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Evaluation of a Variable Thickness Hybrid Composite Bull Gear

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Outline

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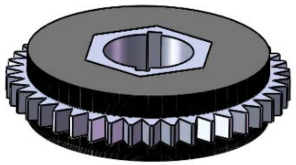
- Motivation
- Background
- Past efforts
- Bull gear design
- Static Torsion Experiments
- Dynamic and Endurance Experiments
- Conclusions
- Future work

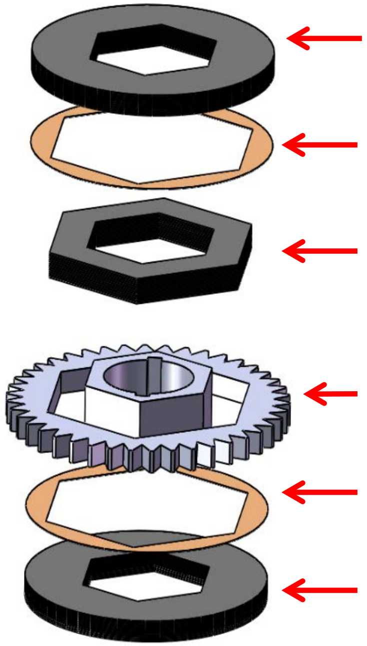
Motivation

- 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

What is a Hybrid Gear?

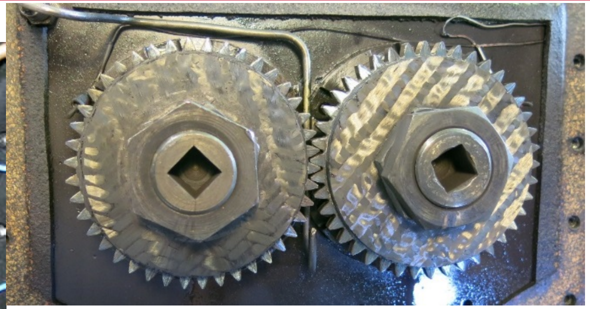




- Replaces steel gear web with lightweight carbon fiber composite
- Loads transferred through adhesive bonds, mechanical interlocks, or fasteners (or any combination)

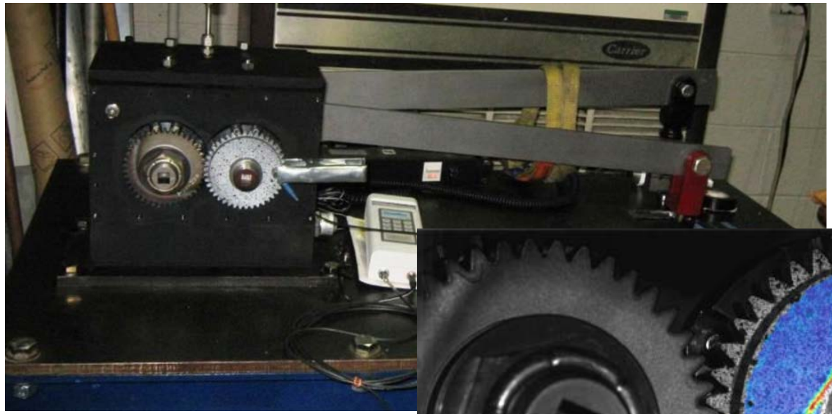
Past Hybrid Gear Efforts

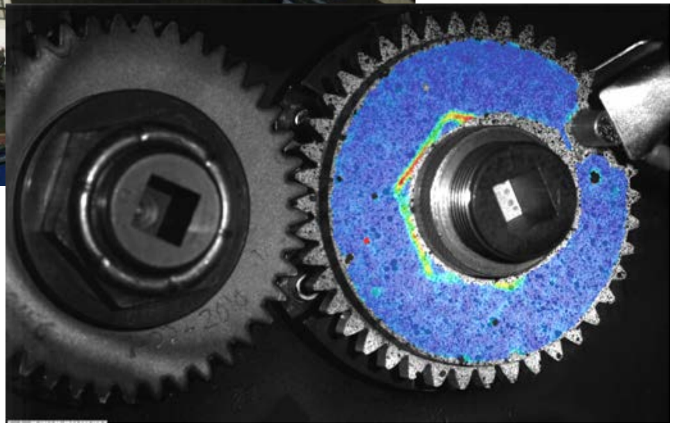
Endurance and dynamic experiments



Loss-of-lubrication experiments

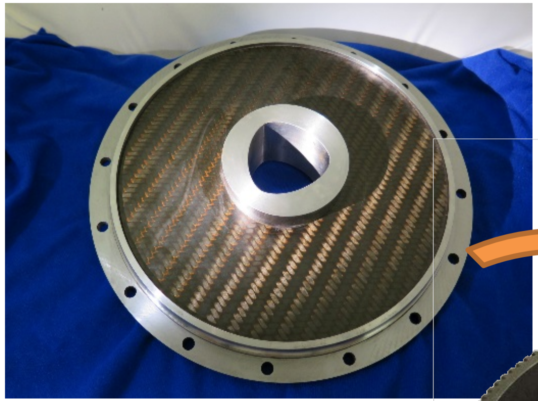
Small-Scale Experiments

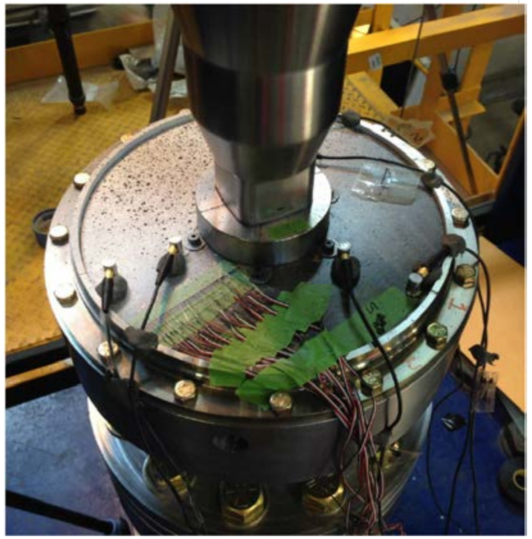




Static torsion experiments

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



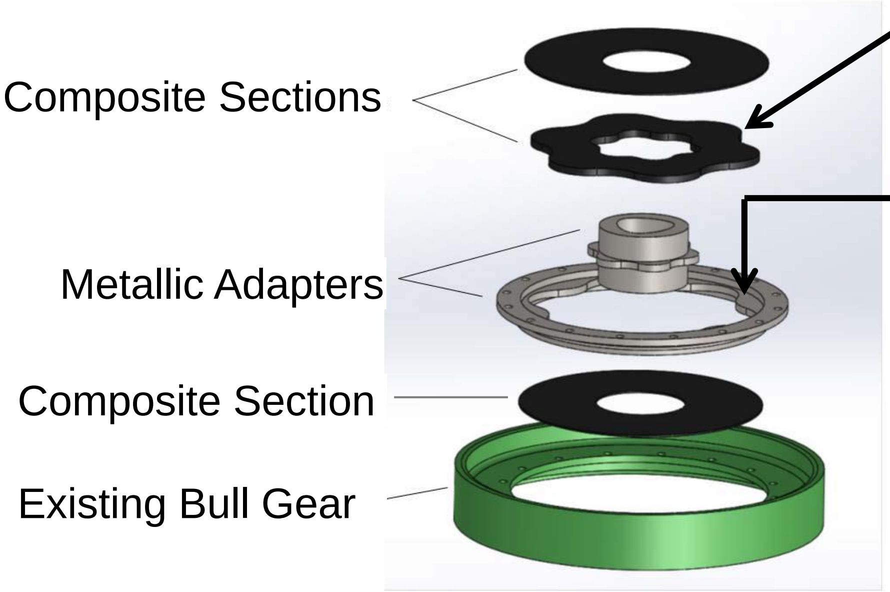


Static torsion experiments

Full-Scale Bull Gear Experiments

Variable Thickness Bull Gear Design

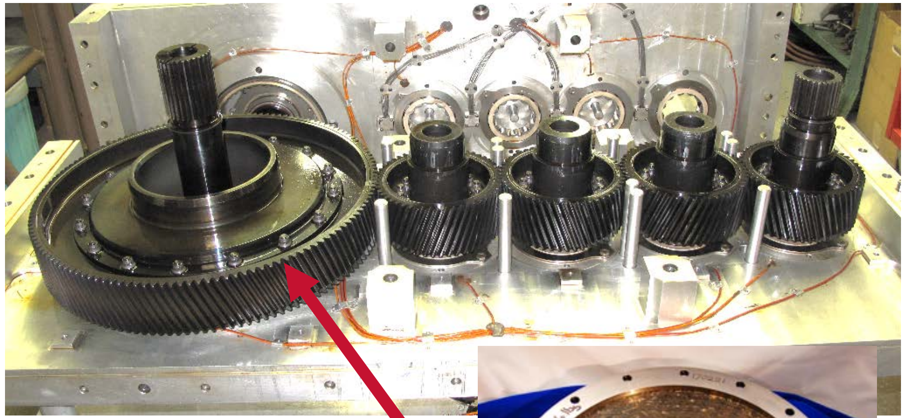
Exploded View of Hybrid Web

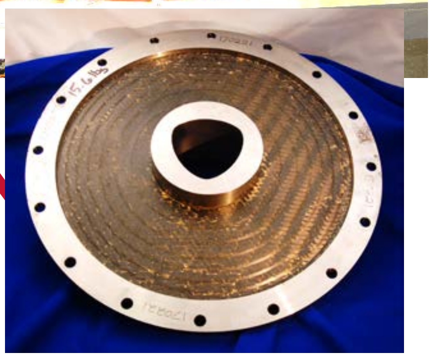


Torque Transfer Mechanisms

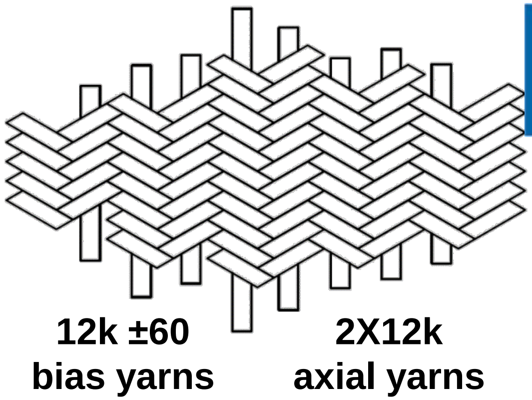
Mechanical interlock

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

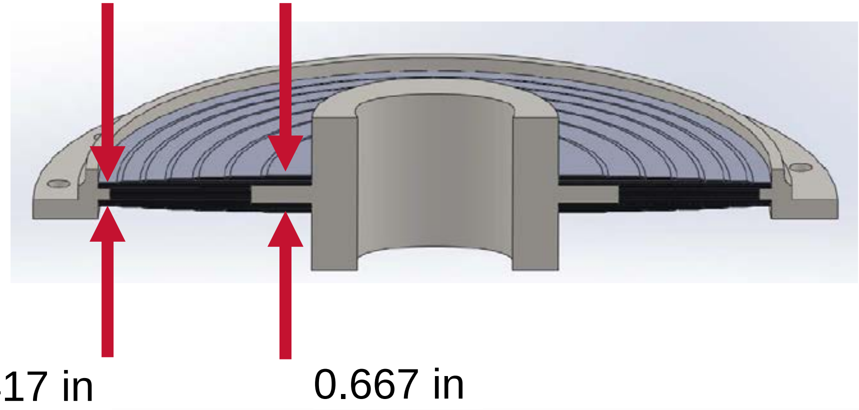




Triaxial Braid Architecture



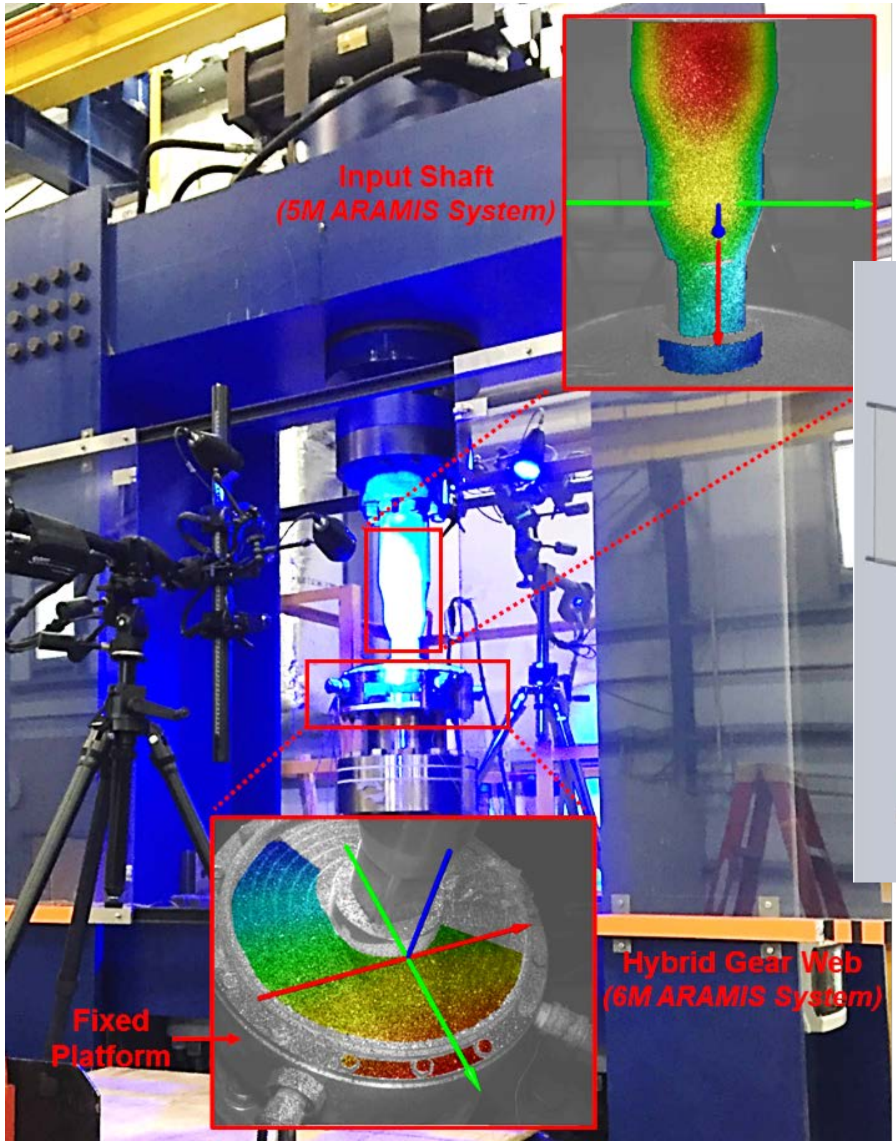
A&P Technology

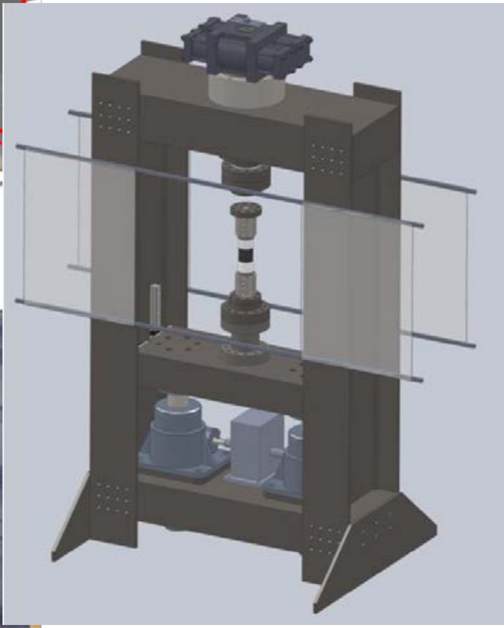


Braided prepreg composite information

- 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

Static Torsion Experiments

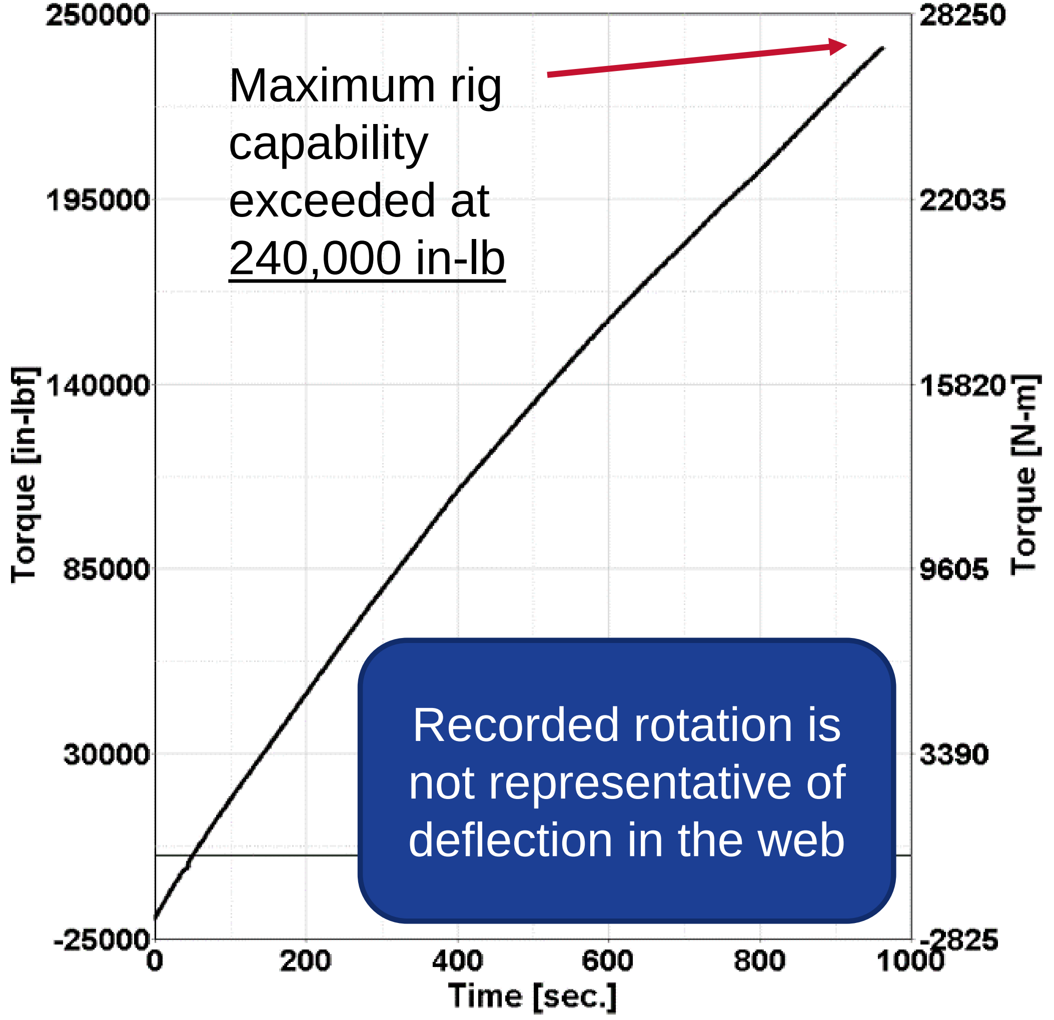




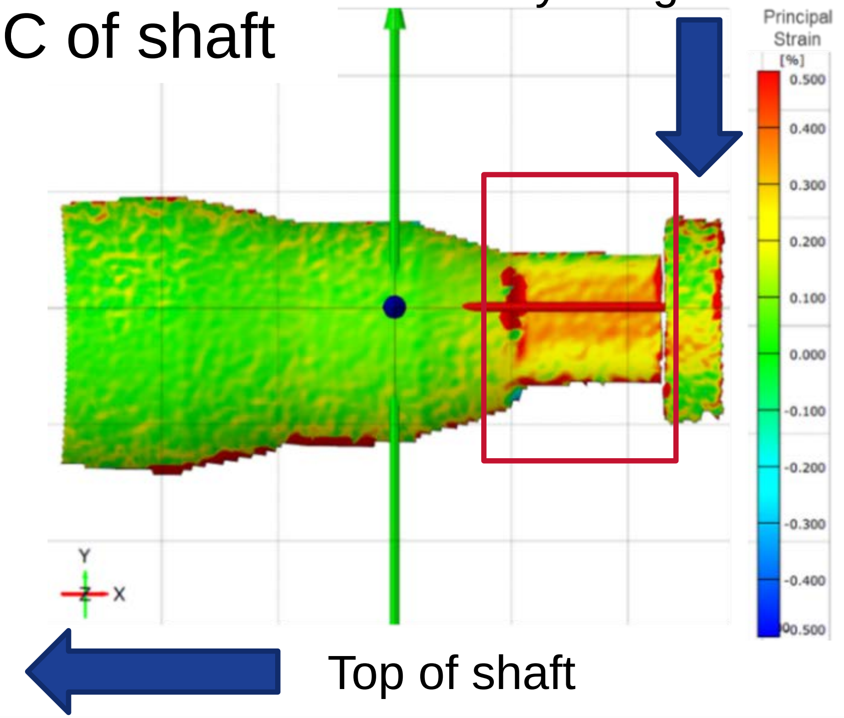
Equipment

- 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

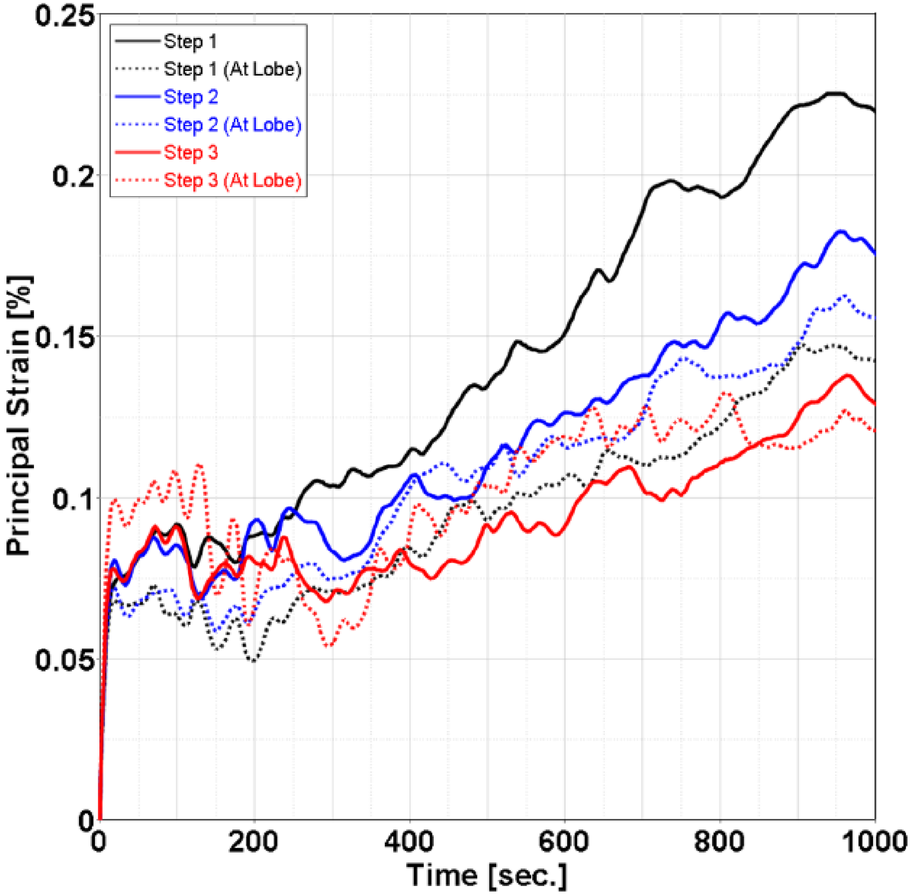
Results – Static Torsion Experiment



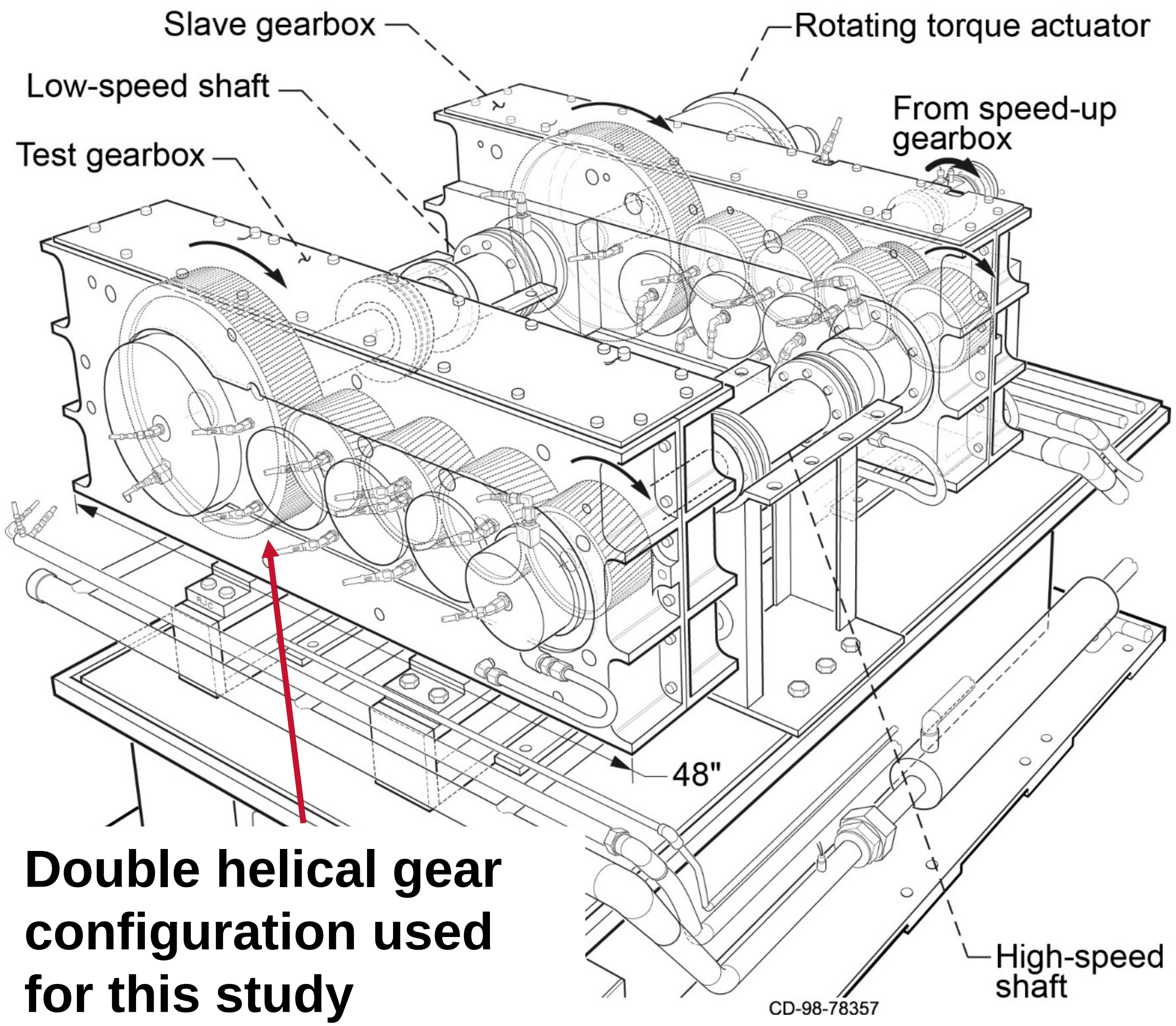
- **Experiment discontinued after maximum rig capability was reached**



Results – Static Torsion Experiment



Dynamic Experiment



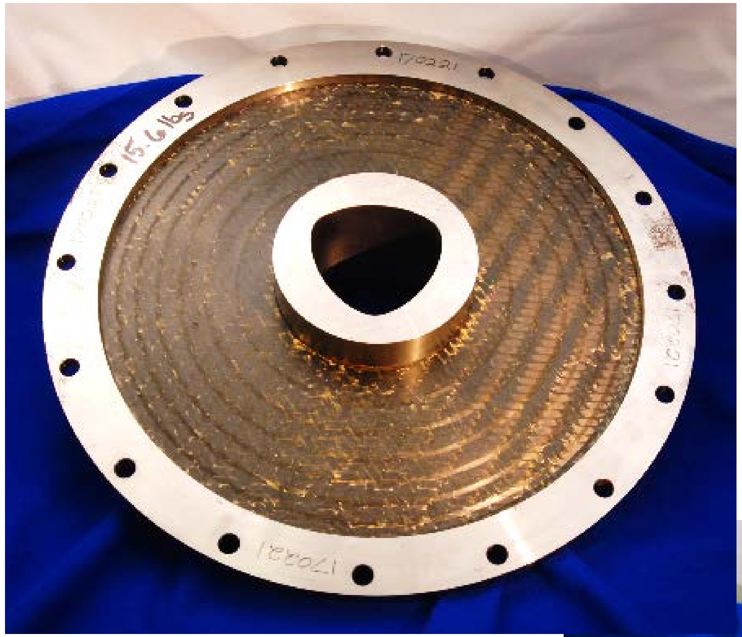
Double helical gear configuration used for this study

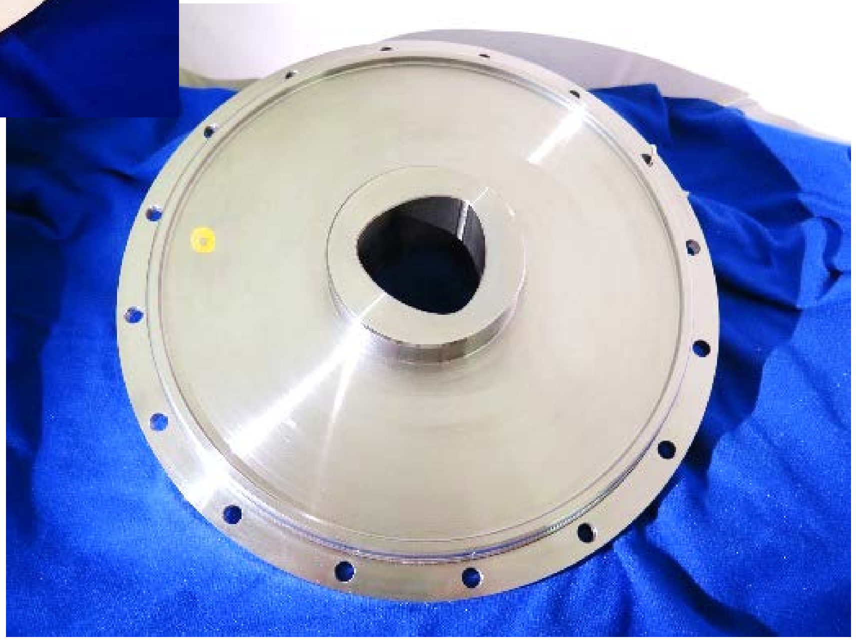
High-Speed Helical Gear Train Rig at NASA Glenn Research Center

- **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

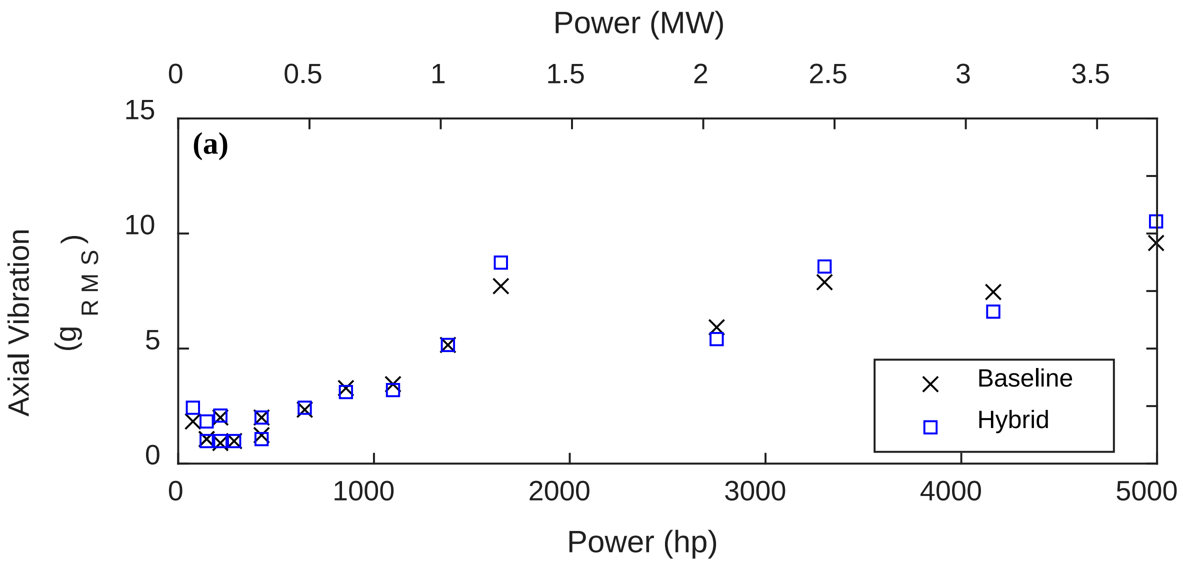
Condition Number	Speed RPM	Torque in-lb (N-m)	Power hp (kW)
1	900	5000 (570)	70 (50)
2	900	10000 (1130)	140 (110)
3	900	15000 (1700)	210 (160)
4	1800	5000 (570)	140 (110)
5	1800	10000 (1130)	290 (210)
6	1800	15000 (1700)	430 (320)
7	2700	5000 (570)	210 (160)
8	2700	10000 (1130)	430 (320)
9	2700	15000 (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)

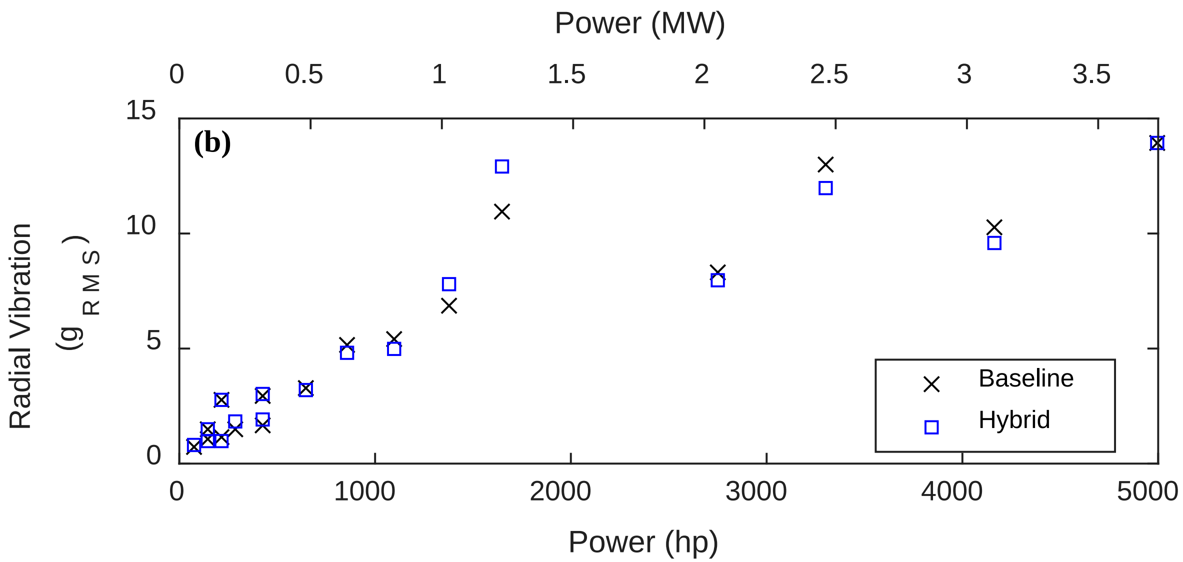




Results – Dynamic Experiment

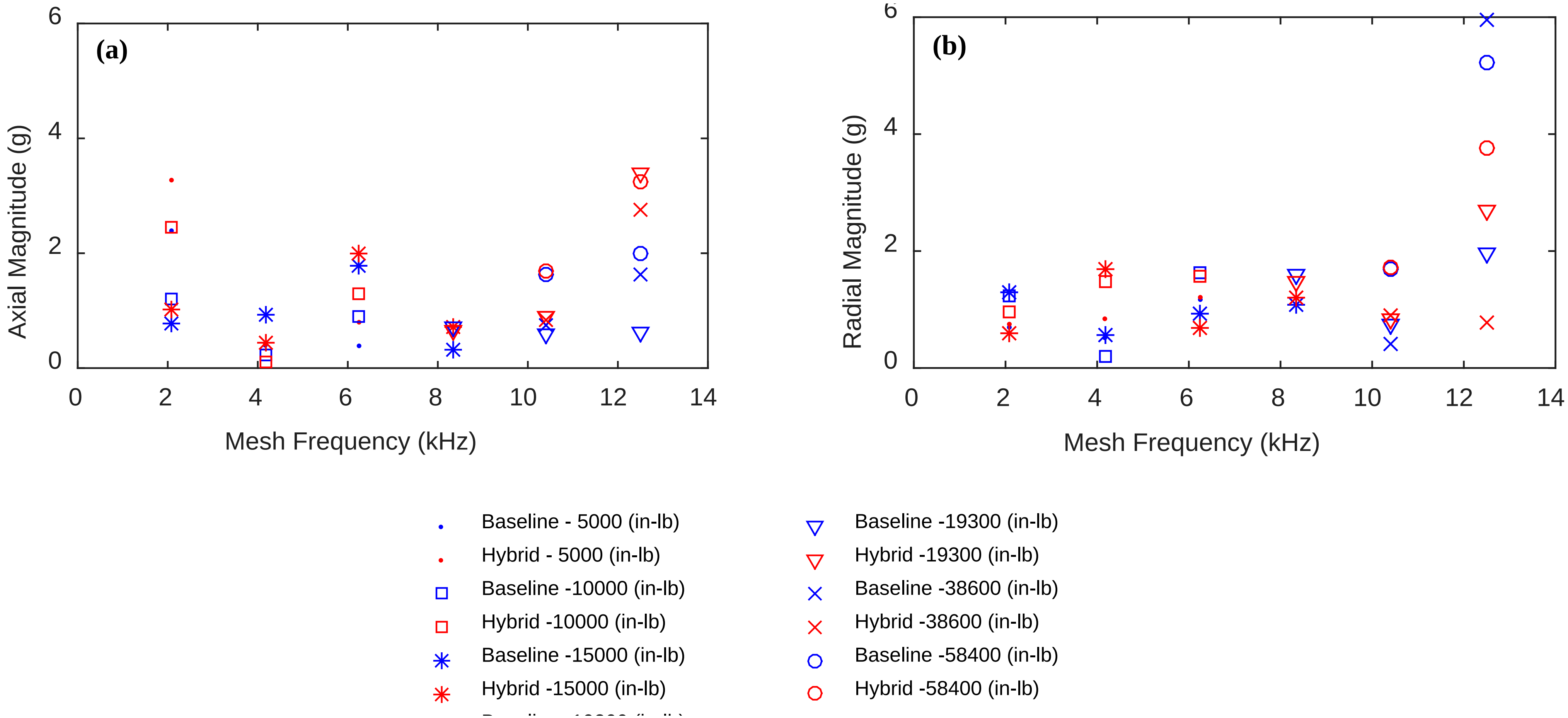
RMS Vibration Level





Results – Dynamic Experiment

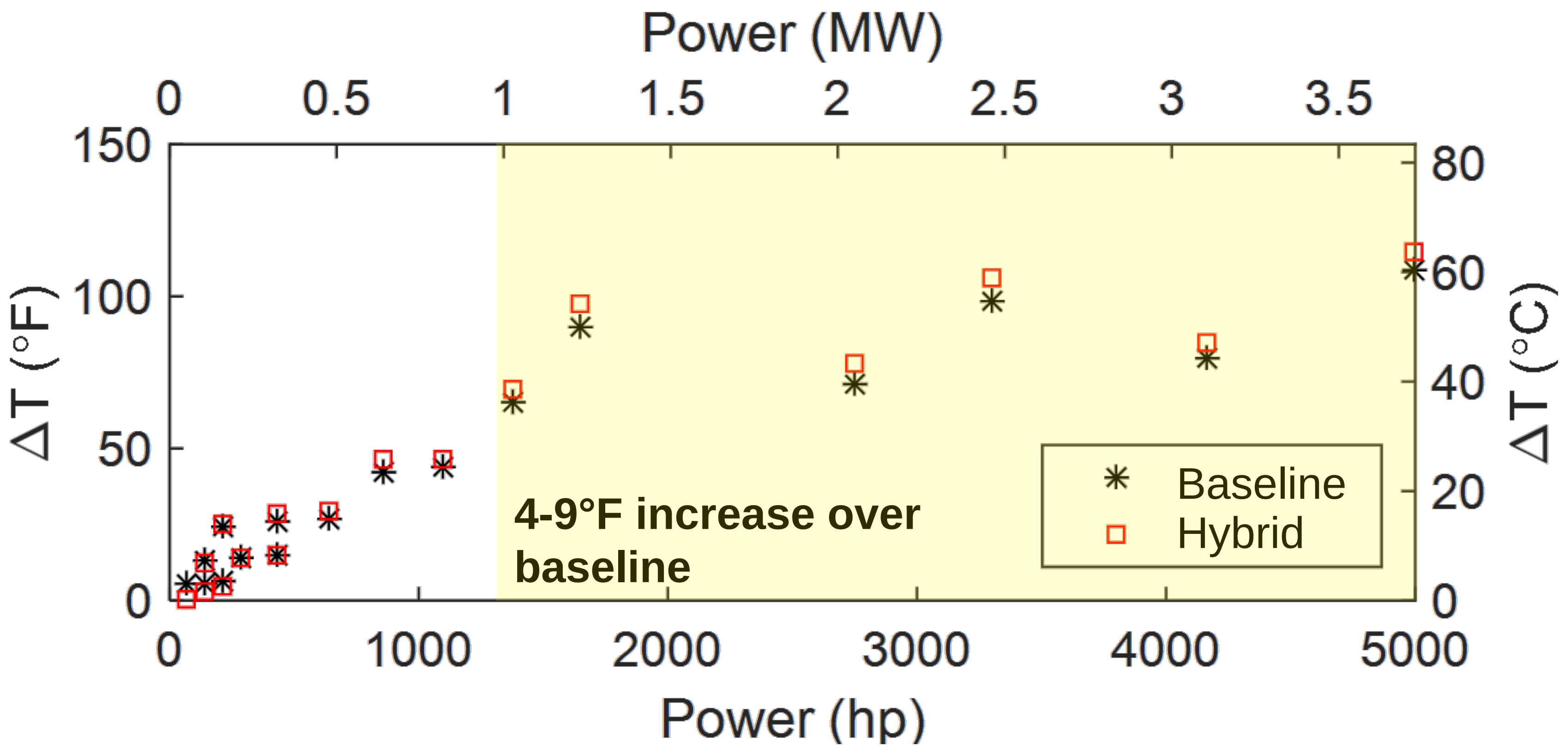
Mesh Frequency Magnitude
Time Synchronous Averaged Signal



Results – Dynamic Experiments

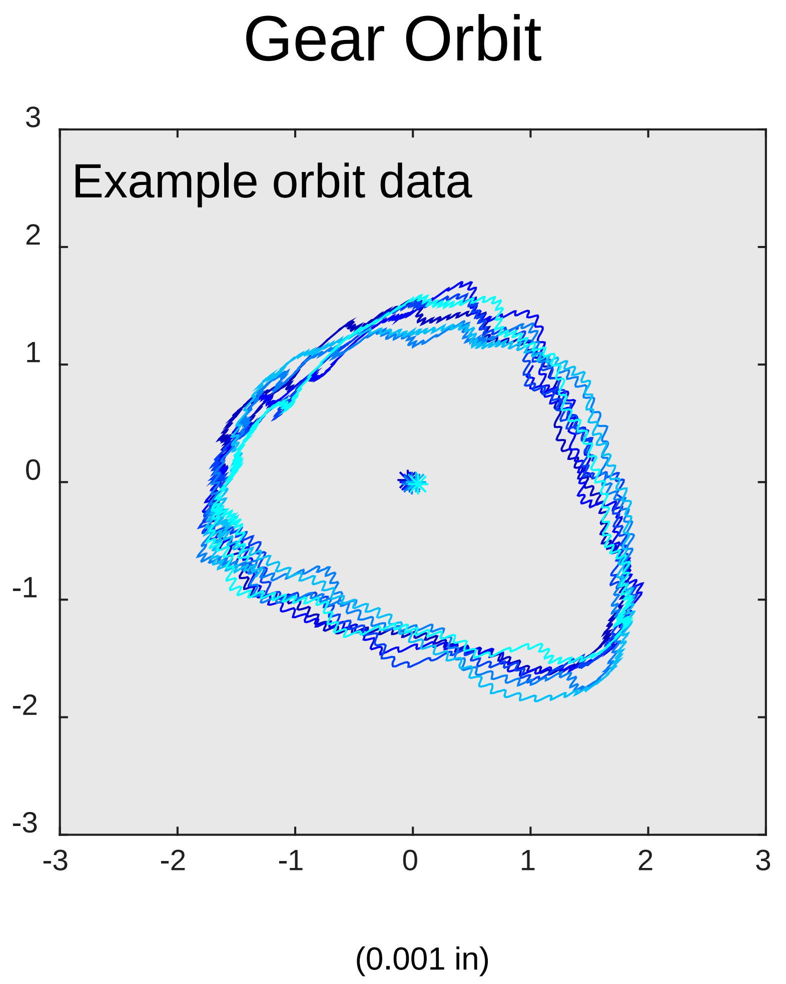
Temperature Differential

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



Results – Endurance Experiment

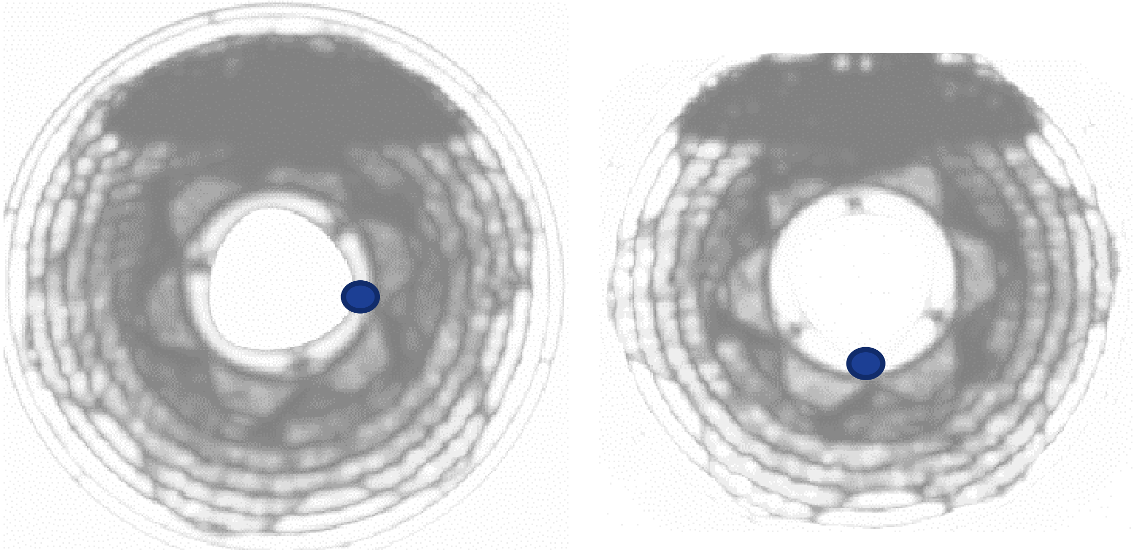
- **Goal – To accumulate a million cycles at full power (5000 hp)**

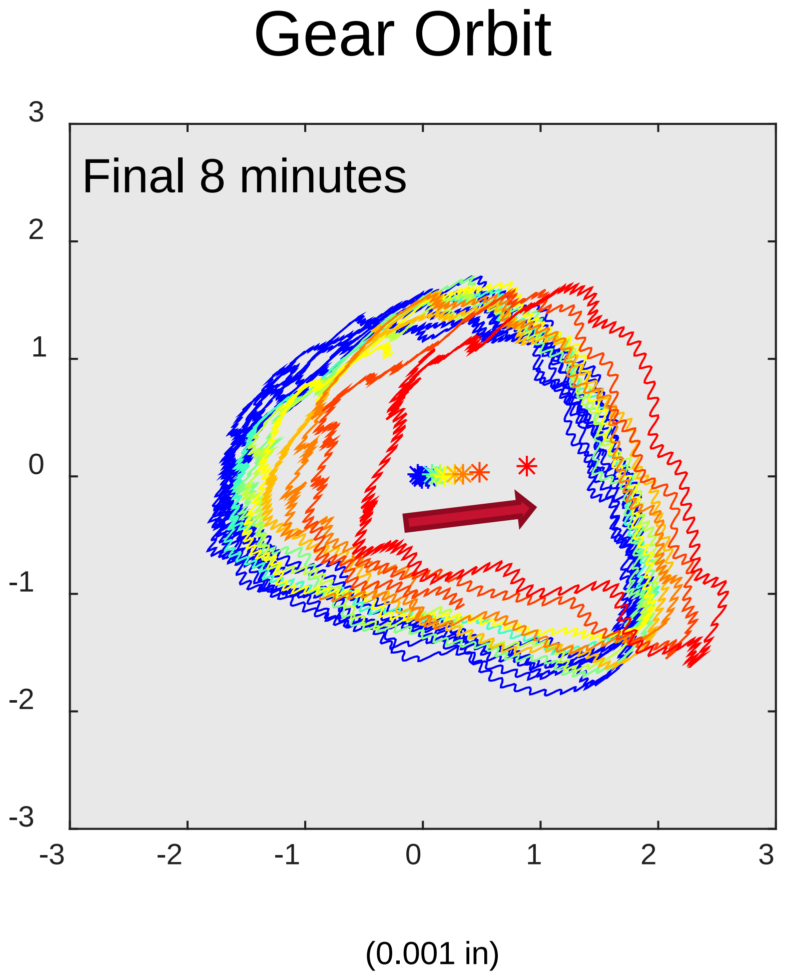


Results – Endurance Experiment

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

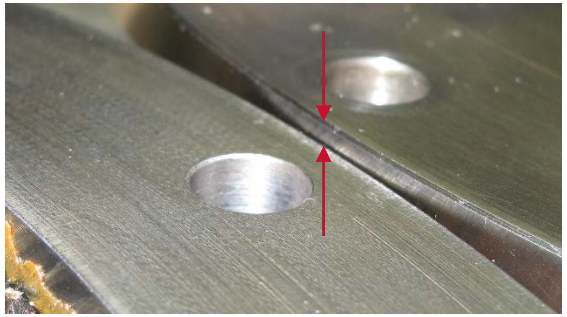
Experiment discontinued after ~530,000 cycles at 5000 hp

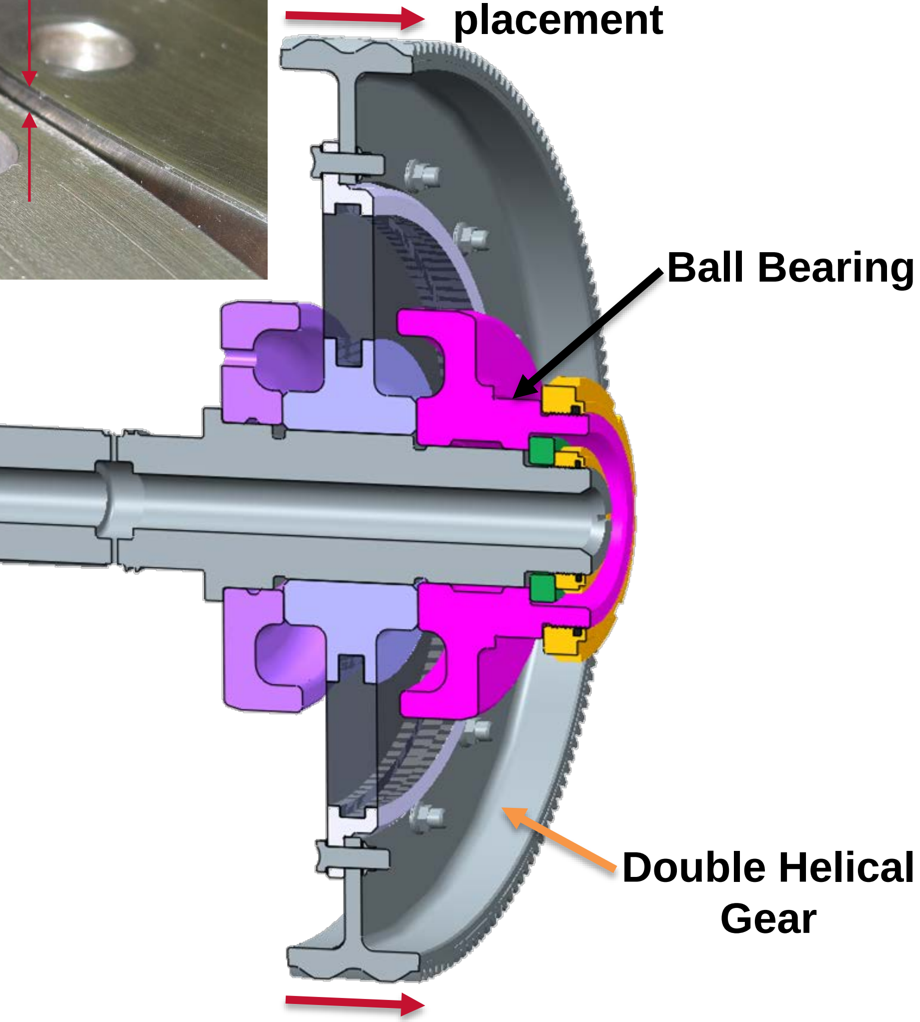




Gearbox Assembly

- 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.

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

Future Work

- 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
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