Drive System Research
NASA Glenn Research Center
Cleveland, Ohio, U.S.A.

by
Dr. Robert F. Handschuh

Abstract

An overview of the NASA Glenn Research Center Drive Systems Research will be presented. The primary purpose of this research is to improve performance, reliability, and integrity of aerospace drive systems and space mechanisms. The research is conducted through a combination of in-house, academia, and through contractors. Research is conducted through computer code development and validated through component and system testing. The drive system activity currently has four major thrust areas including: thermal behavior of high speed gearing, health and usage monitoring, advanced components, and space mechanisms.

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Drive Systems Team Lead

Topics

- Drives Team background, objectives, and approach
- Thermal behavior / loss-of-lube operation of high-speed helical gear trains
- Gear crack propagation
- Health and Usage Monitoring Systems (HUMS)
- Advance component research: noise, wave bearings, superfinishing, & gear geometry
- New capability development
- Space mechanisms / RSB actuator activities
- Summary

Drive System Research at NASA GRC

Drive System Team Objectives:

Perform research and development in mechanical component and systems technologies to improve the performance, reliability, and integrity of aerospace drive systems and space mechanisms.

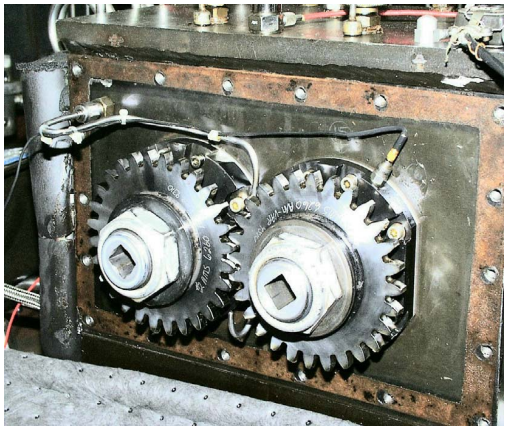
Approach:

- Experimental facilities
- Analytical model development
- Industry cooperative projects
- University grants
- Other government agency projects

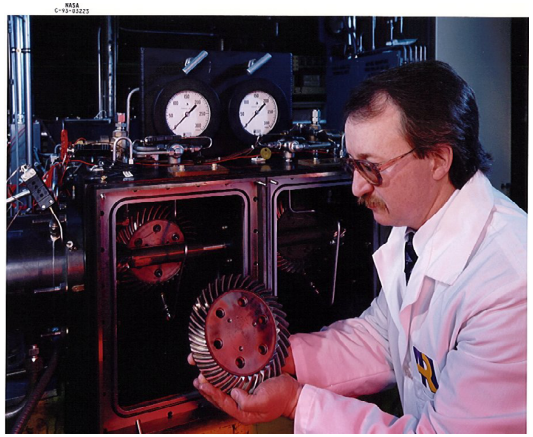
Funding:

- NASA Focus Programs (RC / UEET)
- Code T work
- Other government agencies (Army, NRTC,…)

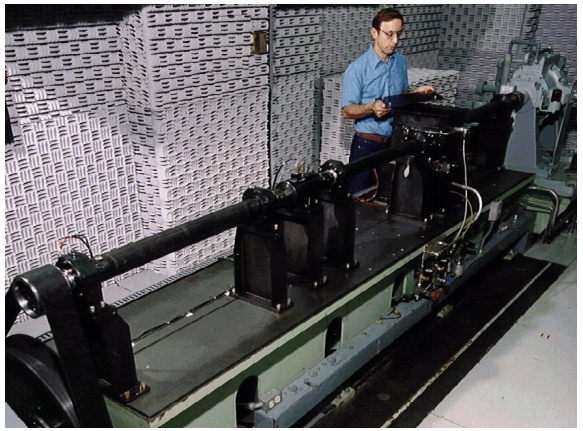
NASA GRC Drive System Facilities



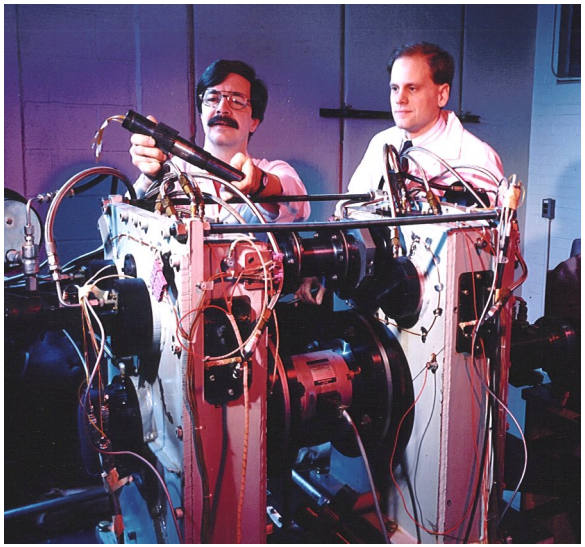
Spur Gear Fatigue Test Rigs



Spiral Bevel Fatigue Test Facilities

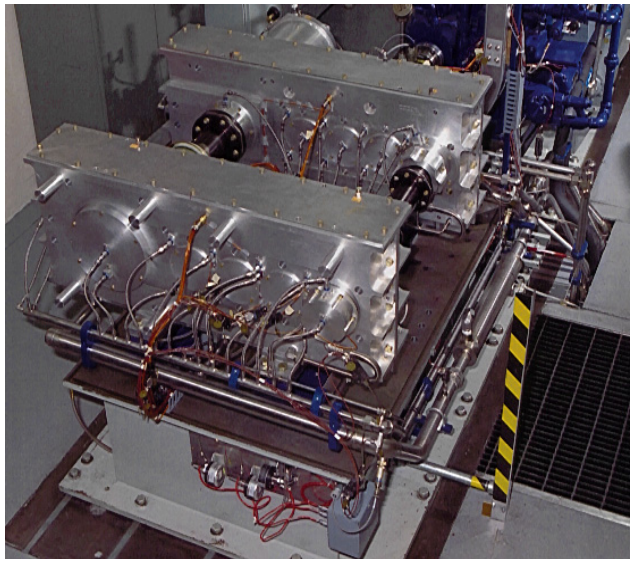


Gear Noise / Dynamics Test Facility



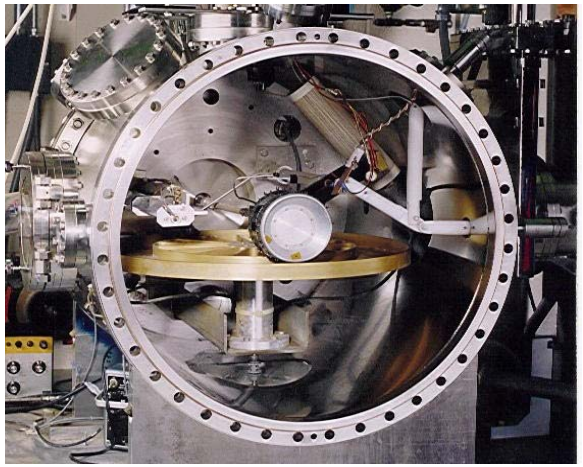
Planetary Test Facility

OH-58 Transmission Test Facility

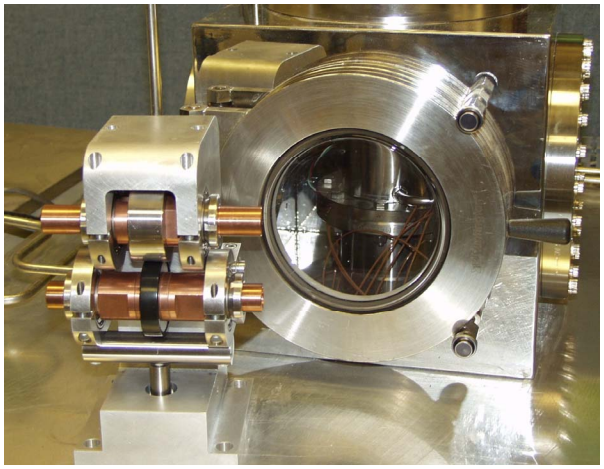


High Speed Helical Gear Train Test Facility

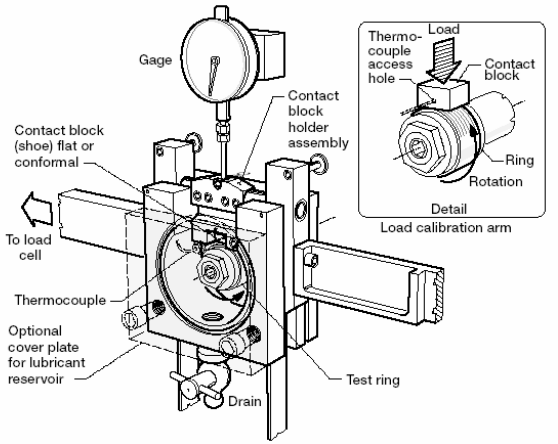
NASA GRC Space Mechanisms Facilities



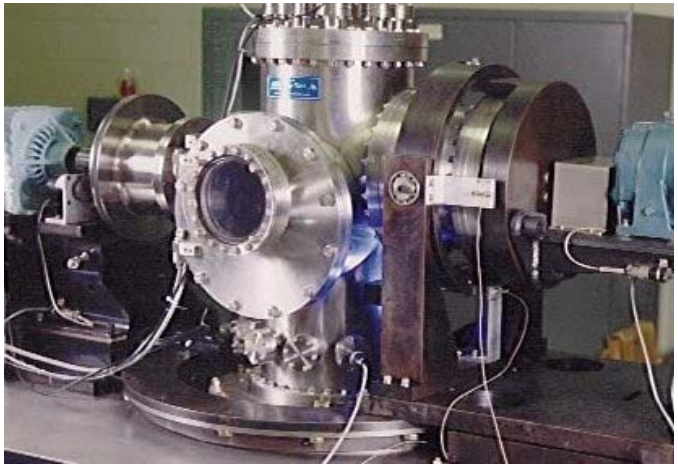
Environmental Rig



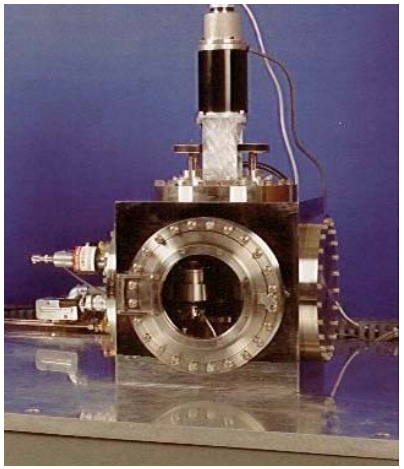
Roller Drive Rig



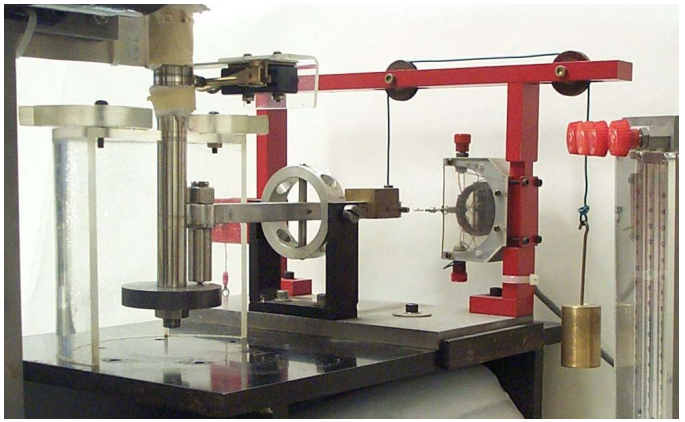
Block on Ring Rig



Variable Slide Ratio Rig



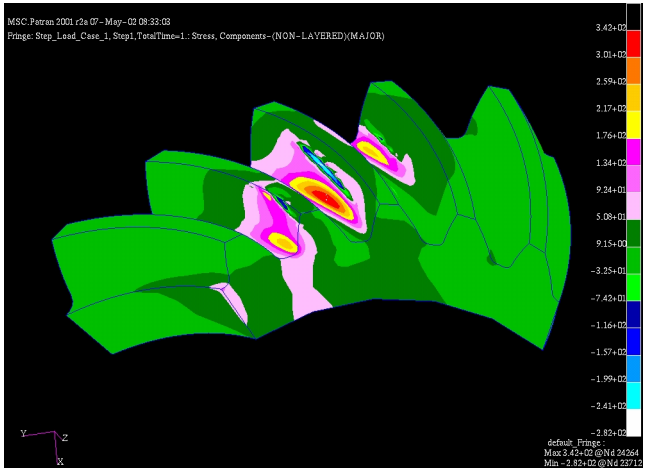
Vacuum Bearing Rig



Pin-on-Disk Tribometer

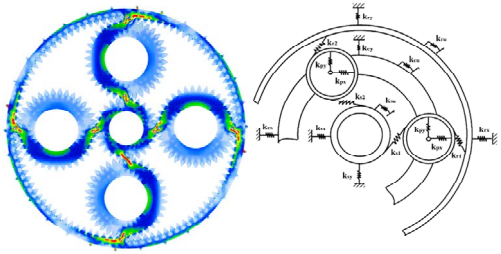
NASA GRC Analytical Capabilities

Finite Element Based
Structural - Thermal



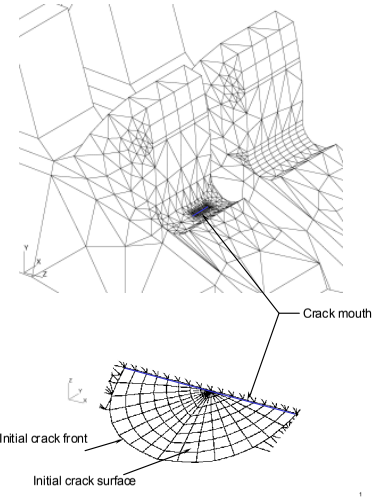
Helical Gear Dynamics

Planetary Gear Dynamics

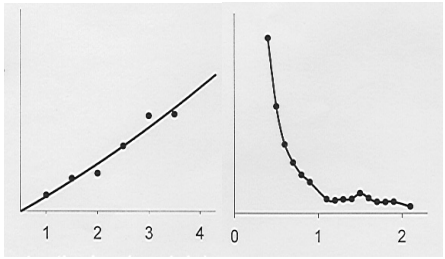


Physics-Based Models

Fracture Mechanics - BEM



Gear Noise



Tooth Size (Module) Face Contact Ratio

Drive System Thermal Management Activities

Objective:

Develop an understanding of the thermal behavior of high speed gear systems operating in normal and emergency conditions that include loss-of-lubrication.

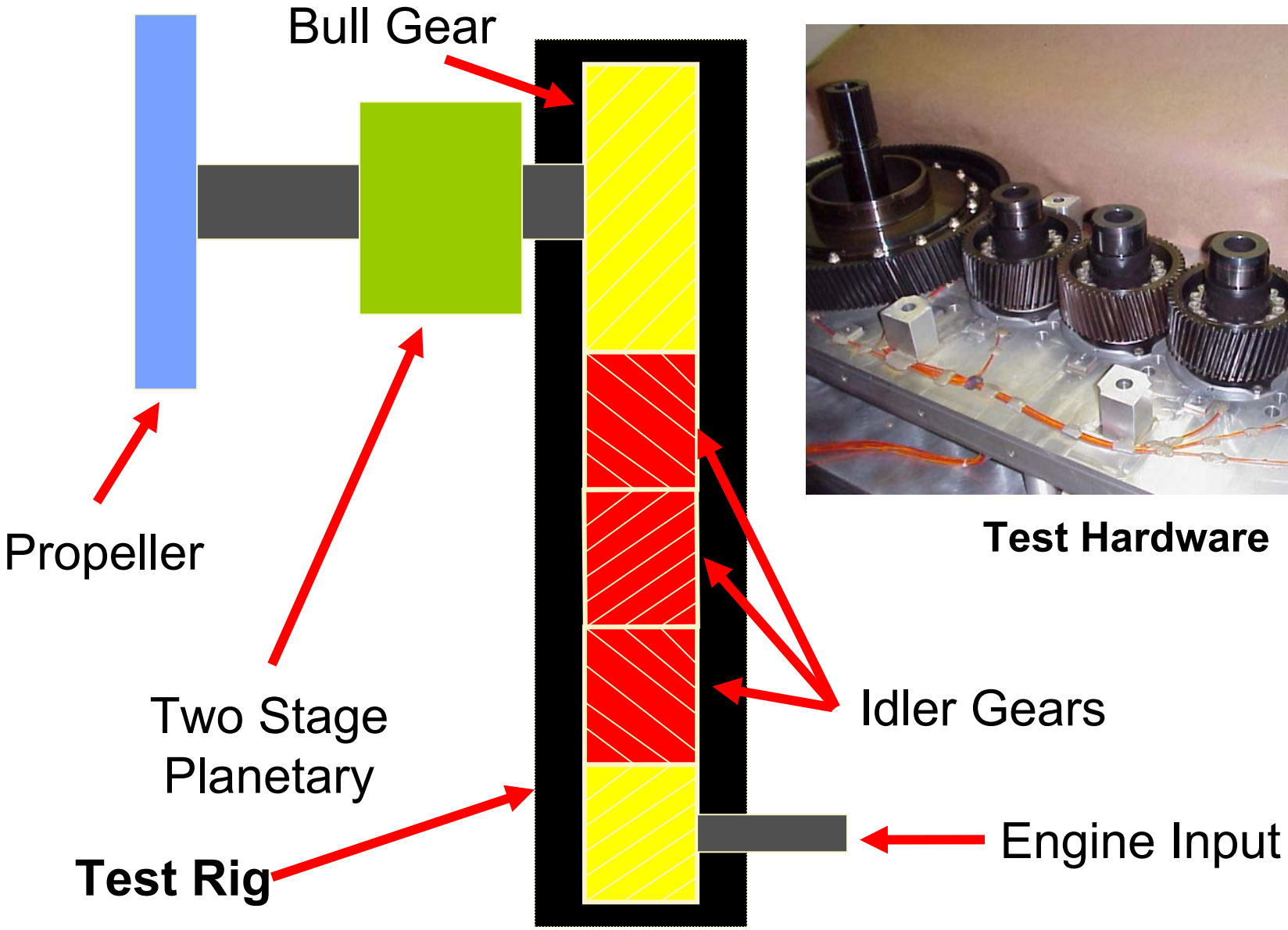
Approach:

- Cooperative project with Bell Helicopter
- NASA GRC conducting full scale / component tests
- NRTC funded activity for “Lubrication Model for High-Speed Transmission Components”

Status:

- Facility operational
- Currently testing baseline design

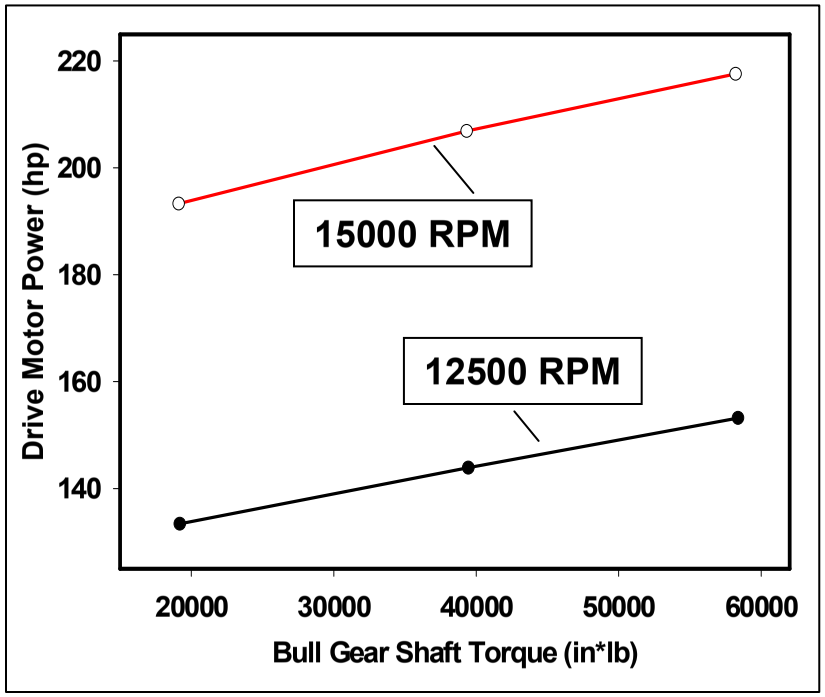
High Speed Helical Gear Train



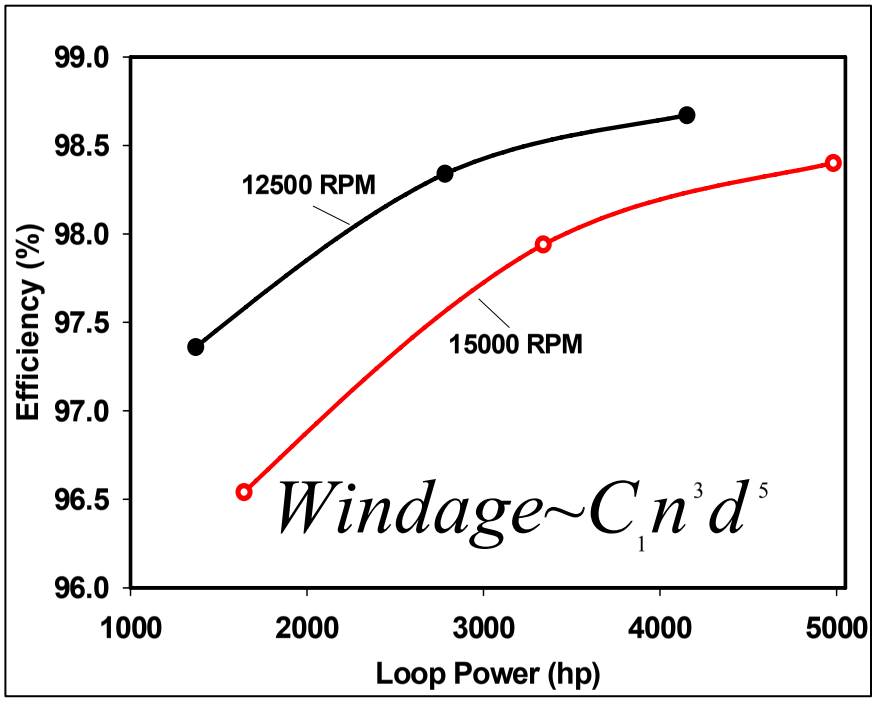
Test Hardware

High Speed Helical Gear Train
Recent Results

Effect of Shaft Speed at High Torque



Efficiency Prediction at High Speed and Load



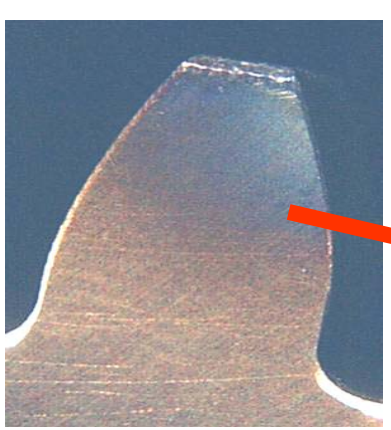
Loss-of-Lubrication Component Activity

Objective / Approach:

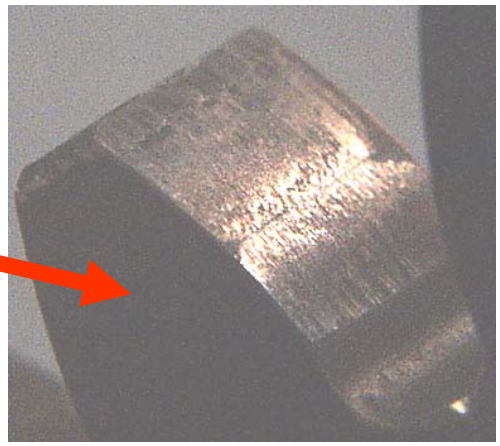
Utilize fatigue specimen to conduct screening tests for loss-of-lubrication performance enhancement tests.

Status:

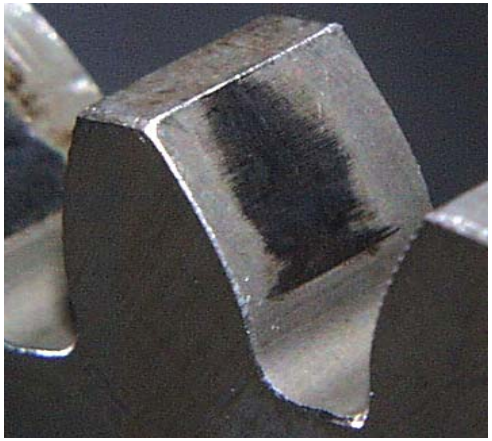
- Completed baseline testing using a synthetic liquid lubricant.
- Recent testing with new oil-mist lube had minimal wear, low operating temperature, minimal amount of lubricant required (modified polyphenyl ether)



Overheated



Previous SOA Lube



New Oil-Mist Lube

Gear Crack Propagation Investigations

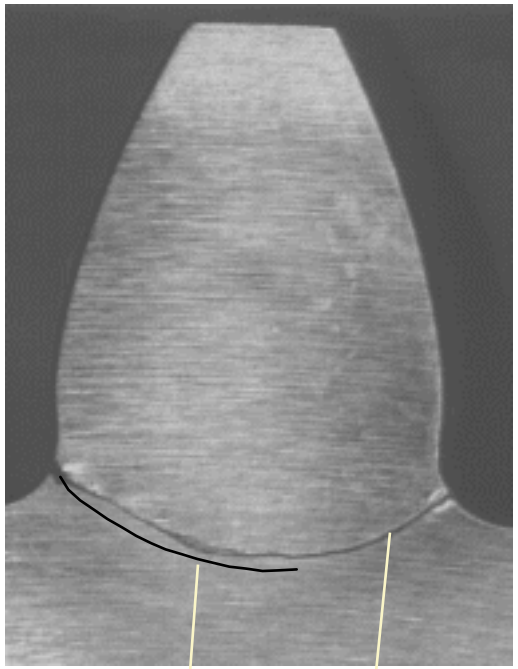
Objective:

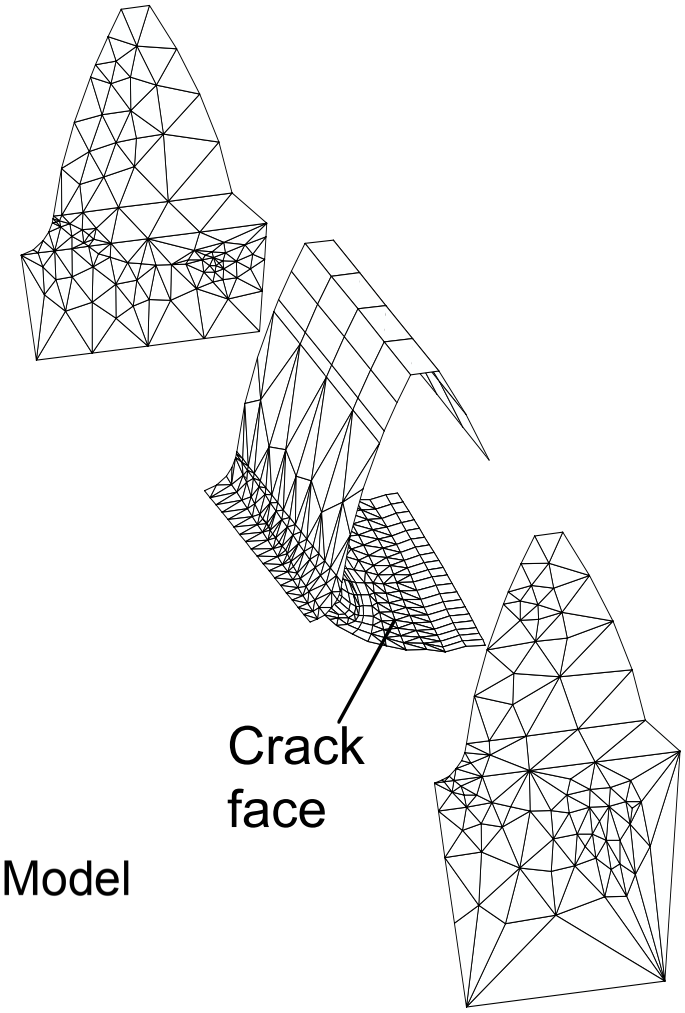
Provide design guidelines for ultra-safe gear design.

Accomplishments / Results:

- The effect of rim thickness on gear crack propagation path using FEA, BEM, & fracture mechanics was investigated.
- Analysis methodology validated by gear experiments.
- Design guidelines have been established to prevent catastrophic rim fracture modes when considering gear tooth bending fatigue.
- Effects of rim and web thickness, initial crack locations, and gear tooth geometry factors such as diametral pitch, number of teeth, pitch radius, and tooth pressure angle were considered.

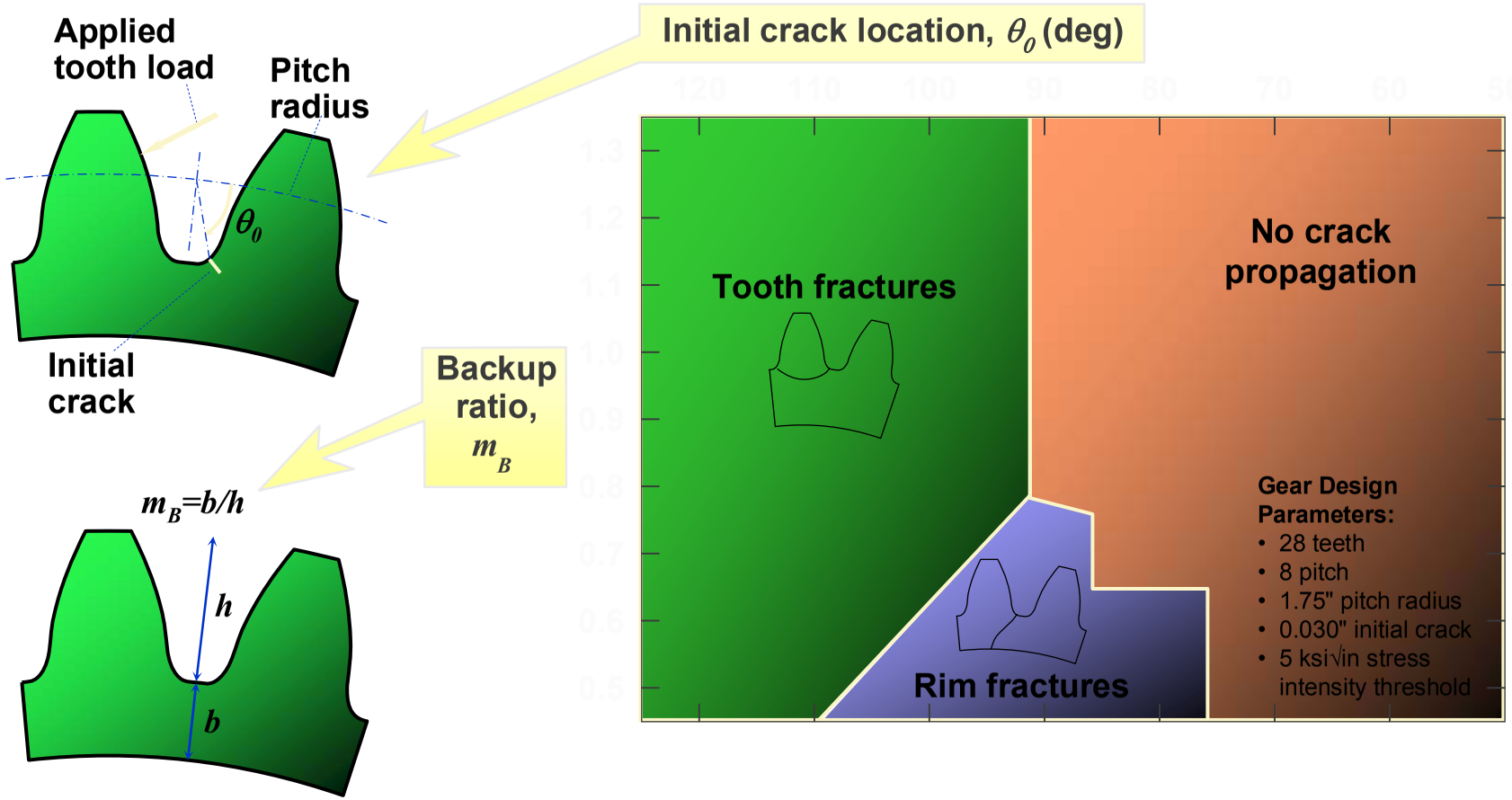
Spur Gear Experiments and 3-D Analytical Model





3-D Model

Gear Crack Propagation Design Map



Drive System Health and Usage Monitoring

Objectives: Increase reliability and decrease false alarms for mechanical component diagnostics. Demonstrate integration of oil debris and vibration based damage detection techniques results in improved capability.

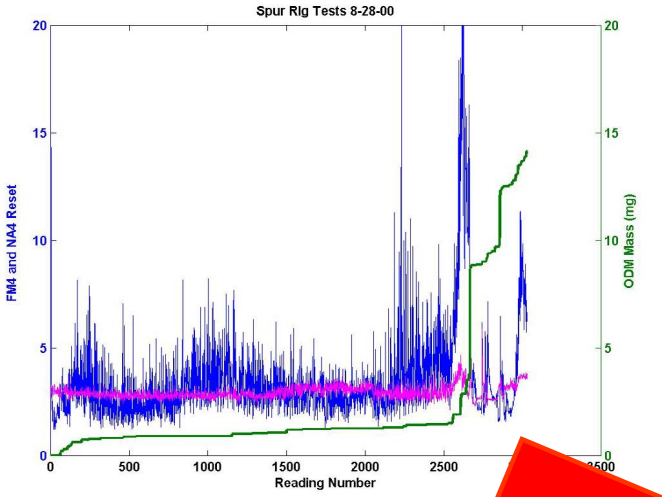
Approach:

Instrument and monitor all GRC gear fatigue test facilities and work with other govt. agencies, university, and industry

Accomplishments / Results:

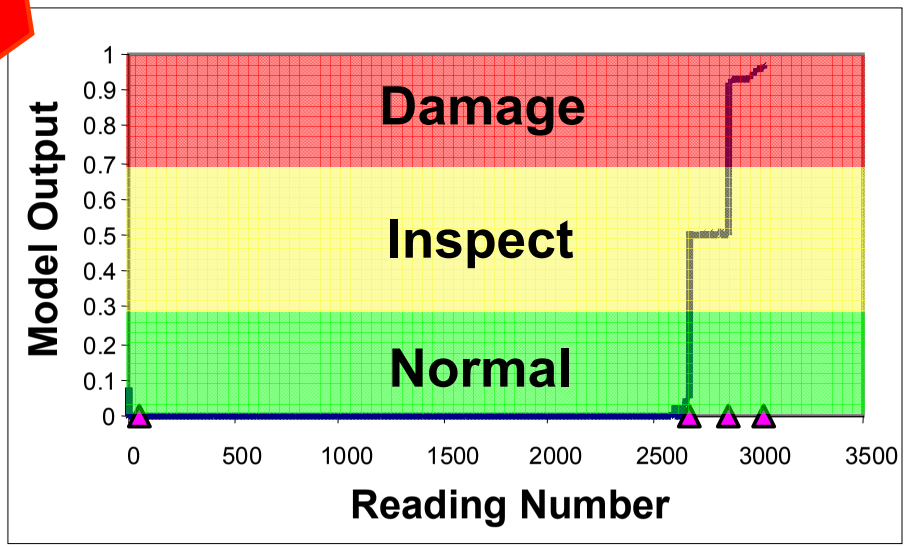
- Preliminary tests show oil debris mass comparable to vibration metrics in detecting pitting damage
- Developed a technique for minimizing the effect of load on vibration techniques
- Applied fuzzy logic analysis techniques to oil debris data to predict transmission health.

Data Fusion Results



Vibration Techniques (FM4,NA4) and Oil Debris

Output of Fuzzy Logic Model



Gear Noise and Vibration

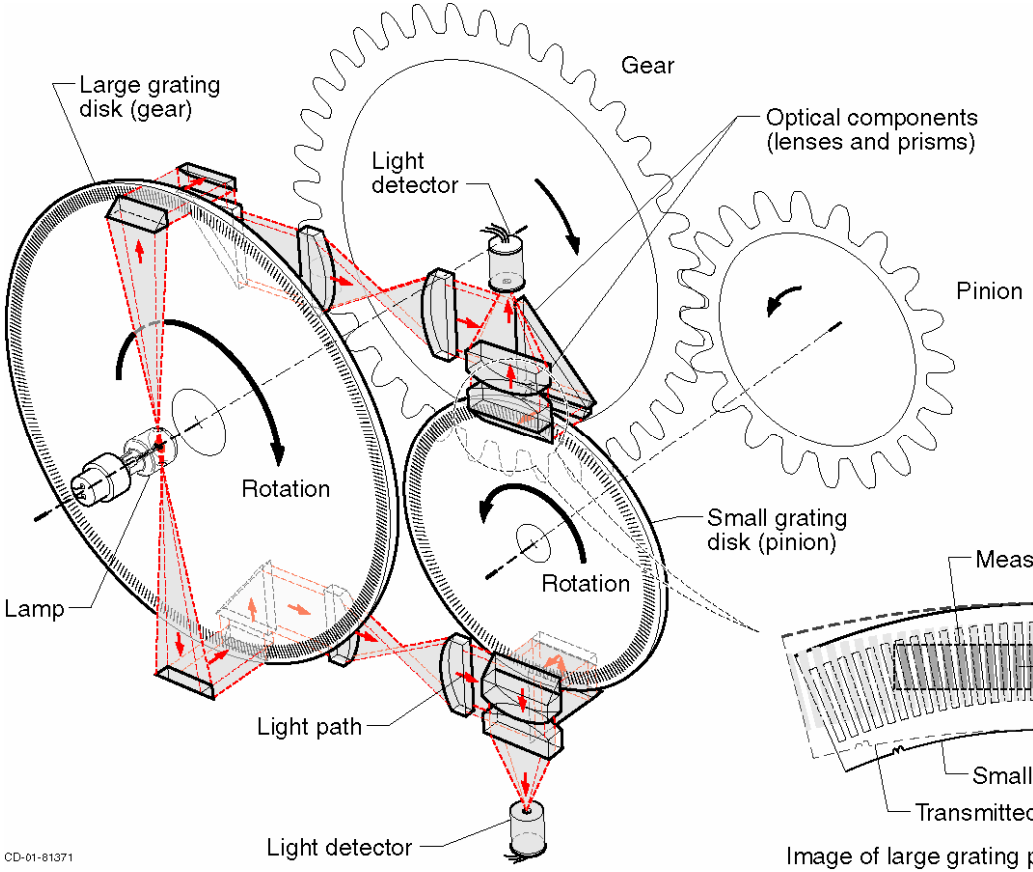
Objective: Develop validated tools and technologies for reduced source noise and vibration.

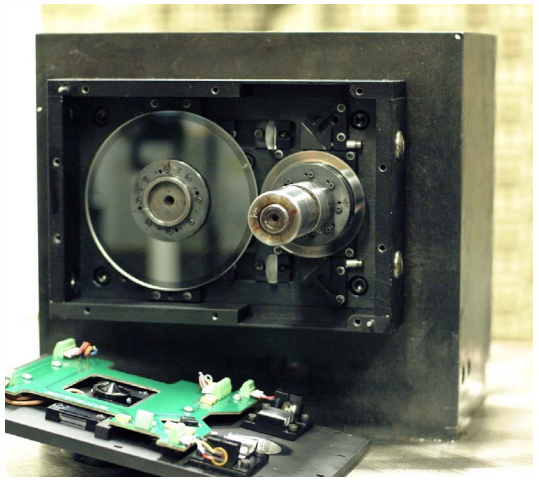
Approach: In-house experimental facility for analytical model validation for noise, vibration and transmission error reduction.

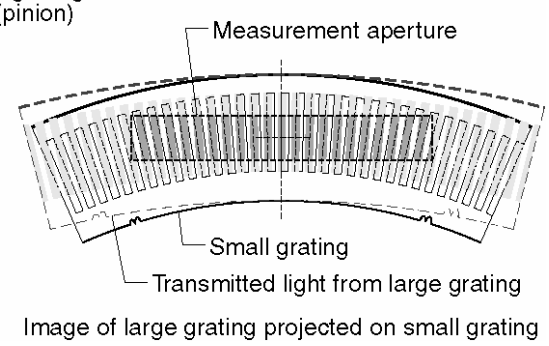
Accomplishments / Plans:

- Gear Noise and Transmission Error test gearbox delivered for GRC test facility
- Collaboration with Ohio State University Gear Dynamics Laboratory
- Other noise reduction technologies designed for use in facility (i.e. Fluid Film Bearings)

Gear Transmission Error Measurement System







Optics and electronics

Capabilities: Measure static and dynamic transmission errors, resolution 0.1 micrometer (4 micro-inch)

Fluid Film - Wave Bearing

Objective: Develop validated model data for high load and high speed applications such as that needed in drive systems in geared turbine engine and advanced power transmission applications

Approach:

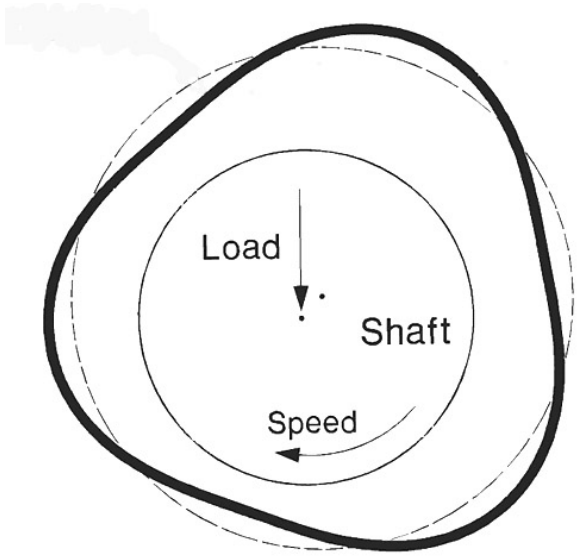
- In-house test facility currently screening coating technology for start – stop performance and starved lubrication operation
- Facility enhancement currently being designed to have capability to test UEET planet bearing at full scale (13000 RPM, 30000#, 68 mm bearing diameter, 82 mm width)

Status / Plans:

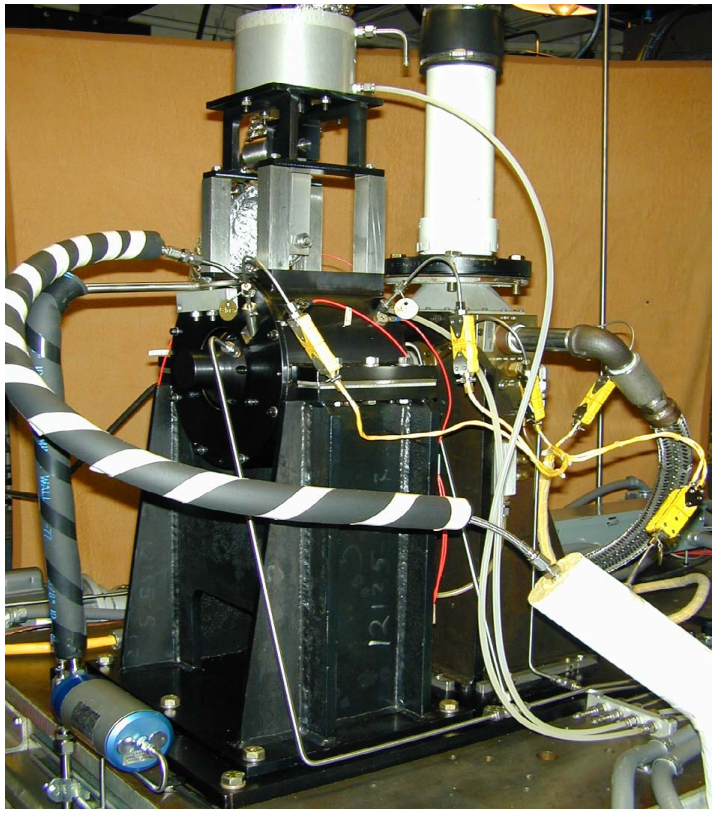
- Demonstrate coating effectiveness (multiple of coating types)
- UEET bearing test operational September 05
- Validated configuration ready for UEET demonstration tests

Wave Bearing Technology

Bearing Concept



Test Facility



- Improved stability and cooling
- Ability to tailor stiffness and damping
- Use of hard sleeves

Surface Enhancement Activities

Objective:

Determine drive system benefits derived from improved surface finish and coating technologies.

Approach:

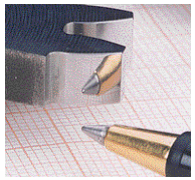
- University of Cardiff (Wales, UK) conducted roller tests / superfinish gear specimen
- NASA GRC conducted gear fatigue tests

Status:

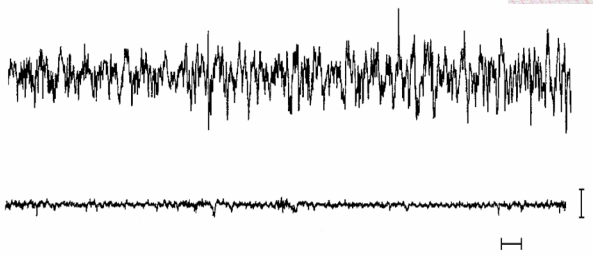
- Testing completed at GRC, report published

Gear Performance - Superfinishing

1 Surface Finish Improved

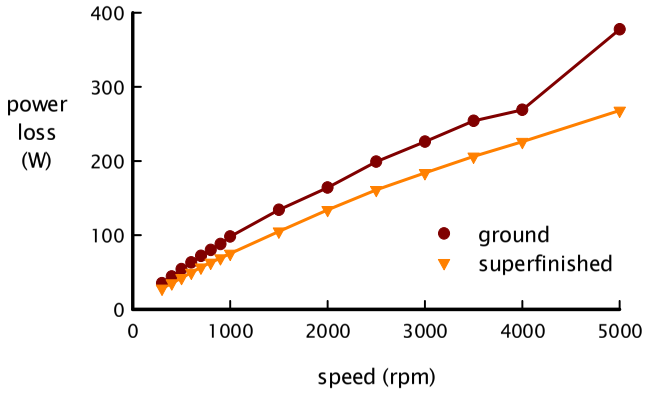


ground

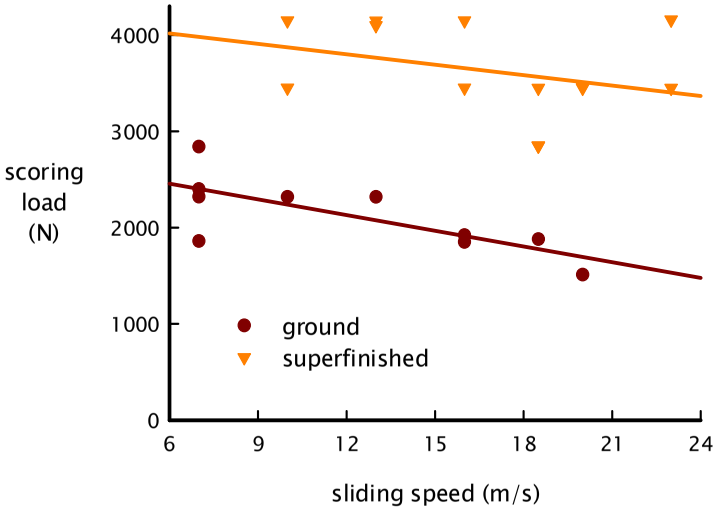


superfinished

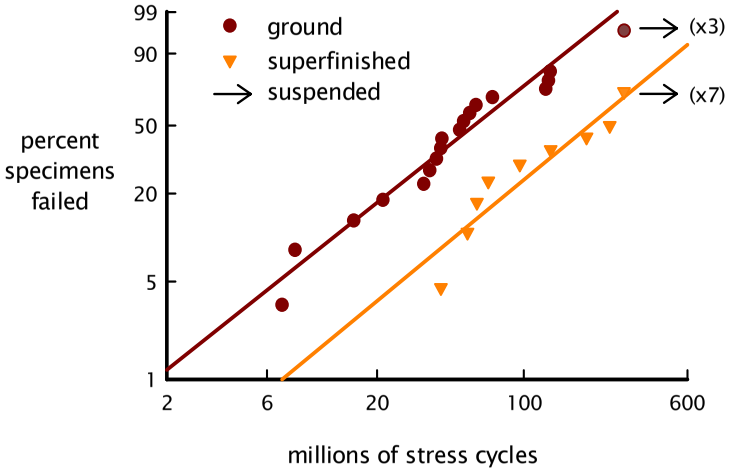
2 Power Loss Reduced



3 Scoring Load Increased



4 Surface Fatigue Life Increased



Advanced Gear Geometry

Objective:

Investigate gear geometry configurations to increase drive system ratio without sacrificing gear performance.

Approach:

- Multi-year effort at the University of Illinois at Chicago
- Dr. Faydor Litvin, Principal Investigator, world renowned gear geometry theoretician

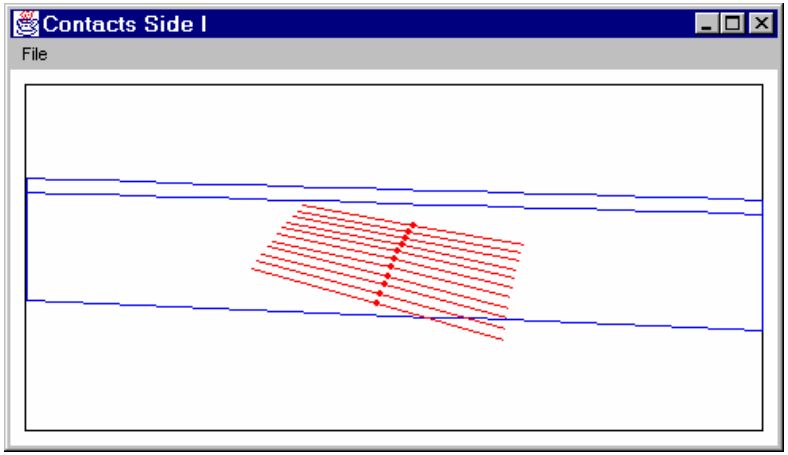
Status:

- Currently in the third year of grant effort
- Many NASA Technical Reports / Journal Articles in the publication process

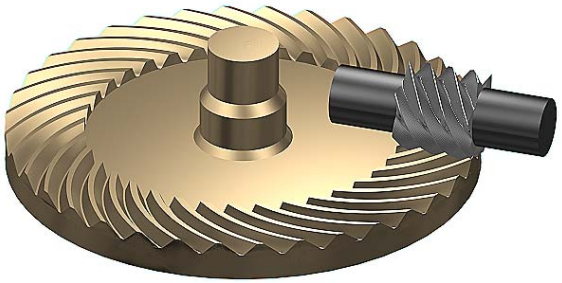
Advanced Gear Geometry

Analysis Methodology:

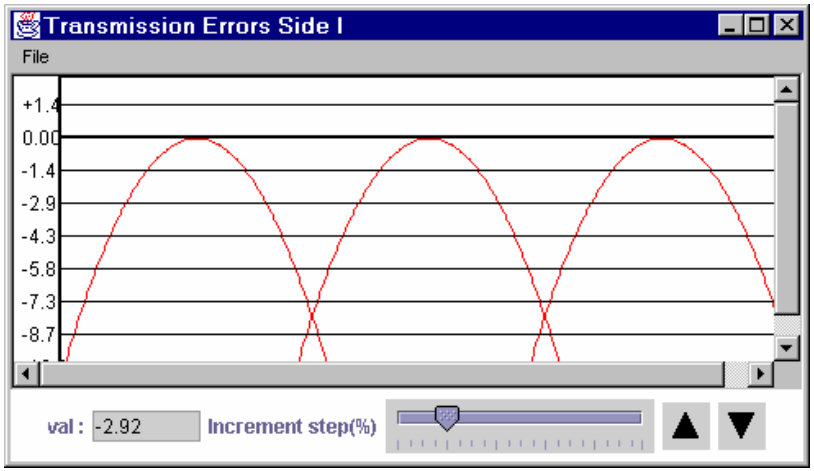
- Differential geometry used to describe the surfaces in 3-D
- Tooth contact analysis performed using the theoretical surfaces
- 3-D finite element models for stress analysis produced using these surfaces



Contact Path Prediction



Advanced Hybrid Gear Arrangement



Transmission Error Curves

New Testing Capabilities Under Development

- **Bearing Diagnostics Test Facility**
  - High-speed and load capability to be used for rolling element bearing HUMS testing
  - Test facility designed, fabrication and installation ongoing
  - Facility operational December 05

- **Single Tooth Bending Test Facility**
  - High-speed load application to 1 kHz
  - Test fixture designed, MTS machine purchased, July 05 installation
  - Facility operational September 05

Space Mechanism Activities

Objective: Develop technologies to enable durable and highly reliable space mechanisms for current and future space exploration vehicles

Approach:

- Leverage GRC mechanical systems and tribology expertise with that from other centers
- Utilize extensive mechanical component facilities at GRC to validate new technologies

Status / Plans:

- Continue support for shuttle RTF
  - dither / wear testing of gears
  - fault tolerance testing of gears
  - adapt / develop single tooth bending fixture for gear load capacity investigation
- Plan / initiate Code T mechanisms / tribology task

Summary

- Four main focus areas in the drive system area:
    * Thermal Behavior of High-Speed Gearing
    * Health and Usage Monitoring
    * Advanced Component Research
    * Space Mechanisms
- Currently conduct / manage research within our center as well as at contractor and university locations
- Involved in analytical and experimental developments
- Work closely with the aerospace industry, other government agencies / NASA centers, NESC….