The Jetting Phenomena in Meshed Spur Gears

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Topics

• Gearbox Efficiency and Windage Power Loss (WPL)
• Summary of NASA shrouded WPL experiments
• Jetting phenomena in the literature
• Pocketing analysis
• An improved shrouded test configuration
• Conclusions
Gearbox Efficiency & Power Losses

• Mechanical efficiency (load dependent)
• Bearing, shaft losses (load dependent)
• Current talk concerned with windage losses (load independent)

Windage Power Loss (WPL)

• Definition
    • Drag on gear
    • Viscous drag on gear faces
    • Air/oil impingement on tooth surface (inertia effects)

• Category
    • Load-independent, spin-loss

• Significance
    • Pitch-line velocities greater than 10,000 ft./min. (51 m/s)
    • Gearbox efficiency losses
    • Reduced rotorcraft performance (i.e. payload, range)

• Shrouding may mitigate WPL

Highest Surface Speeds at the Input Shaft

OH-58: ~35,000 rpm
~20,000 ft/min (pitch-line velocity)

UH-60: ~20,000 rpm

AH-64: ~20,000 rpm
Engine Torque versus Altitude

- Helicopter Performance Chart
  FAA Helicopter Flying Handbook
  Chapter 7, Fig. 7.3

- Torque required for cruise or level flight

- Available engine torque (e.g. 2-3%) can affect altitude, gross weight, skid height

![Graph showing engine torque versus altitude](image)
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NASA Glenn Windage Power Loss Research

![Diagram of windage power loss research](image)

- Pitch-line velocity [m/s]
- Windage Power loss [hp]

- Unshrouded
- Small axial, small radial, 13%

![Graph showing windage power loss vs. pitch-line velocity](graph)
NASA Glenn Windage Power Loss Research
An Unexpected Result

Delgado, I., and Hurrell, M., 2017, “The Effectiveness of Shrouding on Reducing Meshed Spur Gear Power Loss – Test Results,” AGMA Fall Technical Meeting, Columbus, Ohio
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Literature on Jetting

- Data from 1960s to present
  - Analytical closed form, CFD
  - Pressure measurements, PIV
- Pocketing Losses (aka trapping, squeezing)
  - Compression followed by acceleration of the fluid
  - Fluid discharge axially and via backlash
- Discharge velocity may reach sonic conditions
  - Occurs prior to the pitch point
  - Dependent on geometry and speed
- Axial discharge then suction during meshing cycle
  - Volumetric compression followed by expansion
- Jetting
  - Axial discharge due to air/oil compression
  - Possible sonic conditions
  - Narrow faced- gears
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End Velocity Calculation

- Conservation of mass
- Control volumes described at times $t_1$ and $t_2$
- End velocity, $v_e$, as a function of volume, density, area, surface speed, gear radius
The pocketing power loss due to axial jetting varies with the end velocity cubed and for high pitch line velocities, the end velocity can approach the speed of sound.
Pocketing Power Loss Calculation

- Conservation of momentum
- $P_{\text{windage}} = P_{\text{pumping}} + P_{\text{drag}}$
- $P_{\text{drag}} \rightarrow P_{\text{drag1}}, P_{\text{drag2}}$
- $P_{\text{pumping}} \rightarrow P_{\text{ends}}, P_{\text{backlash}}$
Meshed Spur Gear Windage Losses at 25,000 ft./min. pitch-line velocity

Unshrouded configuration

- Unaccounted Windage: 30%
- Drive Gear Drag: 18%
- Driven Gear Drag: 21%
- Backlash Pocketing: 14%
- End Pocketing: 17%

Min. axial, min. radial shroud configuration

- Unaccounted Windage: 41%
- Drive Gear Drag: 11%
- Driven Gear Drag: 13%
- Backlash Pocketing: 16%
- End Pocketing: 19%
Additional windage terms to investigate

\[ P_{\text{windage}} = P_{\text{pumping}} + P_{\text{drag}} \]

\[ P_{\text{drag}} \rightarrow P_{\text{drag1}}, P_{\text{drag2}}, P_{d12} \]

\[ P_{\text{pumping}} \rightarrow P_{\text{ends}}, P_{\text{backlash}}, P_{s} \]


Shroud Guidelines

• Applicable for pitch-line velocities greater than 10,000 ft/min.

• Avoid recirculation of the air/oil mixture in the meshing region.

• For spur gears, allow for a means of the fluid flow to exit the meshing region in the axial direction.

• Allow lubricant to cool, lubricate, and quickly exit the meshing region
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Results: Modified Shroud Test

- Small axial, small radial: 13%
- Large axial, small radial: 28%
- Unshrouded: 38%

![Graph showing windage power loss vs. pitch-line velocity with different shroud configurations and their respective percentages.](image-url)
Conclusions

• Windage power losses (WPL) affect gearbox efficiency and rotorcraft performance

• Shrouding has been shown to reduce WPL

• Meshed spur gear axial jetting (near sonic conditions) are an additional source of WPL

• Analyses indicate additional secondary and drag interaction windage losses on meshed spur gears

• At 25,000 ft/min, the modified shroud test showed a 38% decrease in WPL relative to unshrouded conditions.

• Understanding the component mechanisms of windage power loss is critical for the high speed gear trains of modern rotorcraft applications
Questions?
Appendix
Turbine Helicopter Fleet


Source: JETNET LLC, www.JETNET.com
Input Shaft Location
Further Work

• Quantify pressure and velocity at mesh region
• Explore feasibility of CFD models
• Explore feasibility of flow visualization studies