A Perspective on Condition Monitoring in US Army Aviation

Wind Turbine Condition Monitoring Workshop

by

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September 20, 2011

US Army Condition Monitoring

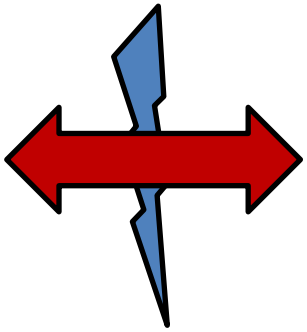
- DoD Instruction 5000.02
  - Requires PMs to "optimize operational readiness through affordable, integrated, embedded diagnostics and prognostics…and iterative technology refreshment."
- The US Army operates world's largest helicopter fleet
  - 3500 helicopters worldwide in austere conditions
- Four CM Objectives

Reduce Maintenance

>10 MMH/flight hr

Reduce O&S Cost

$5k to 10k/flight hr



Increase Safety

1-2 Class A/100k flight hrs

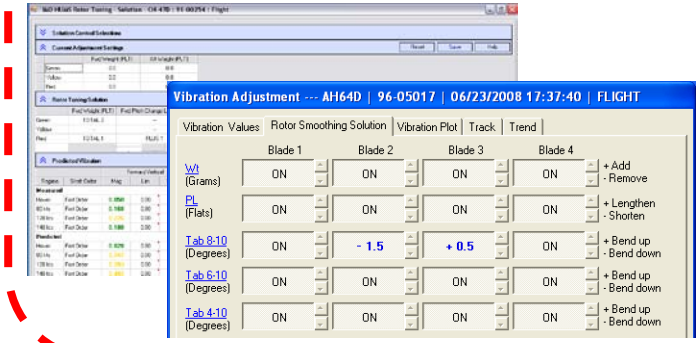
Increase Availability

80% for $30M asset

Condition Monitoring for Rotorcraft

1 Rotor Smoothing

Reduce Main and Tail Rotor Vibs and Track
Adjust Weight, Pitch Link and Trim Tabs

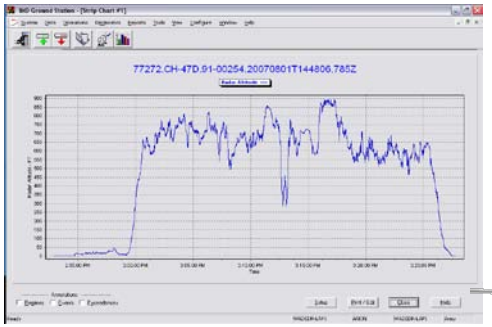


2 Drive Train Health

Assess health of Swashplates, Drive Shafts, Hanger Bearings, Transmissions, Gearboxes Oil Coolers, APU and Engines

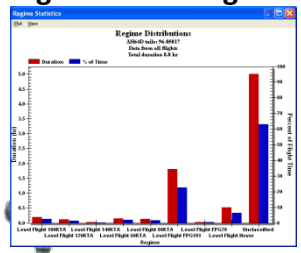
3 Exceedance Monitoring

Record Overtemp, Overtorque, etc.



4 Structural Health

Regime Recognition and Fatigue Life Management



5 Engine Health

Power Assurance

6 Logbook Interface

Talk to ULLS-A(E)

Army Aviation CM Fielding Status

Through 31 JAN 11

Aircraft Type	Total # of Aircraft	DSC Equipped		Percent Complete	Percent Complete EOY FY11	Percent Complete EOY FY12
AH-64 A *	110	0	563	78%	88%	88%
AH-64 D	614	563				
CH-47 D	461	118	176	38%	44%	60%
CH-47 F **		0				
MH-47 G		58				
UH-60 A	1862	459	1244	67%	72%	79%
UH-60 L		475				
UH-60 M		285				
MH-60 L		15				
MH-60 M		10				
MH-6	51	15		29%	59%	59%
OH-58 D	336	123		37%	86%	100%
TOTAL	**3434**	**2121** EOY FY11/2461		62%	72%	77%

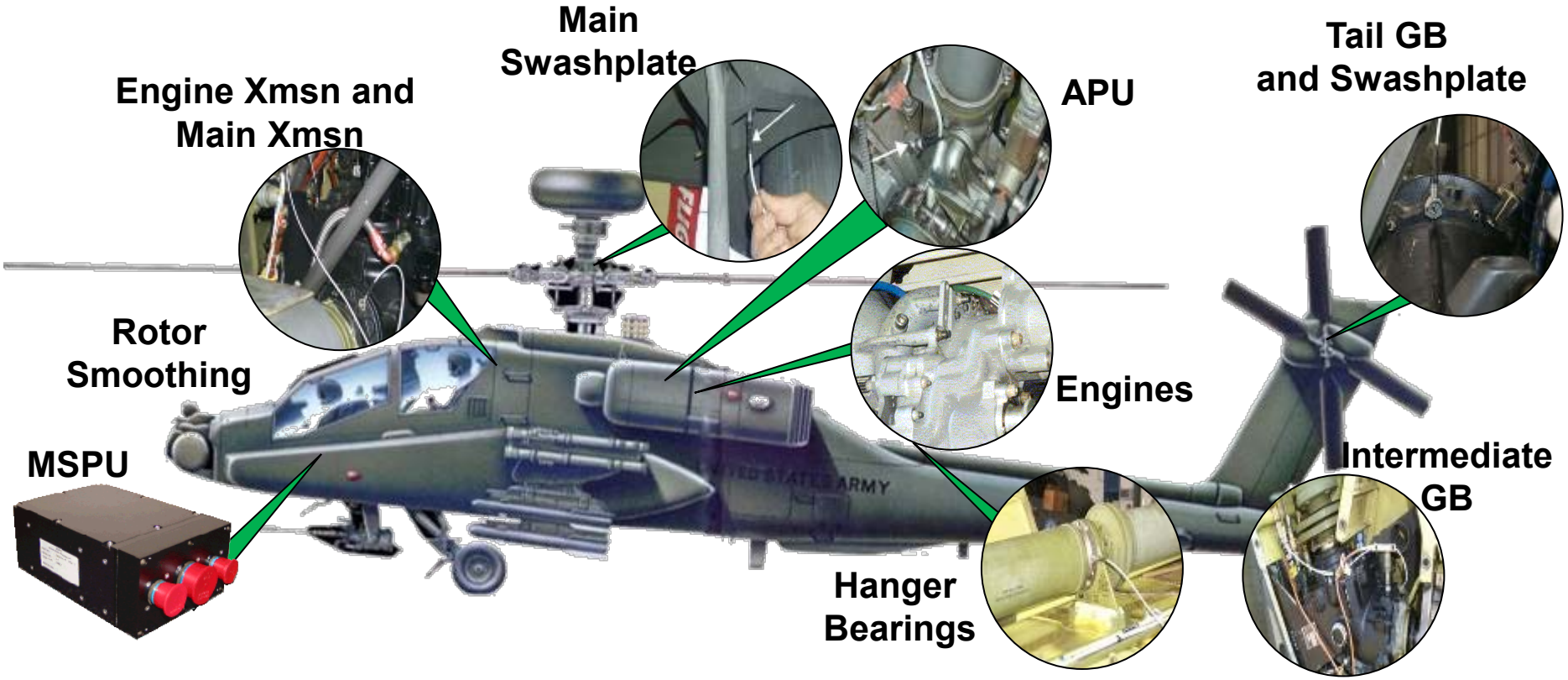
Ref: Smith, C. "US Army Condition Based Maintenance," AHS CBM Conference, Feb 2011

US Army Aviation Condition Monitoring

- Background
- Condition Monitoring
  - On-Aircraft
  - At-Aircraft
  - At-Enterprise
- Engineering Analysis
- Results

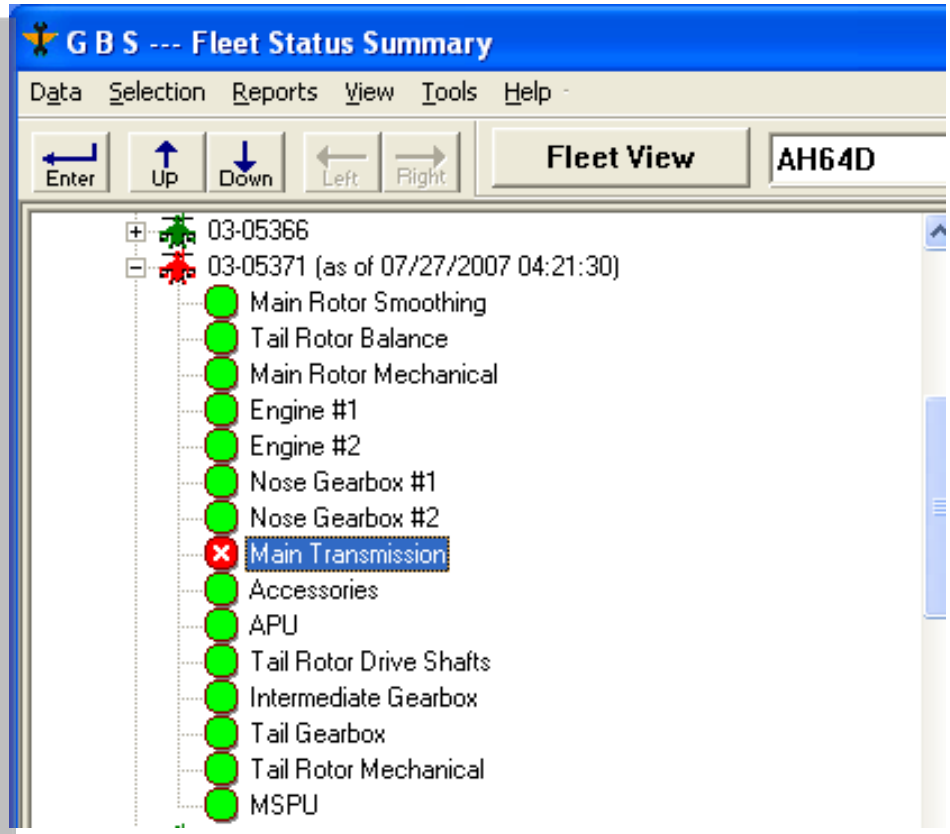
On-Aircraft: Apache

- CM vendor package with Army/OEM approval
  - Line Replaceable Unit (4lb)
  - Sensors (18 accelerometers and 3 tachometers, 14 lb)
  - Discrete signals & aircraft MIL-STD-1553 bus



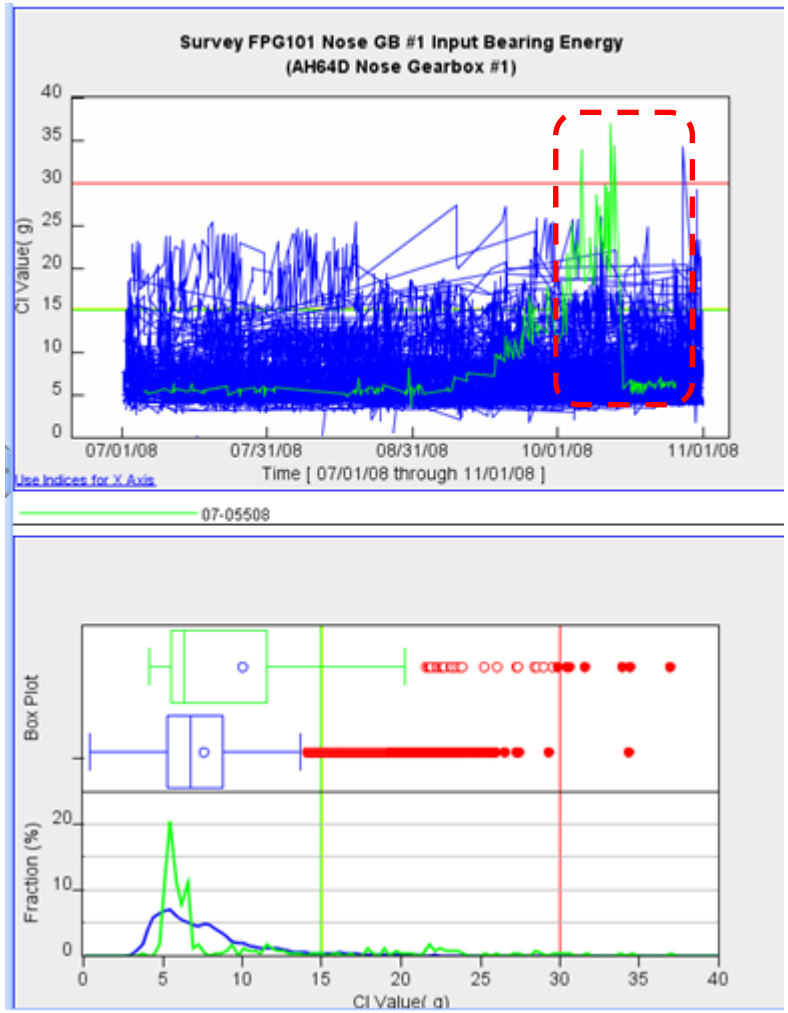
At-Aircraft

- Toughbook with CM System Ground Station
  - Show maintainer (MTP or crew chief) aircraft health
  - Give corrective actions for any faults (link to IETM)



At-Enterprise: Analysis

- Quickly find events in large data sets

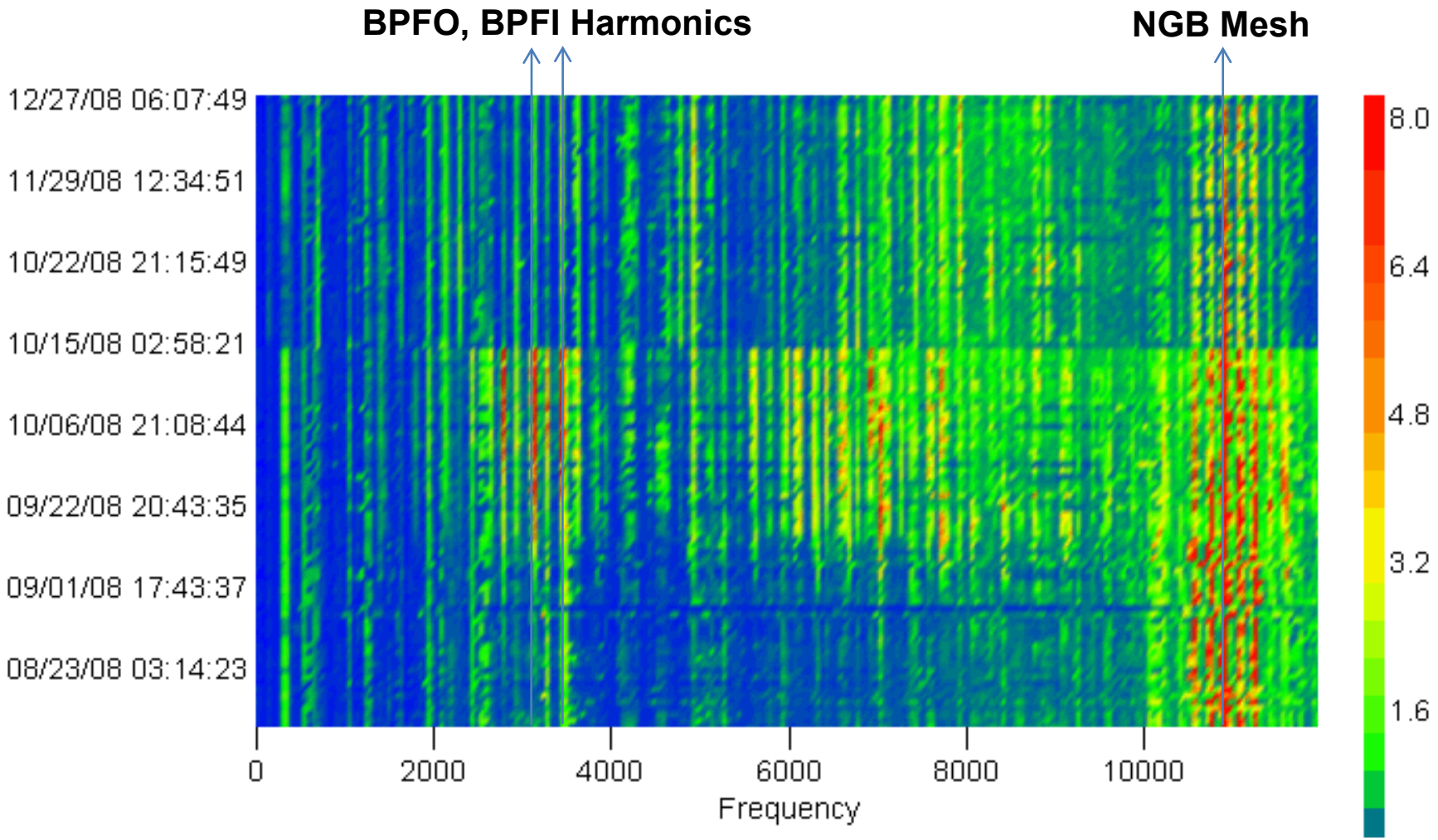


– Was there a maintenance action?
  - Drastic reduction on Oct 15, 2008
  - Drain and Flush?
  - Gearbox Replacement?
    – Time Change or Removed for Cause?

– How “different” is this CI/data?
  - From the fleet averages?
  - From how it was in July?
  - From how it was in November?

At-Enterprise: Analysis

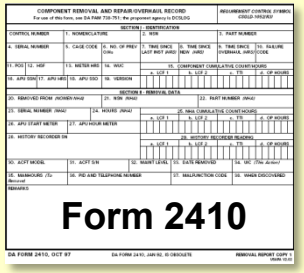
- Waterfall plot of vibration spectra



US Army Aviation Condition Monitoring

- Background
- CM On-Aircraft and At-Aircraft
- Engineering Analysis
  - Diagnostic Validation Database
    - Apache Nose Gearbox Bearing Spalling
    - Apache Main Transmission Sprag Clutches
- Benefits

Analysis: Turning Data Into Knowledge



FMECA
Failure Modes, Effects and Criticality Analysis

Depot Teardown Data

Reliability Centered Maintenance Analysis

CBM Data Analysis

Failure Mode 1 (ex. Spalling)

Failure Mode 2 (ex. Corrosion)

Failure Mode 3 (ex. Crack)

Failure Mode 4

Relevant

1 per Million Flight Hours

Not Relevant

Failure Mode 5

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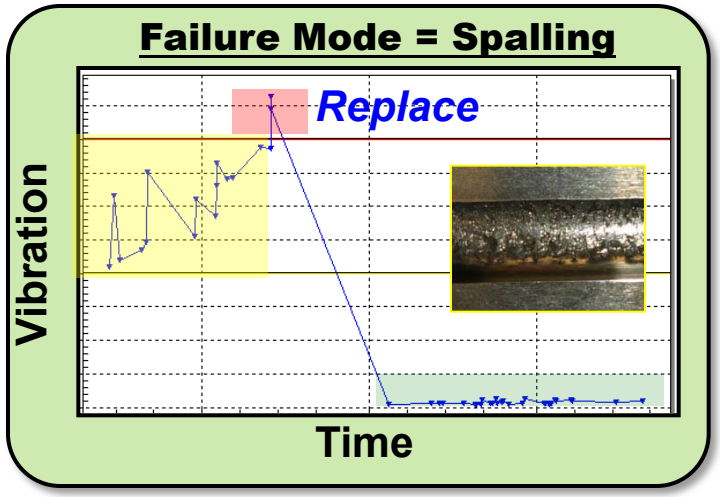
Failure Mode N

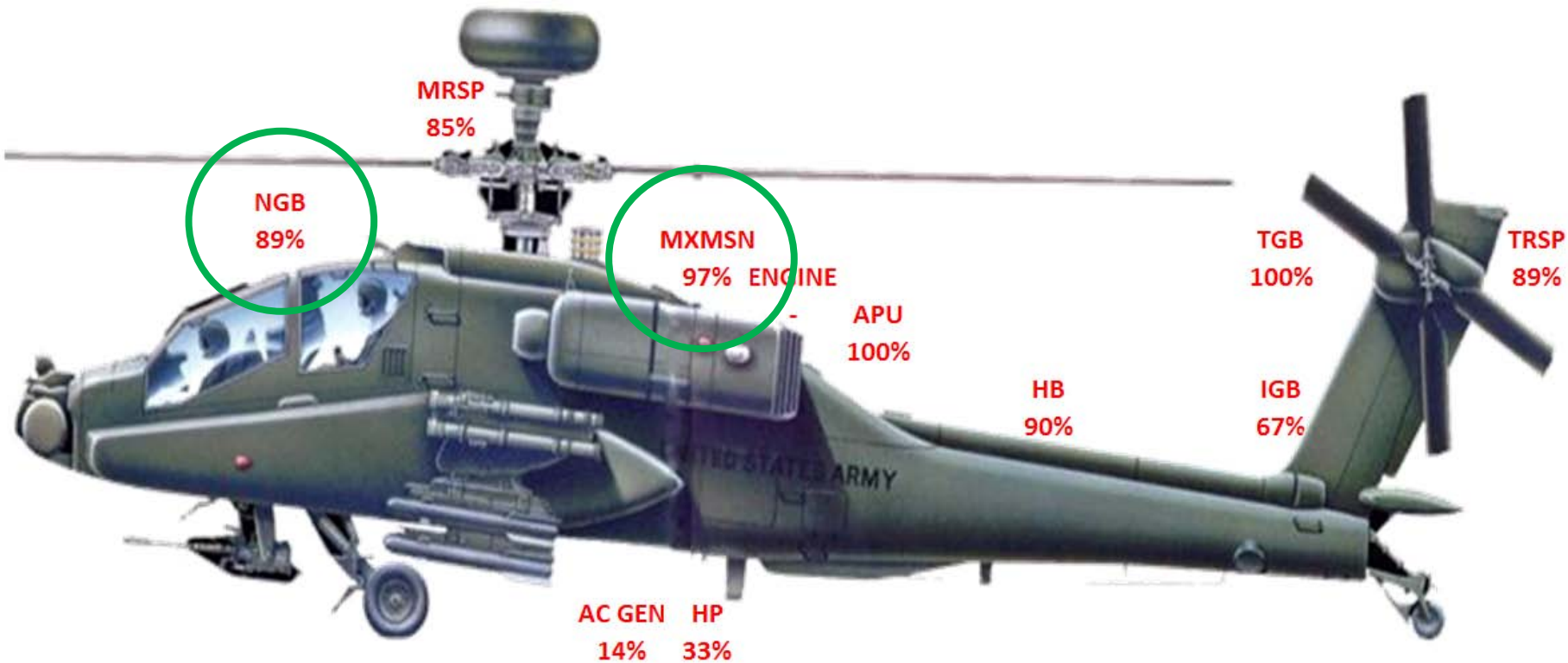
Sensors	Algorithms	Actions
Vibration	Condition Indicators & Health Indicators	*Do Nothing*
Temp		*Inspect*
Oil Debris		*Repair*
Pressure		*Replace*



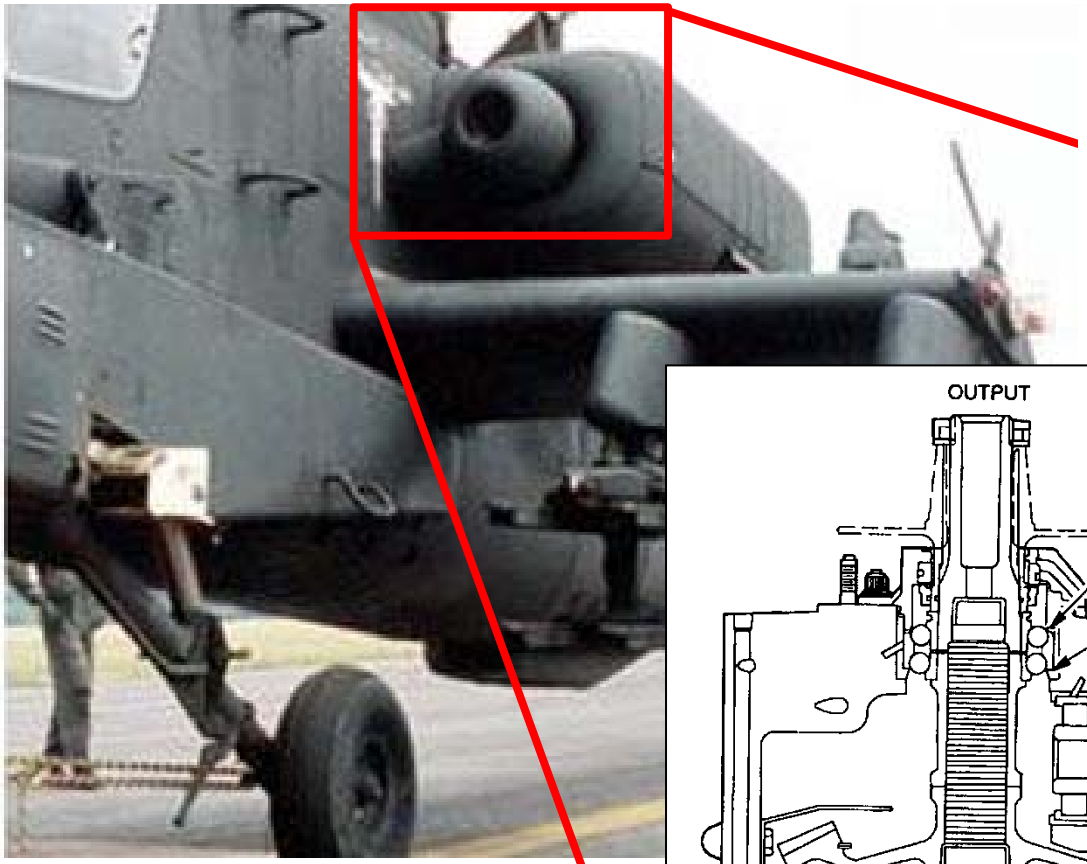
Analysis Develops A National Level Knowledge Foundation That Gives Actionable Information to Maintainers in the Field

Diagnostic Accuracy

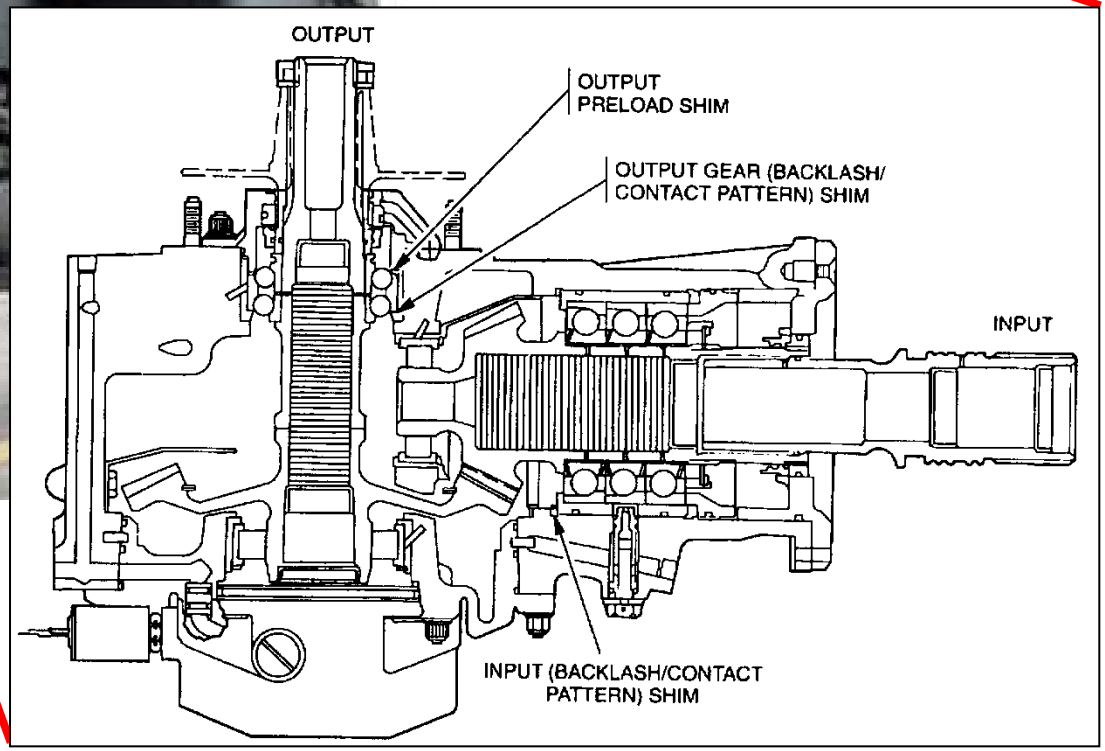
- Accuracy defined per ADS-79 and SAE 5783
  - Both true positives and true negatives identified correctly
  - Requires dedicated inspections and collection of data
- High accuracy enables all four CM objectives to be met
  - Reduction of cost and burden while increasing safety and availability



Apache Nose Gearbox

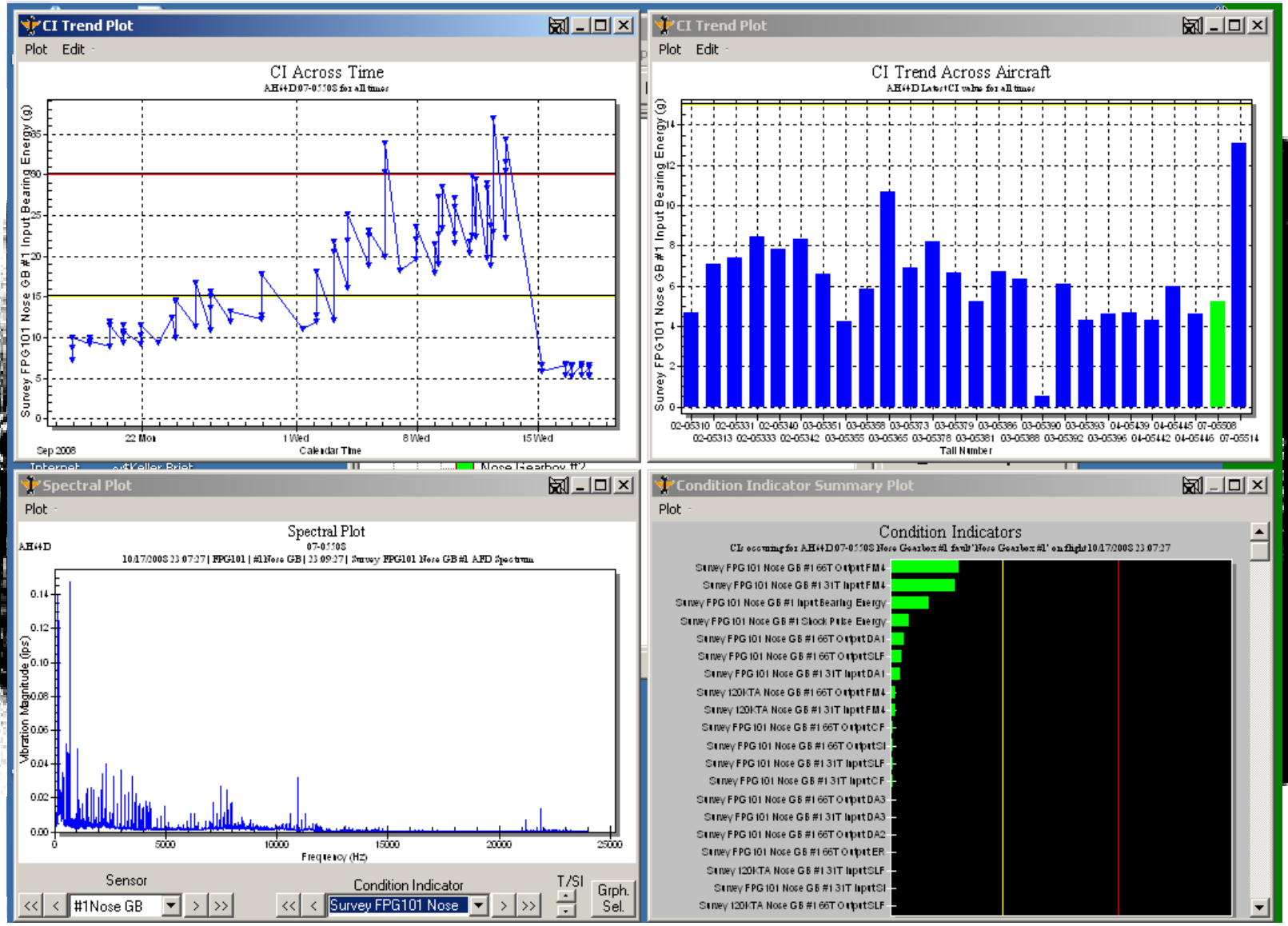


Spiral Bevel Gears
2.13:1 Gear Ratio
2 Roller Bearings
1 Duplex Ball Bearing
3 Single Ball Bearings



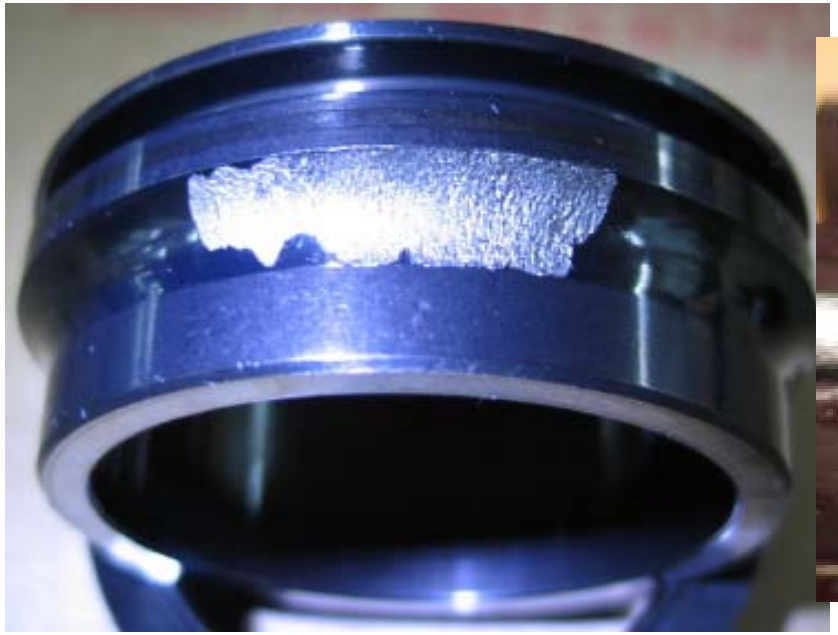
CM Systems:
Chip Detector (legacy)
Temperature (legacy)
+ Accelerometer (new)

Apache NGB Fault: Unit Level



Overhaul Results in Failure Database

- Depot Overhaul findings formally documented
  - “Input pinion gear and bevel gearshaft both scrapped due to excessive gear tooth damage. Output shaft duplex bearing had severe spalling on inner race. Input seal retainer was grooved. No other material defects found.”



Apache NGB Fault: Summary

- CM System correctly identified severe fault
  - Legacy chip detector and temp probe did not
- Unit performed opportunistic maintenance
  - Reduced downtime as much as possible
  - Avoided eventual in-flight chip light & precautionary landing
- CBM Goals met?

✓ Increase Availability - Opportunistic maintenance
No waiting for parts
Avoided PL

✓ Reduce O&S Cost - Avoided recovery operation
Eventual goal to signal removal while asset is still economically repairable

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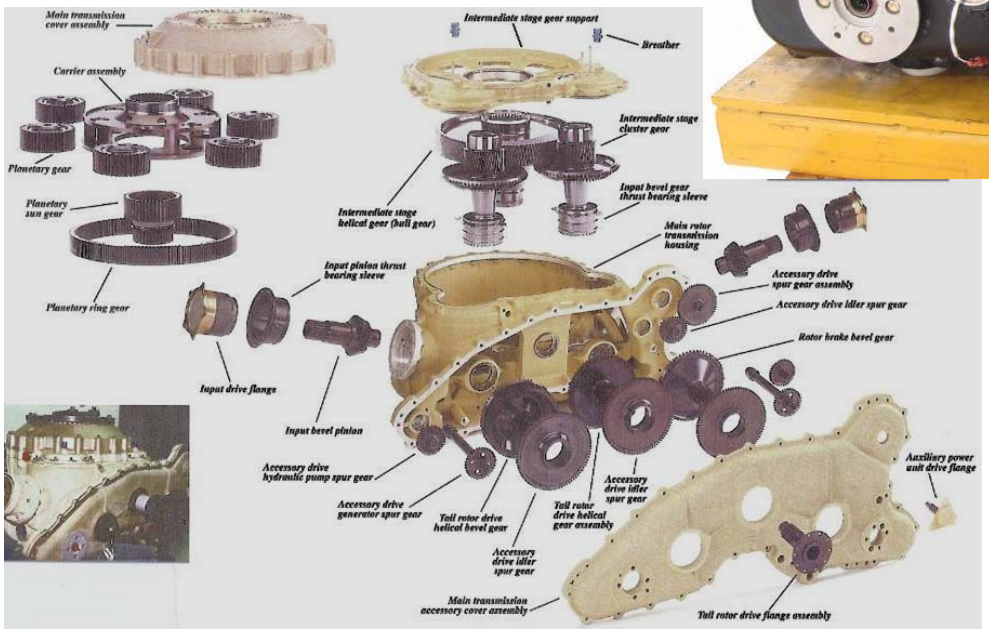
Apache Main Transmission

- Single stage planetary system
- Aircraft accessories driven by engines or APU (ground ops)

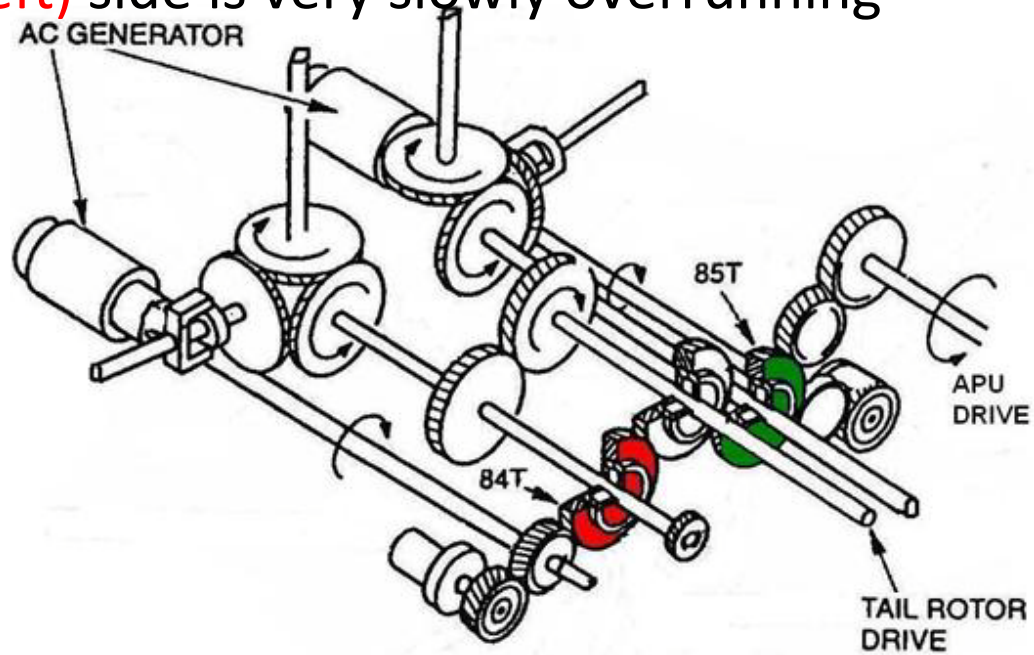


Necessitates 5 clutches

2 engines
1 APU
1 Primary
1 Secondary

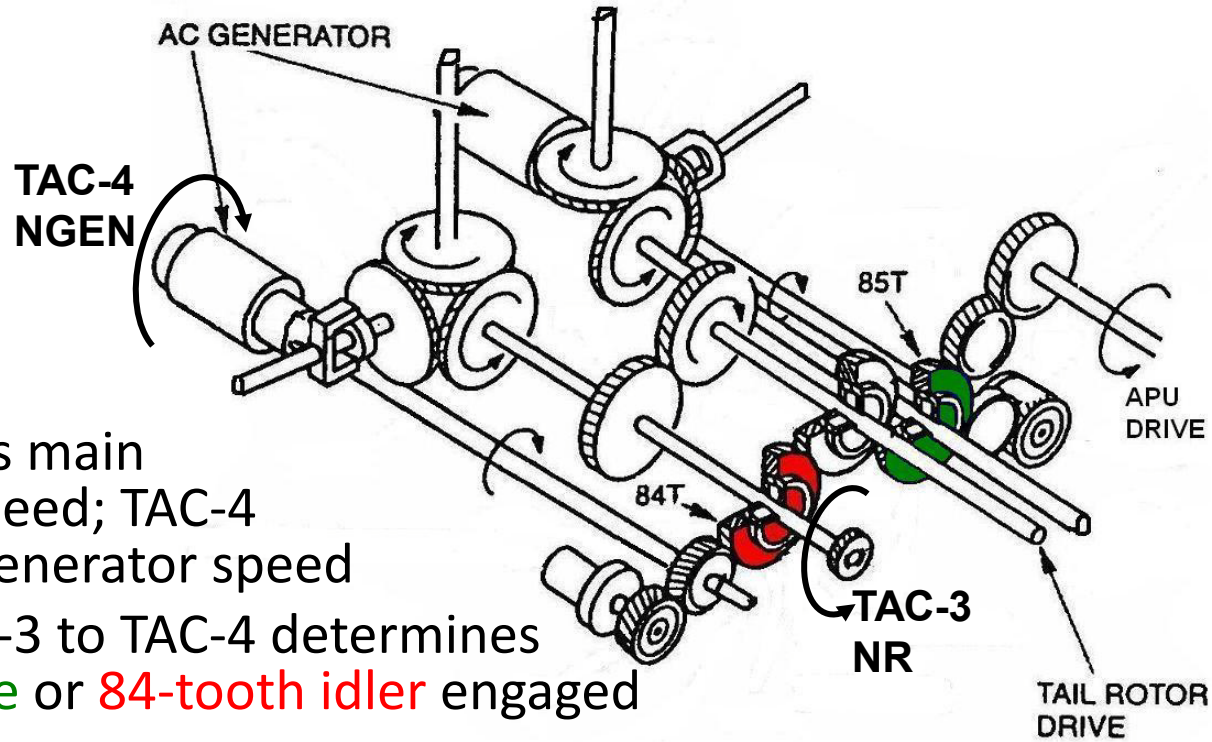
Apache Main Transmission

- Apache Main Transmission has two sprag clutches which transmit torque to the accessory section (generators & hydraulics) under APU or engine power
  - Under APU power, both clutches overrunning
  - Under engine power, the primary (right) side is engaged while the secondary (left) side is very slowly overrunning



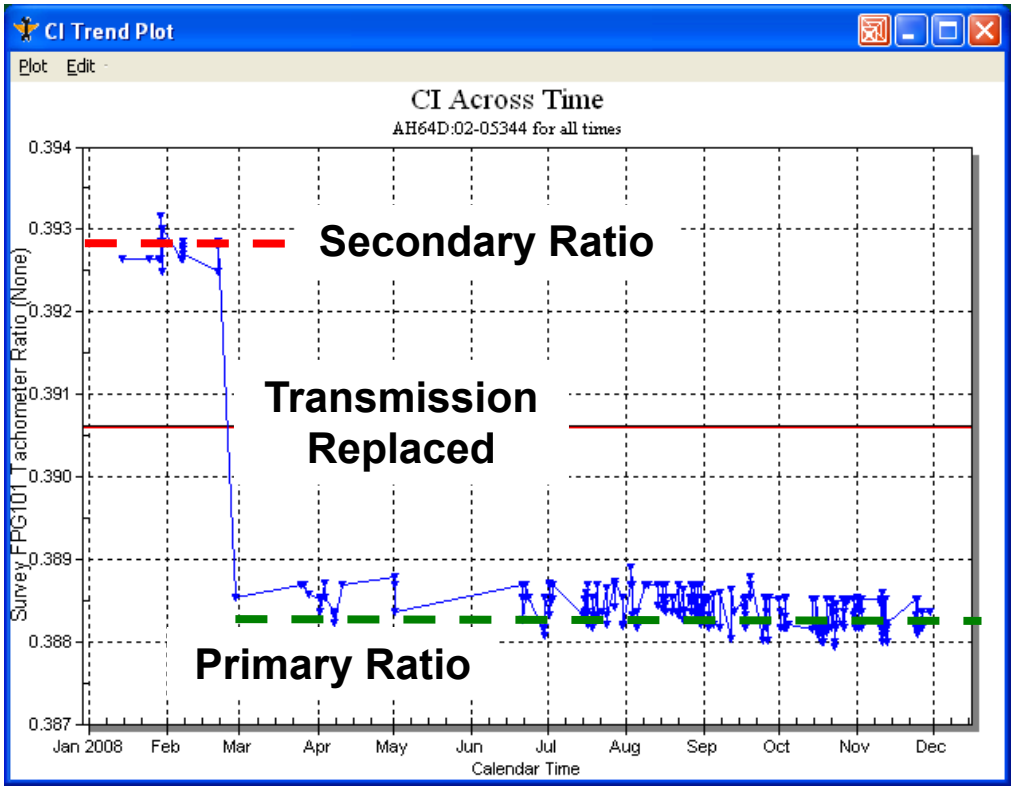
Diagnostic Approach

- The accessory drive gear has 85-teeth while the accessory idler gear has 84-teeth
  - AC Generators turn at different speed (just 1.2%) depending on which clutch is engaged; but, the speed of main body is constant
  - TAC-3 measures main transmission speed; TAC-4 measures AC Generator speed
  - Comparing TAC-3 to TAC-4 determines if 85-tooth drive or 84-tooth idler engaged



Field Results

- CM system indicated failure of primary clutch
  - Unit confirmed via manual check on ground that the secondary clutch was engaging
- Unit removed & replaced the xmsn
- Operating on primary for 9 months



Overhaul Results in Failure Database

- Transmission torn down & inspected at Boeing Mesa
  - Overhaul records transmitted to Army
  - Transmission recently overhauled (36 hours TSO)
- Built incorrectly with two 84T secondary gears
  - Evidence of “Ping-ponging” was found
  - Conservative (worst-case) estimate of remaining clutch life was 54 and 141 hours left out of 1000 hours published life
  - Equates to using ~90% of clutch life in only ~4% of operational time

Apache Sprag Clutch: Summary

- CM System correctly identified installation fault

- CBM Goals met?
  - ✓ Increase Safety – Dual clutch failure potential Class-A
  - ? Intangible – Depot overhaul procedure improved
    Has led to service life extension program for clutch, potentially doubling overhaul interval for main transmission

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CBM Benefits Measured

- 160th Special Operations MH-47G

	FY08	FY09
Mission Capable	70%	86%
Non-Mission Capable	30%	14%
Mean Time Between Maintenance Actions	46 hours	53 hours
Unscheduled MMH	71	66

51 MH-6M

Light Assault
Light Attack
Armed Recon
(Reconfigurable)

72 MH-60M

Medium Assault
Medium Attack
C2
(Reconfigurable)

61 MH-47G

Heavy Assault
C2
Resupply
(Reconfigurable)

Reduced MTF hours for RTB by 80%, reclaiming approximately 300 MH47 flight hours resulting in increased combat power equaling an additional MH47 on the battlefield

Ref: Blasey, S. "Integration of HUMS into the SOAR(A) Rotor Wing Fleet," AHS CBM Conference, Feb 2011

CBM Benefits Measured

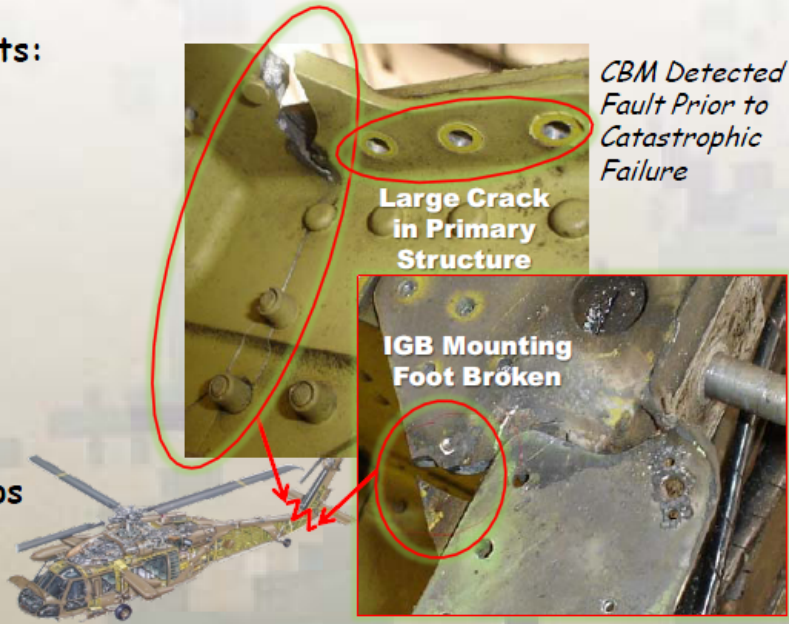
- **Decrease in Maintenance Cost & Soldier Burden**
  - Maintenance Test Flight Reduction 1-4%
  - Over 125 Maintenance Procedures Improved or Eliminated

Return On Investment

41 UICs of Data ~700 Aircraft

Platform (# BNs)	Parts Costs per FH (FY07-FY09) Non-CBM	CBM	Difference	Difference
UH-60 Black Hawk A/L (19)	$2,823.89	$2,366.86	($457)	-16.2%
AH-64 Apache (18)	$3,656.88	$3,210.51	($446)	-12.2%
CH-47 Chinook (4)	$4,189.14	$3,230.72	($958)	-22.9%

- **CBM-equipped Fleets Have Lower Class IX Parts Costs:**
  - UH-60: 16.2%
  - AH-64: 12.2%
  - CH-47: 22.9%
- **Gains in Readiness/Combat Power:**
  - Experienced 3.8%-12.4% NMCM Reduction
  - 1 Less Mission Abort Per 100 Flt Hrs
  - 5-8% Increase in Readiness
  - For Every 20 CBM-Equipped Aircraft, 1 More of Them Available for Missions
- **Enhanced Safety – Avoided 3 Class A (Major) Mishaps**
  - Fully Equipped CBM Fleet Could Have Reduced Mishaps (Class A-E) By 9-12% From FY02-08
  - Predicted To Avoid 11-12 Additional Class A Mishaps Over Next 10 Years



CBM Detected Fault Prior to Catastrophic Failure

Ref: Smith, C. "US Army Condition Based Maintenance," AHS CBM Conference, Feb 2011