

NASA's 5.5K Rotator

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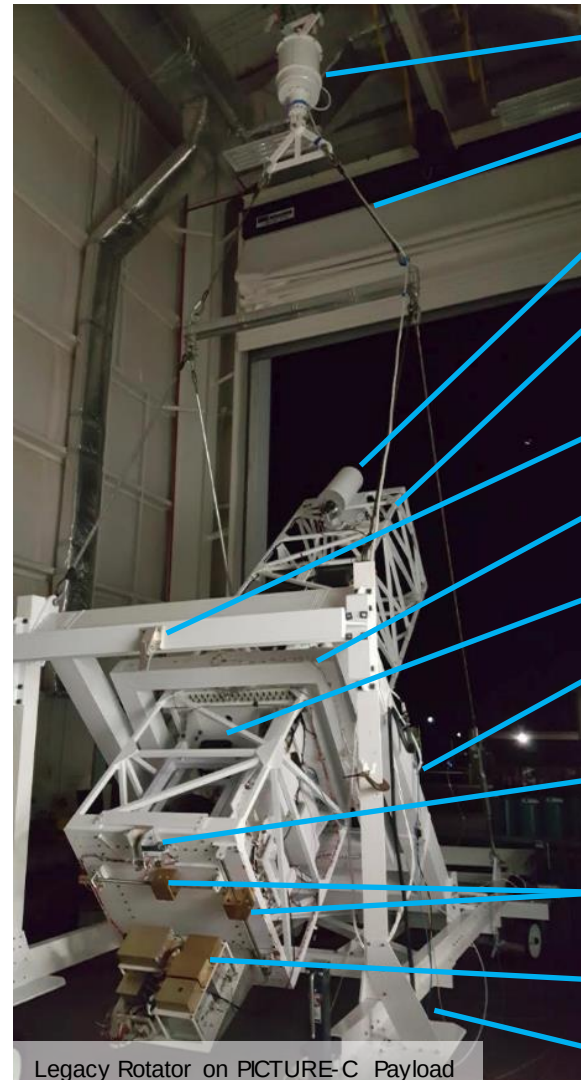
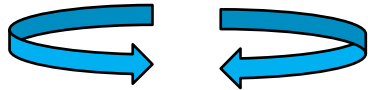
Agenda

- Background – Legacy Rotator
- Why 5.5K Rotator?
- 5.5K Rotator Design
 - Requirements
 - Material Selection
 - Design Updates
- Pathway to Qualification
 - Tensile Test
 - Thermal Test
 - Friction Assessment Test
 - Test Flights
- Summary



5.5K Rotator

- Legacy Rotator
 - Coarse azimuth payload pointing system
 - With iRACE Avionics within $\pm 2^\circ$
 - Maximum payload of 8,000 lbm
 - Withstand a 10G axial load
 - Does not exceed 5 watts average continuous power draw
 - Typical station keeping without heaters



Legacy Rotator on PICTURE-C Payload

Legacy Rotator

Suspension Bridle

Star Tracker

Instrument Support Structure

Caging Mechanism (passive half)

Inner Gimbal Frame

Inertial Measurement Unit

Outer Gimbal Frame

Caging Mechanism (active half)

Flight Adjustable Trim Weights

WASP Flight Electronics

Main gondola structure

Balloon

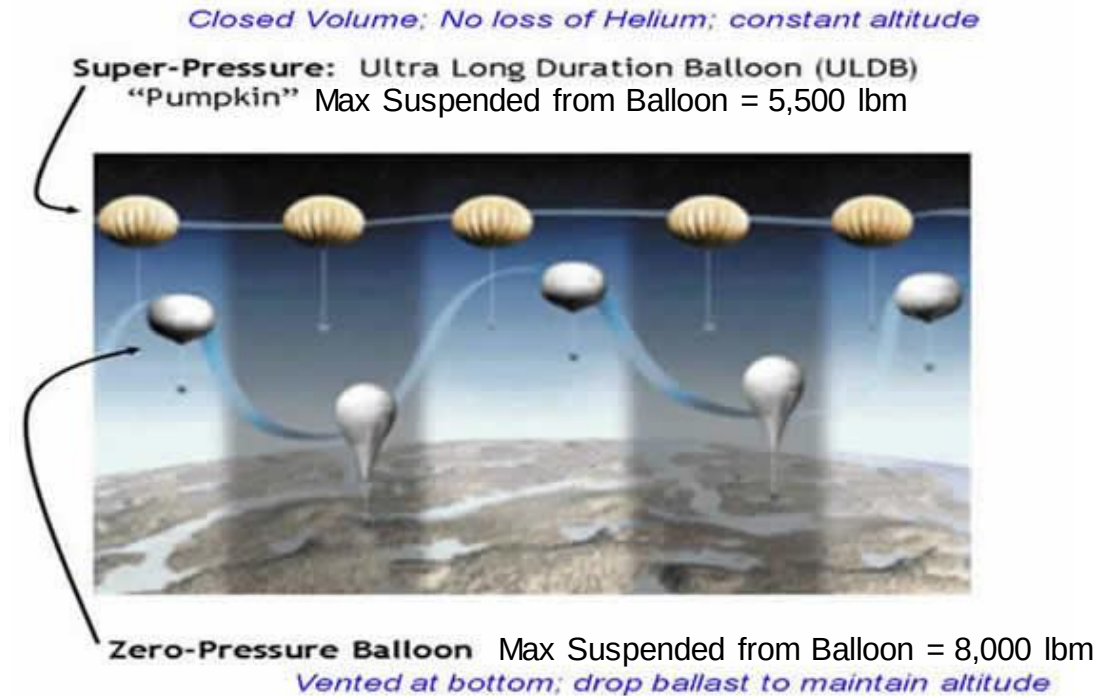
Recovery Parachute

Cable Ladder

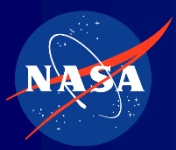
Rotator

Payload

- Balloon Program Office (BPO) desired a rotator specifically for super pressure balloons (SPB), with a maximum suspended payload of 5,500 lbm
- Mass reduction of rotator allows:
 - More science mass budget for a SPB payload
 - Either longer flight or more science mass budget for zero-pressure balloon payload

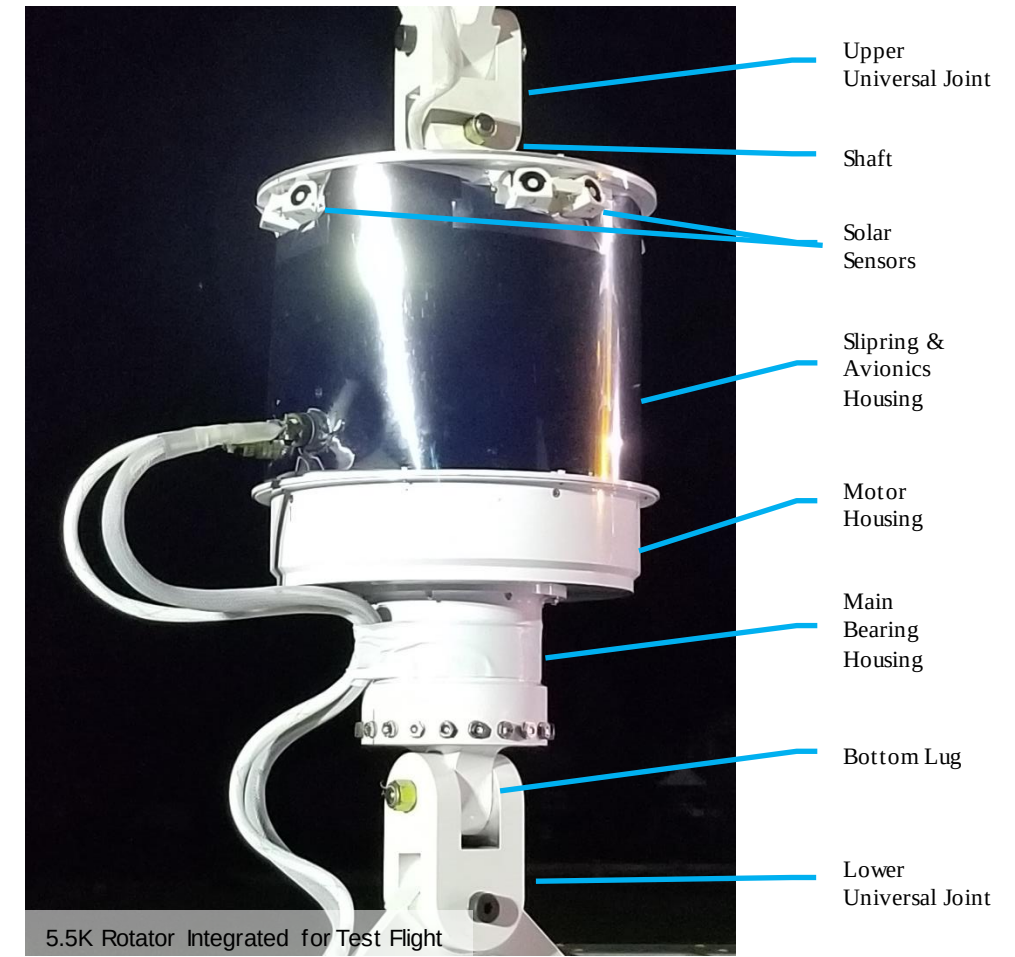


↓ Flight Train Weight = ↑ Science



5.5 K Rotator Design

Mechanical Design Criteria		Requirements/ Goal	Design
Maximum Payload	5,500 lbm	Requirement	Met
Satisfy Termination Load Factors	10G Axial	Requirements	Met
	5G Horizontal at 45°		N/A
	5G Lateral		N/A
	1.4 SF if non-brittle, 1.5 SF if brittle (materials less than 10% elongation at -60 °C, upon consideration)		Met
Reusable	Does Not Exceed Material Tensile Yield Strength	Goal	Met
Temperature Range	-80 °C to 50 °C (-112 °F to 122 °F)	Requirement	Met
Motor Power Draw	Daytime Average Does Not Exceed 3.5 W	Requirement	3W
Slip Ring	Minimum 20 Channels	Requirement	Met
Mass Reduction	Minimum 25%	Goal	34%

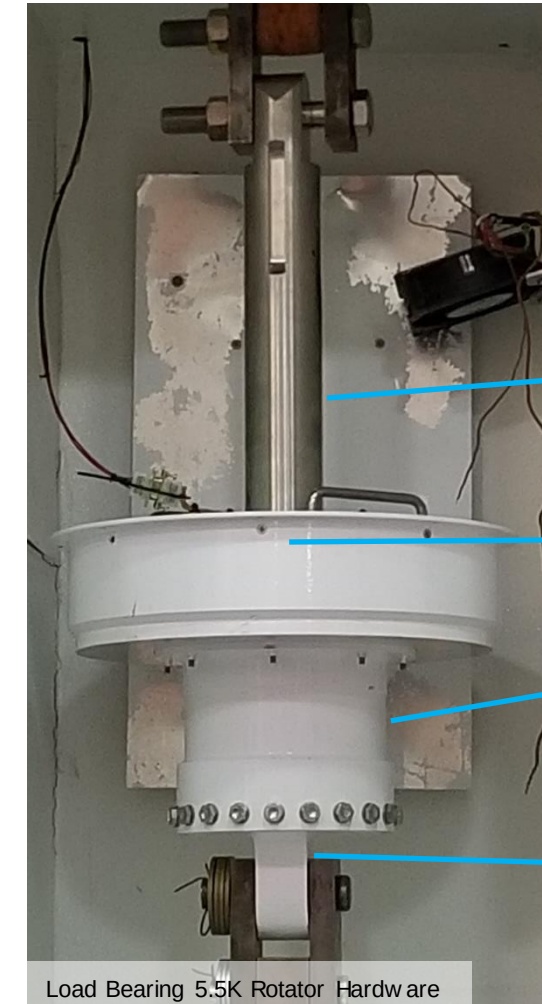


	AISI 4340 Steel	Aluminum 6061-T6	Aluminum 2024-T351	Aluminum 7075-T651	Ti-6Al-4V	Ti-6Al-2Sn- 4Zr-2Mo
Density ($\frac{lb}{in^3}$)	0.283	0.098	0.1	0.101	0.16	0.164
Ultimate Tensile Strength, F_{tu} (ksi)	260	42	62	76	130	125
Tensile Yield Strength, F_{ty} (ksi)	217	35	42	67	120	120
Young's Modulus, E (10^3 ksi)	29	10.1	10.7	10.3	16	16.5

Legacy load
bearing hardware

Rest of hardware
for legacy and
5.5K rotators
*Excluding bearings
and fasteners*

Selected for 5.5K
load bearing
hardware



Shaft

Radial Bearing
Housing
(within Motor
Housing)

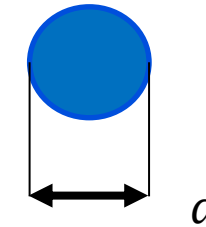
Main
Bearing
Housing

Bottom Lug

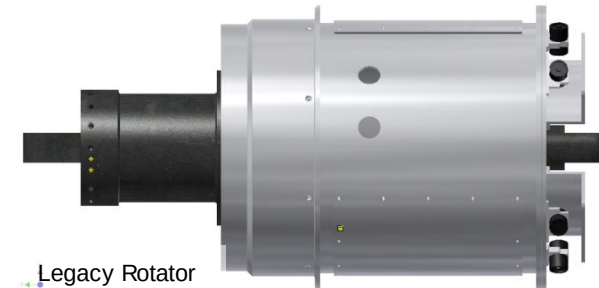
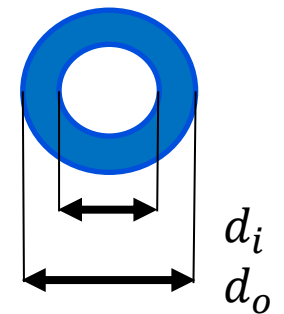
Load Bearing 5.5K Rotator Hardware

- New Bearings Selected
 - Adjusted for smaller maximum axial force (5.5K) than the legacy rotator (8K)
- New Motor Selected
 - Selected lighter, shorter form factor motor that met power draw requirement
- Shaft
 - Ti-6Al-4V
 - Made hollow
 - Decreased length (shorter motor and bearing stack up)
 - Ensured $\frac{e}{D} \geq 1.5$ to be conservative in shear or tear-out cases
- Bottom Lug
 - Ti-6Al-4V
 - Ensured $\frac{e}{D} \geq 1.5$ to be conservative in shear or tear-out cases
- Bearing Housings
 - Ti-6Al-4V
- Solar Sensor Assembly
 - 3D Printed ABS: Reduced mass and part count
- Avionics brackets
 - 3D Printed ABS to curvature of housing: aids in pointing performance

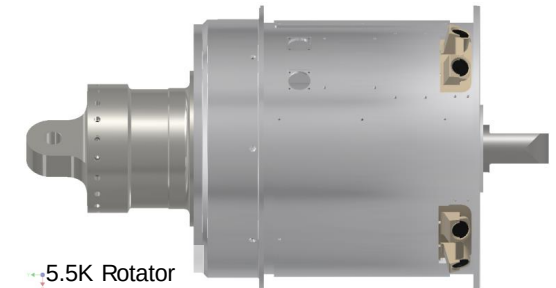
Solid Shaft



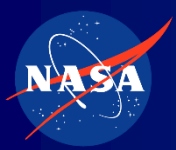
Hallow Shaft



Legacy Rotator

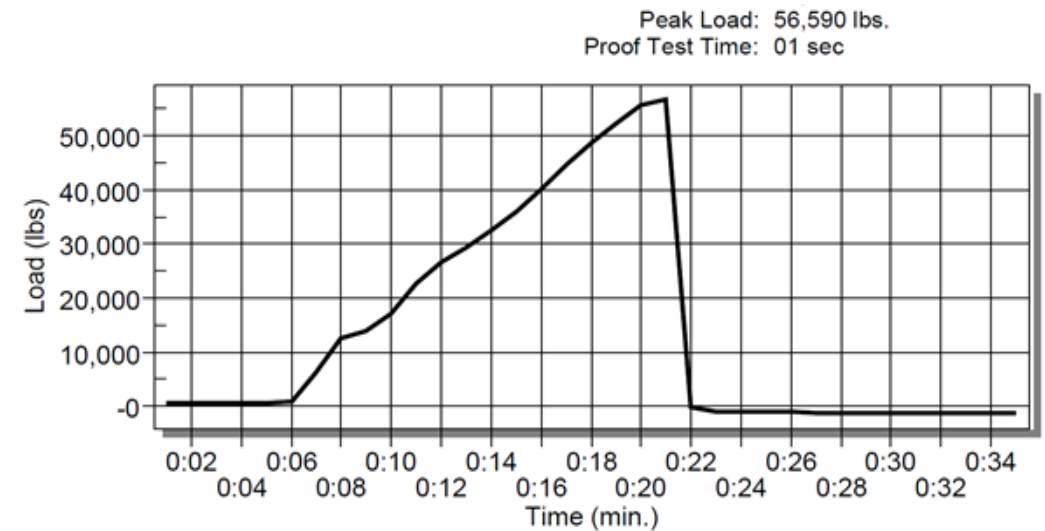
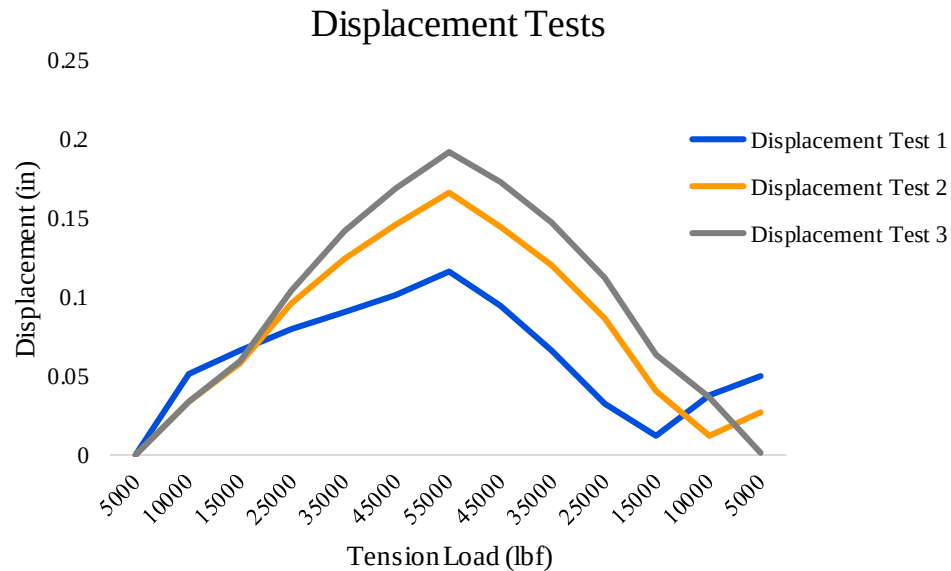
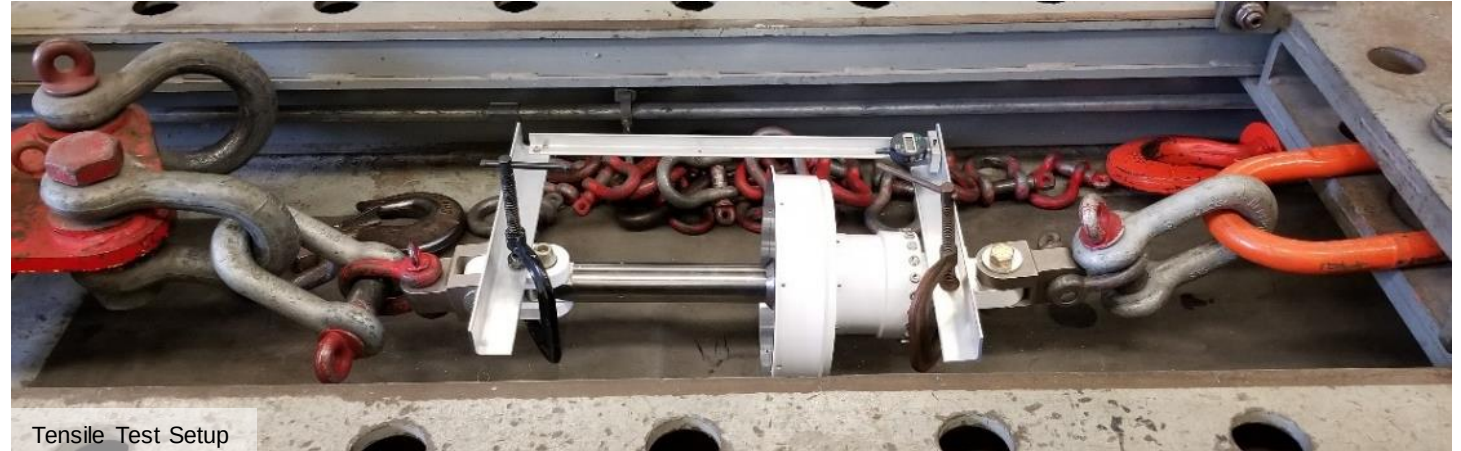


5.5K Rotator

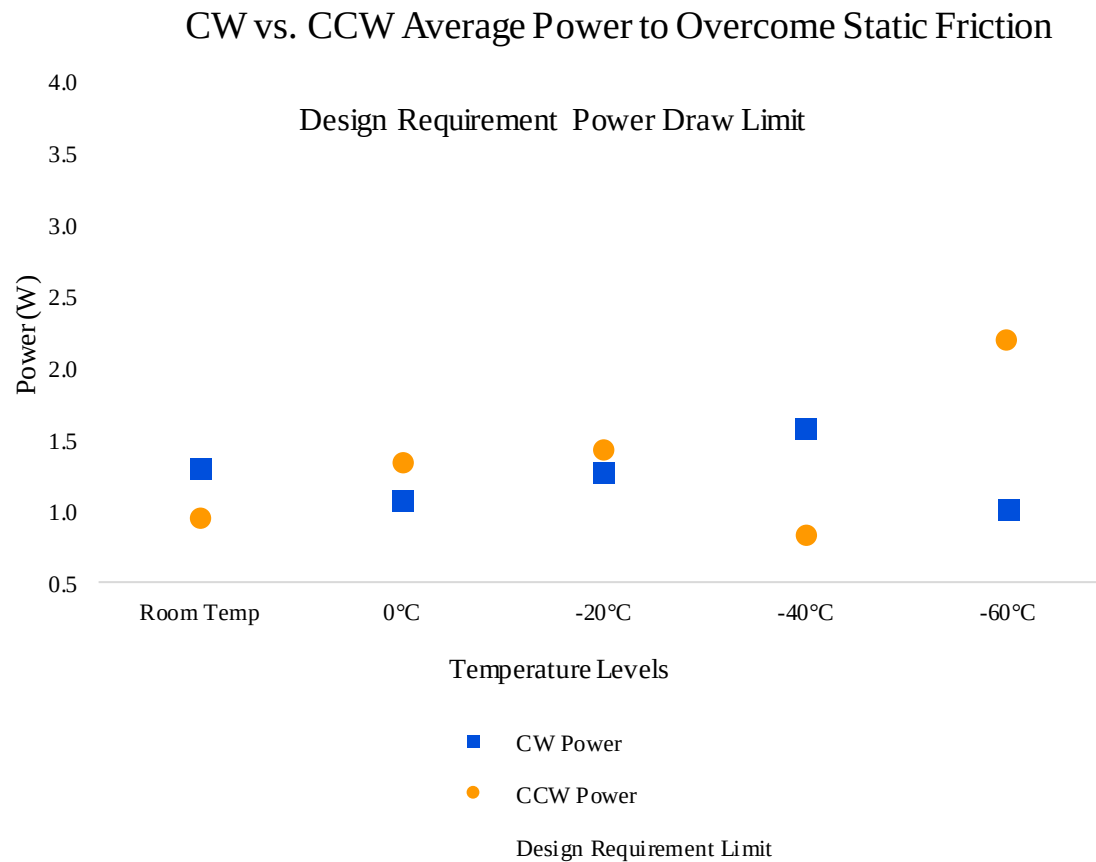


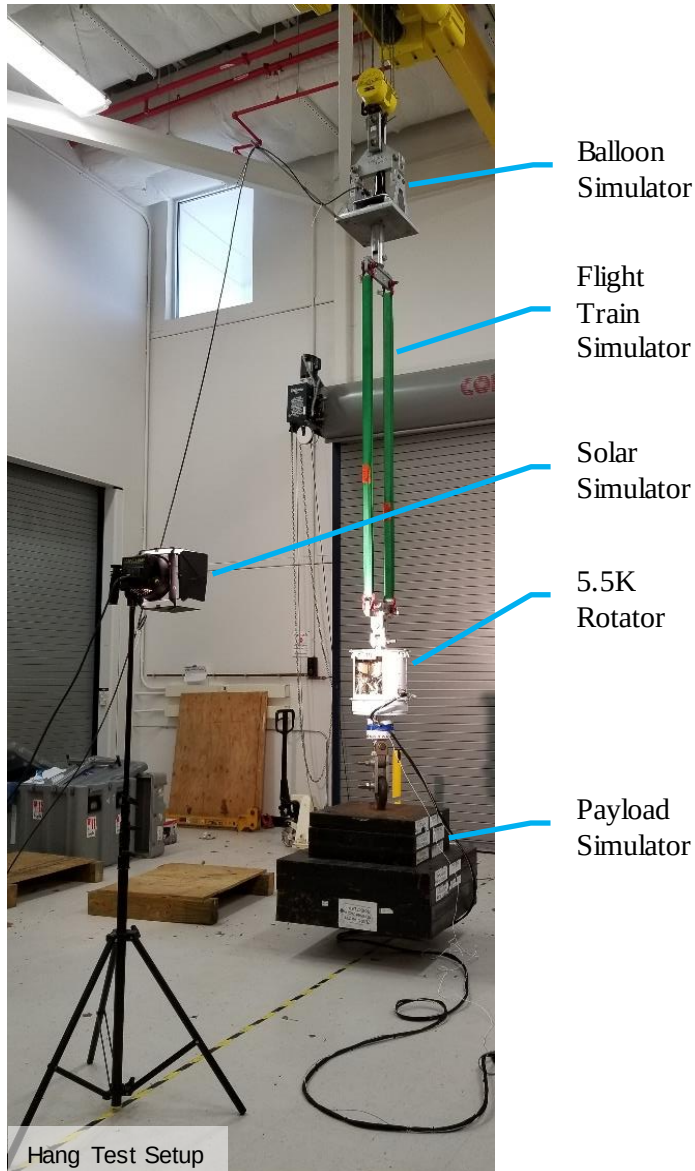
Pathway to Qualification

- Displacement test
 - Incremental tensile load to 55,000 lbs three times
- Rapid tensile load test
 - Peak load = 56,590 lbs

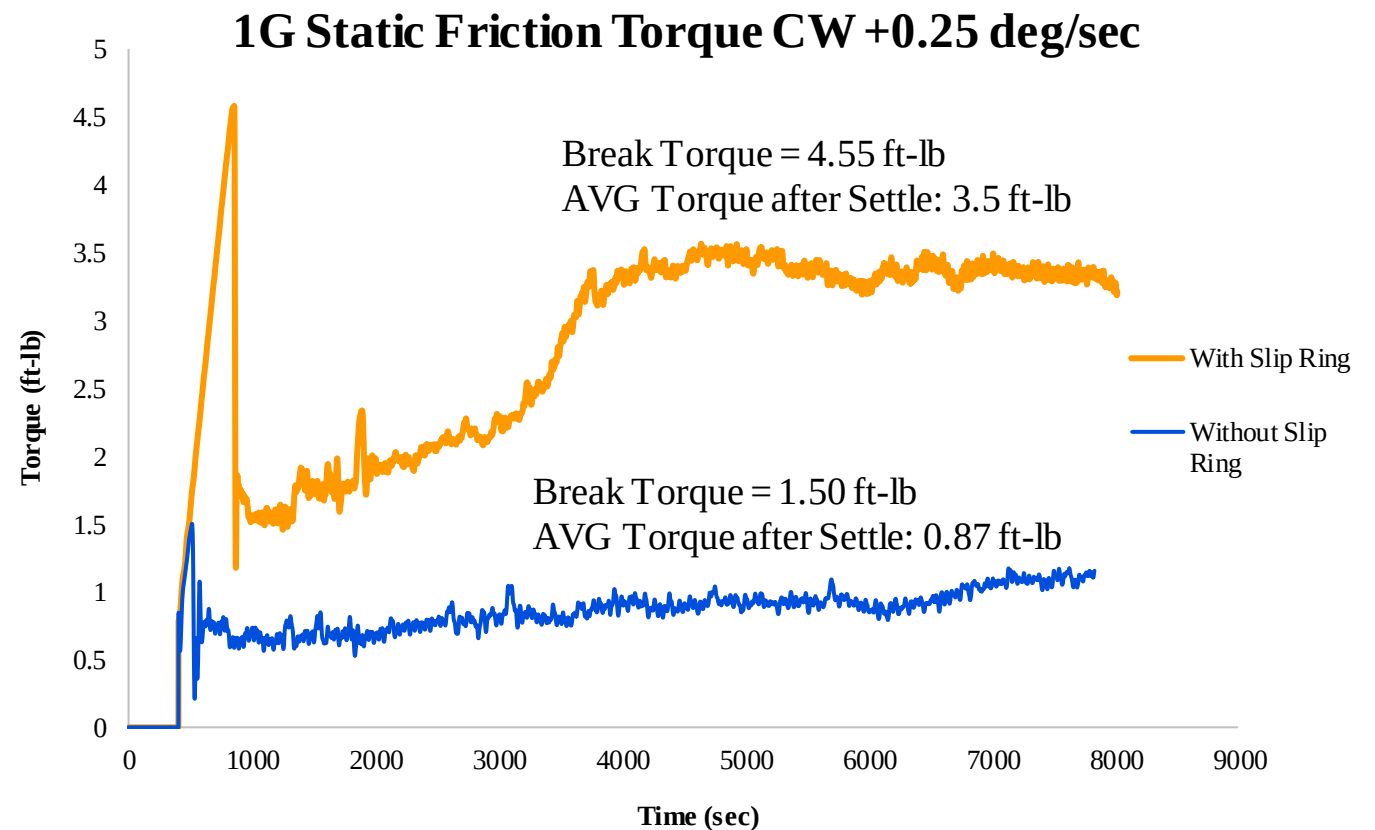


- Rotator loaded to 5,500 lbs in thermal chamber around Instron machine

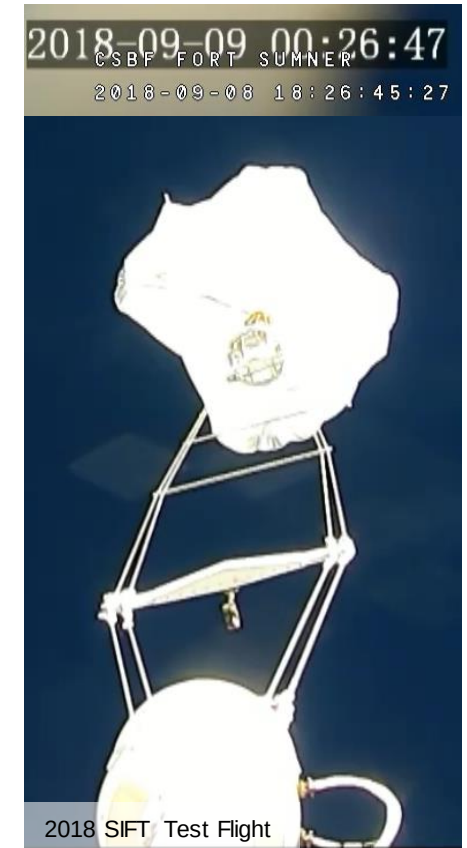




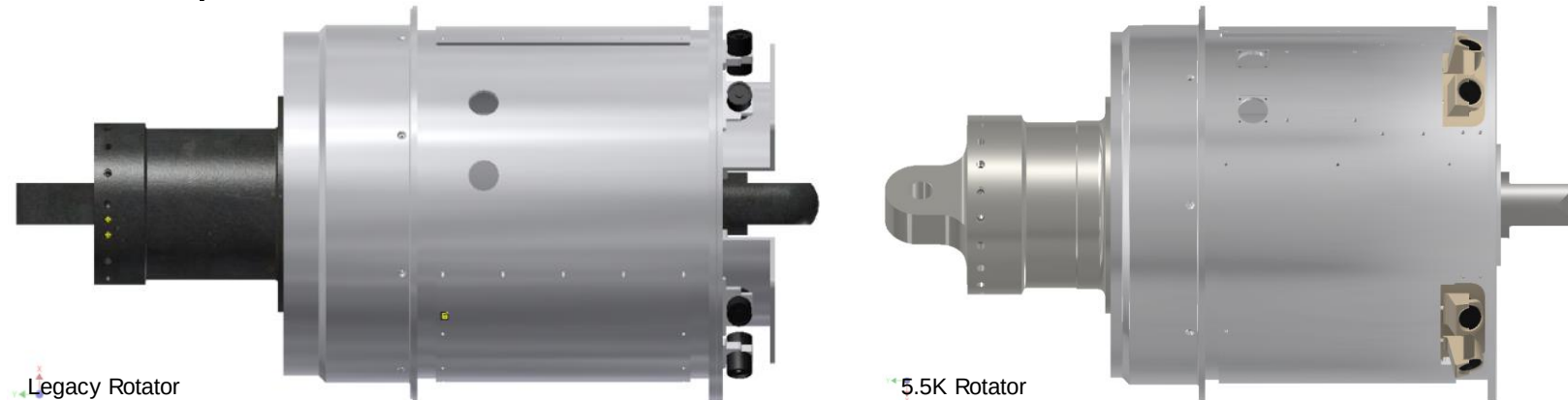
- Rotator loaded to 5,565 lbs
 - Measured motor resistance test
 - Static friction maximum and minimum torque clockwise and counterclockwise
 - Kinetic friction average torque clockwise and counterclockwise



- Test Flights:
 - 2018 Fort Sumner
 - 2019 Fort Sumner
 - Upcoming: 2022 Fort Sumner
 - After 3rd test flight the 5.5K rotator will be fully flight qualified and become a standard system!

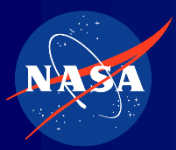


- 5.5K Rotator **43 lbm lighter** than Legacy Rotator with the same pointing capability!
 - Is **34% less mass**, goal was 25% reduction
 - With iRACE Avionics, pointing capability within $\pm 2^\circ$
- Reduced part count by 20 (24% reduction)
 - Legacy Rotator = 83 parts
 - 5.5K Rotator = 63 parts



BPO prioritizes science mass and power budget.

Future work includes creating an even lighter rotator (i.e. for Big 60 balloons).



Backup

- Use 3 different types of sensors to achieve within $\pm 2^\circ$ pointing capability:
 - A solar sensor ring with a 360° view gives absolute sun relative azimuth ($\pm 5^\circ$)
 - A global positioning system (GPS) gives absolute true-north relative azimuth ($\pm 0.1^\circ$)
 - An inertial rate sensor measures the angular rate with respect to an inertial reference frame ($\pm 0.01^\circ/\text{second}$).
- Provides interface for external azimuth/attitude sensors (i.e. from NASA WASP system)