Evaluation of a Variable Thickness Hybrid Composite Bull Gear

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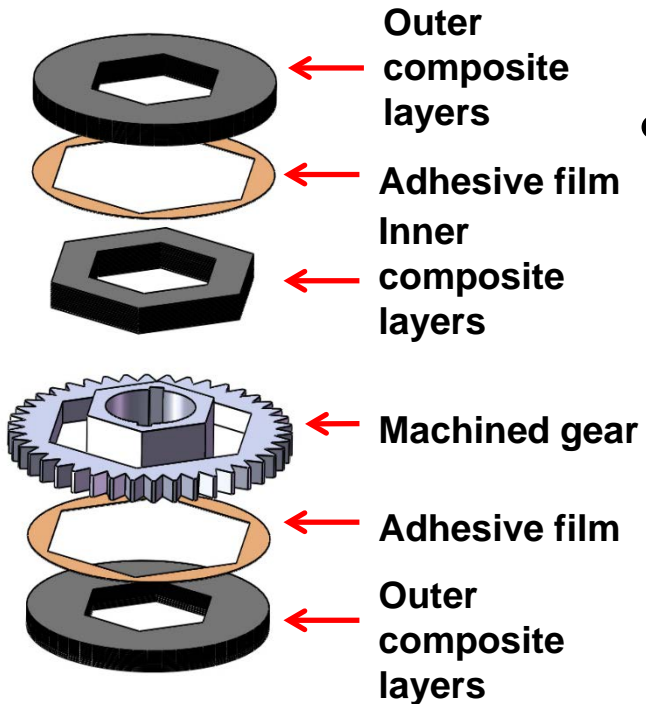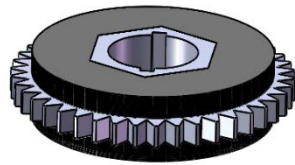**May 16th, 2018 – AHS Forum 74**

- **Motivation**
- **Background**
- **Past efforts**
- **Bull gear design**
- **Static Torsion Experiments**
- **Dynamic and Endurance Experiments**
- **Conclusions**
- **Future work**

Motivation

- Reducing drive system weight is always desired
- Future Vertical Lift platforms are expected to have increased speed, range, and payload requirements
- Advanced vertical lift platforms require the ability to change rotor speed to satisfy these requirements
- Multi-speed transmission components increase transmission weight and complexity

- Hybrid (composite/steel) gears are being investigated as a technology to enable weight neutral multi-speed transmissions

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What is a Hybrid Gear?

Outer composite layers

Adhesive film

Inner composite layers

Machined gear

Adhesive film

Outer composite layers

- **Replaces steel gear web with lightweight carbon fiber composite**

- **Loads transferred through adhesive bonds, mechanical interlocks, or fasteners (or any combination)**

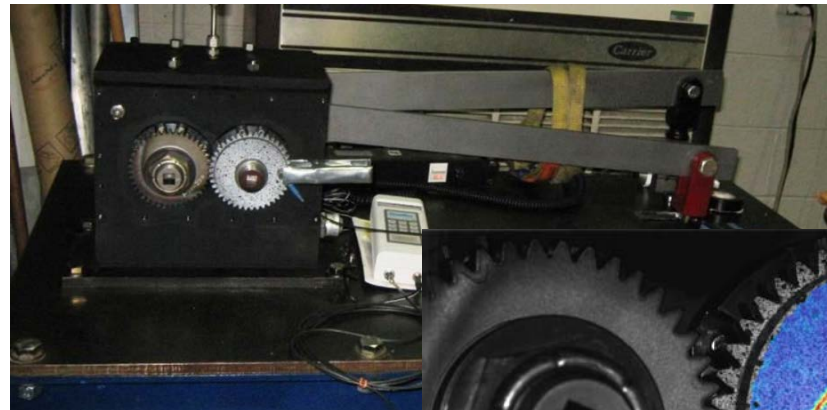**The Nation's Premier Laboratory for Land Forces**

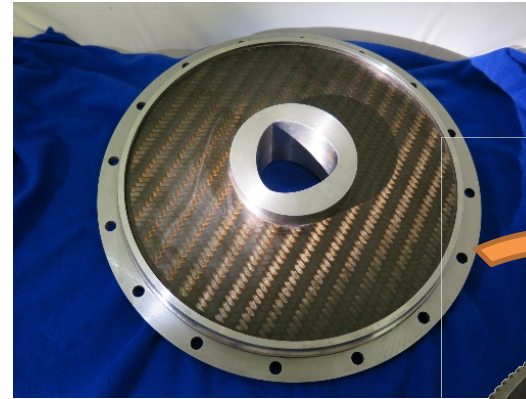# Past Hybrid Gear Efforts

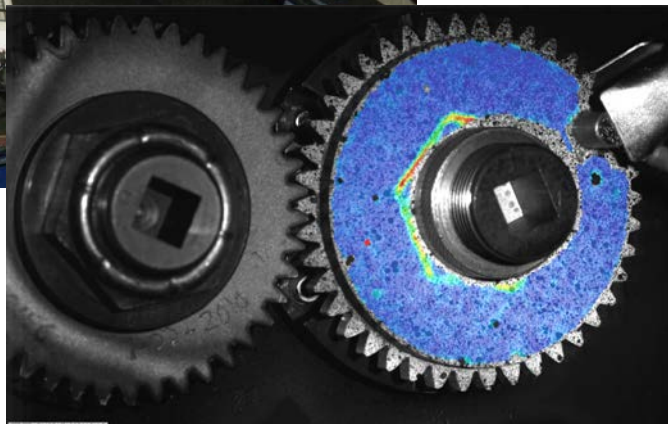Endurance and dynamic experiments

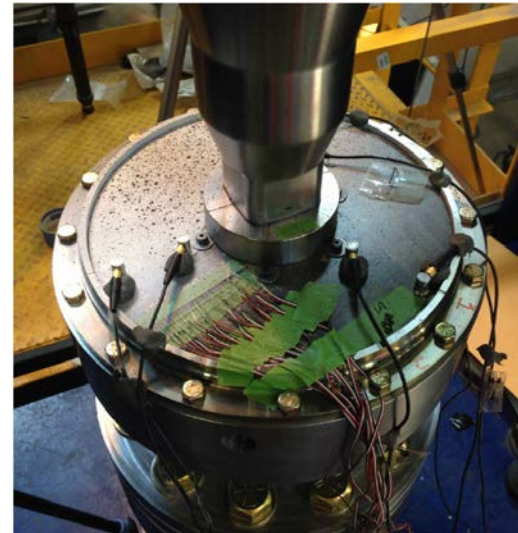Loss-of-lubrication experiments
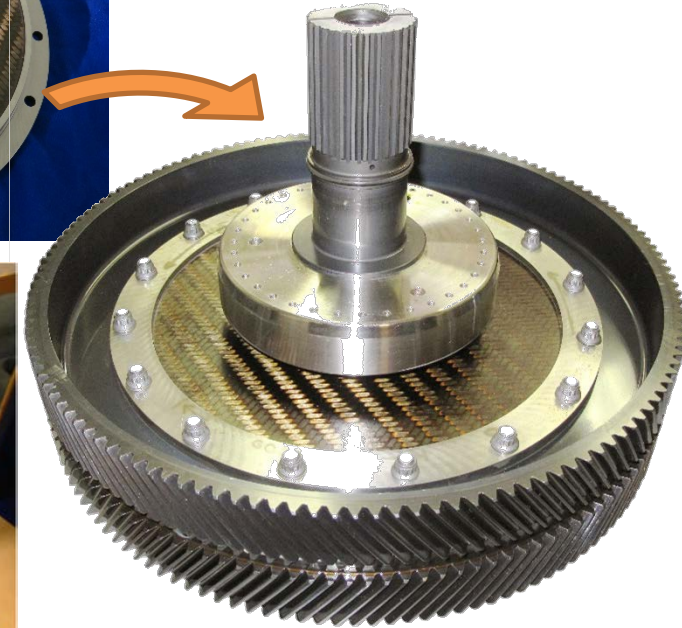
Small-Scale Experiments

Static torsion experiments

Dynamic and endurance experiments (limited to 3300 hp in previous configurations)

Static torsion experiments

Full-Scale Bull Gear Experiments

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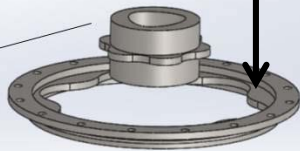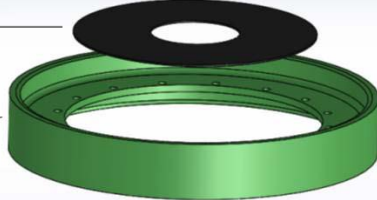# Variable Thickness Bull Gear Design

Exploded View of Hybrid Web

Composite Sections
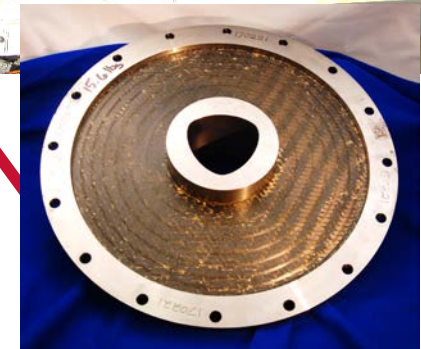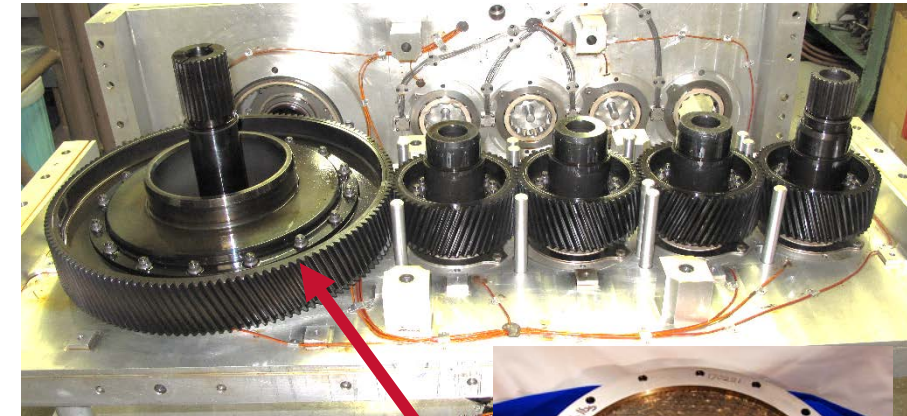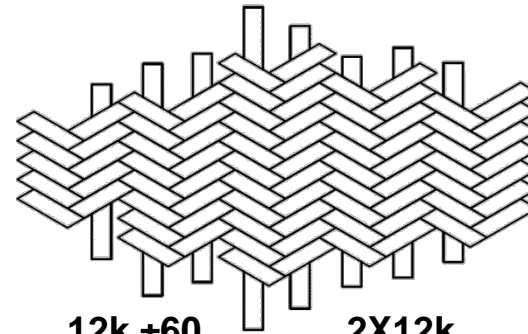
Metallic Adapters

Composite Section

Existing Bull Gear

Torque Transfer Mechanisms

Mechanical interlock

Adhesive bond at axial steel/composite interface (Cytec MTA-241 film adhesive)

Triaxial Braid Architecture

A&P Technology

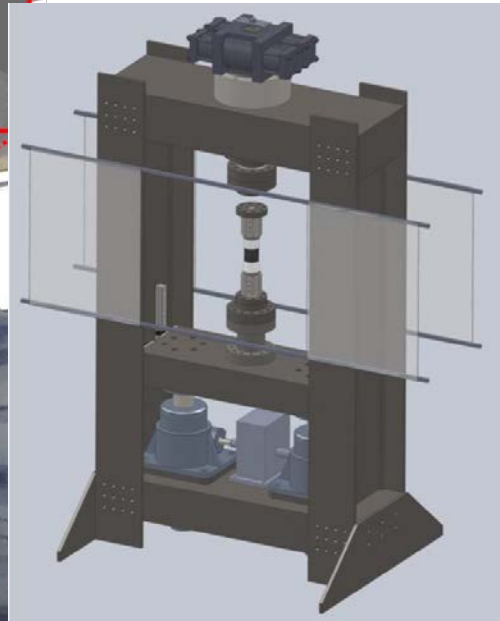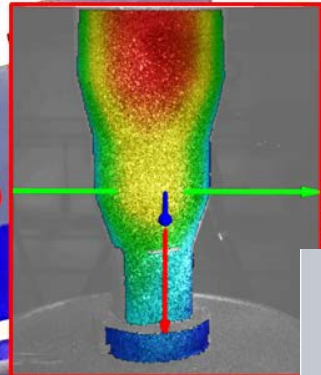**12k ±60 bias yarns**   **2X12k axial yarns**

Braided prepreg composite information

- T-700 SC carbon fibers
- Prepreg 0^0, +/- 60^0 braided architecture
- Equal fiber volume in all directions
- Tencate TC-250 resin with 56% fiber volume
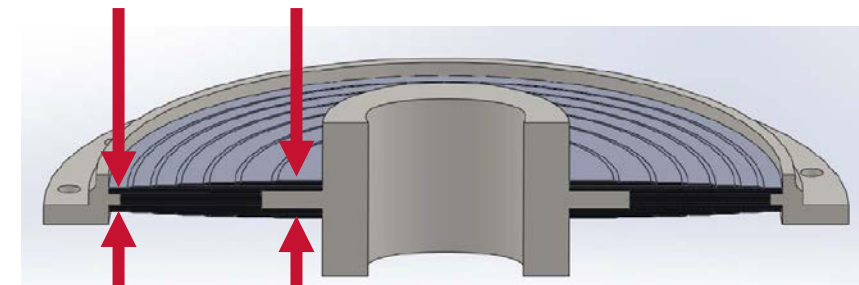
0.417 in   0.667 in
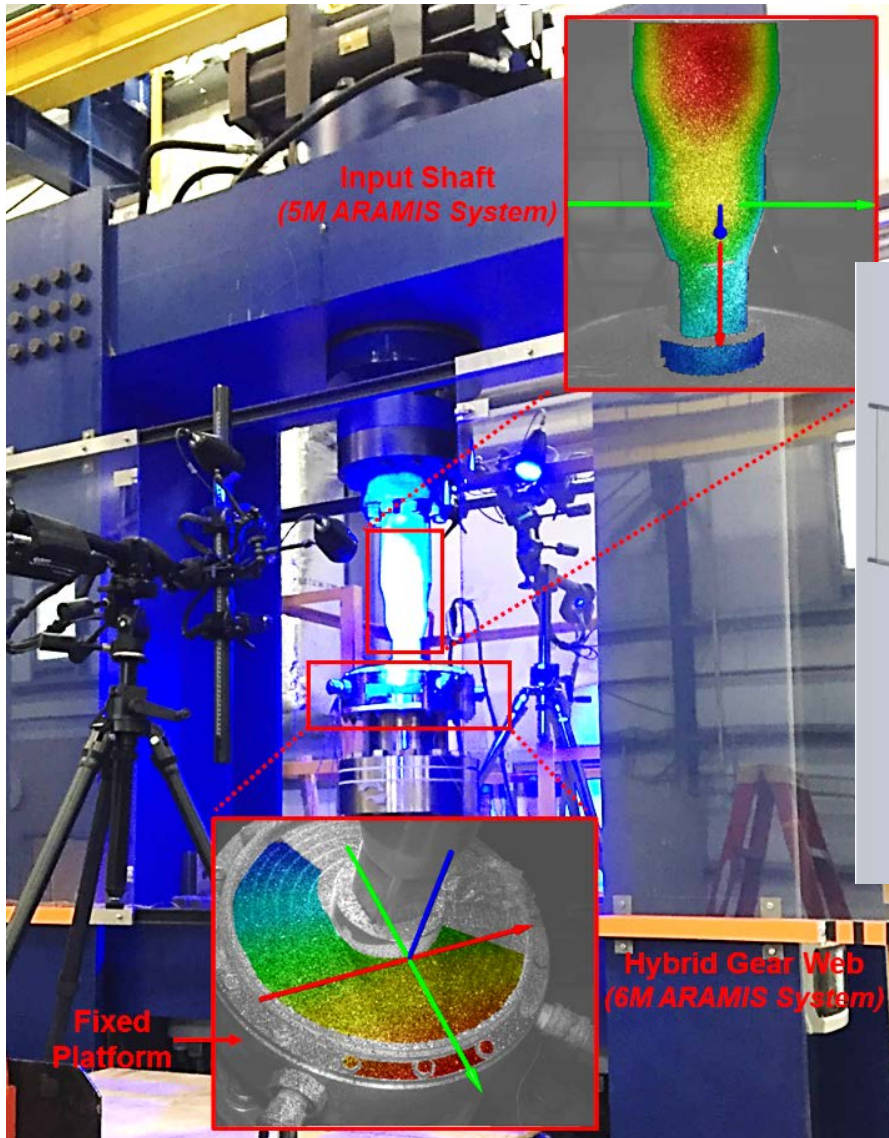
Equipment

- **90° rotational range**
- **Maximum torque of 240,000 in-lb (27,100 N-m)**
- **Outer flange held stationary**
- **Shaft used to apply torque through a square polygon**
- **0.2°/min rotation applied through a hydraulic rack and pinion actuator**
- **Torsion increased until failure or maximum torque is reached**

Results – Static Torsion Experiment

Maximum rig capability exceeded at 240,000 in-lb

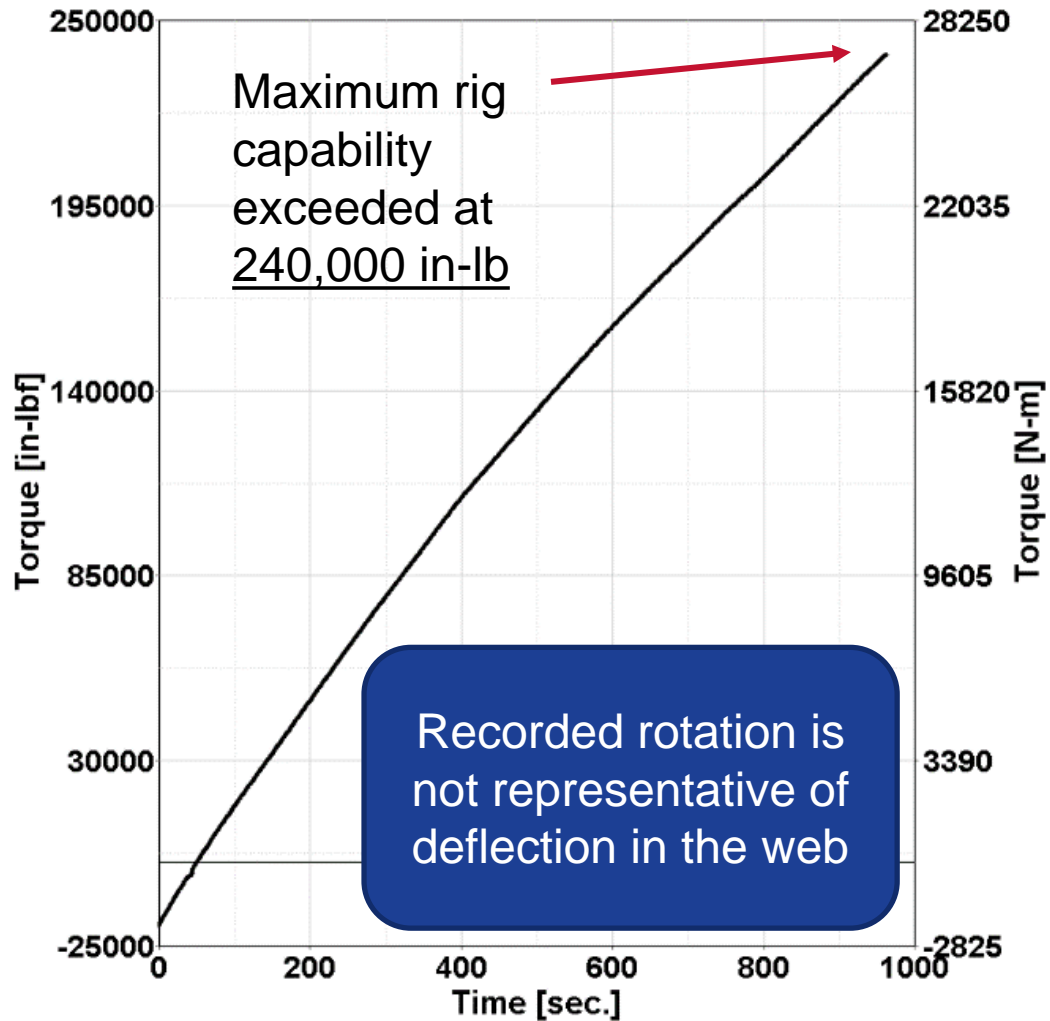Recorded rotation is not representative of deflection in the web

- **Experiment discontinued after maximum rig capability was reached**

DIC of shaft

Inner metallic adapter of hybrid gear web

Principal Strain [%]

Top of shaft

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Results – Static Torsion Experiment

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Dynamic Experiment

Slave gearbox
Rotating torque actuator
Low-speed shaft
Test gearbox
From speed-up gearbox
48"
High-speed shaft
CD-98-78357
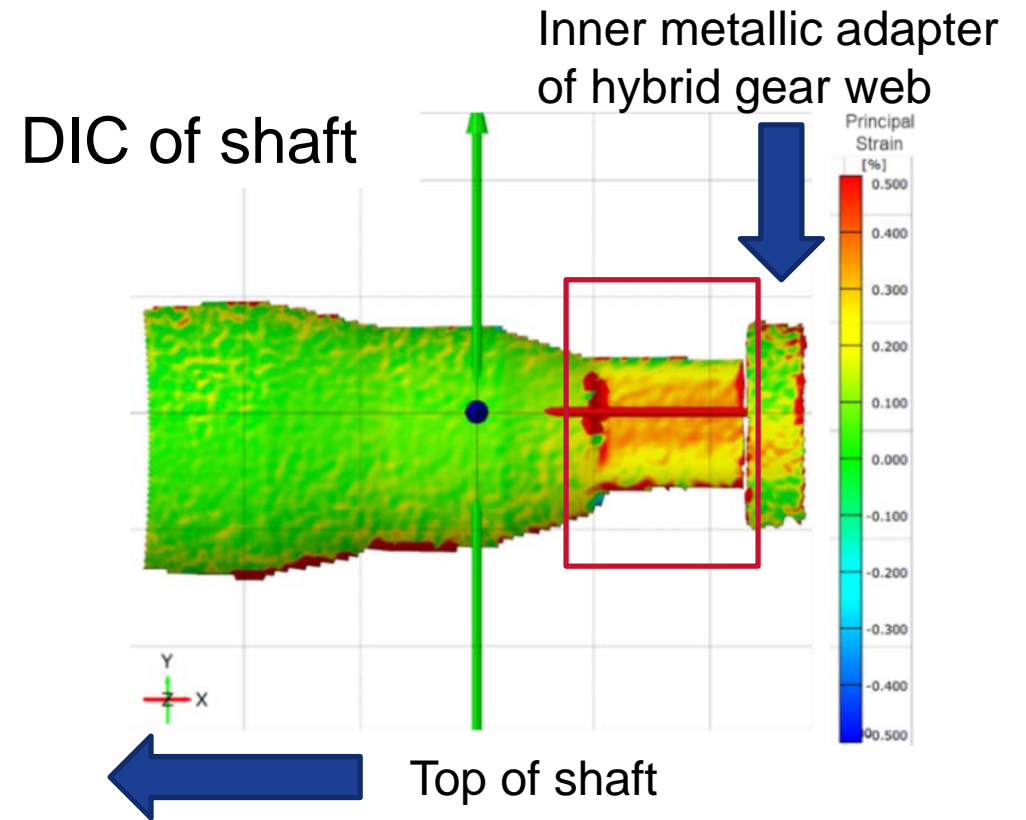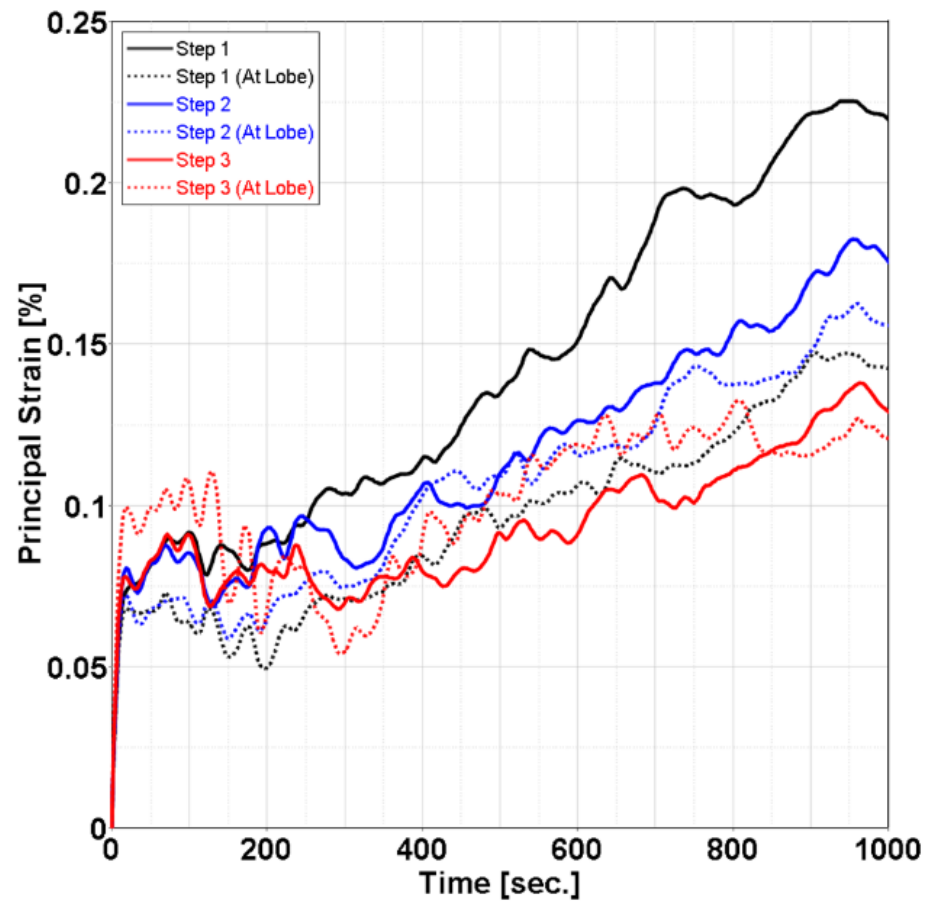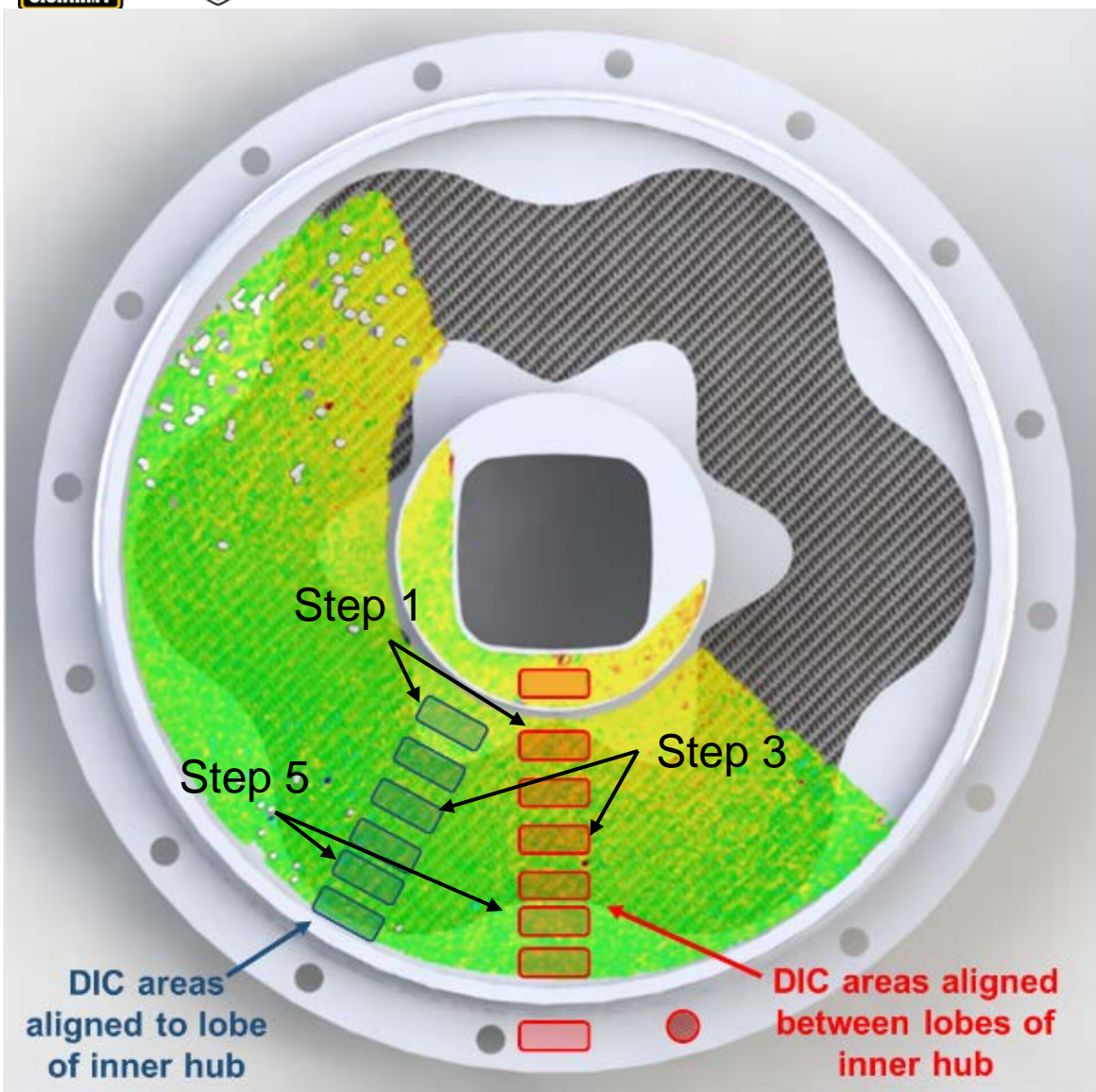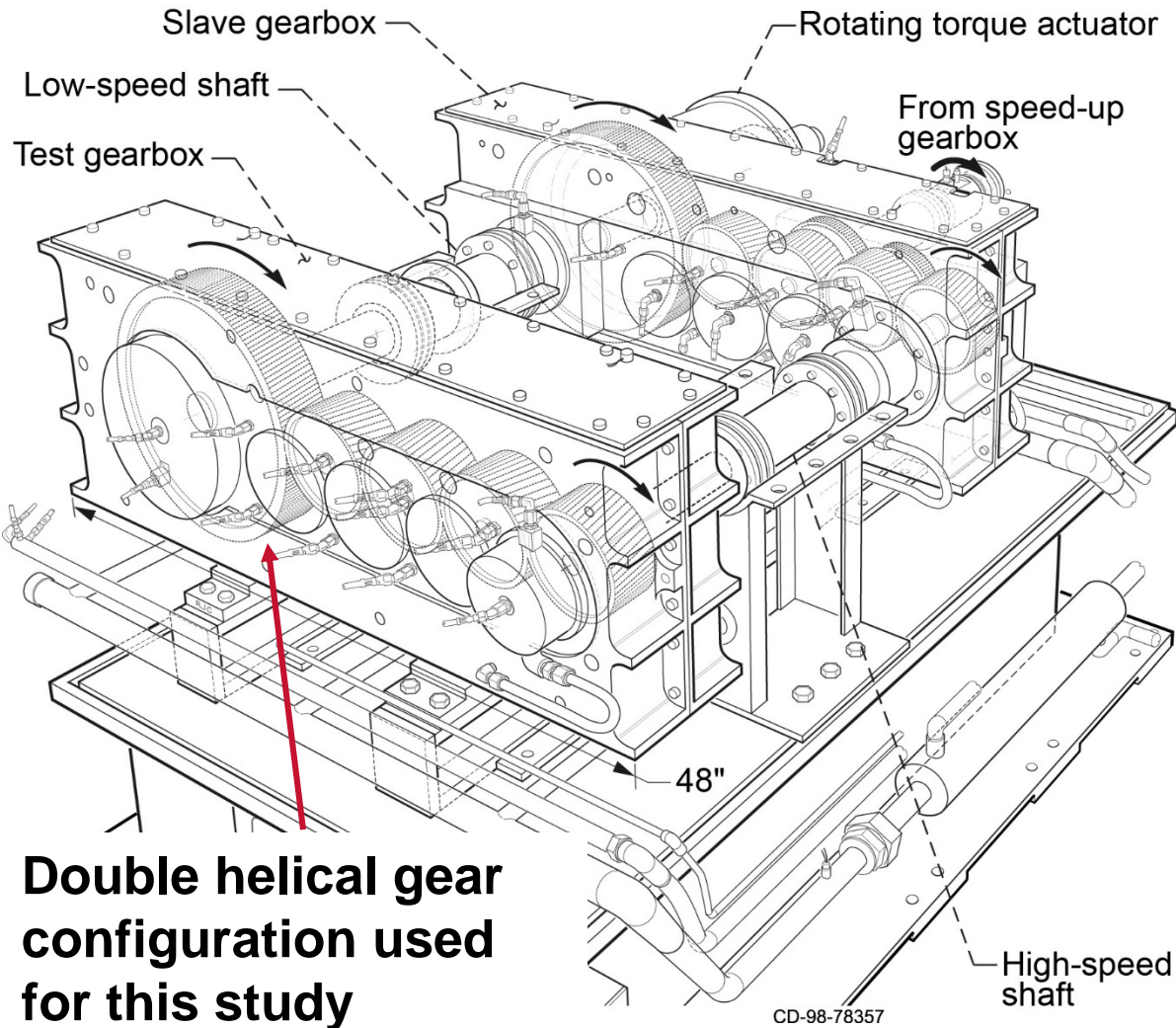
Double helical gear configuration used for this study

High-Speed Helical Gear Train Rig at NASA Glenn Research Center

- **Rig Capabilities**
  - **Max Power: 5000 HP**
  - **Input Pinion: 15,000 RPM at 21,000 in-lbs**
  - **Bull Gear: 5475 RPM at 58,400 in-lbs**
  - **Up to 250°F oil inlet temperature**

- **Instrumentation**
  - **Axial and radial vibration monitoring at bull gear bearing housing**
  - **Proximity sensors for monitoring bull gear orbit**
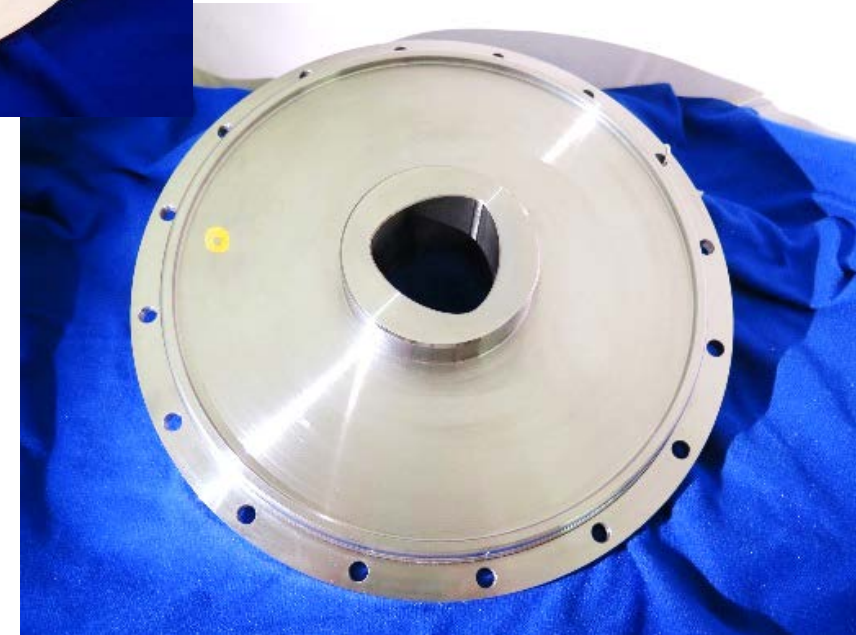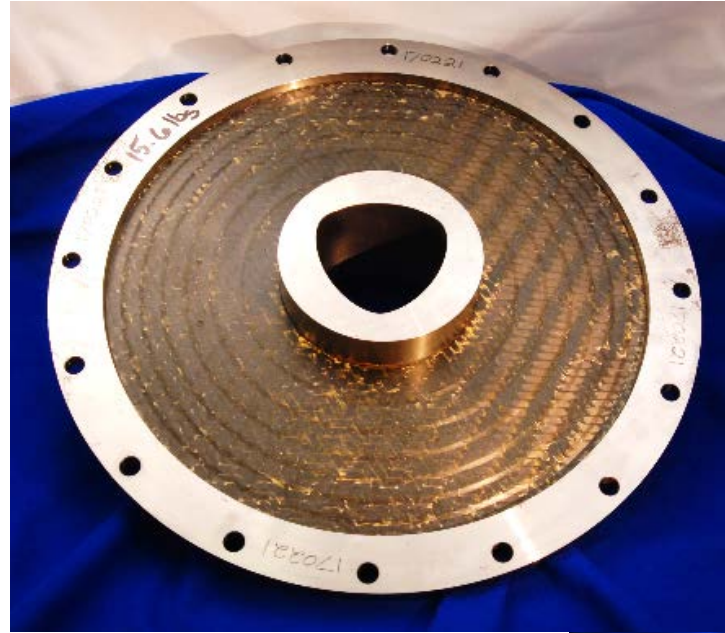 - **Thermocouples at several locations**

- **Oil Inlet Temperature: 120°F**

Results – Dynamic Experiment

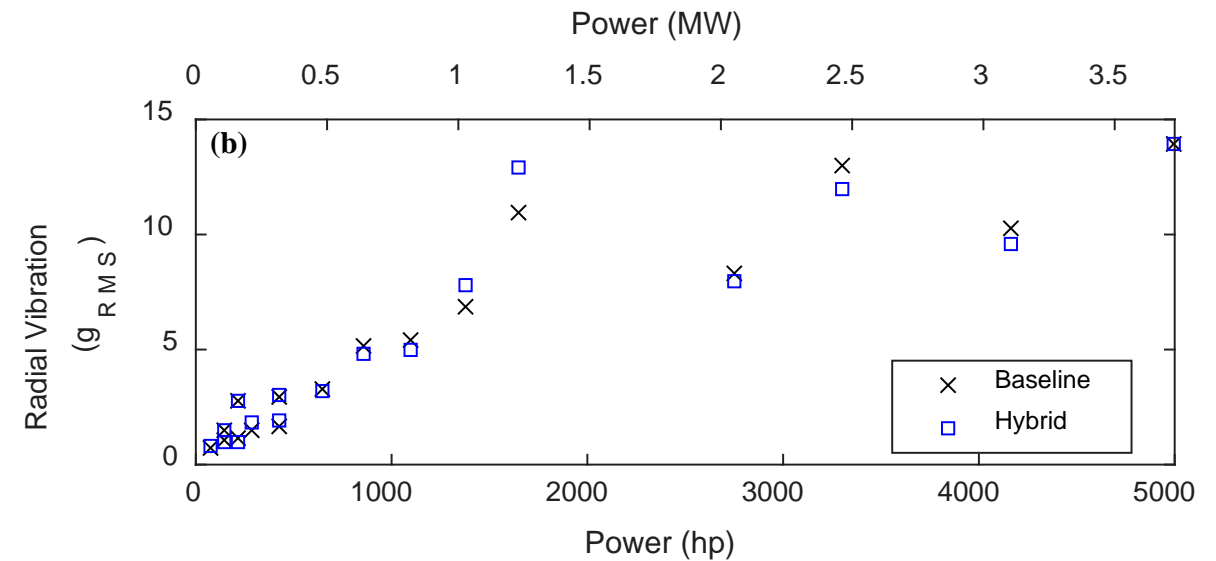| Condition Number	Speed RPM	Torque in-lb (N-m)	Power hp (kW)
1	900	5000 (570)	70 (50)
2	900	10000 (1130)	140 (110)
3	900	15000 (1700)	210 (160)
4	1800	5000 (570)	140 (110)
5	1800	10000 (1130)	290 (210)
6	1800	15000 (1700)	430 (320)
7	2700	5000 (570)	210 (160)
8	2700	10000 (1130)	430 (320)
9	2700	15000 (1700)	640 (480)
10	3600	15000 (1700)	860 (640)
11	3600	19300 (2180)	1100 (820)
12	4500	19300 (2180)	1380 (1030)
13	4500	38600 (4360)	2760 (2060)
14	4500	58400 (6600)	4170 (3110)
15	5400	19300 (2180)	1650 (1230)
16	5400	38600 (4360)	3310 (2470)
17	5400	58400 (6600)	5000 (3730)

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RMS Vibration Level

Mesh Frequency Magnitude
Time Synchronous Averaged Signal
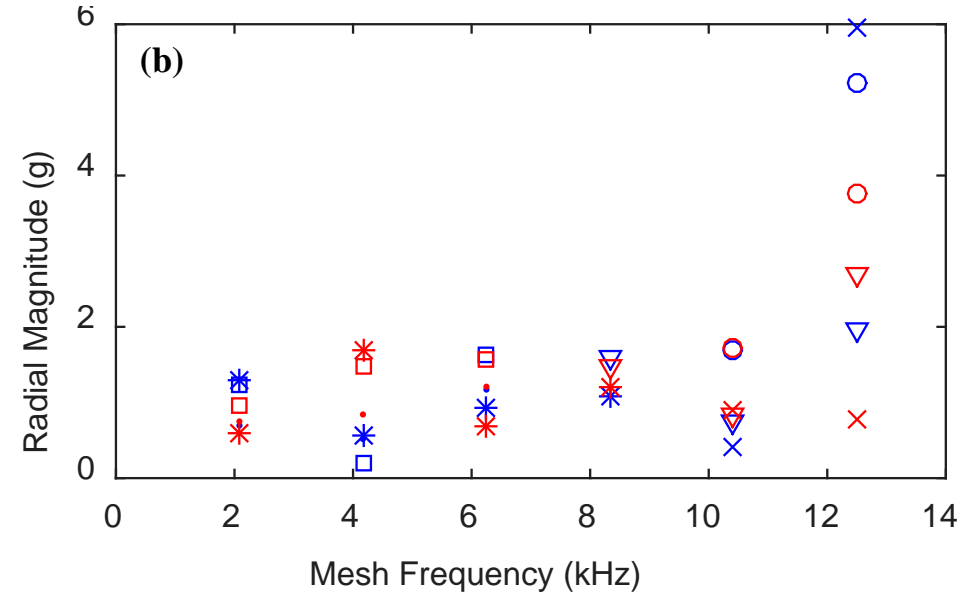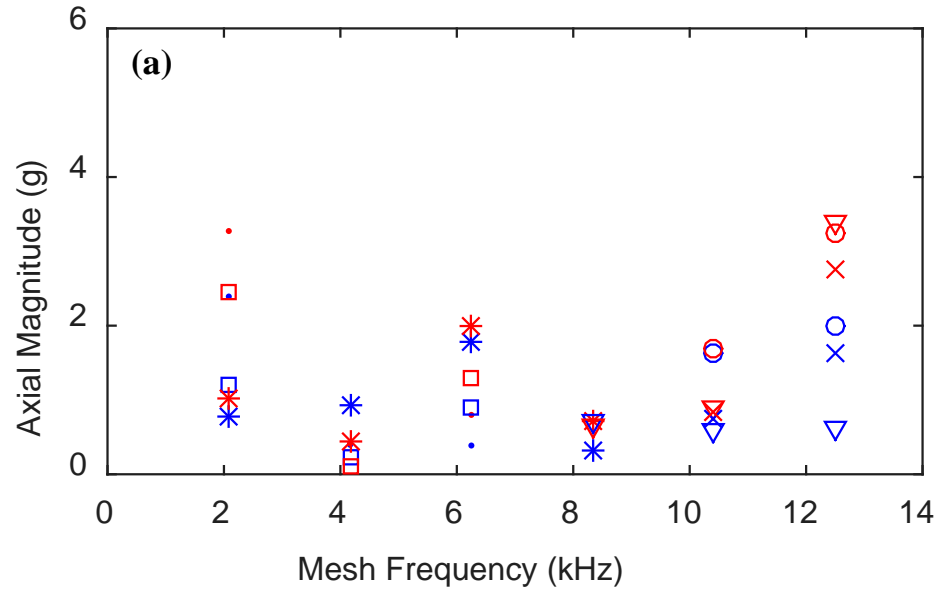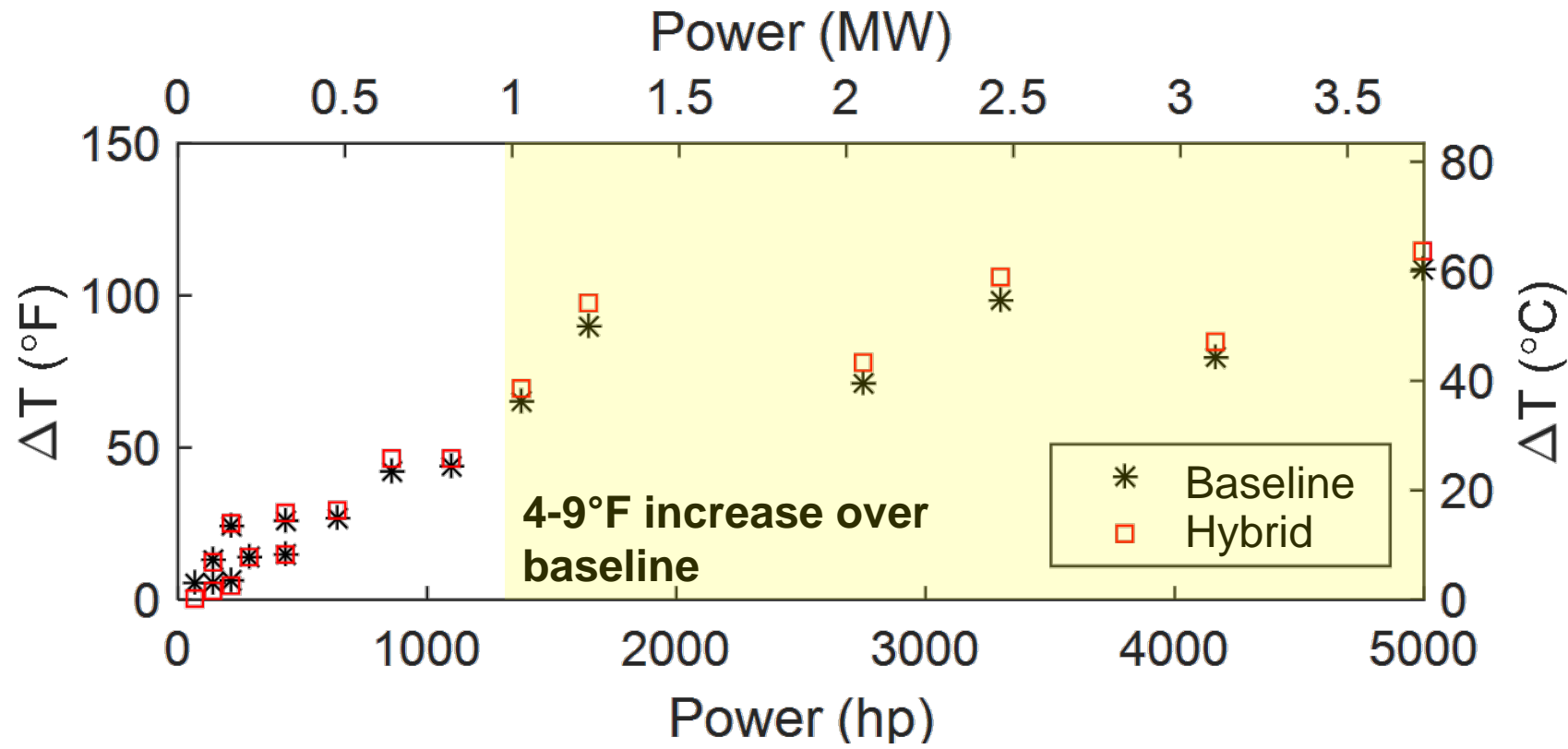

Legend:
- • Baseline - 5000 (in-lb)
- • Hybrid - 5000 (in-lb)
- □ Baseline -10000 (in-lb)
- □ Hybrid -10000 (in-lb)
- ✳ Baseline -15000 (in-lb)
- ✳ Hybrid -15000 (in-lb)
- ▽ Baseline -19300 (in-lb)
- ▽ Hybrid -19300 (in-lb)
- ✕ Baseline -38600 (in-lb)
- ✕ Hybrid -38600 (in-lb)
- ○ Baseline -58400 (in-lb)
- ○ Hybrid -58400 (in-lb)

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Temperature Differential
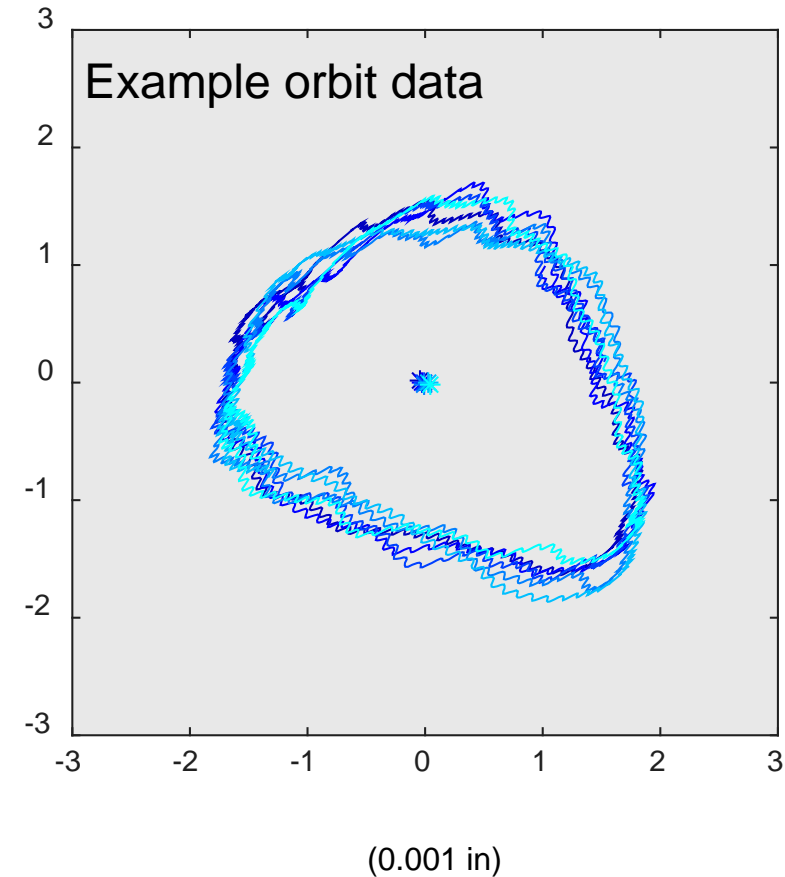$$\Delta T = T_{bull\_fling} - T_{oil\_inlet}$$

4-9°F increase over baseline

Results – Endurance Experiment

- **Goal – To accumulate a million cycles at full power (5000 hp)**

Gear Orbit

Example orbit data

(0.001 in)

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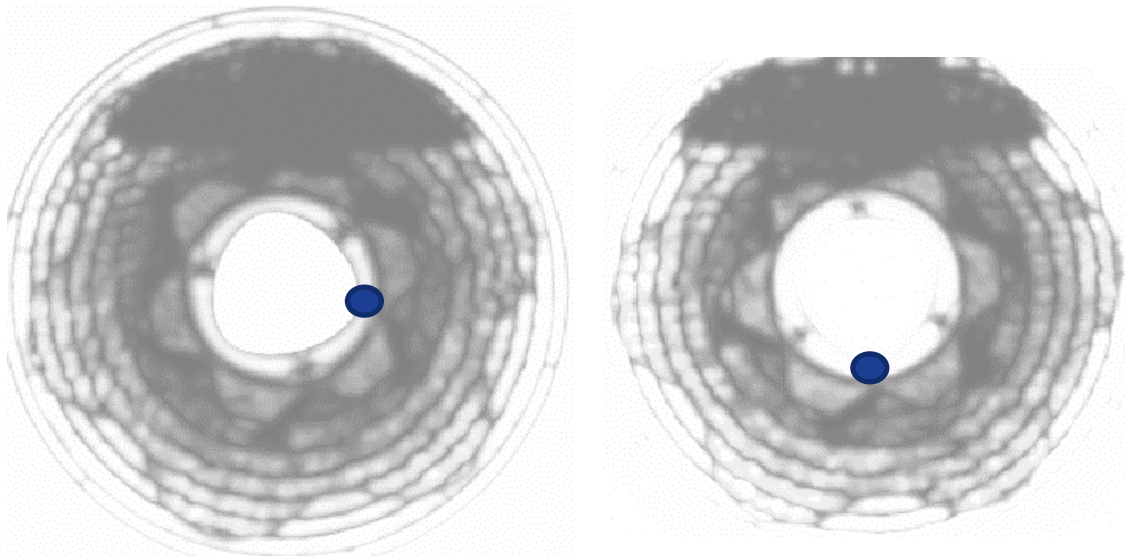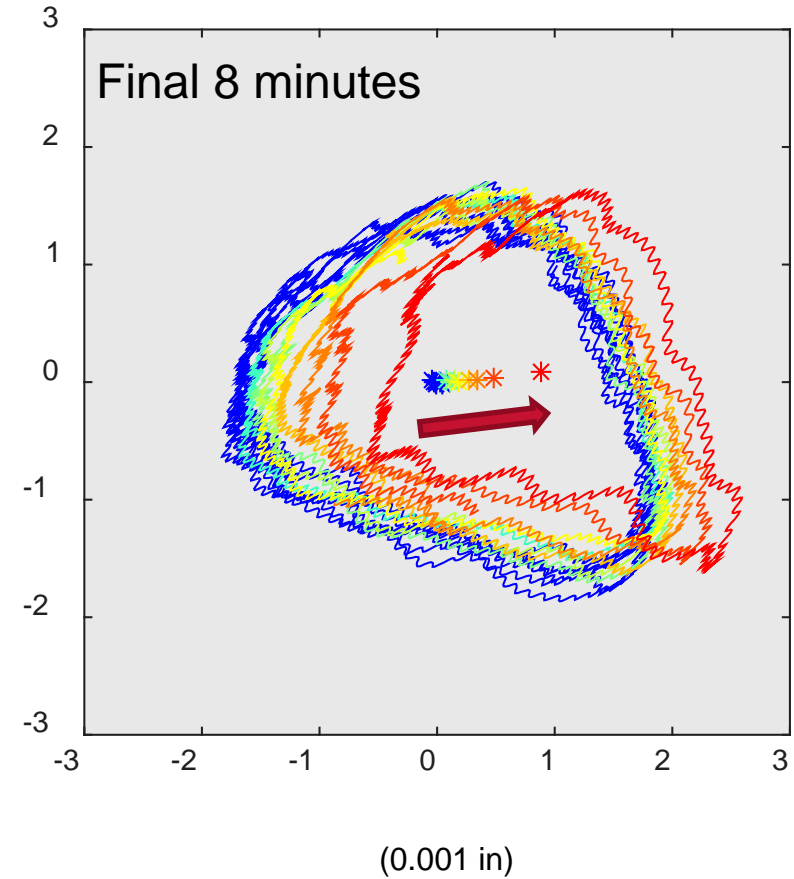
- **Goal – To accumulate a million cycles at full power (5000 hp)**

Experiment discontinued after ~530,000 cycles at 5000 hp

Gear Orbit

Final 8 minutes

(0.001 in)

Gearbox Assembly

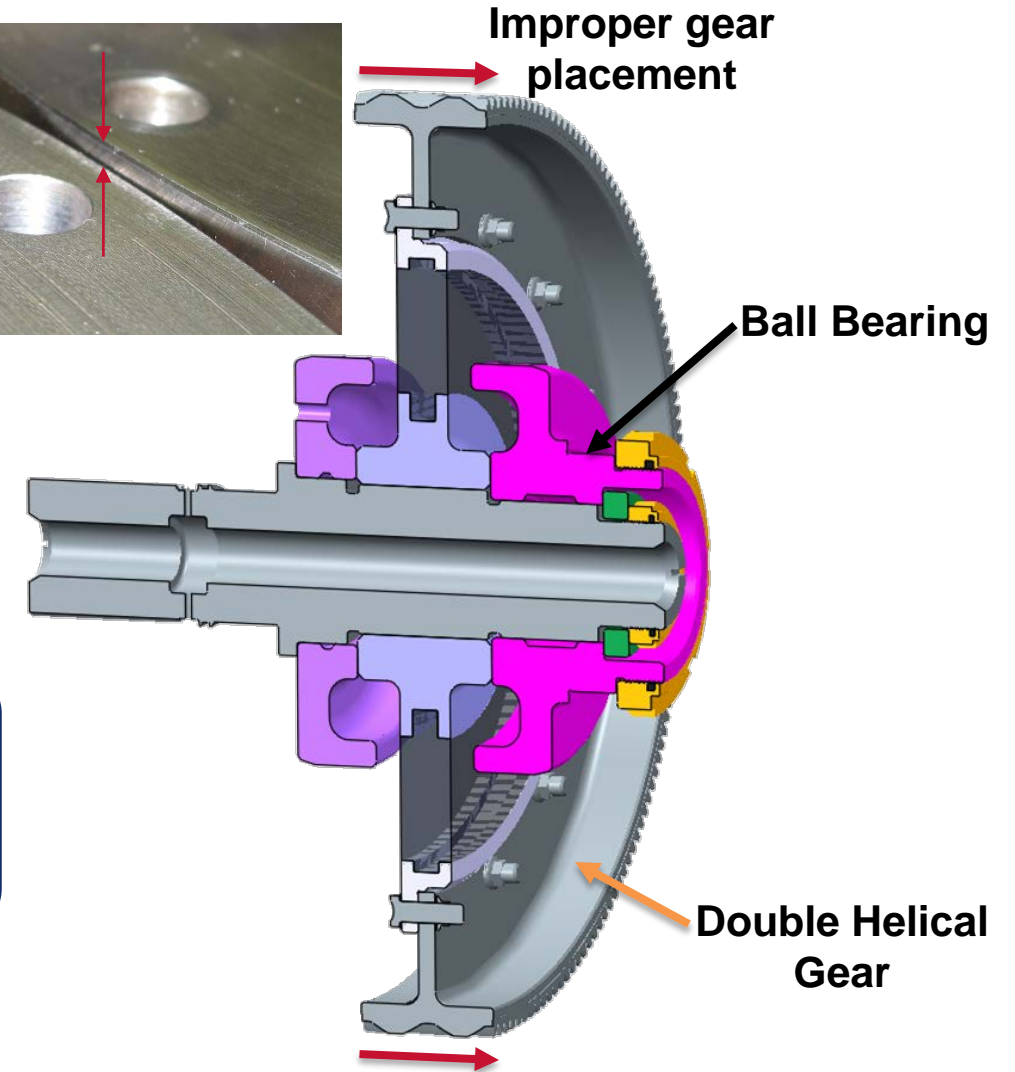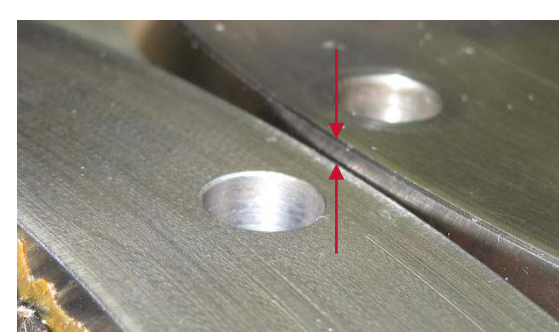- **Test article axial flange offset by 0.0625 in.**

- **First assembly attempt resulted in a gearbox that could not be rotated by hand**

- **Modifications made to eliminate the problem**

Unexpected axial loading during the experiment may be the source of the increase in fling off temperature.

Improper gear placement

Ball Bearing

Double Helical Gear

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Conclusions

- **Variable thickness hybrid gear design far exceeded performance of previous designs in static torsion experiments**

- **Hybrid gears can be used for high-power applications up to 5000 hp**

- **Vibration during the variable thickness hybrid gear experiments was comparable to baseline experiments**

- **The design is sensitive to axial loading**

- **While a failure occurred, it was benign in nature and did not result in a loss of torque or damage to other major rig components**

- The authors plan to repeat these experiments with a gear of the same design (without axial flange offset)

- DIC data from static torsion experiments is being used to validate a finite element model of the gear web

- An all composite web is being designed to eliminate the metallic adapters

Questions?

Acknowledgements:

- **A&P Technology**

- **Sig Lauge – Technician support**
- **NASA Revolutionary Vertical Lift Technology**

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