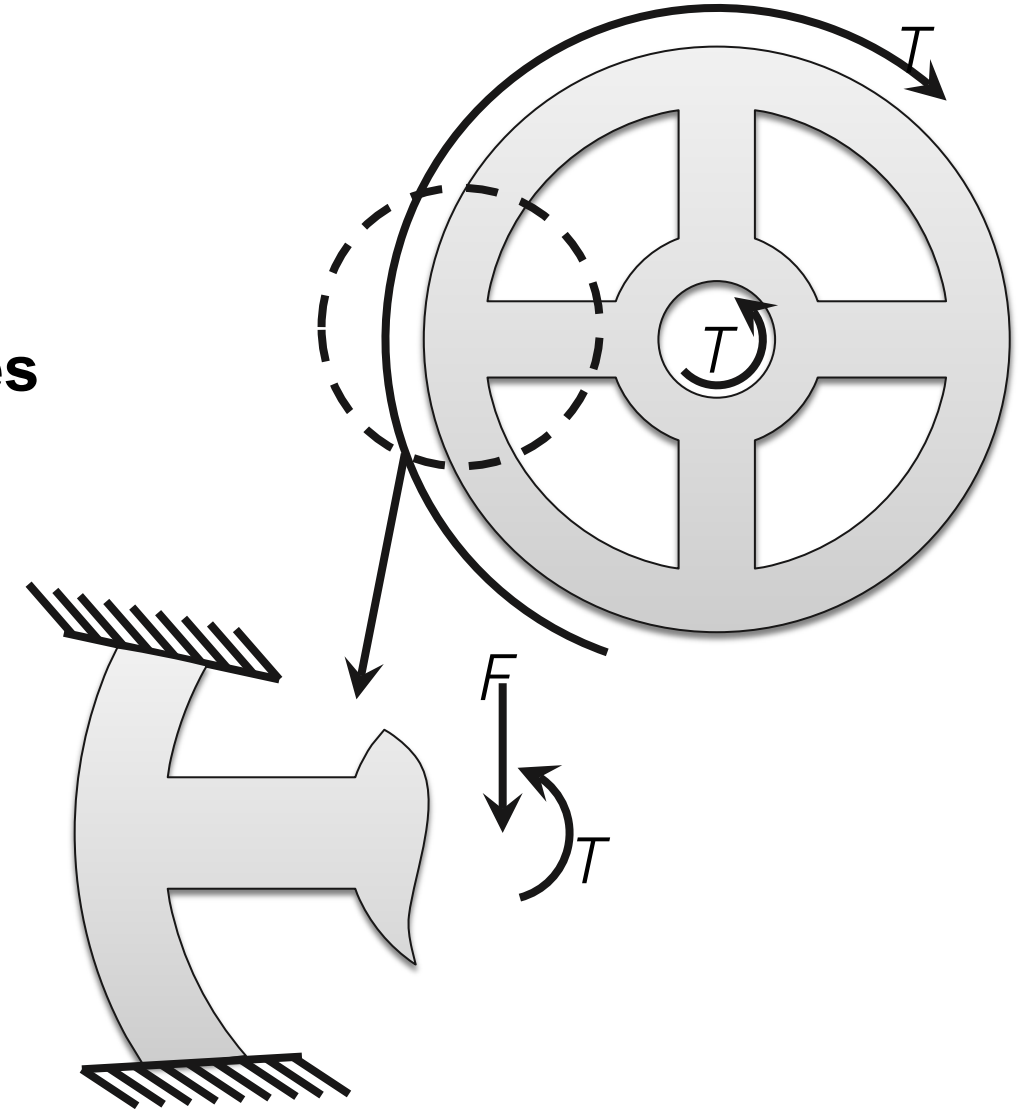
- **Behavior of the outer diameter is similar to another known balance feature, the T-Strap**
- **A T-strap is a design used to reduce normal force interactions on the axial measuring beam**
- **This design feature reduces the double bending of the axial beam**
- **See NASA/TM–2019-220248 for more details**





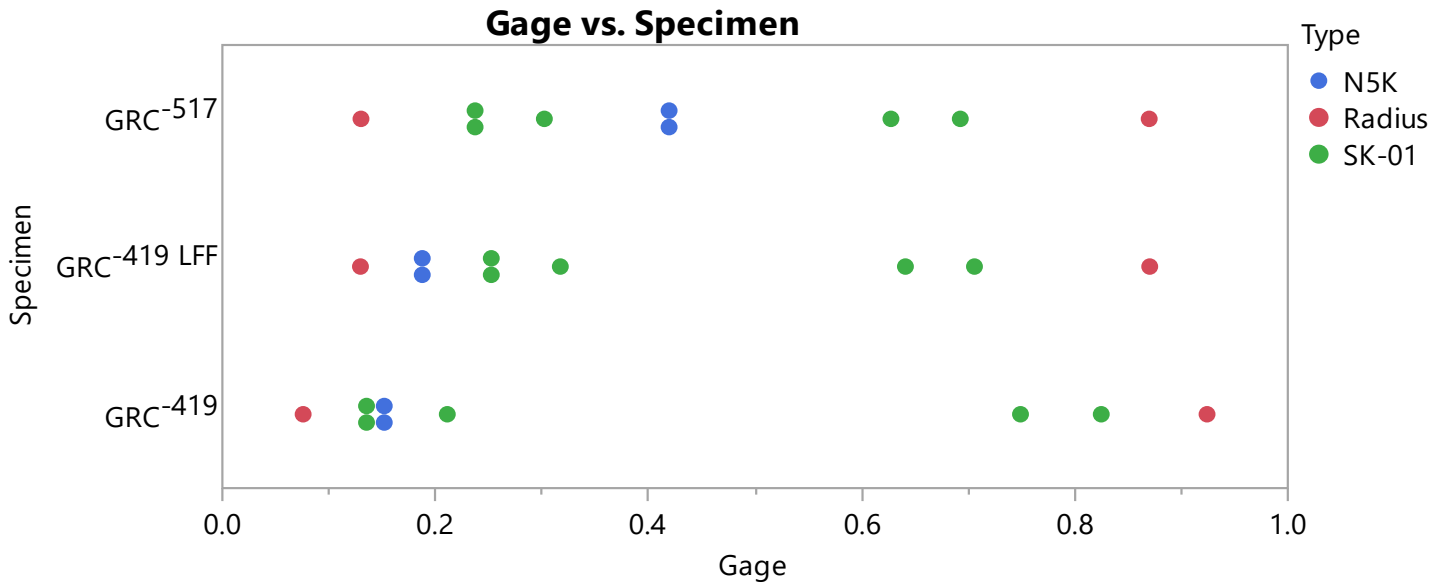
T-Strap Applied to Rotating Balances

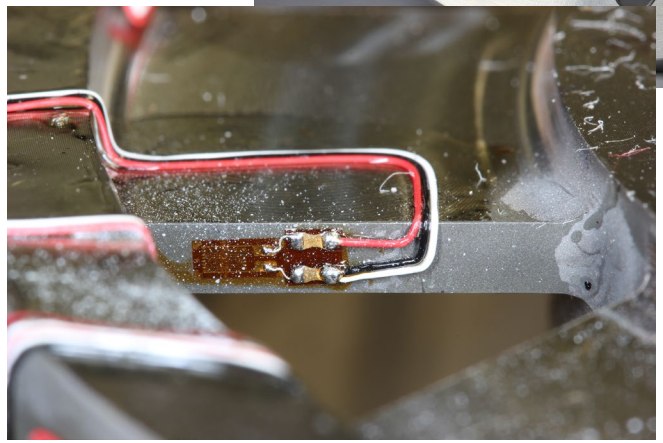
- **A single spoke of the rotating balance can be viewed as a T-Strap**
- **Modification to the T-Strap calculations involves reevaluating the derivation to include torque at balance center**
- **Assumption is made on effective strap width**



Test Specimens

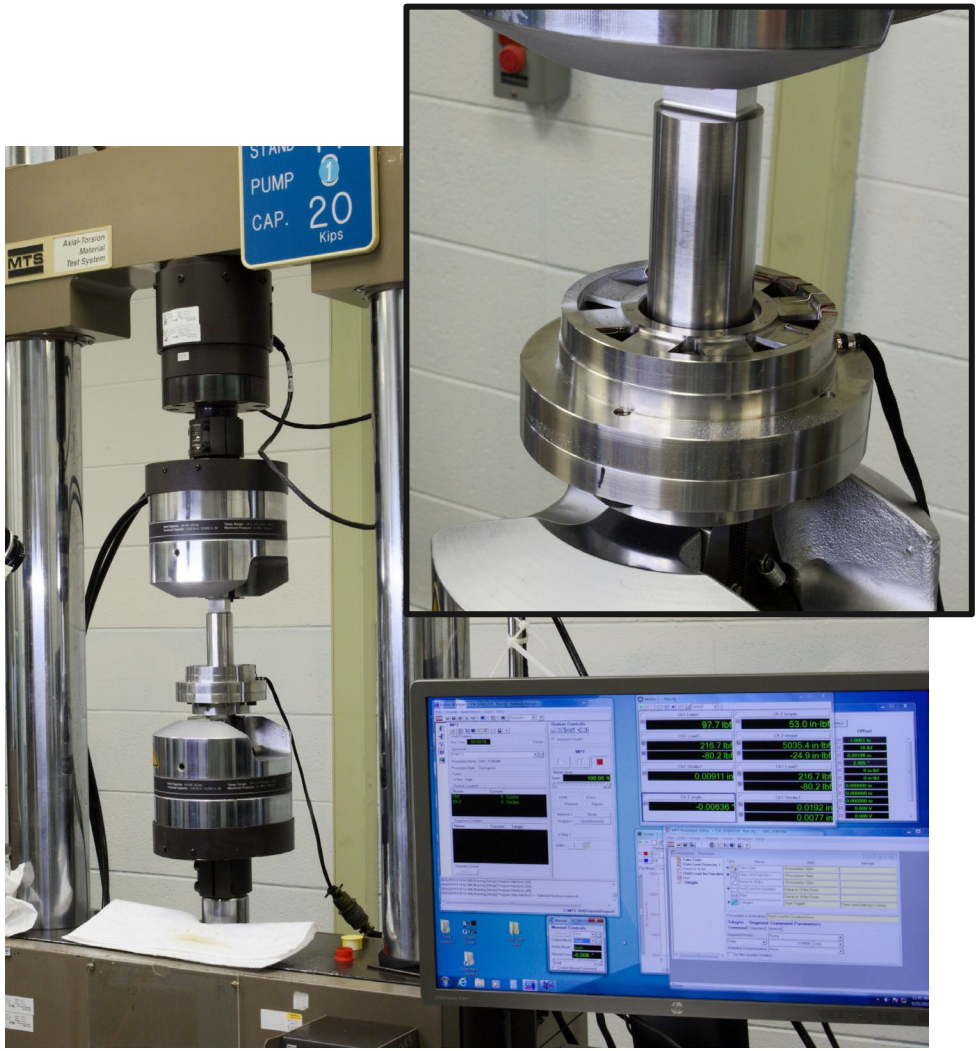
- **17-4PH conventionally machined using mill/lathe operations, no EDM**
- **8 strain gages placed at various locations with two locations per specimen having replicates**





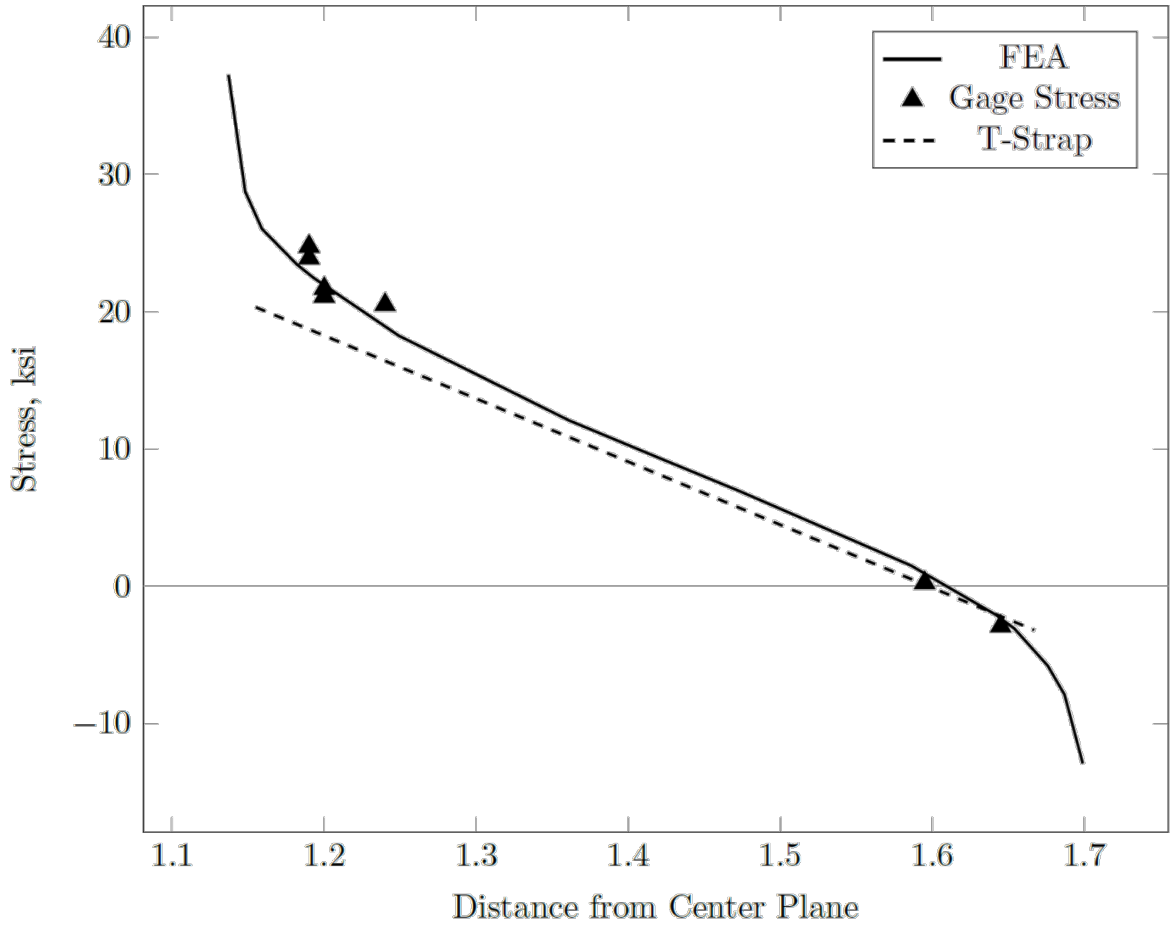
Test Method

- **MTS Tension-Torsion machine was used to apply loads to specimens**
- **Torque was only applied to the specimen, small tension load to engage grippers**
- **Maximum torque was scaled from balance design loads based on difference in material properties**



Model Validation Results

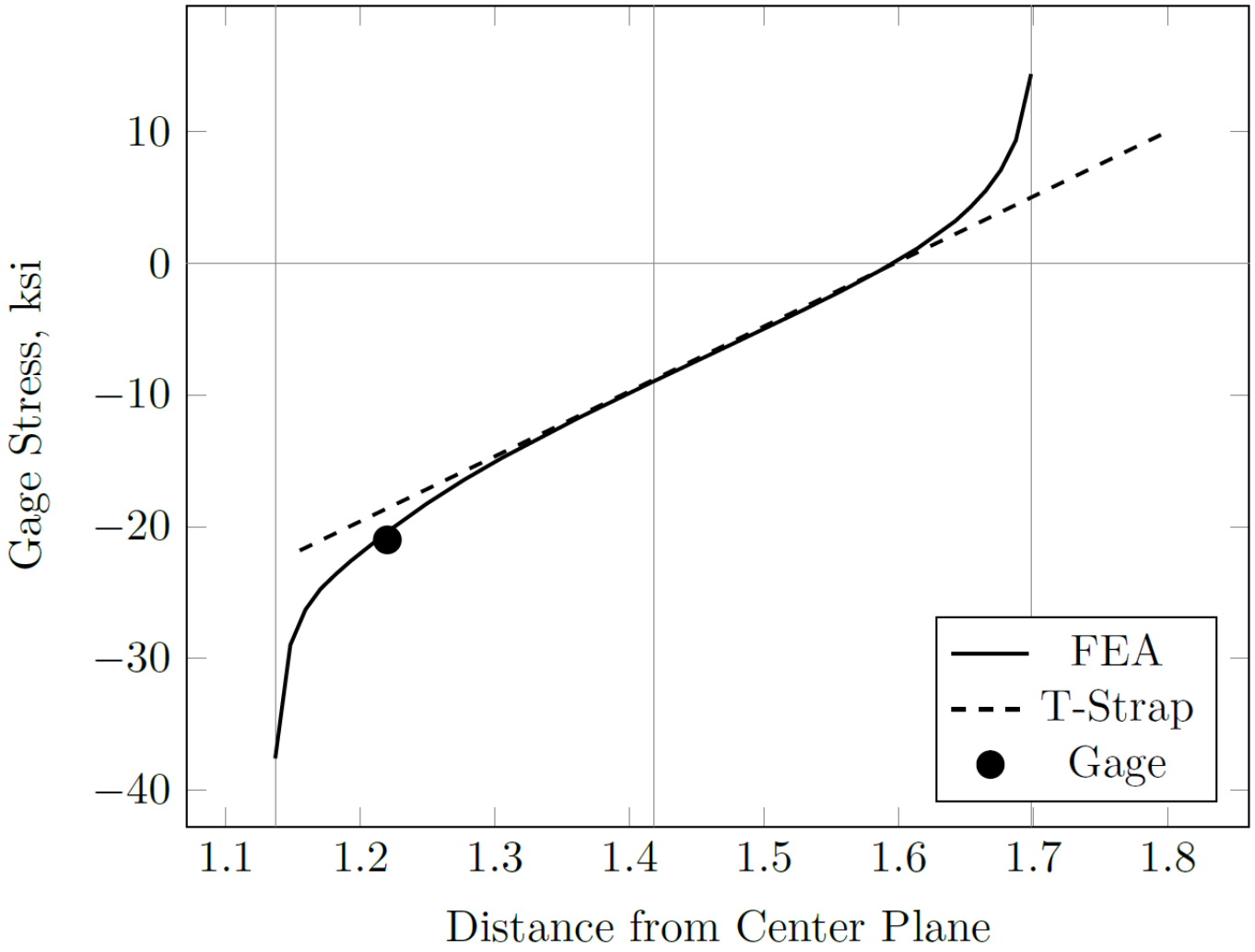
- **FEA conducted on test specimen**
  - Constraints applied dowels
  - Stress measurements taken along beam length for torque
- **Gage data taken for maximum torque load applied**
- **Stress gradient illustrated large reduction of double bending due to torque**



GRC-419R Test Specimen

Model Fit on GRC-419R Calibration Data

- **FEA conducted on full-span balance**
  - Constraints applied to keys and mating surfaces to replicate fit
  - Stress measurements taken along beam length for torque
- **Gage data taken for maximum torque load applied during calibration**

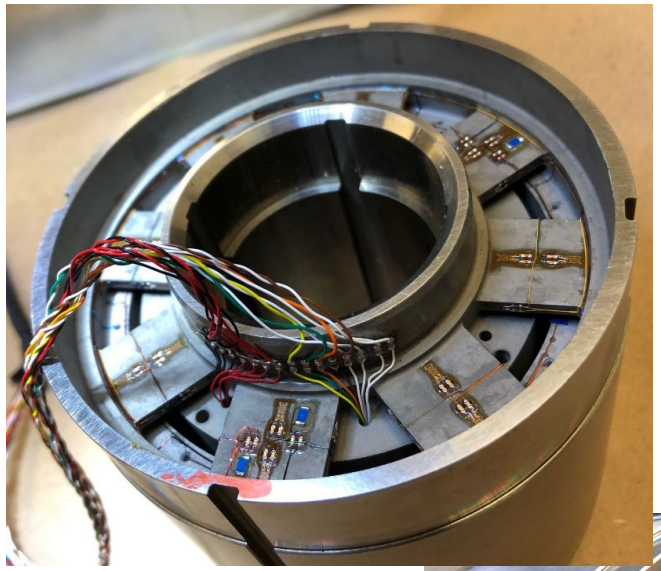


Calibration Summary

- **Broken into multiple phases:**
  - Phase 1: Gaged and wired
  - Phase 2: Temperature Loadings
  - Phase 3: PCBs Integrated
- **Outputs at full scale loads:**

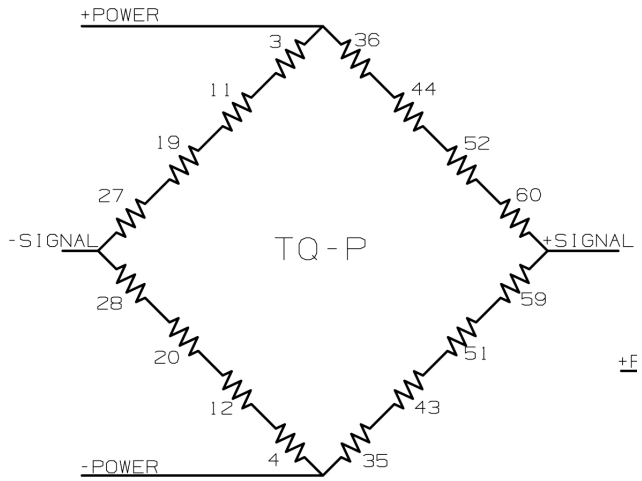
	Output, μV/V	
	Primary	Secondary
Torque	1,685	1,756
Thrust	914	928

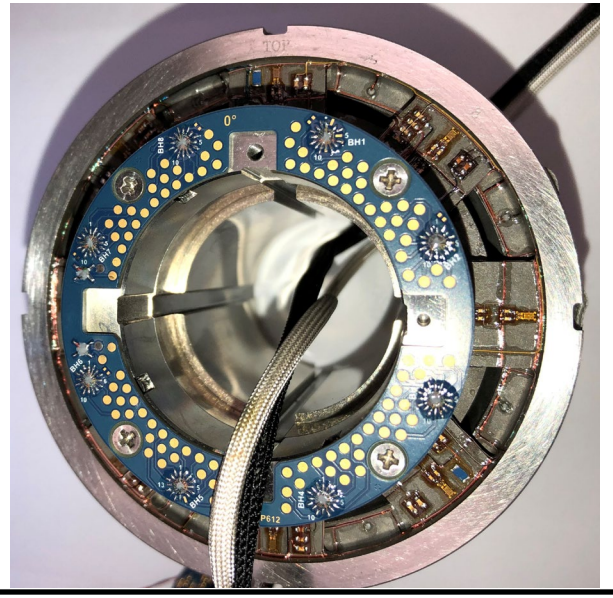
- **No interactions to out-of-plane forces and moments**



Balance Gaging and Integration

- **Gaging of this balance had to follow strict requirements of the telemetry system**
- **Wiring and terminal placements were predefined to ease PCB integration**
- **Communication between Telemetry Team, Balance Team, and Fabrication was critical**

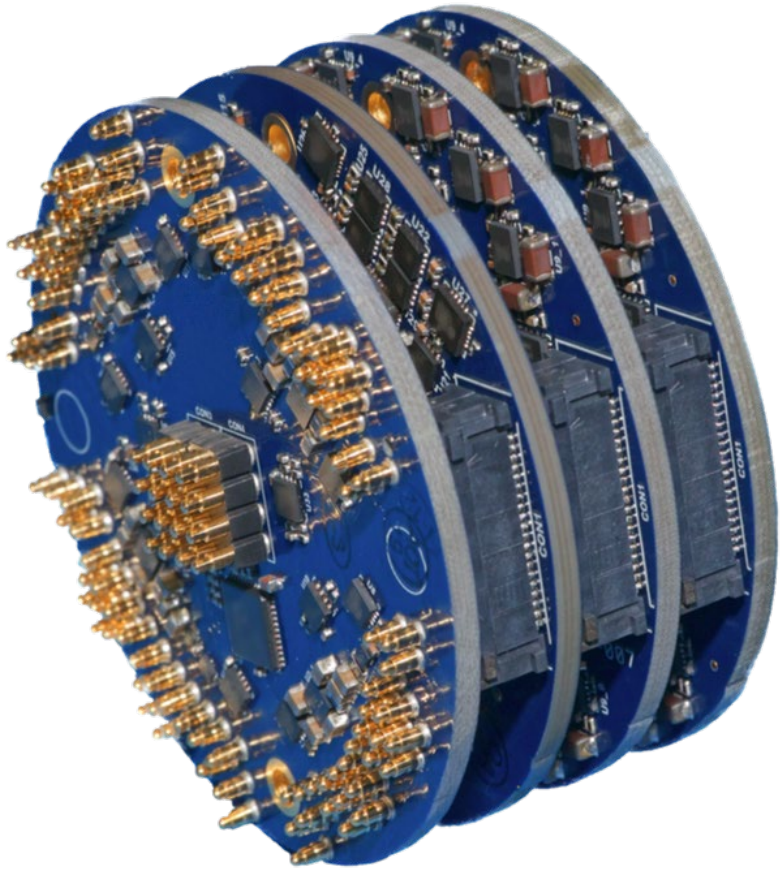




Telemetry System

- **Utilizes a custom telemetry system to condition and acquire balance signals and fan blade strain gauges**

- **GRC-419R and GRC-517R use a common telemetry system**



Temperature Model

- **Linear temperature correction to the sensitivity constant:**

$$SC_{@T} = SC_{@RT}(1 - K(T_{op} - T_{ref}))$$

- **All hardware pre-heated in oven and moved to calibration stand**

- **Temperature corrected residuals were within 0.2%F.S.**

Summary

- **GRC-419R project required high level of integration between all team members**
  - Complex model integration
  - Embedded electronics interfacing
  - Multiple mating interfaces
- **Modifications to analytical methods allowed for prediction of beam stresses for rapid design space exploration**
  - Validated analytical modes and FEA models with fast/low-cost testing
- **Successfully calibrated and temperature corrected balance to below 0.25% F.S.**