CURTISS WRIGHT Controls
Defense Solutions

Defnding the Defenders with StressWave Monitoring

January 2012





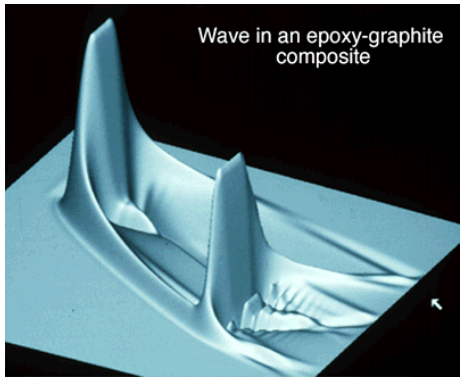
Why is the military interested in prognostics or CBM+?

- **Condition-Based Maintenance Plus (CBM+) - What is it?**
- **The CBM+ is a DoD proactive equipment maintenance capability**
  - Uses system health indications to identify and **predict functional failure in advance** of the event
  - Provides the ability to take appropriate action

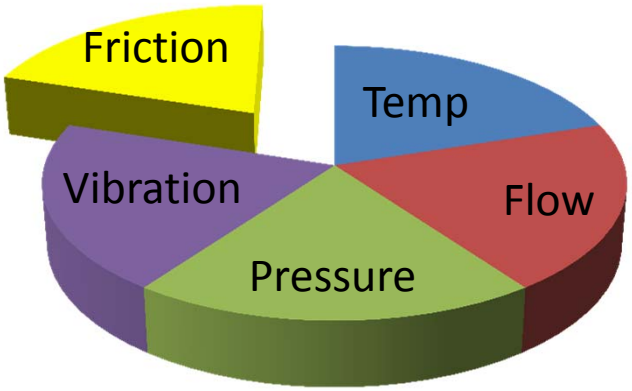
- **Benefits**
  - Increase **operational availability and readiness** throughout the weapon system life cycle
  - Automation to improve maintenance productivity
  - **Reduce the deployed footprint** required to provide maintenance services to combat units
  - Provide visibility of equipment status needed to implement **anticipatory logistics concepts**

Why is the military interested in StressWave Technology?

- **Technology initially demonstrated at U.S. Army Aviation Research and Technology Activity (AFSCOM) Fort Eustis, Virginia on a UH-60 helicopter transmission**
- **Has been used by the U.S. Navy on LCAC for over 10 years for pre-deployment availability**
- **Insensitive to operational vibration (e.g. helicopters, ground vehicles)**
- **Real time condition assessment**
- **New parameter which can be used to enhance current analysis techniques**



Stress Wave Visualization – Virginia Tech



Current Markets Served

Marine

40 Ocean Liners

Wind Energy

4000 WTGs Serviced

100+ WTG 24/7

Over 10 sites

Process/Oil & Gas

Steel Mill *Chemical* *Oil & Gas*

Power

Fossil Fuel *Nuclear*

Military Program Demonstrations

Military Maritime

Hovercraft

Surface Navy

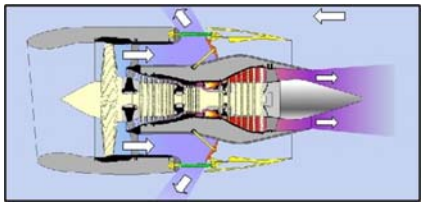
Ground Military

LAV

Bradley/Abrams

Air

Tankers



Transport/Cargo

Rotorcraft

Helicopter

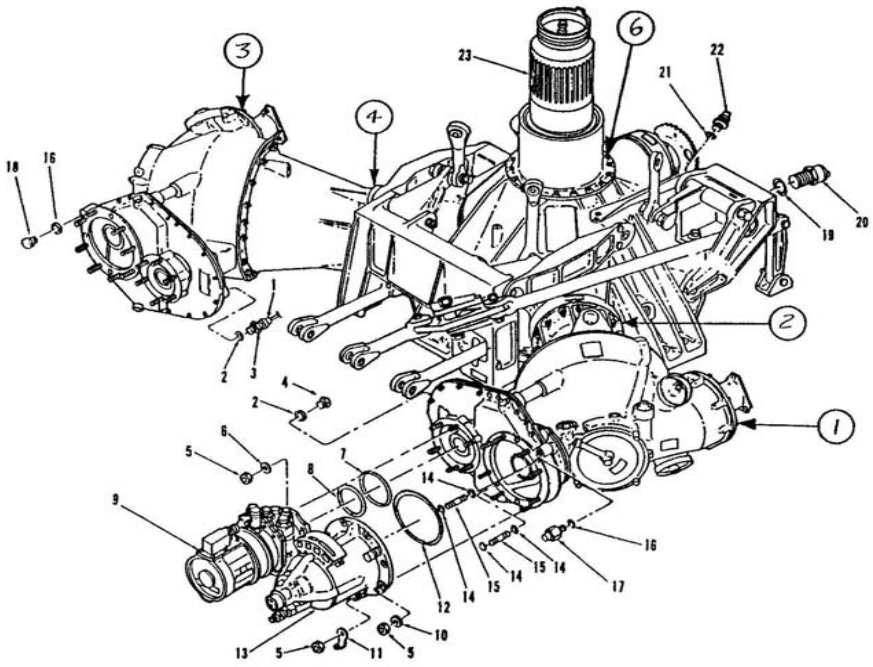
Tilt Rotor

Demonstration of a StressWave System in the U.S. Army Helicopter Transmission Test Cell

Main Rotor Transmission
Testing of StressWaves

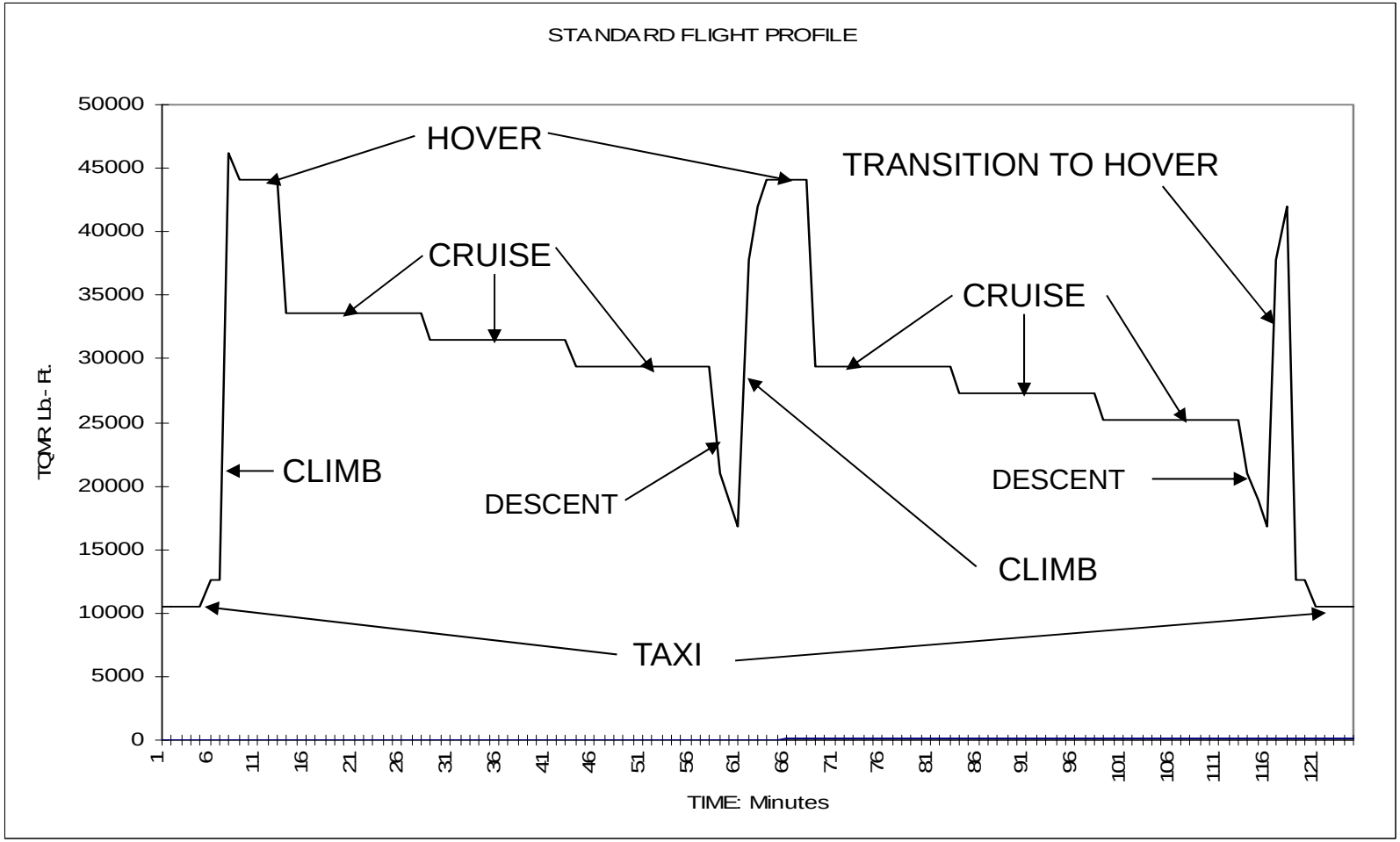
Seeded Faults

- Spalled planet gear rolling element
- Spalled planet gear
- Main Module (MM) Timken bearing spall
- MM input pinion gear spall
- MM input pinion gear broken tooth
- MM input pinion bearing integral race spall
- Input module EDM'd roller bearing
- Input module EDM'd ball bearing
- Input pinion high vibration

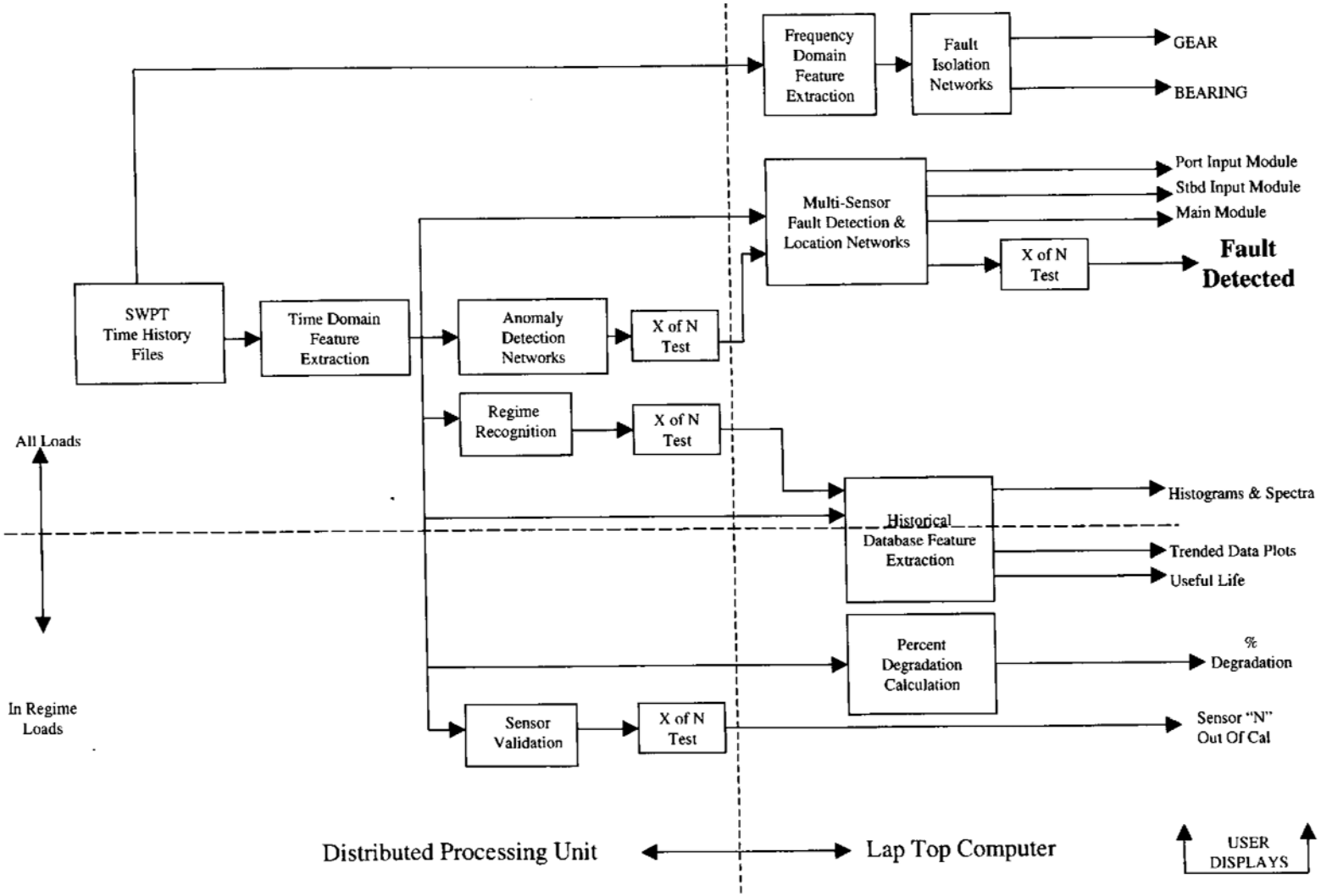


MAIN TRANSMISSION SWAN SENSOR LOCATIONS

Helicopter Standard Flight Profile



Data Fusion Architecture



StressWave System Test Results

TEST CASE	ADN		FDN		FLN		FIN	
	Actual	Indicated	Actual	Indicated	Actual	Indicated	Actual	Indicated
"Best-build " Baseline	OK	OK	OK	OK				
Shim survey Baseline	A	A	OK	OK				
Spalled planet roller	A	A	F	F	MM	MM	BRG	BRG
Spalled tapered roller brg	A	A	F	F	MM	MM	BRG	BRG
Tooth spall + broken tooth	A	A	F	F	MM/SIM	MM/SIM	GR	
Bearing race spall	A	A	F	F	MM	MM	BRG	BRG
Gear spall	A	A	F	F	MM	MM	GR	GR
"EDM'd " ball & roller brgs	A	A	F	F	PIM/SIM		BRG	BRG/GR
"EDM'd " ball & roller brgs plus planet gear tooth fault	A	A	F	F	PIM/SIM/MM	SIM/MM	BRG/GR	BRG
"EDM'd " ball & roller brgs plus "metal maker " MM	A	A	F	F	PIM/SIM/MM	PIM/SIM/MM	BRG	BRG

Example of Deployed StressWave System in the U.S. Navy

Landing Craft Air Cushion (LCAC)

Importance of LCAC Worldwide Operations

Navy ACV Operational Relevance

Jan'05 Tsunami Relief

Mar'03 Iraqi Freedom

Jan'10 Haiti Relief

Jul'06 Beirut Evacuation

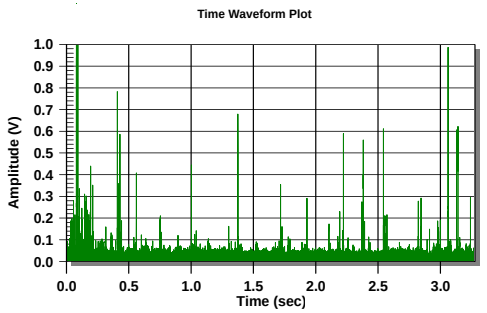
How does the Navy use StressWaves?

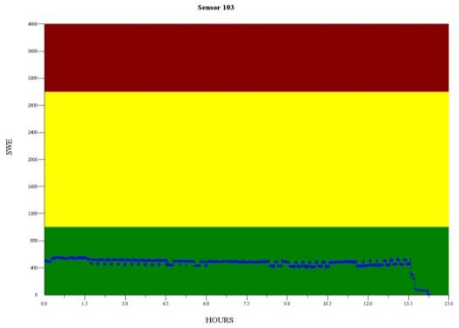
- **The U.S. Navy uses a portable StressWave System with deployments in Little Creek, VA and Camp Pendleton, CA**
- **The system monitors each of the four (4) main engine gearboxes, the (2) forward offset gearboxes and the two (2) aft offset gearboxes**
- **Testing is performed at the following intervals**
  - Initial gearbox baseline condition assessment
  - Seventy-five (75) hour intervals of operation
  - Sixty (60) days prior to deployment
  - Sixty (60) days prior to induction into the Service Life Extension Program (SLEP) or the Fleet Modernization Program (FMP)

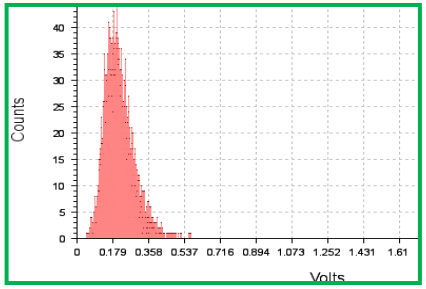
Portable StressWave System

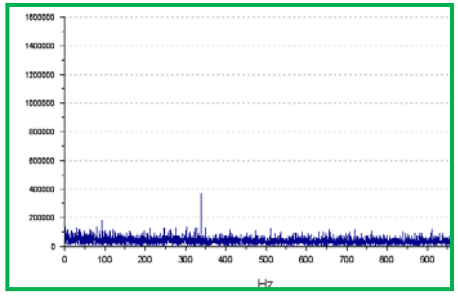
Navy StressWave Data Analysis

- **Data Analysis is then performed on the StressWave Energy (SWE) data, Voltage Distribution (Histogram) data and Frequency Spectra (Fast Fourier Transform - FFT) data**









- **Results of the analysis determine if gearbox removal and replacement is warranted**

CONCLUSION

- **The Navy has found a number of issues using the StressWave System which would have resulted in critical failures during deployment and operations putting personnel and equipment at risk**

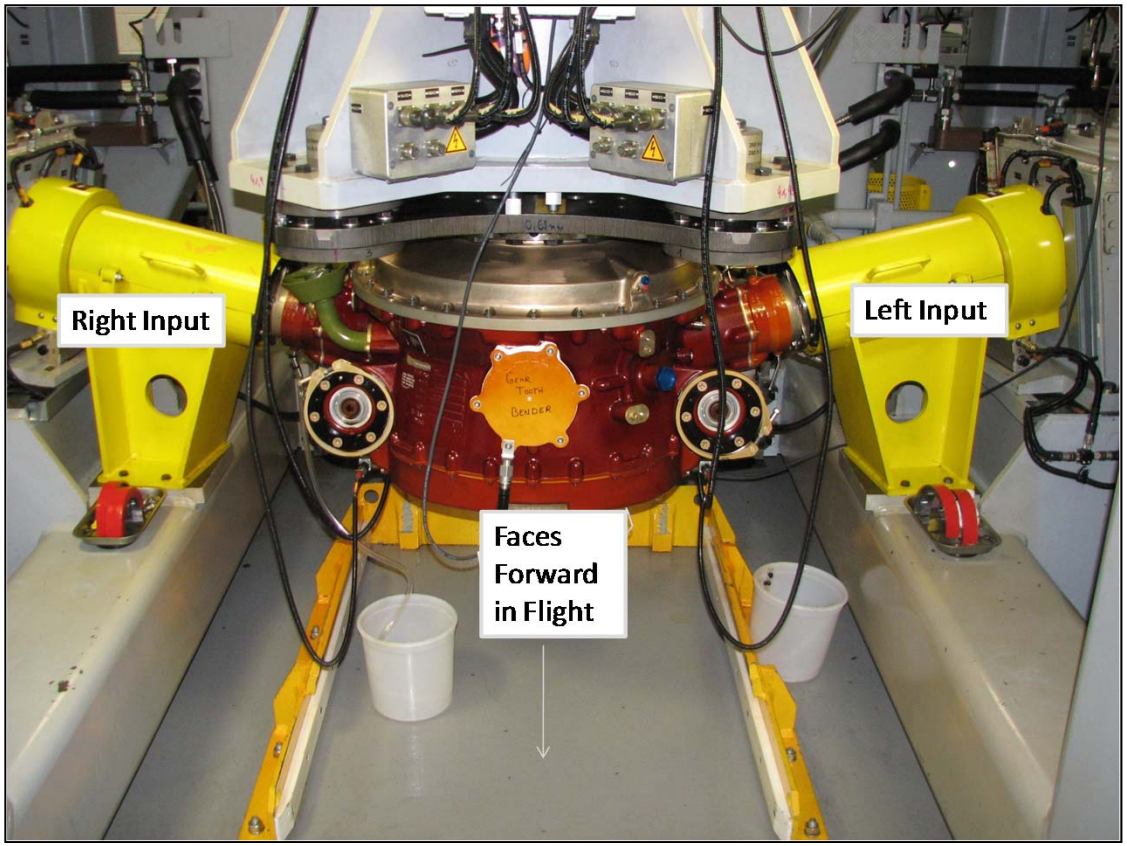
SPS-49 Health Evaluation Case Study

SWAN sensors were attached to the machine surface via epoxy on type mounts at various locations providing a structural path between the sensor and the machine component being monitored. SWANview system configuration was achieved on a known good SPS-49 unit for both the Elevation and Azimuth Drives, and then two units of questionable condition were subsequently tested. A determination was easily made that the EL drive and AZ drive of one of the questionable units was failing as compared to the known good unit without disassembly of the units.

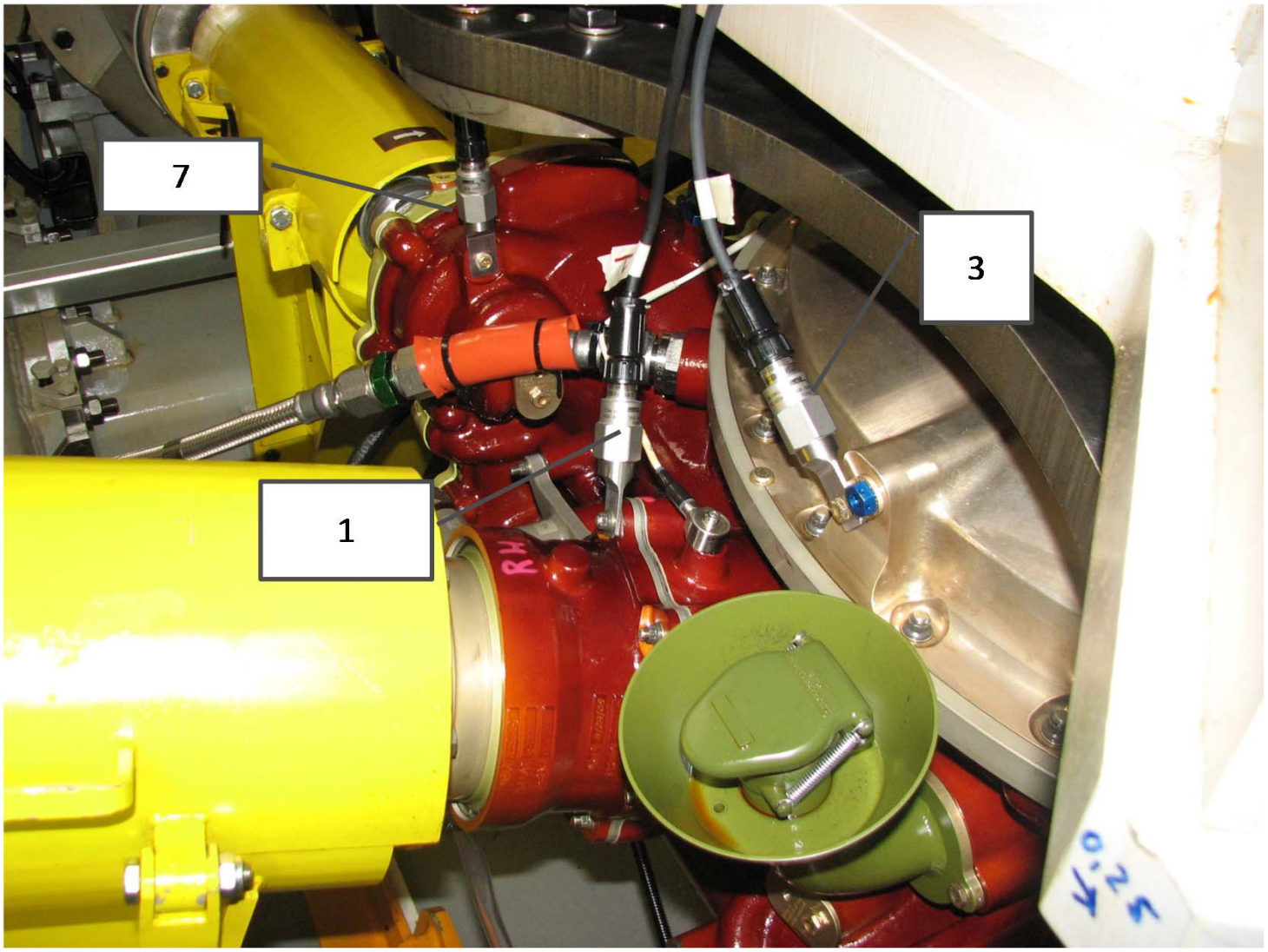
SPS – 49 Elevation and Azimuth Drive Systems – Case Study

EL & AZ Gear Box Sensors

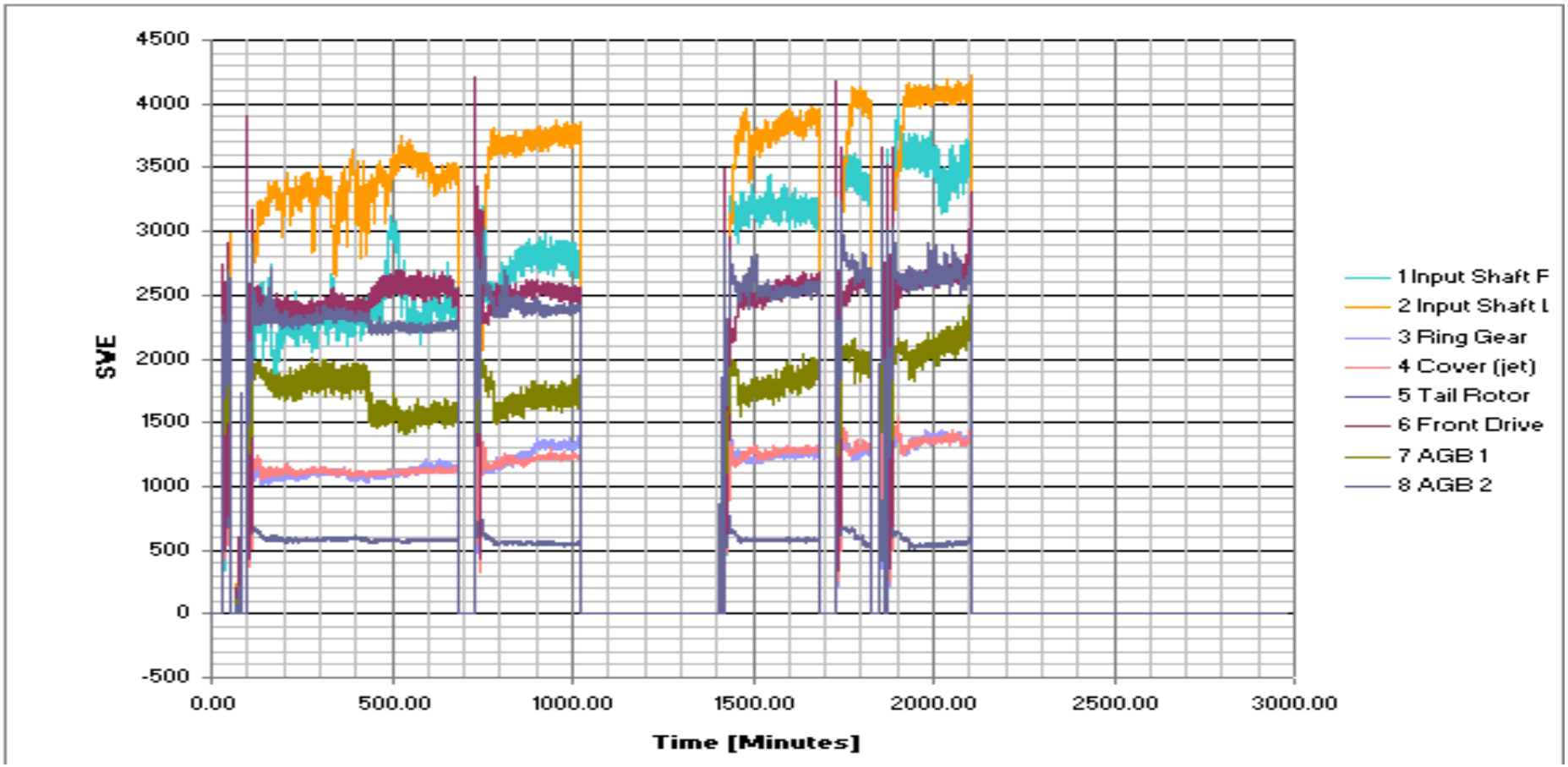
Safety Demonstration of StressWave System in new Helicopter Transmission



Example Sensor Placement



StressWave Operating History Comparison



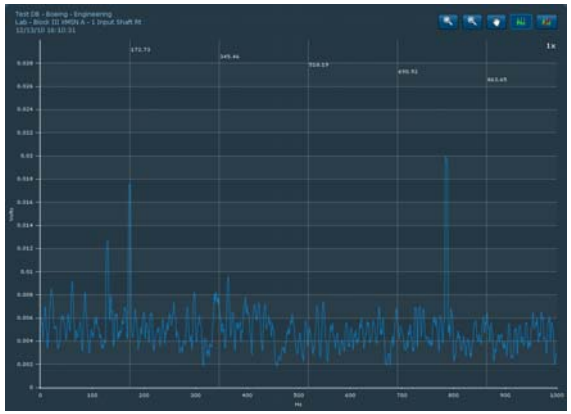
Increasing and/or erratic SWE trends are signs of increasing contact stresses and imminent or existing damage

Predictive Trend in SWE

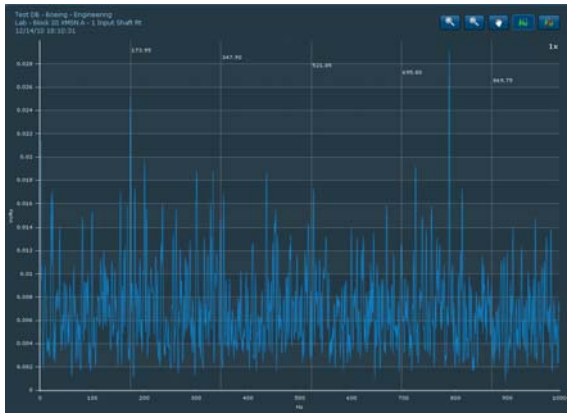
SWE increases significantly and consistently over three days prior to critical operational failure

FFT Plots

Significant increases in the amplitude and number of both synchronous and asynchronous periodic friction/shock events throughout test. Significant growth of pinion 1/rev & harmonics are a particular concern.



13 Dec @ 16:10

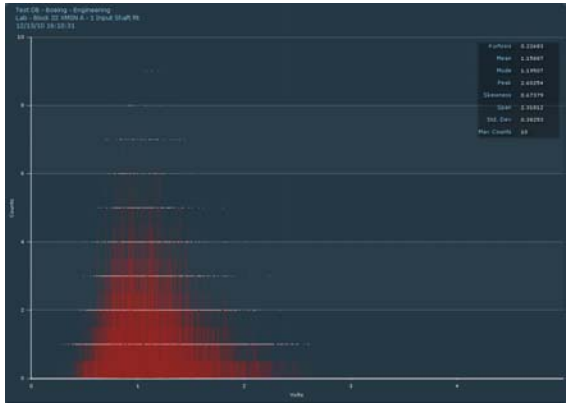


14 Dec @ 18:10

15 Dec @ 01:16

Peak Amplitude Histograms

Decreasing kurtosis, and skewness changes from positive, through 0, to negative, are signs of increasing dynamic contact stresses.



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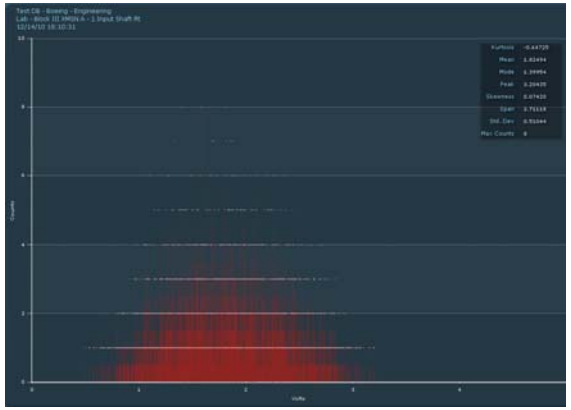

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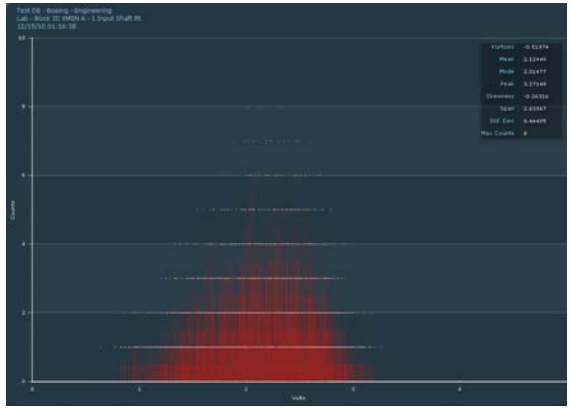

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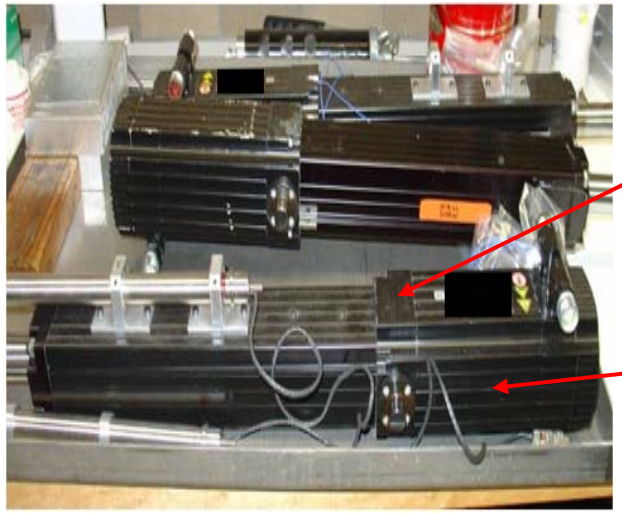
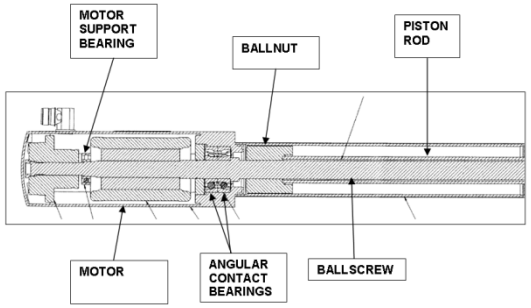
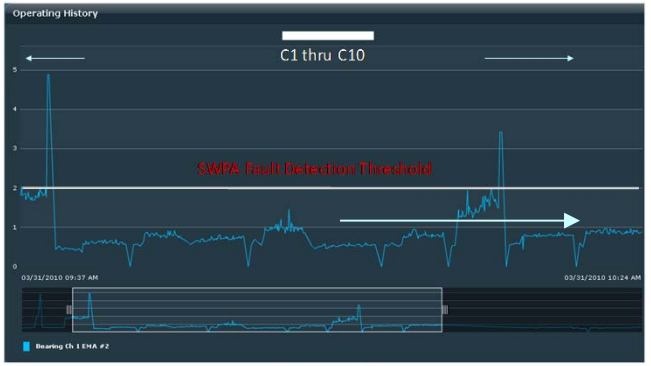
Electro-Mechanical Actuators (EMAs)

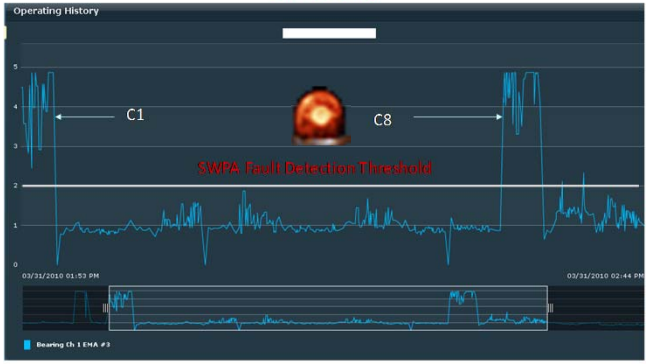


- **Seeded Fault Testing**
  - Good
  - Bad Bearing
  - Bad Ballscrew

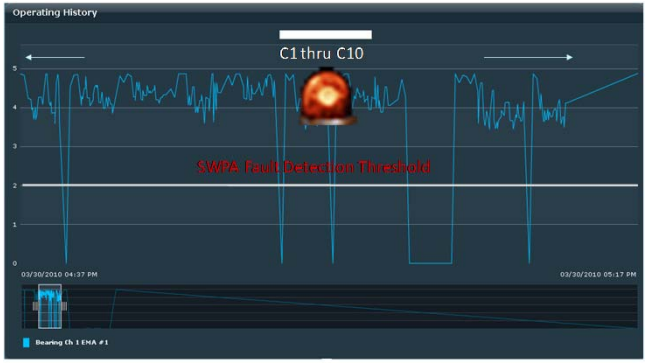




HEALTHY EMA

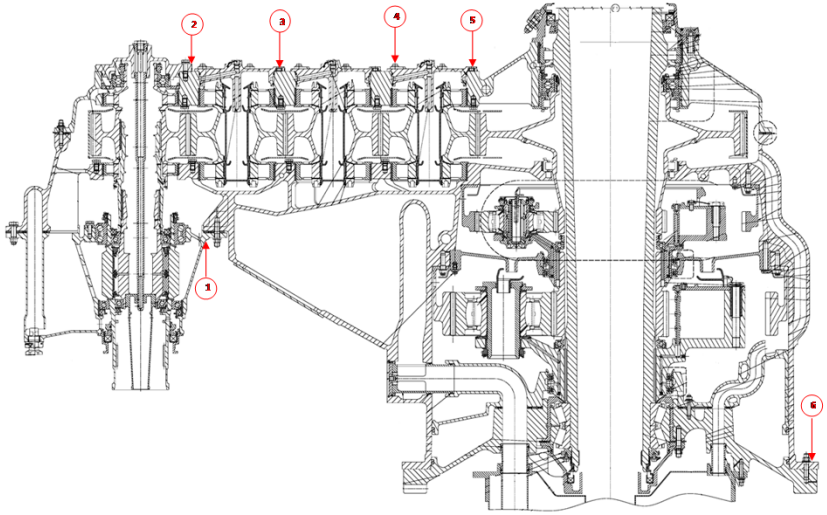


BEARING DEFECT



BALL SCREW DEFECT

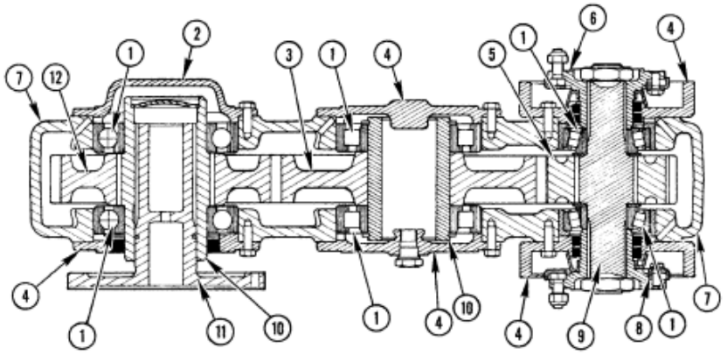
V-22 Prop Rotor Gear Box (PRGB)

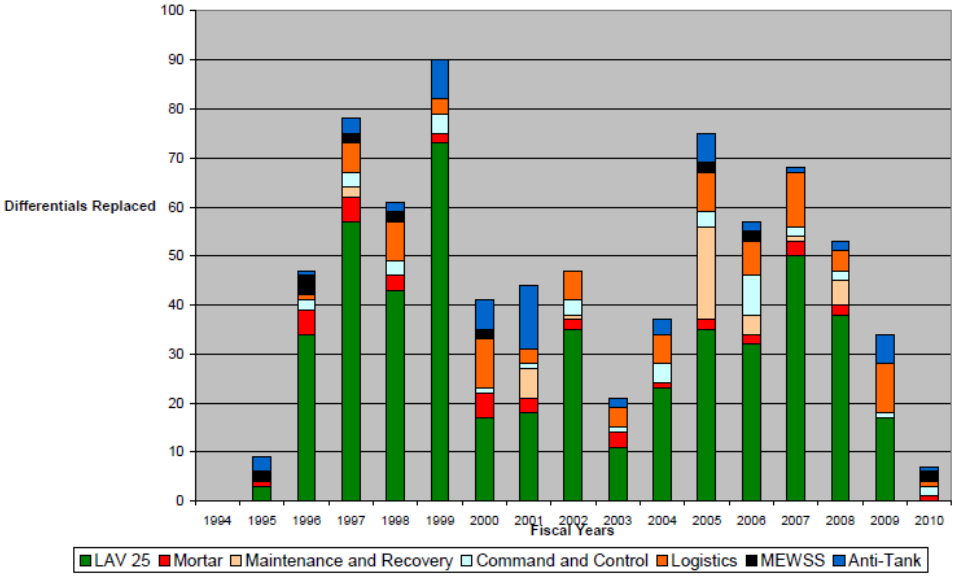


- **Gearbox Oil Debris & Component Defect**
- **Green Run Testing – Reduce Production Costs**
- **Test Stand Monitoring**
- **Future On-board application for safety/availability**

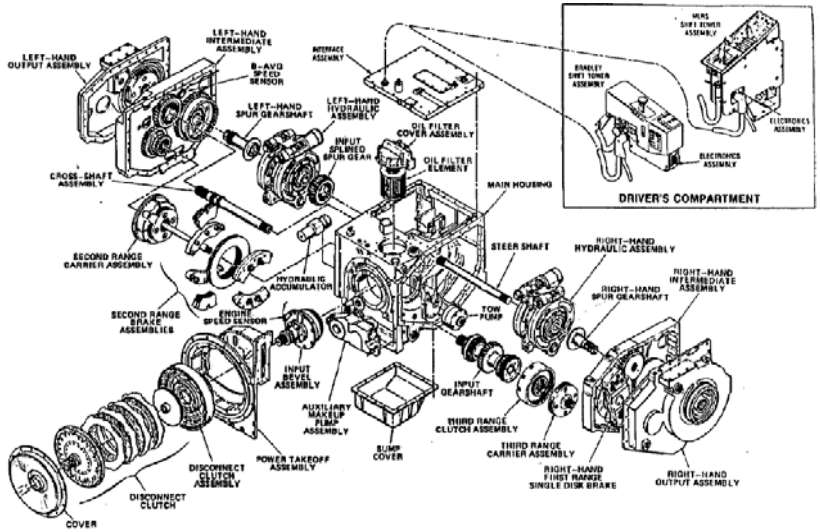
USMC LAV Differentials

- **Lubrication and Failure Prediction**
- **Water and Sand Debris in Differentials cause early failures**
- **Constant Oil Analysis not cost effective**

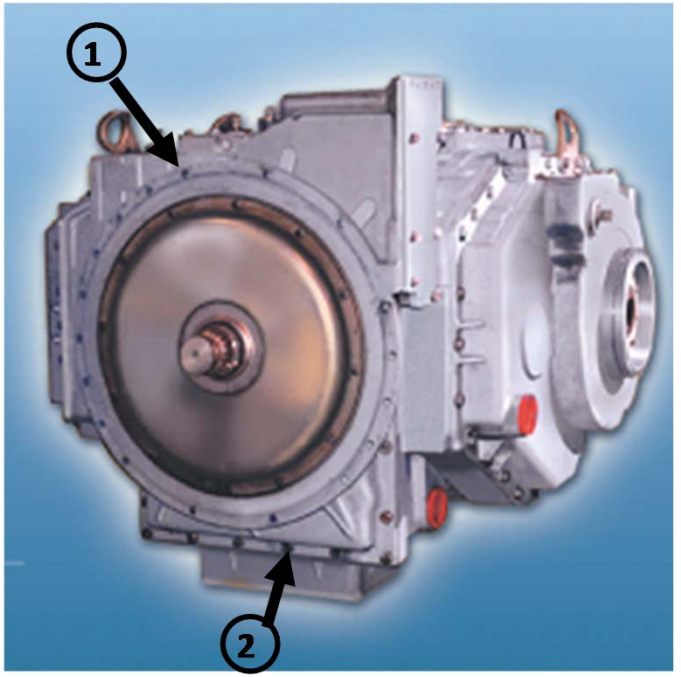




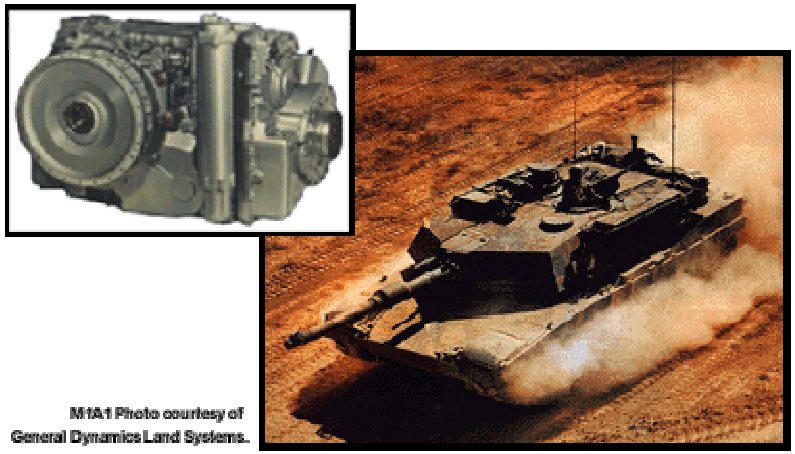
Bradley Transmissions



- **Life Tests - Transmission Failures**
- **Data collection on transmissions during HALT Testing**

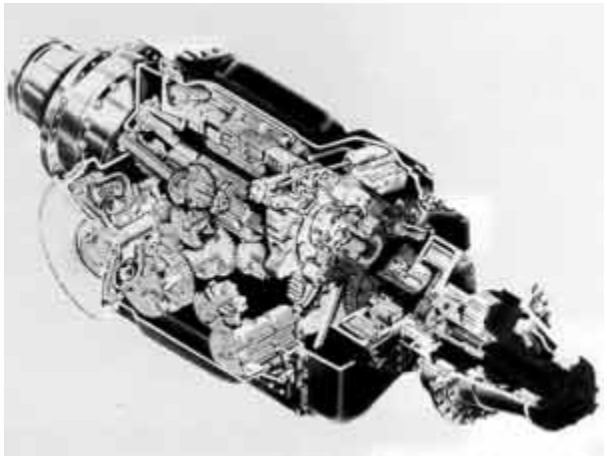


Abrams Engine & Transmission



M1A1 Photo courtesy of General Dynamics Land Systems.

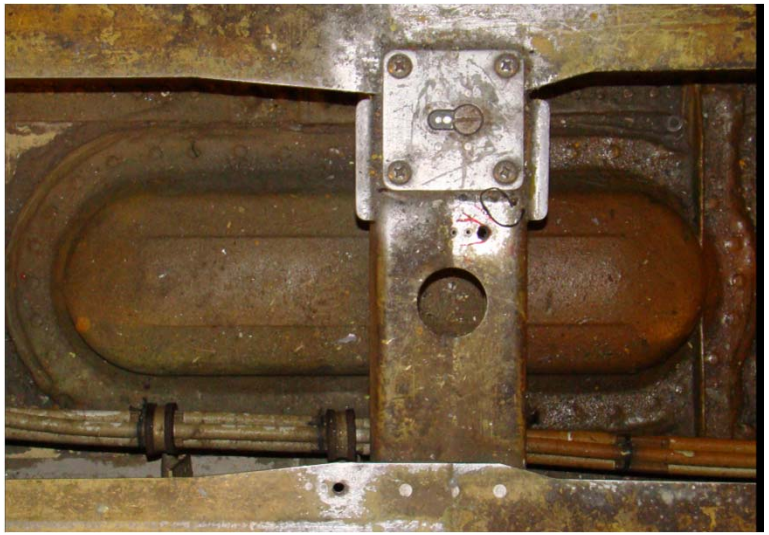
- **Funding to support business case and testing at Aberdeen**



2006			M1A2 Abrams	
Top 10 Repairables by Total Cost				
Nomenclature	Consumer	Qty.	Cost	Per Mile
ENGINE,GAS TURBINE,	256,431	291	$74,621,426.28	$134.84
TRANSMISSION,HYDRAULIC	59,121	137	$8,099,632.01	$14.64
WHEEL,SOLID RUBBER	315	6,964	$2,190,819.00	$3.96
FUEL SYSTEM ASSEMBLY	10,421	165	$1,719,406.66	$3.11
ELECTRONIC UNIT,FIR	46,696	31	$1,447,590.18	$2.62
SIGHT UNIT	48,491	26	$1,260,766.57	$2.28
GENERATOR,ENGINE AC	7,547	269	$2,030,223.53	$3.67
HEATER,VEHICULAR,CO	4,309	230	$991,139.68	$1.79
AZIMUTH DRIVE ASSEMBLY	11,913	77	$917,324.29	$1.66
COOLER-DEWAR GROUP	17,305	52	$899,843.79	$1.63

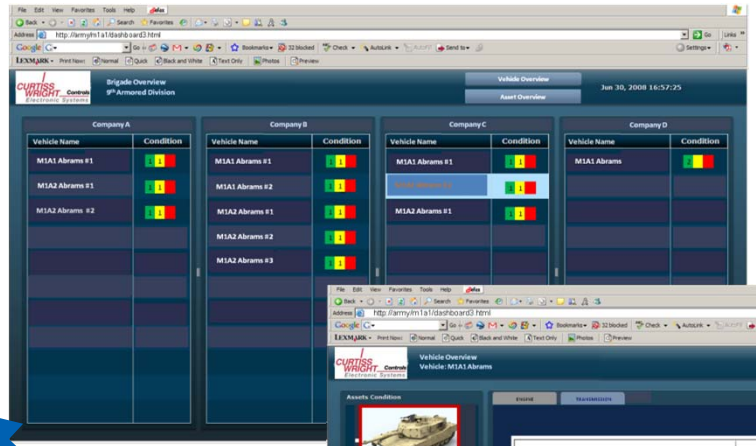
Tanker Fuel Bladder

- Fuel Bladder separates in flight and leaks fuel
- Need non-intrusive technology outside fuel vapor

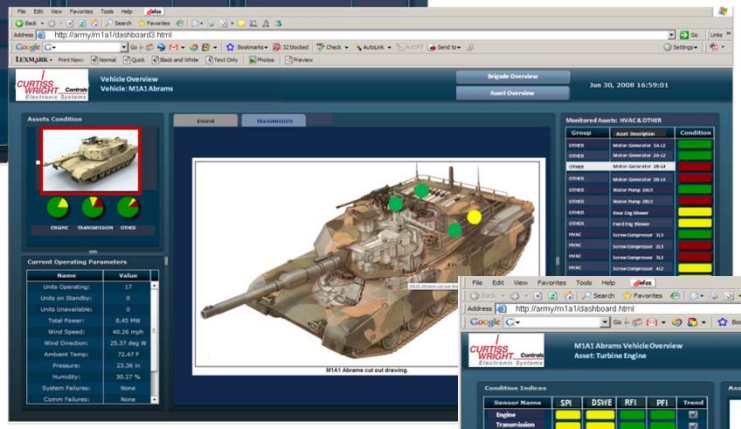


Fleet Management for Condition Based Maintenance

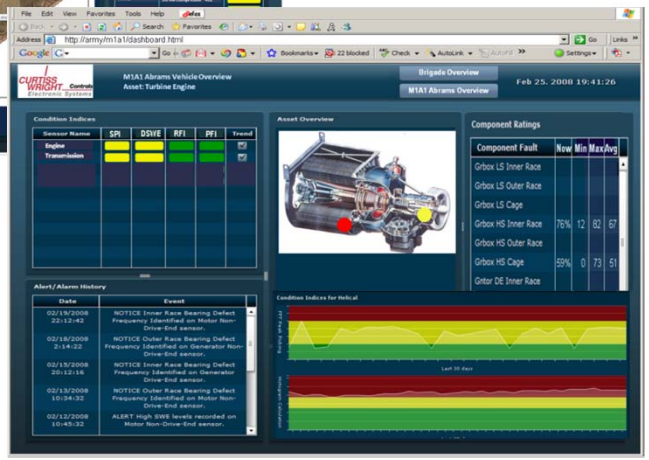
Brigade Level Status



Vehicle Level Status



Engine/Transmission Level Status



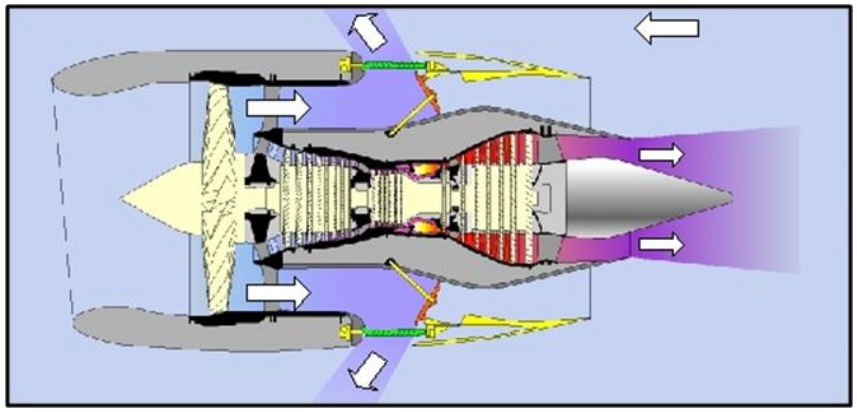
Greater Detail

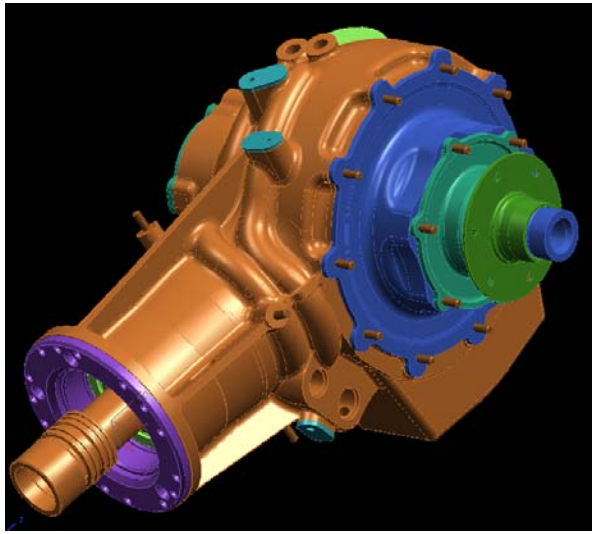
Brigade Overview:
Multiple user-defined regions
Unlimited sites per region
Unlimited assets per site
Huge asset density on one page

Greater Density

Vehicle Overview:
User defined asset categories
Multiple user-defined sub-areas
Unlimited assets per site
All assets on one page if desired

Projects in Progress





Questions?

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