Data Fusion Applied to Health Monitoring of Dynamic Mechanical Components

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Paula J. Dempsey

NASA Glenn Research Center

BACKROUND

Damage in transmission components (gears, bearings, shafts) produce specific fault patterns in vibration signatures.

Vibration-based condition indicators (CI) are used to assess transmission health and diagnose component damage.

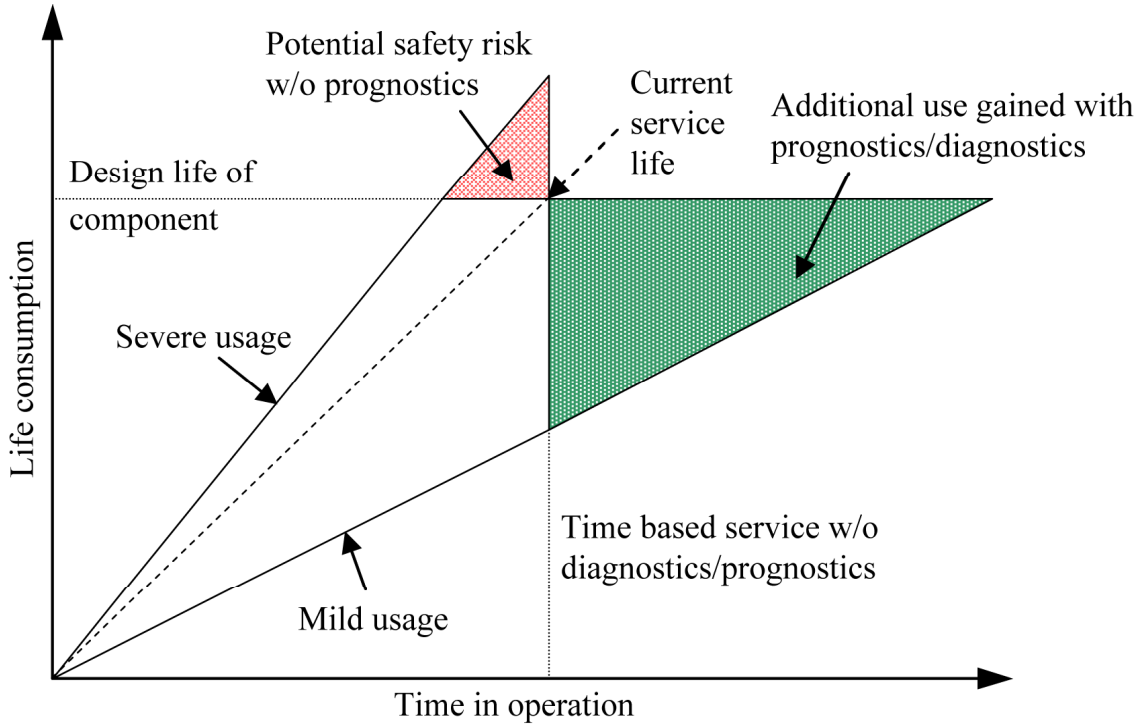
Oil analysis (chip detectors, inductance sensors) of wear debris is also used to indicates abnormal wear of mechanical components.

Experience with mechanical component diagnostics in rotorcraft HUMS (Health Usage Monitoring Systems).

BACKGROUND

Health Usage Monitoring System (HUMS)
Potential for both safety and economic benefits

- Service life extended if HUMS indicates lower usage.
- Safety improved if HUMS indicates more severe usage.



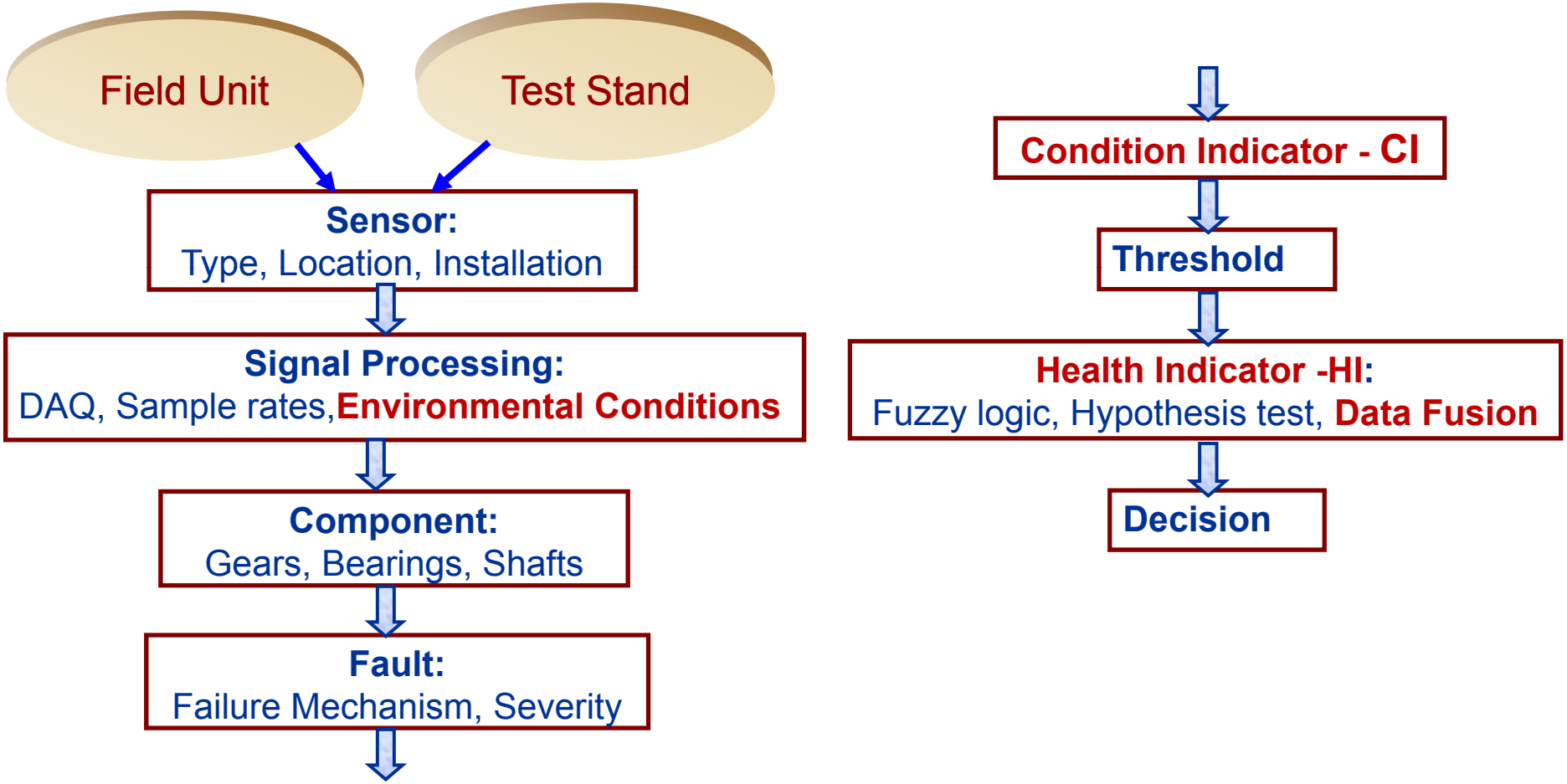
OBJECTIVES

Investigate health monitoring methods to detect early onset of fault conditions and their progression for maintenance actions.

Provide examples of multi-sensor data fusion for detecting mechanical component health.

Demonstrate improved diagnostic tool damage detection and decision-making performance using fused system over individual CI.

HUMS MECHANICAL DIAGNOSTICS



BEARING CI

Fault/defect frequencies generated when bearing fails.

Calculated by bearing dimensions and speed.

Frequency Domain:

- FFT used to identify characteristic bearing defect frequencies and their change in amplitude.
- Envelope analysis used to identify bearing resonances excited by periodic impacts

Time domain:

- Statistical parameters: RMS, peak, kurtosis.

SHAFT CI - peak vibration spectrum at shaft 1, 2 and 3 X RPM.

GEAR CI

Gears produce vibration signals synchronous with speed (repeat periodically with shaft rotation).

Gear CI's are calculated from accelerometer data sampled then the time synchronous averaged to shaft speed.

Time synchronous averaging (divide signal into 1 revolution segments, then average) averages vibration signal for over several shaft revolutions.

Statistical parameters from calculated from this data, and data with gear characteristic frequencies (gear mesh) included, excluded or referenced

OIL DEBRIS CI

Oil debris CI using inductance type oil debris sensor - measures number, size and mass of particles

Oil debris mass and particle size distributions recorded from tests performed in NASA Glenn Research Center Test Stands:

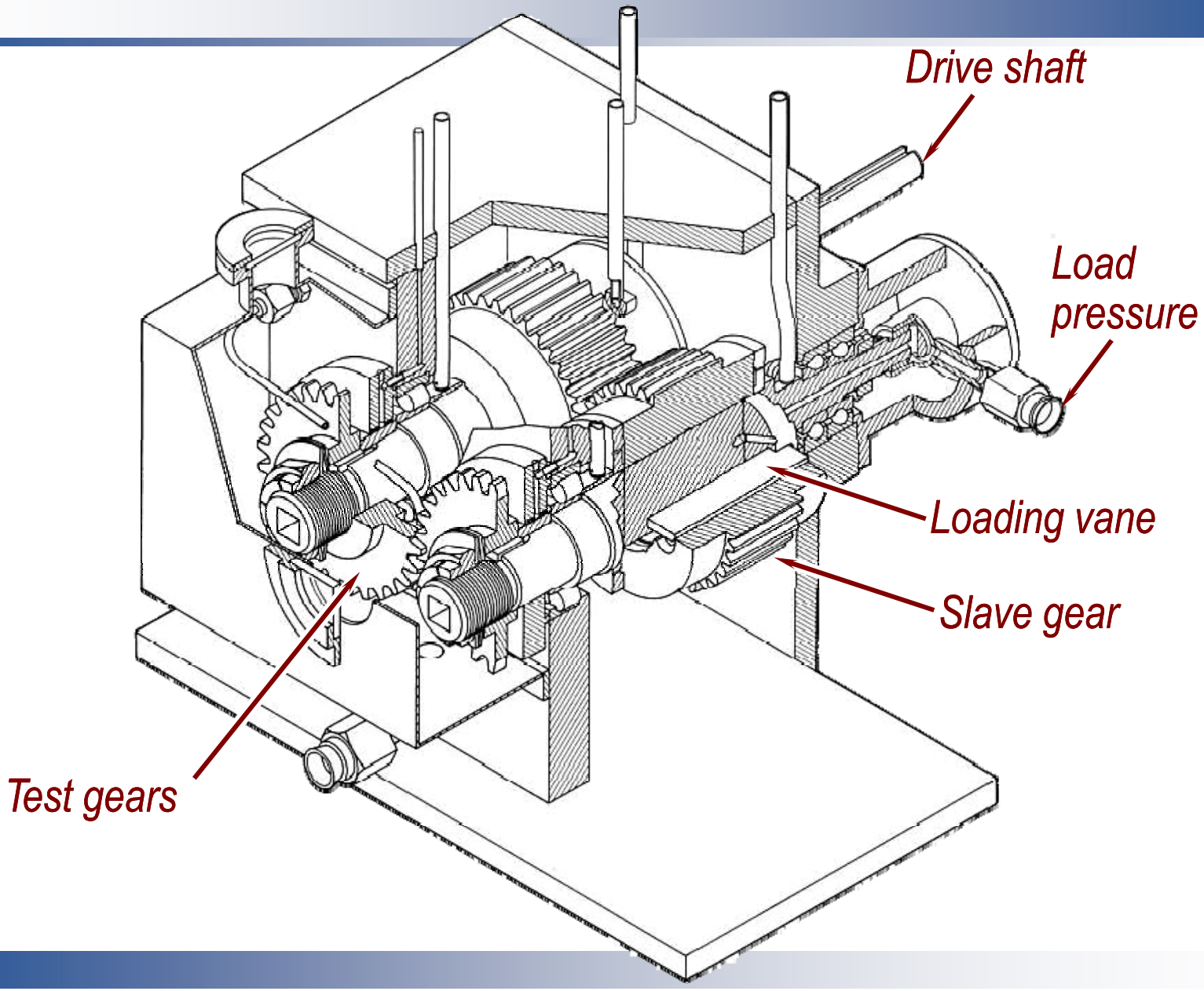
- Spur Gear Fatigue Test Rig
- Spiral Bevel Gear Test Rig
- 500HP Helicopter Transmission Test Stand.

Distributions similar for gear and bearing fatigue damage

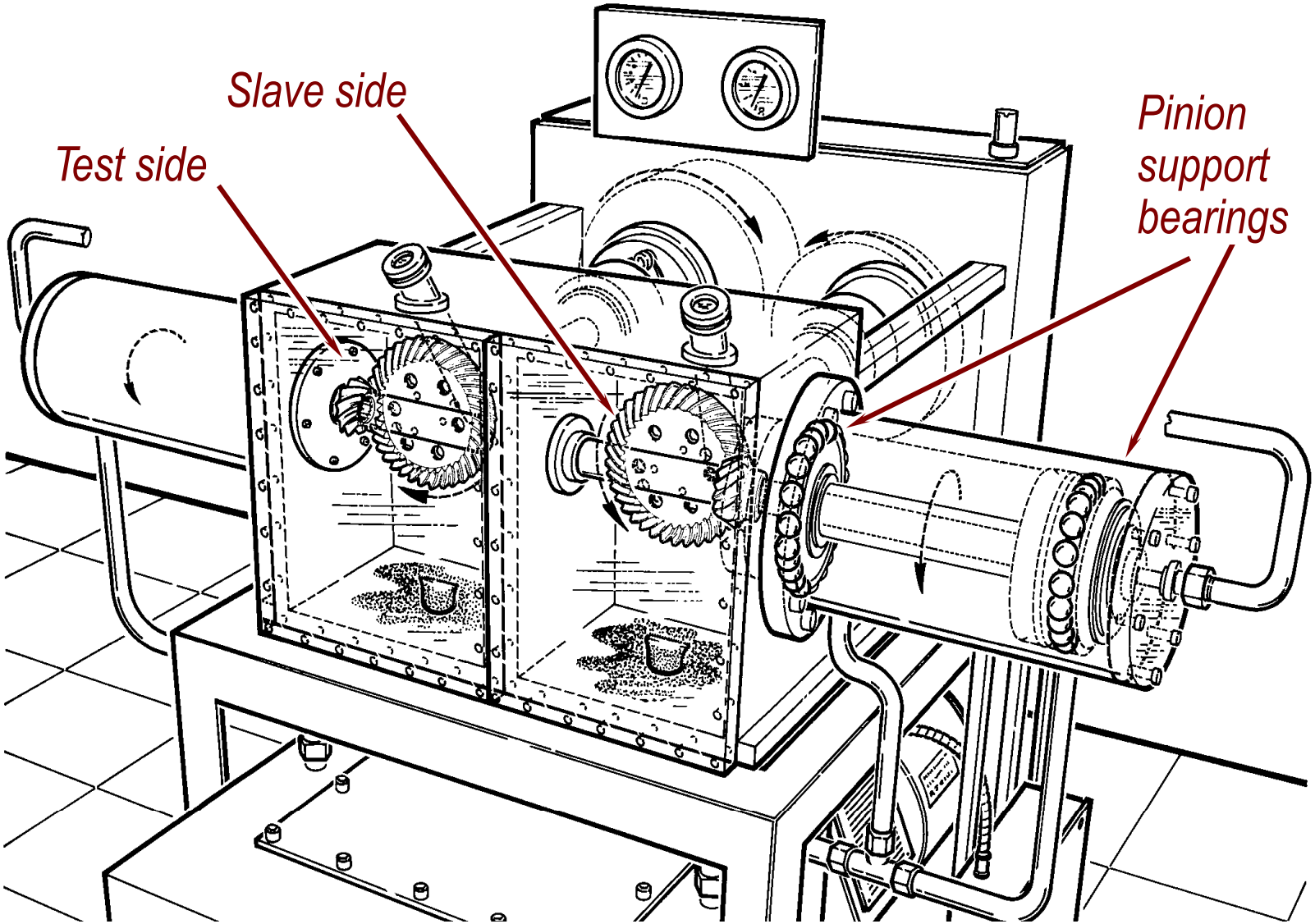
Oil debris alone cannot discriminate between components that share a common lubrication system

Accumulated mass used as oil debris CI

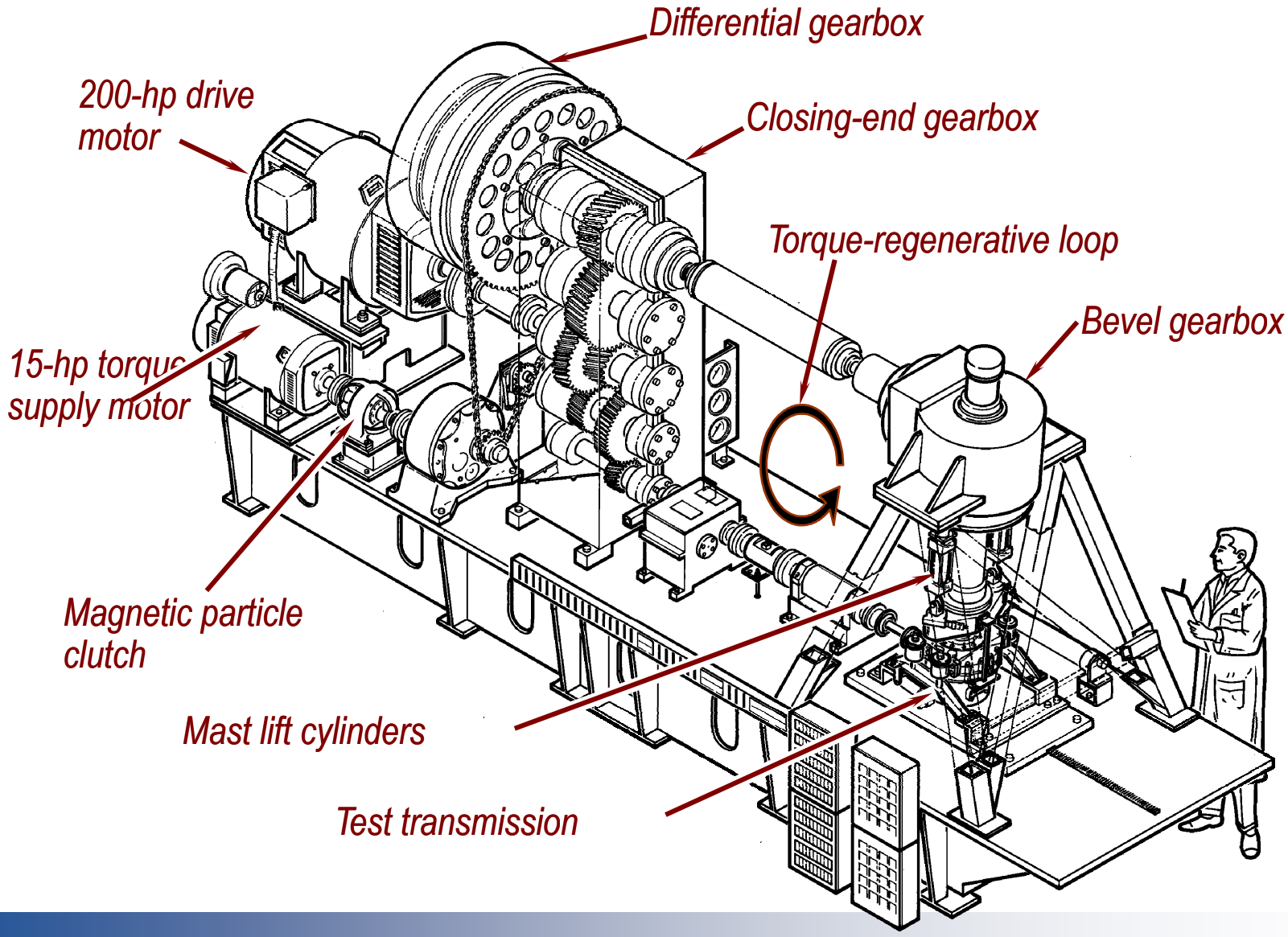
NASA Glenn Spur Gear Rig



NASA Glenn Spiral-Bevel Gear Rig



NASA Glenn 500-hp Helicopter Transmission Rig



DATA FUSION ANALYSIS

Data fusion used to integrate vibration and oil debris CI

Data from multiple sensors combined to perform inferences that are not possible from a single sensor.

Similar to how we integrate data from multiple sources and senses to make decisions.

Sensor data can be fused at the raw data level, CI level, or decision level.

Data fusion performed at the decision fusion level to determine component health.

Output – HI provides the health status of the component to the end user.
(O.K., Inspect, Shutdown)

DATA FUSION HI

Sensors

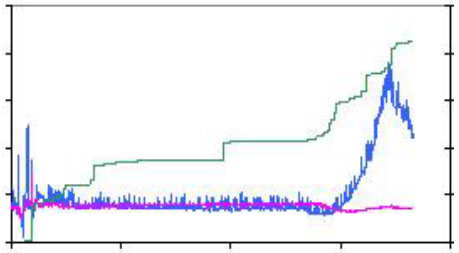
Accels

1X/Rev

Oil Debris

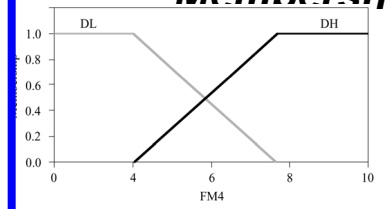
CI – Inputs

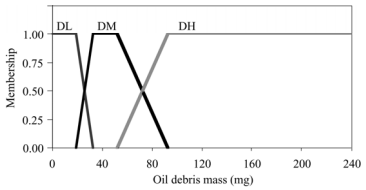
FM4, NA4, Debris

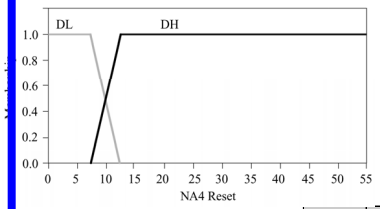


Damage Level Fusion

Membership Functions



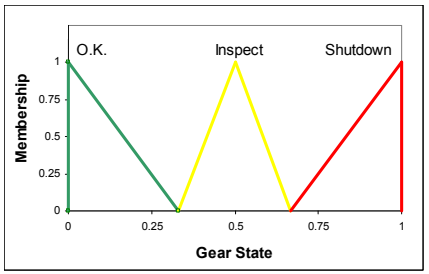




Rules

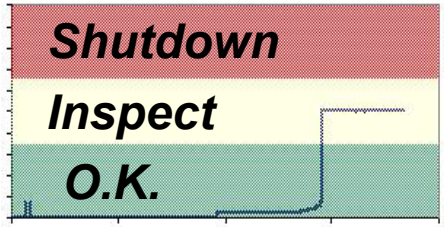
Damage Levels

Rule	FM4	NA4	Debris	Output
1	DL	DL	DL	O.K.
2	DH	DH	DH	Shutdown
3	DL	DL	DM	Inspect
4	DL	DH	DL	O.K.
5	DL	DL	DH	Inspect
6	DH	DL	DL	O.K.
7	DH	DL	DM	Inspect
8	DH	DH	DL	Inspect
9	DH	DL	DH	Shutdown
10	DH	DH	DM	Inspect
11	DL	DH	DH	Shutdown
12	DL	DH	DM	Inspect

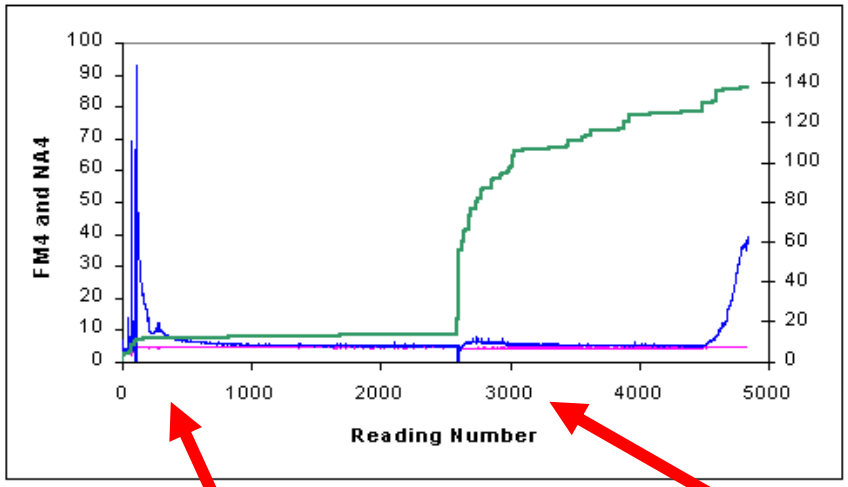


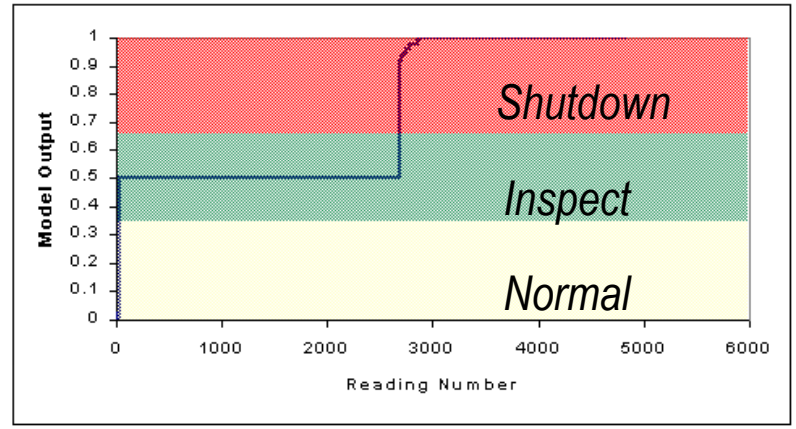
Decision

HI - Gear Health



DATA FUSION APPLIED TO SPIRAL BEVEL GEARS & BEARINGS

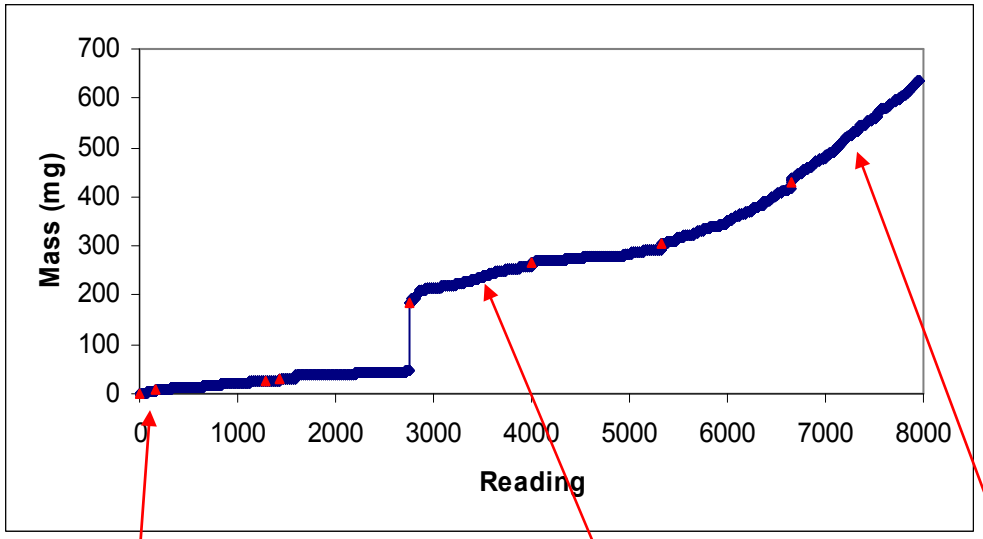


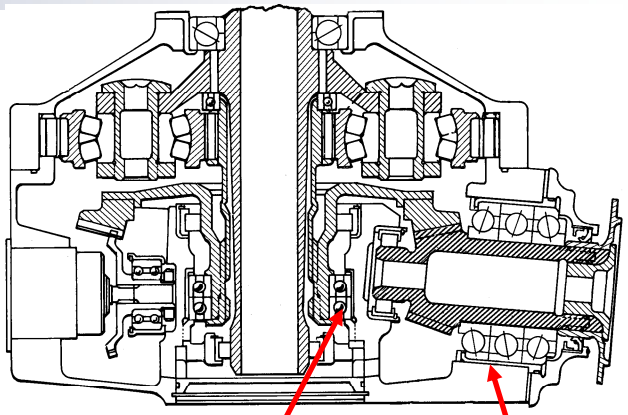


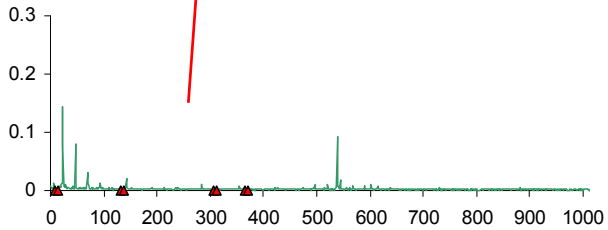
Improved diagnostic tool performance

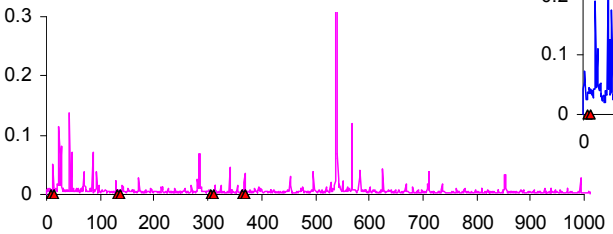
Unanticipated bearing failure reinforces importance of data fusion

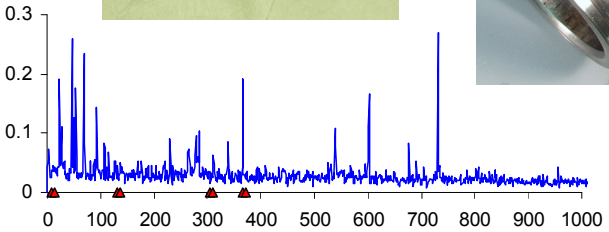
DATA FUSION APPLIED TO 500HP TRANSMISSION BEARINGS



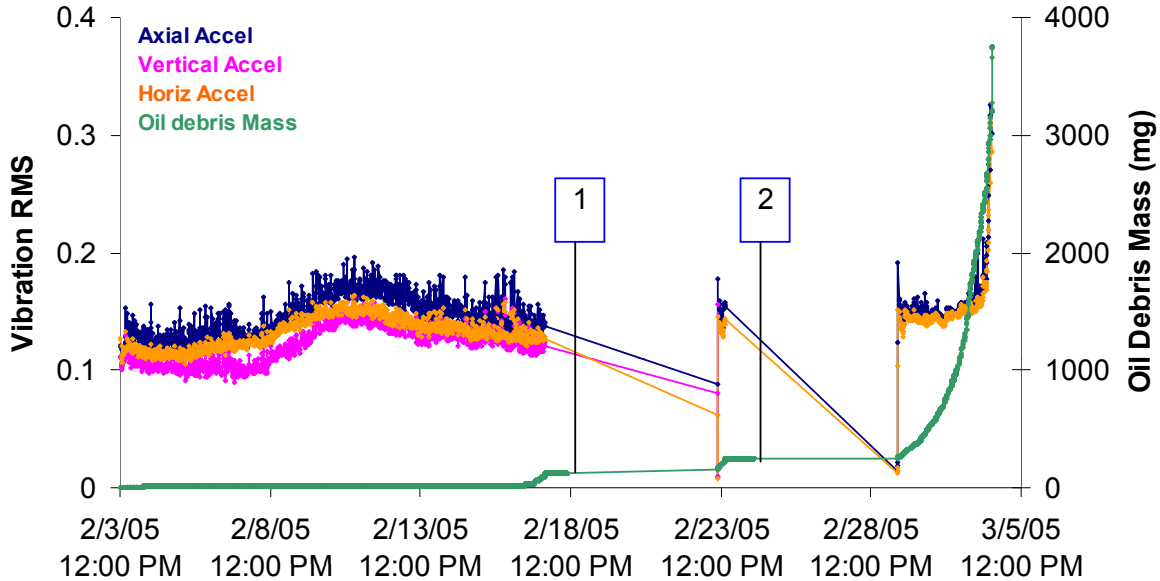


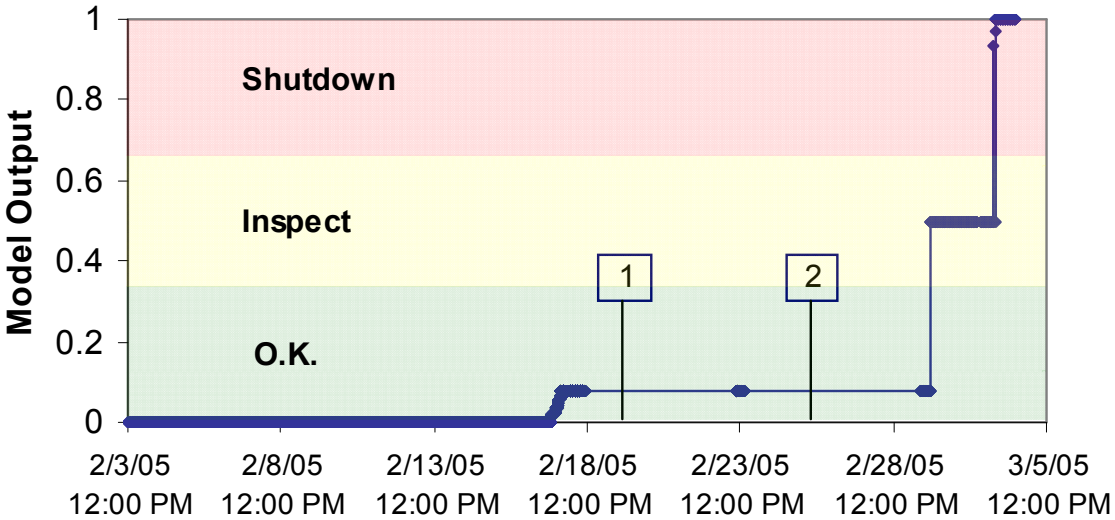






DATA FUSION APPLIED TO TAPERED ROLLER BEARINGS

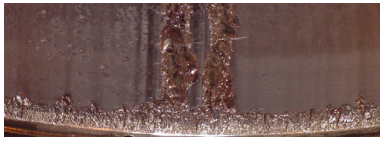




1 *Roller Damage*

2 *Roller Damage*

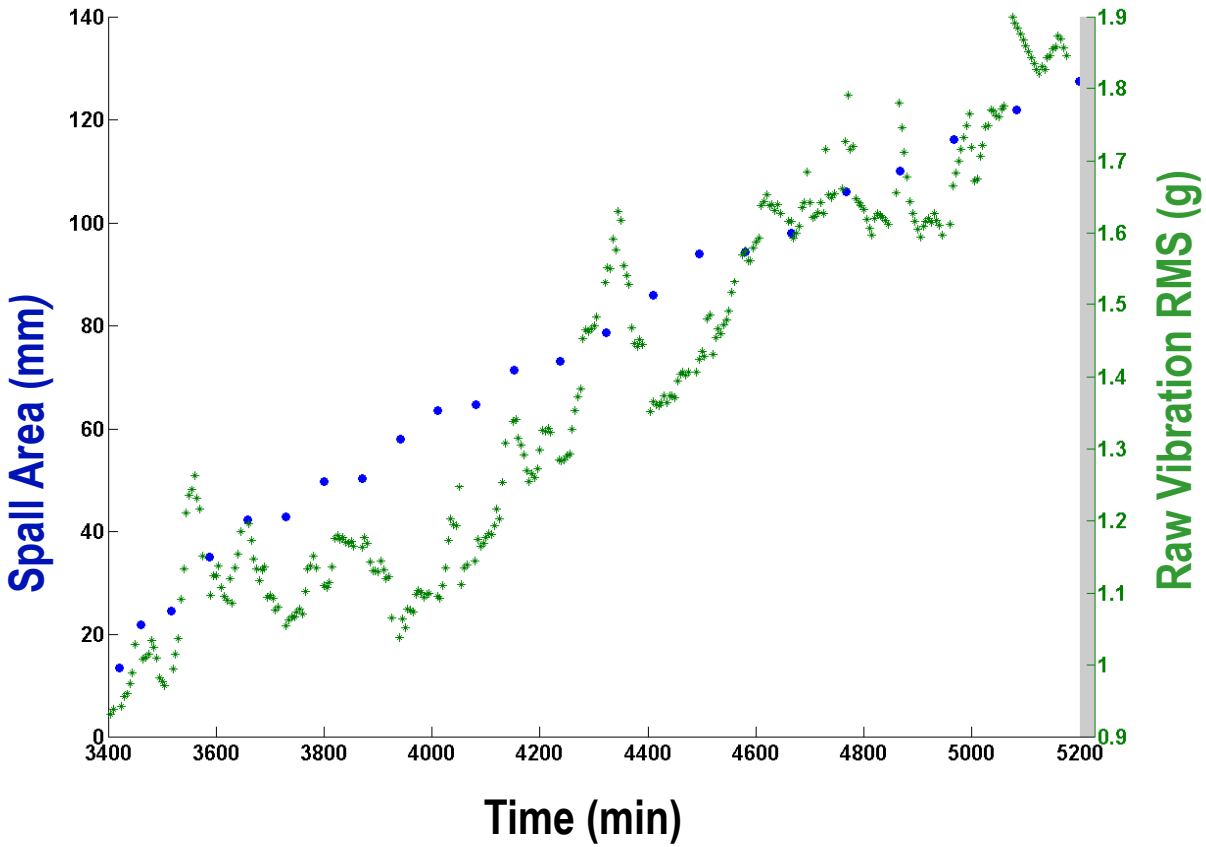
Roller & Cone Damage

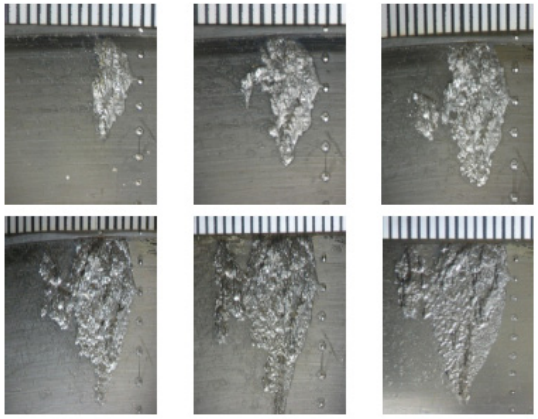


THE NEXT STEP - RUL

Remaining Useful Life (RUL) Prediction Tool

Correlate component damage life models/spall propagation to CI/HI





Spall Propagation

SUMMARY

Integrating oil debris and vibration improves CI damage detection and decision-making.

Strengths, weaknesses and constraints of each measurement technology must be identified to capitalize on CI strengths.

Expert knowledge/operational data/environmental data can be incorporated into the system.

Validation of the diagnostic tools is required to diagnose damage severity and component remaining life.

Need to move from fault detection to magnitude assessment and remaining useful life for condition based maintenance.