Concepts for Multi-Speed Rotorcraft Drive System -
Status of Design and Testing at NASA GRC

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Objective

Overview the Status of Three Drive Designs from an earlier concept study:

1. Design/testing of two *multi-speed drives*.
   Highlight some positive/negative aspects and future development areas.

2. Update to the design of *third concept*.
   *Variable-speed gear drive* based on a dual-input planetary differential.
Background

Future advances in rotorcraft propulsion systems require increased efficiency, power, and enhanced capabilities.

Studies show that *variable rotor speed* is required for:

- Reduction in noise
- Increased performance
- Enhanced capabilities (speed - capacity - range)

*Advances are contingent upon varying rotor speeds 50%. Present Limitations ~15% (via engine control).*
Future Rotorcraft Propulsion System Configuration
V/M-S Gearbox Application

Hover Ratio 131.4 : 1    Forward Flight Ratio 243.6 : 1
Test Article Design Requirements

• 250 HP nominal (200 HP facility capacity)
• Inline configuration (input-output shafts)
• Input Speed 15,000 rpm
• Output Speeds 15,000 rpm (hover), 7,500 rpm (cruise)
• Employ straight spur gear geometry (budget consideration)
• Drive should fail safe to the high-speed (hover) mode
• Lubricant: DOD-PRF-85734A, synthetic ester-based oil
  – 40C 104F 23.0 cSt
  – 100C 212F 4.90-5.40 cSt
  – -54C -65F pour point
• a Provide high-speed positive drive element
• b Light-weight rotating components (flight like)
• c Housing design (modular, possibility of windage shrouds)

   a requirement dropped due to complexity and budget
   b requirement dropped due to scope and budget
   c not an original requirement
Modules: Gear & Clutch

2x Gear Modules

2x Clutch Modules

Forward Bearing

Low-Speed Shaft

Aft Bearing

Hydraulic Feed-Through

Input Shaft

Gear Train

Clutch (Main)

Sprag

Output Shaft

1:1 Direct Drive (Vertical Flight)

2:1 Reduction Drive (Cruise)

Main Clutch Engaged

Main Clutch Disengaged
Baseplate/Supports/Housing

Fwd Brg Support  Intermediate Brg Support  Aft Brg Support  Rotating Feed-Through Support

Fixity - Main Rotating Ass’y
Fixity - Offset Cluster Gear
Floating
Two-Speed Drive Test Configurations

Configuration 1: OCG / Dry-Clutch (Tested)

Configuration 2: DSI / Dry-Clutch (Tested)

Configuration 3: OCG / Wet-Clutch (In assembly)
Gear Module 1: (OCG) - Offset-Compound Gear

- Sun Gear
- Ring Gear
- Sun Gear
- Ring Gear

Offset Axis

Cluster Gear (OCG)

Mesh 1 Oil Jets

Mesh 2 Oil Jets

2:1

1:1
Balancing the OCG Cluster Assembly

Input Shaft 1

OCG Cluster Ass’y

Drive Belt System
Shaft 1 Support
OCG Cluster Supports
Shaft 1 Support

OCG Offset C/L
Gear Module 2: (DSI) - Dual Star-Idler Planetary

Star Gear   Idler Gear

Input Shaft

Sun Gear   Ring Gear

Carrier (Fixed)

2:1

1:1
DSI Planetary Gear Design

Bearing Loads vs. Rotational Direction

Ring  CCW Out
Star  CW Out
Idler

Sun  CCW In
CW In

Bearing Load
Load CW
Load CCW

Oil In (Typ)
Spacer Sleeve
Planet Gear Assembly

Mesh Jets
Pass-Thru

Brg Jet
Brg Jet
3-Plate Carrier

Carrier Ass’y

Oil-In Plane

www.nasa.gov
# Gear Parameters - OCG vs. DSI

## OCG Gear Train
Material: 9310, Backlash: 0.006-0.011 inch,  
Width: 0.375 inch, Contact Angle 20°

<table>
<thead>
<tr>
<th>Gear</th>
<th>Pitch</th>
<th>Pitch Dia (inch)</th>
<th>$N_{\text{teeth}}$</th>
<th>Rpm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Input</td>
<td>8.727</td>
<td>2.865</td>
<td>25</td>
<td>15,000</td>
</tr>
<tr>
<td>2</td>
<td>8.727</td>
<td>4.240</td>
<td>37</td>
<td>10,135</td>
</tr>
<tr>
<td>3</td>
<td>8.0</td>
<td>3.875</td>
<td>31</td>
<td>10,135</td>
</tr>
<tr>
<td>Ring</td>
<td>8.0</td>
<td>5.250</td>
<td>42</td>
<td>7,481</td>
</tr>
</tbody>
</table>

## DSI Gear Train
Material: 9310, Backlash: 0.010-0.015 inch,  
Width: 0.600 inch, Contact Angle 20°

<table>
<thead>
<tr>
<th>Gear</th>
<th>Pitch</th>
<th>Pitch Dia (inch)</th>
<th>$N_{\text{teeth}}$</th>
<th>Rpm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sun</td>
<td>12</td>
<td>4.1667</td>
<td>50</td>
<td>15,000</td>
</tr>
<tr>
<td>Star</td>
<td>12</td>
<td>1.5833</td>
<td>19</td>
<td>39,474</td>
</tr>
<tr>
<td>Idler</td>
<td>12</td>
<td>1.6667</td>
<td>20</td>
<td>37,500</td>
</tr>
<tr>
<td>Ring</td>
<td>12</td>
<td>8.4167</td>
<td>101</td>
<td>7,426</td>
</tr>
</tbody>
</table>

Observations: DSI planet gears spin at 4x the speed of the OCG cluster gear.
# Bearing Parameters - OCG vs. DSI

**OCG Bearing Parameters.**

<table>
<thead>
<tr>
<th>Site</th>
<th>Rpm</th>
<th>Size</th>
<th>(D_{brg})</th>
<th>(d_{brg})</th>
<th>(dN) factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Input</td>
<td>15,000</td>
<td>206</td>
<td>62</td>
<td>30</td>
<td>450,000</td>
</tr>
<tr>
<td>2</td>
<td>10,135</td>
<td>1822</td>
<td>140</td>
<td>110</td>
<td>1,114,850</td>
</tr>
<tr>
<td>3</td>
<td>10,135</td>
<td>1822</td>
<td>140</td>
<td>110</td>
<td>1,114,850</td>
</tr>
<tr>
<td>Ring</td>
<td>7,481</td>
<td>210</td>
<td>90</td>
<td>50</td>
<td>374,050</td>
</tr>
</tbody>
</table>

**DSI Bearing Parameters.**

<table>
<thead>
<tr>
<th>Site</th>
<th>Rpm</th>
<th>Size</th>
<th>(D_{brg})</th>
<th>(d_{brg})</th>
<th>(dN) factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sun</td>
<td>15,000</td>
<td>206</td>
<td>62</td>
<td>30</td>
<td>450,000</td>
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<tr>
<td>Star</td>
<td>39,474</td>
<td>202</td>
<td>35</td>
<td>15</td>
<td>592,110</td>
</tr>
<tr>
<td>Idler</td>
<td>37,500</td>
<td>202</td>
<td>35</td>
<td>15</td>
<td>562,500</td>
</tr>
<tr>
<td>Ring</td>
<td>7,426</td>
<td>210</td>
<td>90</td>
<td>50</td>
<td>371,300</td>
</tr>
</tbody>
</table>

(Bearing diameters in millimeters)

Observations: Bearing \(dN\) are higher for OCG despite high speeds of the DSI planet bearings.
Observations – Gear Trains

High planet gear speed is an inherent aspect of a single stage planetary gear train with a 2:1 output since the ratio is defined by the ratio of pitch diameters of the ring and sun gears.

For a basic 2:1 Planetary: Ø5.0 sun & Ø10.0 ring yields the following intermediate gear speeds for an input speed of 15,000 rpm

<table>
<thead>
<tr>
<th>Gear Train</th>
<th>Intermediate Speed (rpm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Basic Planetary</td>
<td>30,000</td>
</tr>
<tr>
<td>DSI (idler addition)</td>
<td>37,500 +25% speed increase due to reduced diameter planets</td>
</tr>
<tr>
<td>OCG</td>
<td>10,000</td>
</tr>
</tbody>
</table>

The OCG is simpler to lubricate due to reduced number of gear meshes and bearings.
Clutch Module: (DC) DRY-CLUTCH

* Unique hardware necessary to meet the inline design requirement
Dry-Clutch Design

- Clutch Hub
- Clutch
- Piston (Release Bearing Ass’y)
- Input Flange
- Pre-Load Springs
- 1:1
- Intermediate Output Shaft
- Output Shaft
- Hydraulic Signal
Clutch Module: (WC) Wet-Clutch

- Low-Speed Shaft
- Release Piston
- Sprag
- Output Shaft
- Drive Plates
- Drive Springs
- Rotating Feed-Through
Wet-Clutch Design

- Drive Plates
- Release Piston
- Drive Springs
- 1:1
- Input Flange
- Polygon Drive
- Orifice Bleed
- Hydraulic Signal
- Output Shaft
Output Shaft Hydraulic / Lubrication Passages (Wet-Clutch)

- Bearing Lube Jets
- Drive Plate Lube Jets
- Release Piston
- Sprag Lube Ports
- Orifice (Bleed)
- Low-Speed Shaft
- Drains
- Lube/Oil Inlets
Clutch Release Closed-Loop Load Path

Closed-Loop Load Path (Dry-Clutch)

Closed-Loop Load Path (Wet-Clutch)
Rotating Hydraulic/Lubricant Feed-Through

- 15,000 rpm
- Ring Seals – DuPont Vespel
- Significant drag

Lube Oil A, B, C
Ring Seals
O-Rings
Lube Inlets A, B, C

Rotating Feed-Through
Main Housing Aft Wall
Sprag (Overrunning Clutch)

- Sprag Hub
- Low-Speed Shaft
- Sprag
- Races
- Lube Inlet (Shaft)
- Lube Drain (Hub)

Revisions:
- Addition of aft-sprag bearing forming straddle duplex bearing support

Sprag:
- 16-element
- 4-lube inlets

Races:
- 4-drive pins

Straddle Support Duplex Bearings
Future Design (Concept 3)

Variable-Speed Drive
Dual-Input Planetary Differential

• Concept Variable-Speed Drive leveraged from the DSI Planetary Gear Train & Lubrication Design
  – Sun Gear - Input
  – Carrier - Control (Second Input)
  – Ring Gear – Output

• Direct Point Bearing and Gear Lubrication

Second Input Is Not Within Current Scope
DUAL-INPUT PLANETARY DIFFERENTIAL

1 - Primary Input (Fixed)

2 - Carrier Input (Variable A or B)

Planet Bearing Oil Jets

Carrier Bearing Oil Jets

Output (Variable)

Rotating Feed Through

Mesh Oil Shaft-Fed

Drains (Rotational)
CONCLUDING REMARKS

• Presented an overview of designs and current status of two-speed drive concepts developed at NASA GRC.

• Identified a few areas for future development. Many more are discussed in detail in the paper.

• Presented an updated concept for a variable-speed gear drive based on a dual-input planetary differential.