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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

October 17, 2012

By Phillip Abel

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

OUTLINE

- Historical Introduction
- Gear (and related) Research
- Liquid Lubricants Testing
- Solid Lubricants - "Oil Free"
- Summary

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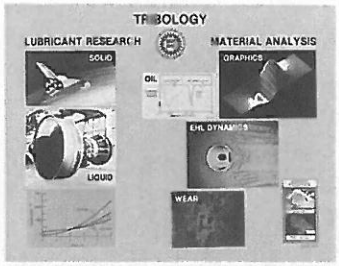
Extreme Lubrication Past and Present - Select Overview of Research at NASA Glenn



Mechanical Components Branch - 1979

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.

1958 - 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. 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?

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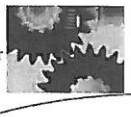
Structures and Materials Division Research - Supporting a Wide Range of NASA Missions

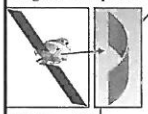
High temperature and lightweight gas turbine engine components



Variable speed transmission for large tiltrotor

Inflatable structure Mars entry, descent, and landing

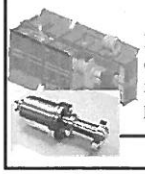
Ultra high temperature material and integrated TPS for reusable hypersonic vehicles



Lightweight radiators for crew exploration vehicle (CEV)

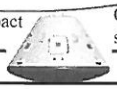
Superconducting motor for turbo-electrics

Large composite structure for Ares V vehicle



Durable components radioisotope power system

CEV low impact docking seal



CEV heat shield seal

Long life lunar wheel / mech.

Multidisciplinary Themes

Core Capabilities

High temperature alloy	Life prediction
Smart materials	Nanotechnology
Ceramics	Structural optimization
Polymers	Structural dynamics
Composites	Rotordynamics
High temp. reaction	Gears and bearings
Protective coatings	Terramechanics
Mechanics of materials	Tribology
	Seals

High temperature structure and materials

Multifunctional structures

Long life mechanical system

Adaptive structures

More electric power and propulsion

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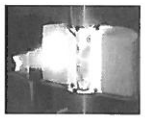
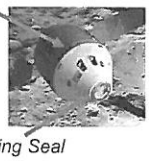
Tribology & Mechanical Components Branch

Aerospace Seals Research

Heat Shield Interface Seal





Docking Seal

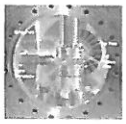
- Space habitat seals for extreme environments
- Structural / thermal protection seals
- Non-contacting turbine seals

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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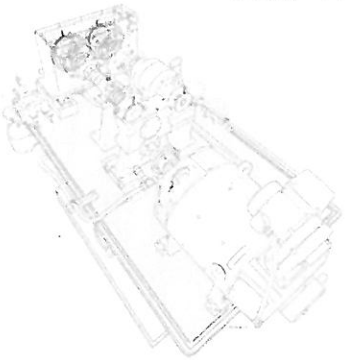
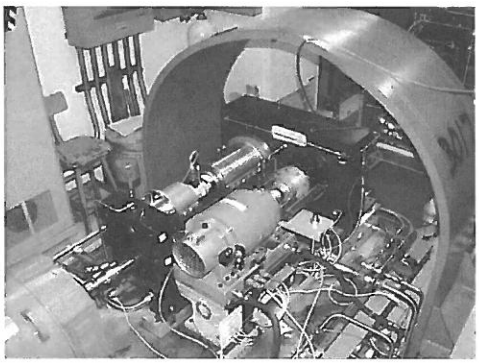
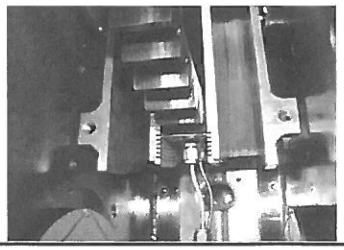
Gear Windage Test Facility







Facility Capabilities:

- **Pitch line velocity to 55,000 ft/min (280 m/s)**
- **Single or meshing gears (parallel axis)**
- **Adjustable shrouding**

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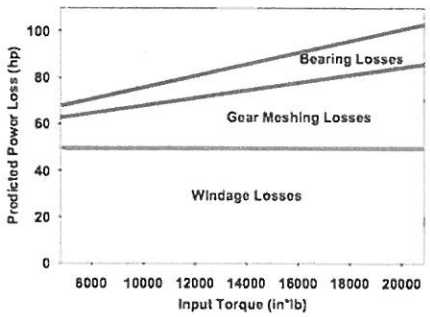
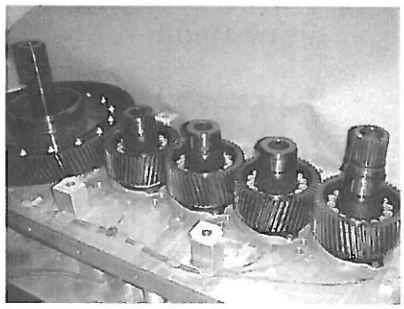
Parasitic Losses in High Speed Gears

High Speed Helical Gear Train
(15000 RPM Input Speed)





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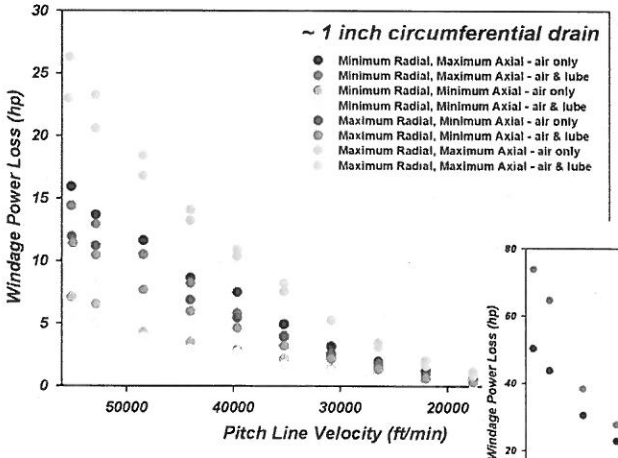
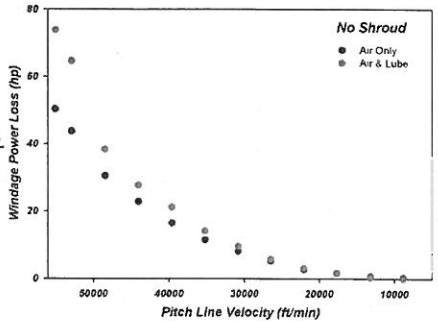
Test Results: Shroud and No Shroud





Results for a single 13 inch pitch diameter gear, 1.12 inch face width

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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

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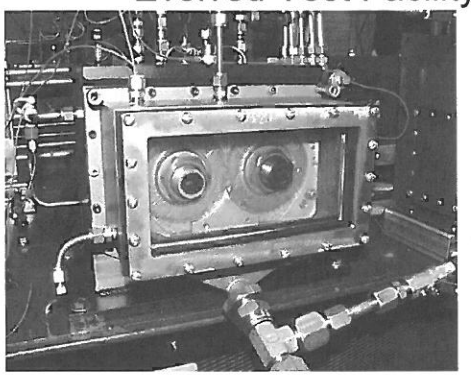
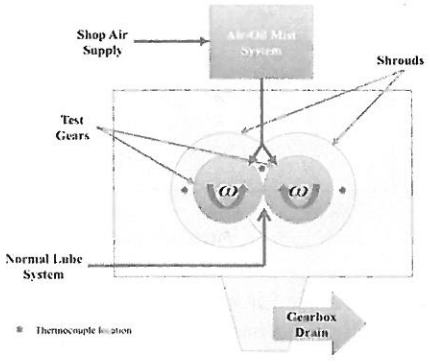
Evolved Test Facility for LOL Operation





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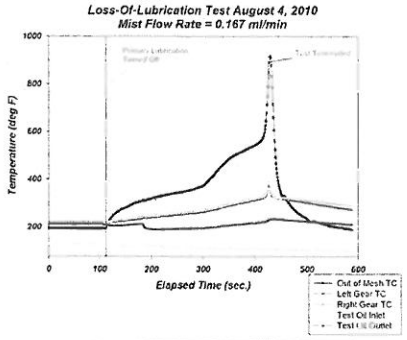
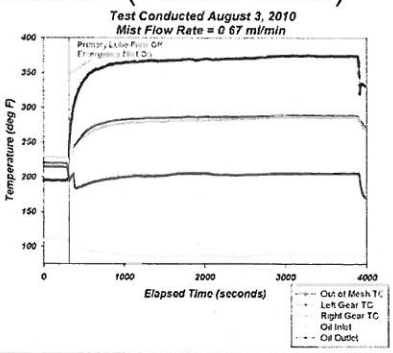
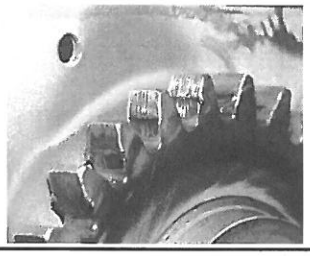
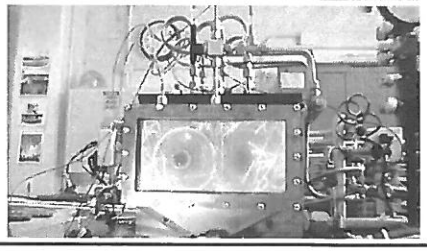
Typical Post-Test Condition (Failed Gear)









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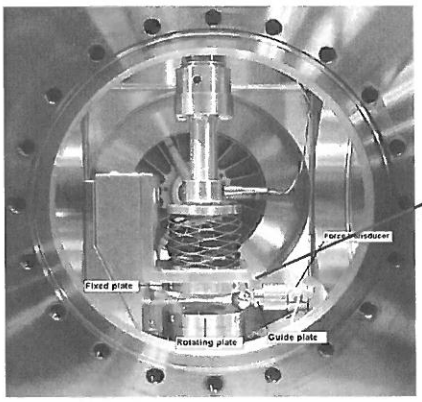
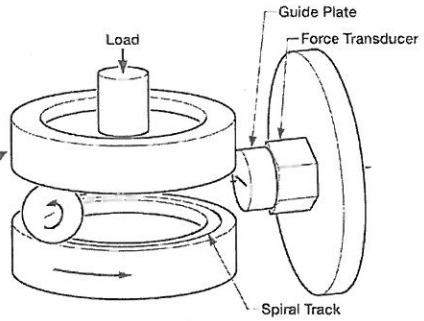
Spiral Orbit Tribometer Test Rig





Specimen configuration

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.

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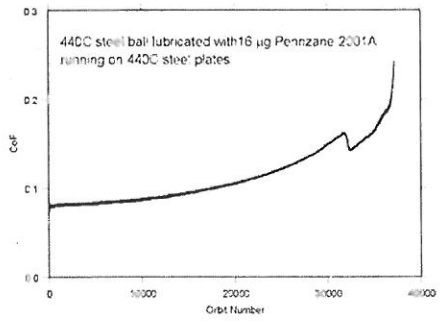
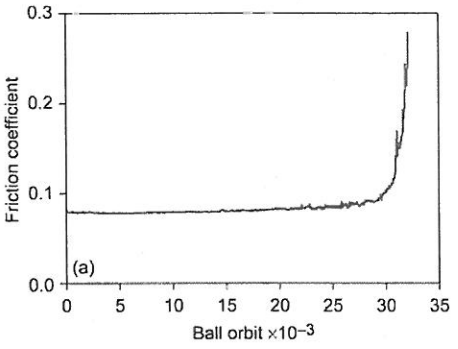
Comparative SOT Results - Lubricants





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

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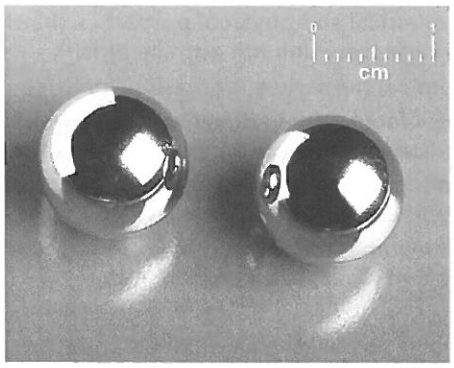
60NiTi: Grade 5 test balls



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).

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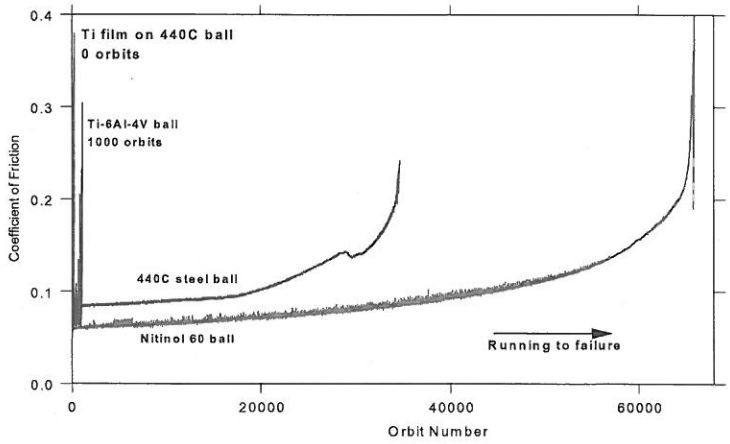
NASA Spiral Orbit Tribometer (SOT) Life Comparison



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

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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.**

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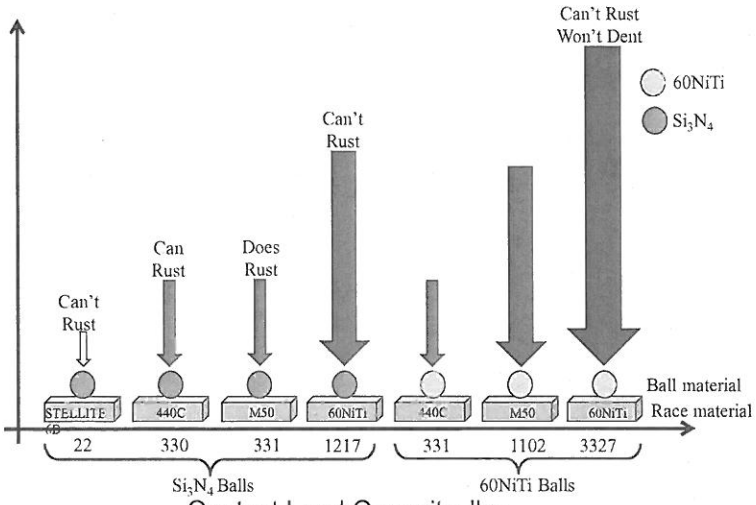
Damage Threshold Load Capacity
(1/2" Diameter ball pressed into plate)

Indent test



Contact Load Capacity, lbs.

Low modulus + high hardness + superelasticity = extreme load capacity

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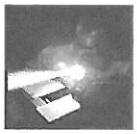
Extreme Lubrication Past and Present

Enabling Technology: <u>High-Temperature Solid Lubricant Coating</u>

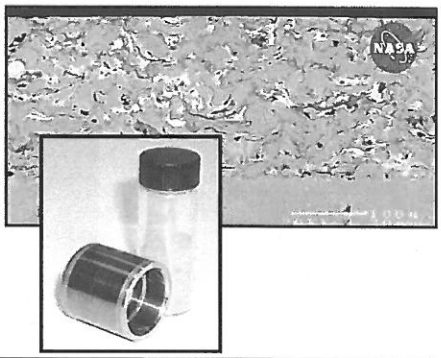


- **Provide start/stop wear protection for foil bearings**
- **Operate from cold start to 850°C**
- **No vaporization or emissions**

<u>NASA PS304</u> *US Patent No. 5,866,518*

60% NiCr	Binder
20% Cr_2O_3	Hardener
10% BaF_2/CaF_2	Hi-Temp Lube
+ 10% Ag	Low-Temp Lube

= Wide temperature spectrum solid lubricant coating, for either aero or space applications



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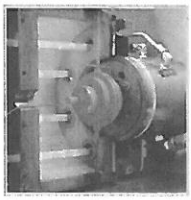
Extreme Lubrication Past and Present

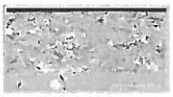
Oil-Free Turbomachinery

CAD

Foil air bearings



Tech Maturation

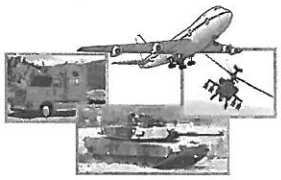


PS304

For cryogenic to 800C sliding contacts

Oil-Free enabling technologies

PM304 bushings for industrial furnaces and valves



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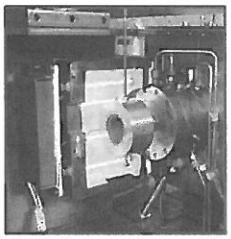
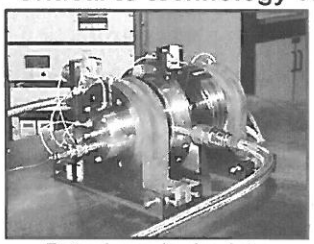
Oil-Free Turbomachinery Research at GRC

Key Facilities & Capabilities

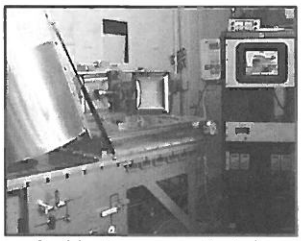
One of a kind - Critical to technology validation to TRL 6+



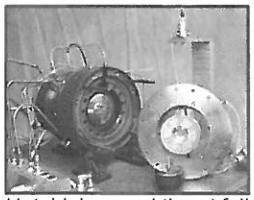
Hot, high speed journal foil bearing test rig



Rotordynamic simulator facility

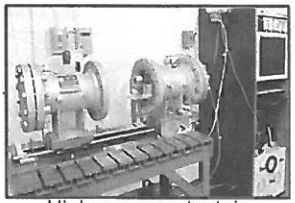


Ambient pressure test rig (altitude simulation)



Hot, high-speed thrust foil bearing test rig

Coating deposition research facility



High pressure test rig (700 psig chamber)

R/N Oil-Free Turbomachinery 1-30-09

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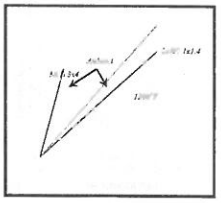
Oil-Free Turbomachinery



Technology Benefits

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

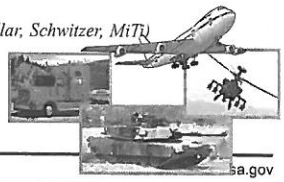
Technical Expertise/Capabilities

- 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, Schwitzer, MiTi)*
- Future: Turbo generators/pumps
  Auxiliary power units
  Gas turbine engines



Compliant Foil Bearings for Oil-Free Turbomachinery

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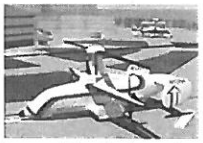
Aeronautics & Space Drive Systems Synergy

Drive Systems for Future Planetary Rovers

Space Drive Systems

Aero Drive Systems



Drive Systems for Future Heavy Lift Rotorcraft

Ultra-Low Temperature

Vacuum Compatible

Radiation Resistant

High Durability

High Power Density

Multi-Speed Capability

Condition Based Maintenance

High Efficiency

Lubricant Free

Lightweight

High Power

Minimal Windage Losses

Drive Systems Technologies Used in Shuttle Actuators Return To Flight Support

Drive Systems Technologies to Increase Capabilities of Military and Civilian Rotorcraft

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

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Thank-you for your attention!

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