Performance Investigation of a Full-Scale Hybrid Composite Bull Gear

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• Motivation
• Past efforts
• Bull gear design
• Experimental setup
• Results
• Conclusions
• Future work
• Several past government programs aimed at increasing rotorcraft power density

• Advanced rotorcraft configurations require the ability to change rotor speed, which requires additional drive components further increasing drive system weight

• No suitable replacement for steel in durable high-stress contacts

• Hybrid composite gears are being investigated to replace the structural portion of a steel gear with lightweight composite material
Small-Scale Proof-of-Concept

- Endurance testing of 3.5” pitch diameter coupon gears
- Static torque tests on coupon level gears

Full-Scale Bull Gear

- Mechanical interlock testing
Modular hybrid bull gear design allows for several hybrid web designs to be evaluated with minimal additional cost.
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

12k ±60 bias yarns

2X12k axial yarns

Braided composite information

- T-700 SC carbon fibers
- Prepreg 0°, +/- 60° braided architecture
- Equal fiber volume in all directions
- Tencate TC-250 resin with 56% fiber volume
• NASA Glenn Research Center High-Speed Helical Gear Rig

• Rig capable of running at aerospace conditions (5,000 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
Tests were run with an oil inlet temperature of 120°F

Test were run according to the test matrix

Vibration level and orbit size were monitored during testing

Note: Tabulated horsepower values in the paper are incorrect!
Tests were run with an oil inlet temperature of 120°F
- Test were run according to the test matrix
- Vibration level and orbit size were monitored during testing
- Hybrid bull gear tests were limited to 40% the static torque capacity of the web, eliminating conditions 14 and 17.

<table>
<thead>
<tr>
<th>Run Condition</th>
<th>Shaft Speed (RPM)</th>
<th>Torque in-lb (N-m)</th>
<th>Power hp (kW)</th>
</tr>
</thead>
<tbody>
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<td>5,000</td>
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<td>2</td>
<td>900</td>
<td>10,000</td>
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<td>900</td>
<td>15,000</td>
<td>214</td>
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<td>15,000</td>
<td>857</td>
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<td>1,102</td>
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<td>19,300</td>
<td>1,378</td>
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<td>4,500</td>
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<td>5,400</td>
<td>19,300</td>
<td>1,654</td>
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<td>5,400</td>
<td>38,600</td>
<td>3,307</td>
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<tr>
<td>17</td>
<td>5,400</td>
<td>58,400</td>
<td>5,004</td>
</tr>
</tbody>
</table>
Averaged Vibration Level

### Axial Vibration (g_rms)
- **Baseline**
- **Hybrid**

### Radial Vibration (g_rms)
- **Baseline**
- **Hybrid**

### Results - Vibration

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<tr>
<th>Run Condition</th>
<th>Shaft Speed (RPM)</th>
<th>Torque in-lb (N-m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>900</td>
<td>5,000 (560)</td>
</tr>
<tr>
<td>2</td>
<td>900</td>
<td>10,000 (1,130)</td>
</tr>
<tr>
<td>3</td>
<td>900</td>
<td>15,000 (1,690)</td>
</tr>
<tr>
<td>4</td>
<td>1,800</td>
<td>5,000 (560)</td>
</tr>
<tr>
<td>5</td>
<td>1,800</td>
<td>10,000 (1,130)</td>
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<td>6</td>
<td>1,800</td>
<td>15,000 (1,690)</td>
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<tr>
<td>7</td>
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<td>10,000 (1,130)</td>
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<td>19,300 (2,180)</td>
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<tr>
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<td>4,500</td>
<td>38,600 (4,360)</td>
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<tr>
<td>14</td>
<td>4,500</td>
<td>58,400 (6,600)</td>
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<tr>
<td>15</td>
<td>5,400</td>
<td>19,300 (2,180)</td>
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<tr>
<td>16</td>
<td>5,400</td>
<td>38,600 (4,360)</td>
</tr>
<tr>
<td>17</td>
<td>5,400</td>
<td>58,400 (6,600)</td>
</tr>
</tbody>
</table>
$$T_{\text{diff}} = T_{\text{oil-outlet}} - T_{\text{oil-inlet}}$$

No increase in heat generation!
Run Condition 9:  
2700 RPM  
15,000 in-lbs

Run Condition 16:  
5,400 RPM  
38,600 in-lbs

Hybrid gear orbit size starts to increase and change shape while at condition 16.
Results – Averaged Orbit

Testing day 1
Condition 6 – Before max run condition

Testing day 1
Condition 6 – After max run condition

Testing day 2
Condition 6

Change in shape after running at max 3300 HP condition
- Ultrasonic testing was unsuccessful
- Alternatives
  - Scanning acoustic microscope
  - X-ray
- Instrumented hammer tests

Driving Point FRF – Hybrid Web Tested

Driving Point FRF – Flawed Hybrid Web
Conclusions

- Successfully tested a hybrid composite bull gear up to 3300 HP
- Increase orbit size at 3300 HP resulted in discontinuation of test
  - No loss of torque
  - Gear continued to perform at lower power conditions
- No increase in overall vibration level over baseline configuration
- Composite material has no apparent effect on operating temperature
- Instrumented hammer tests give good indication of inconsistencies in the composite material
Future Work

- Continue hybrid bull gear testing with 2 additional web designs
  - Reduced number of capture plies
  - Variable thickness web
- Investigate direct mating of composite to the polygon drive eliminating the inner metallic adapter
- Complete and validate finite element model of hybrid gear
- Investigate additional NDE techniques
- Hot oil material testing
- System level testing in a production gearbox
- Static loading under combined loads
Acknowledgements:

- A&P Technology – NASA SBIR
  - Nathan Jessie
  - Mike Braley

Past Publications:

