Extreme Lubrication Past and Present - A Brief Overview of Select Aero Engine Research at the NASA Glenn Research Center

Presented at NATO AVT-188 Specialists Meeting on "Advanced Lubrication Systems for Gas Turbine Engines" Biarritz, France

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OUTLINE

➢ Historical Introduction
➢ Gear (and related) Research
➢ Liquid Lubricants Testing
➢ Solid Lubricants - "Oil Free"
➢ Summary
National Aeronautics and Space Administration

Extreme Lubrication Past and Present - Select Overview of Research at NASA Glenn

Timeline

1943 - Engine lubrication research moves to Cleveland, Ohio, from Langley Field (NACA).
1950s - New Gas Turbine Engine research for higher temp. lubricants, longer life bearings.
1968 - NASA formed, including NACA sites such as the Lewis Flight Propulsion Laboratory.
1960s - Gear & power transmission research starting at NASA Lewis Research Center.
1980s - Three million DN bearing operation demonstrated at NASA in Cleveland.
1980s - Solid lubricant plasma spray coating developed.
1990s - Oil-Free Turbocharger operation at 95,000 RPM demonstrated.
2000s - Nitinol 60 (re)discovered as bearing material. Thrust foil gas bearings improved.
2010s - Next developments?

Structures and Materials Division Research - Supporting a Wide Range of NASA Missions

Multidisciplinary Themes
- Life prediction
- Nanotechnology
- Structural optimization
- Structural dynamics
- Rotodynamics
- Gears and bearings
- Terramechanics
- Tribology
- Seals
- Adaptive structures
- More electric power and propulsion

Core Capabilities
- High temperature alloy
- High temperature structure and materials
- High temp. reaction
- Protective coatings
- Mechanics of materials
- Smart materials
- Ceramics
- Polymers
- Composites
- High temp. reaction
- Protective coatings
- Mechanics of materials
- Life prediction
- Nanotechnology
- Structural optimization
- Structural dynamics
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Tribology & Mechanical Components Branch

Aerospace Seals Research

- Heat Shield Interface Seal
- Docking Seal
  - Space habitat seals for extreme environments
  - Structural / thermal protection seals
  - Non-contacting turbine seals

Advanced Bearing Technologies

- From basic research to application
- Advanced bearing materials
- Foil bearing modeling methods
- Foil bearing predictive design for space and aero applications
- Rolling element modeling methods

Space Mechanisms & Lubrication

- Terramechanics modeling & testing for low-g mobility
- Novel wheel design for harsh, non-terrestrial surfaces
- Accelerated space lubricant life testing under vacuum
- New mechanism concepts for extreme environments

Aero Drive Systems

- High speed gear lubrication & dynamics
- Drive system health monitoring
- Gear fatigue research
- Fatigue crack modeling
- Rotorcraft transmission systems - efficiency and novel designs

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Gear Lubrication Related Research Goals

• Improve normal operational efficiency of high speed gearboxes for aviation applications

• Improve loss-of-lubrication capability through development of emergency lubrication systems / methods that can extend the time of operation while reducing weight / complexity of these emergency systems

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Gear Windage Test Facility

Facility Capabilities:

• Pitch line velocity to 55,000 ft/min (280 m/s)
• Single or meshing gears (parallel axis)
• Adjustable shrouding
Parasitic Losses in High Speed Gears

High Speed Helical Gear Train
(15000 RPM Input Speed)

Test Results: Shroud and No Shroud

Results for a single 13 inch pitch diameter gear, 1.12 inch face width
Loss-of-Lubrication (LOL) Research

- Thirty minutes of operation after primary lubrication system failure is a qualification requirement for rotorcraft
- High speed and/or load can lead to lubricant starvation conditions
- Lubrication starvation causes high friction, high heat generation, tooth profile wear, and eventual tooth failure due to loss of load carrying capability
Typical Post-Test Condition (Failed Gear)

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Spiral Orbit Tribometry (SOT) provides a rolling tribology test using minimal lubricant that experiences a slight scrub against a guide plate once per revolution. SOT mimics instrument ball bearings very well and is used to evaluate materials / lubricants. Tests can be run in vacuum to simulate the space environment in boundary lubrication.

Comparative SOT Results - Lubricants

Using 440C balls running against 440C plates, ionic liquid exhibits nearly comparable friction and lifetime to Pennzane in the SOT test.
60NiTi: Grade 5 test balls

The ability to achieve required roundness and surface finish in NiTi is predicated upon isotropic mechanical-physical properties of the ball blank (provided by the Abbott process).

NASA Spiral Orbit Tribometer (SOT) Life Comparison

Test Conditions: Vacuum 2x10^-8 Torr, .5" diameter balls running on 440C steel plates, Hertz pressure 1.5 Gpa, Lubricant charge about 20 micrograms Pennzane, Ball orbit speed 30 orbits per minute
Technical Opportunity:
(NITINOL 60 - a newly rediscovered alloy)

- Why bother with 60NiTi?
  - Excellent mechanical and physical properties (hard, strong and tough, lightweight, very smooth surface finish)
  - Excellent chemical properties (corrosion "proof")
  - Impressive tribological properties (compares well to 440C even using conventional lubricants and w/o alloying additions)
  - Electrical conductor and non-magnetic (good for sensitive instruments and electrical machines)
  - Fairly easy to manufacture into complex shapes and components (bearing balls and races, rollers, gears etc.)
  - Only alloy known to possess all of these attributes.

Damage Threshold Load Capacity
(1/2" Diameter ball pressed into plate)

Low modulus + high hardness + superelasticity = extreme load capacity
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Enabling Technology: High-Temperature Solid Lubricant Coating

- Provide start/stop wear protection for foil bearings
- Operate from cold start to 850°C
- No vaporization or emissions

NASA PS304 US Patent No. 5,866,518

- 60% NiCr
- 20% Cr$_2$O$_3$
- 10% BaF$_2$/CaF$_2$
- + 10% Ag

Binder
Hardener
Hi-Temp Lube
Low-Temp Lube

= Wide temperature spectrum solid lubricant coating, for either aero or space applications
Extreme Lubrication Past and Present
Oil-Free Turbomachinery

CAD Foil air bearings

PS304
For cryogenic to 800°C sliding contacts

PM304 bushings for industrial furnaces and valves

Tech Maturation

Oil-Free enabling technologies

PM304 bushings for industrial furnaces and valves

Oil-Free Turbomachinery Research at GRC

Key Facilities & Capabilities
One of a kind - Critical to technology validation to TRL 6+

Hot, high speed journal foil bearing test rig

Rotordynamic simulator facility

Ambient pressure test rig (altitude simulation)

Hot, high-speed thrust foil bearing test rig

Coating deposition research facility

High pressure test rig (700 psig chamber)

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Oil-Free Turbomachinery

Technology Benefits
- Self-acting hydrodynamic bearings
- Low friction
- No lubricant system
- No DN limit
- Operate up to 1200 F
- No maintenance
- Accommodate distortion & misalignment

Technical Expertise/Capabilities
- High-speed rotating equipment
- Rotor/Bearing analysis
- Bearing testing (70 krpm, 1400°F, start/stop cycle: load capacity, power loss, stiffness & damping)

Applications
- Current: Oil-free turbochargers (Caterpillar, Schaeffler, MTU)
- Future: Turbo generators/pumps
  Auxiliary power units
  Gas turbine engines

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Aeronautics & Space Drive Systems Synergy

Space Drive Systems
- Ultra-Low Temperature
- Vacuum Compatible
- Radiation Resistant

Aero Drive Systems
- High Durability
- High Power Density
- Multi-Speed Capability
- Condition Based Maintenance
- High Efficiency
- Lightweight

Drive Systems for Future Planetary Rovers
Drive Systems for Future Heavy Lift Rotorcraft
Drive Systems Used in Shuttle Actuators Return To Flight Support
Drive Systems to Increase Capabilities of Military and Civilian Rotorcraft

OCT Surface Mobility
OCT Low Temp Mech
OCT & NESC Mech
FA - RW Propulsion
US Army Programs

Thank-you for your attention!