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Structural Health Management: A Rotorcraft OEM Perspective

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Sikorsky Aircraft Corporation (SAC)

10th International Workshop on Structural Health Monitoring

Palo Alto, CA

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OUTLINE

- Aircraft Health Management Vision
- HUMS/IVHMS Evolution and Current Capability
- SAC Experience with SHM
- SHM Assessment & Transition Challenges
- Mechanical Diagnostics Analogy
- Thoughts on a SHM Transition
- Concluding Remarks

SAC HEALTH MANAGEMENT VISION

Eliminate Unscheduled Maintenance

Optimize Scheduled Maintenance

Focus Troubleshooting & Reduce False Removals

Maximize Detection Time Before Failure

Enhance Safety

SAC HEALTH MANAGEMENT EVOLUTION

S-61™

S-76C++™

S-92®

CH-148

CH-53E

UH-60A,L,M

CH-53K

VXX

SAFETY

MAINTENANCE & TROUBLE SHOOTING

CONDITION BASED MAINTENANCE

SAC HEALTH MANAGEMENT SYSTEM

Customer

Sikorsky

S-92® Operators

HUMS Collected Data

MFD

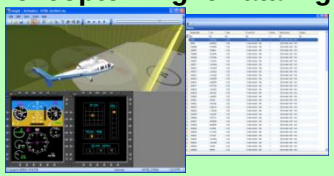
Ground Station

Drivetrain Diagnostics

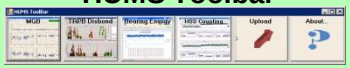
Exceedance Display

Rotor Track & Balance

Helicopter Flight Data Mgt.



HUMS Toolbar



HUMS/Maintenance Data & Field Events

Data Transfer Multiple time a day

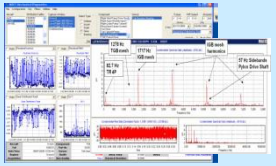
Proactive Support

Web Portal

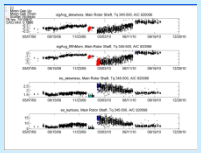
KDT

CI Box Plot

MDAT



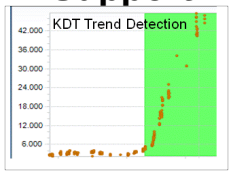
Matlab



Value: new tools, maintenance credits, etc.

New HUMS Tools

Pro-Active Support



Retirement Time Adjustment

S-92 Hub

S-92® HUMS

Ten years of maturation and value

Over 250+ aircraft monitored

~750,000 Flight Hours
10GB+ data daily

Analysis & Tool Development

Web Portal

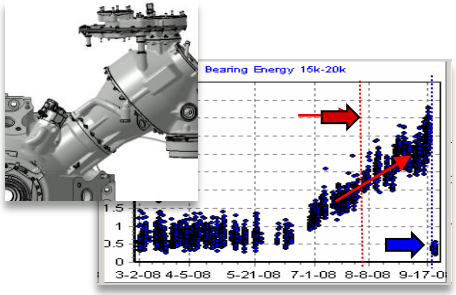
SAC Ground Based App

KDT

Part Tracker

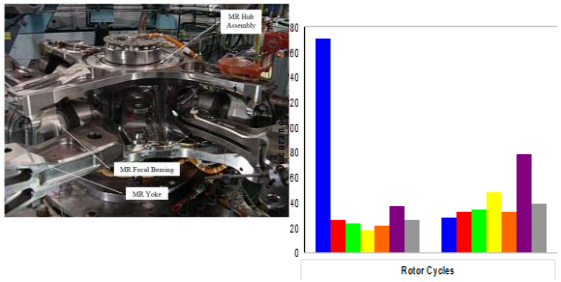
Downtime Avoidance

High-sensitivity vibe analysis enabled early detection and proactive response.



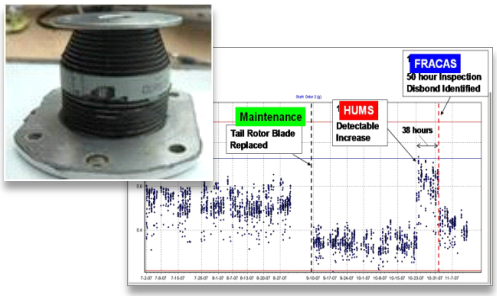
Extended Time-on-Wing

Leveraged S-92® Main Rotor Hub life adjustment to gain additional retirement time adjustment credits



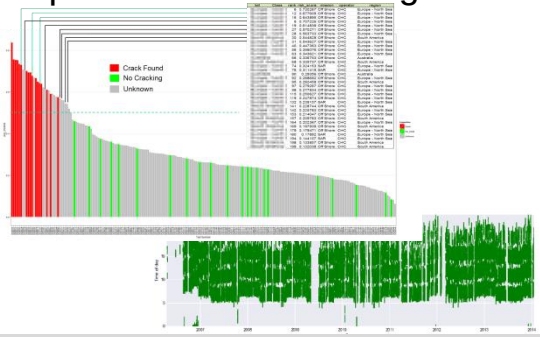
New Detection Capability

Isolated vibe-signature of previously undetectable pivot bearing issue and enabled software enhancement



Decision Support

Data mining and analysis to understand field issues and improve decision making



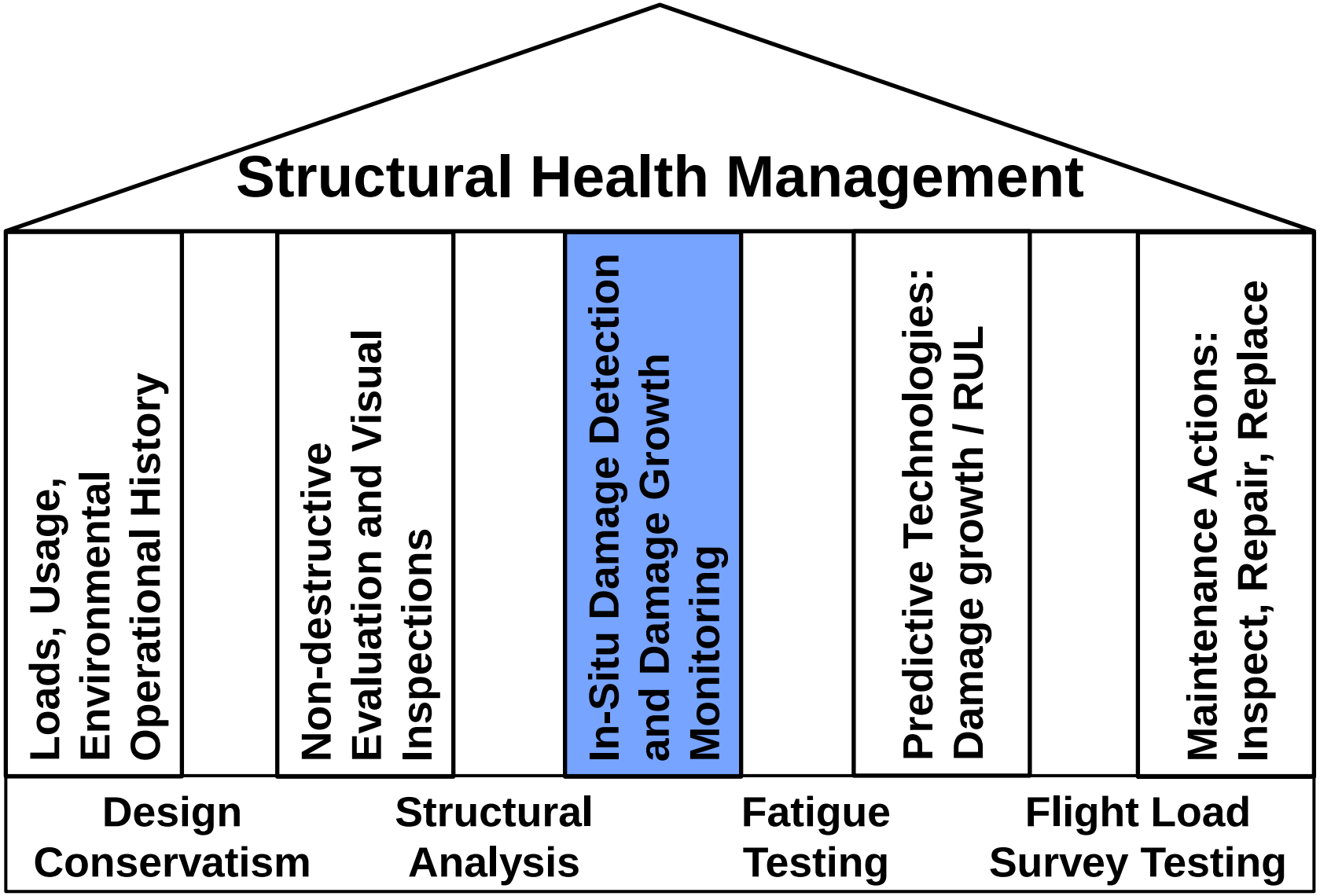
WHAT IS SHM?

Common Perspective: Structural Health Monitoring
Technologies required to detect, isolate, and characterize structural damage (e.g., cracks, corrosion, FOD, battle damage). Typically synonymous with monitoring of airframe structural damage.

SAC Perspective: Structural Health Management
Holistic cradle-to-grave approach to ensure aircraft structural integrity, safety, and reliability through optimized balance of

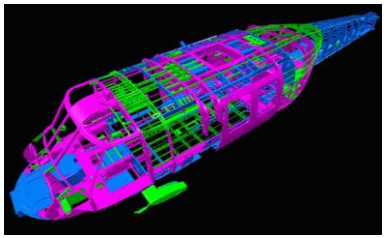
- design conservatism;
- monitoring of usage, loads, and structural damage;
- fleet management of flight critical components
- certification of SHM enabled condition-based maintenance (CBM).

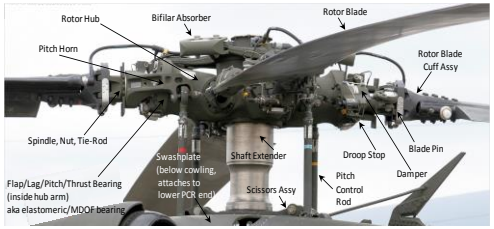
STRUCTURAL HEALTH MANAGEMENT

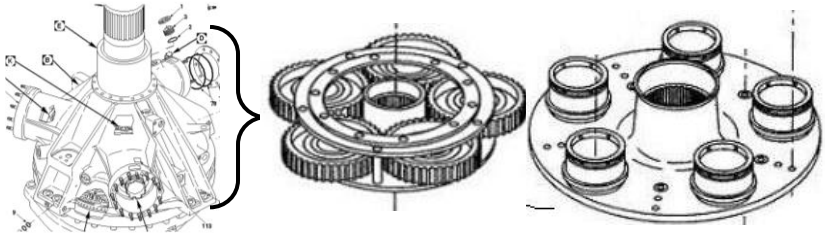


ROTORCRAFT SHM CHALLENGES

Variability and Complexity of Physics of both Probabilistic & Random Failure Modes

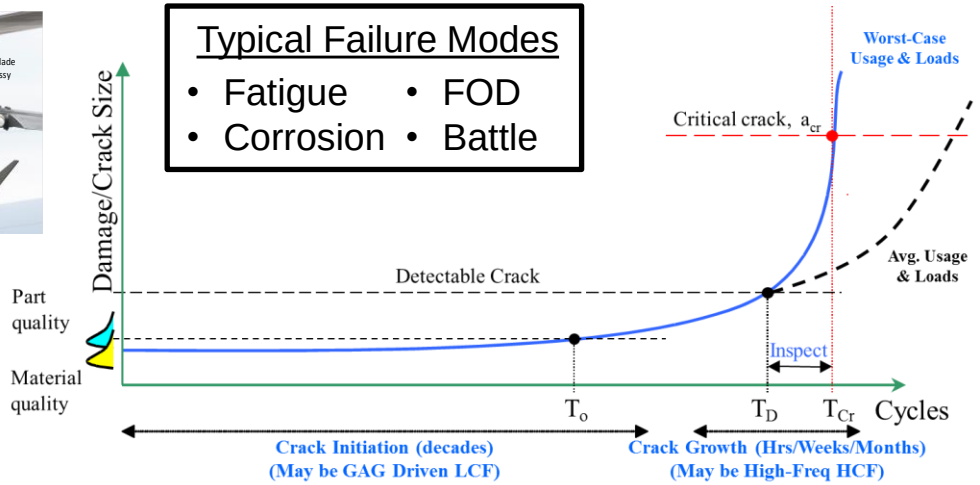






Typical Failure Modes

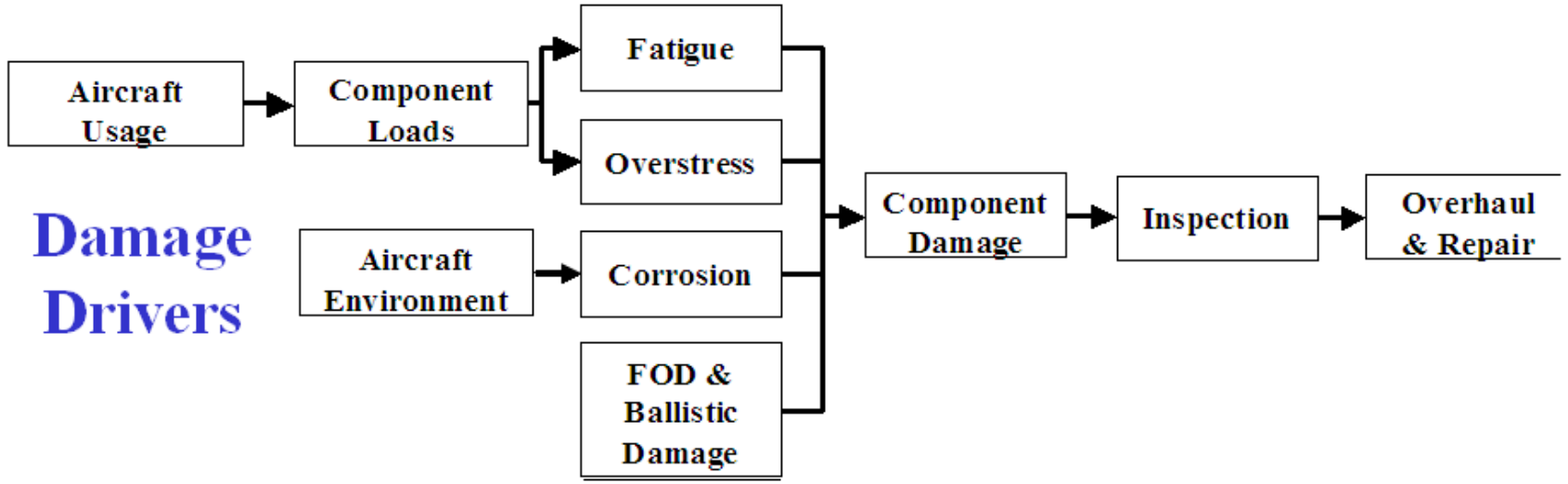
- Fatigue
- Corrosion
- FOD
- Battle

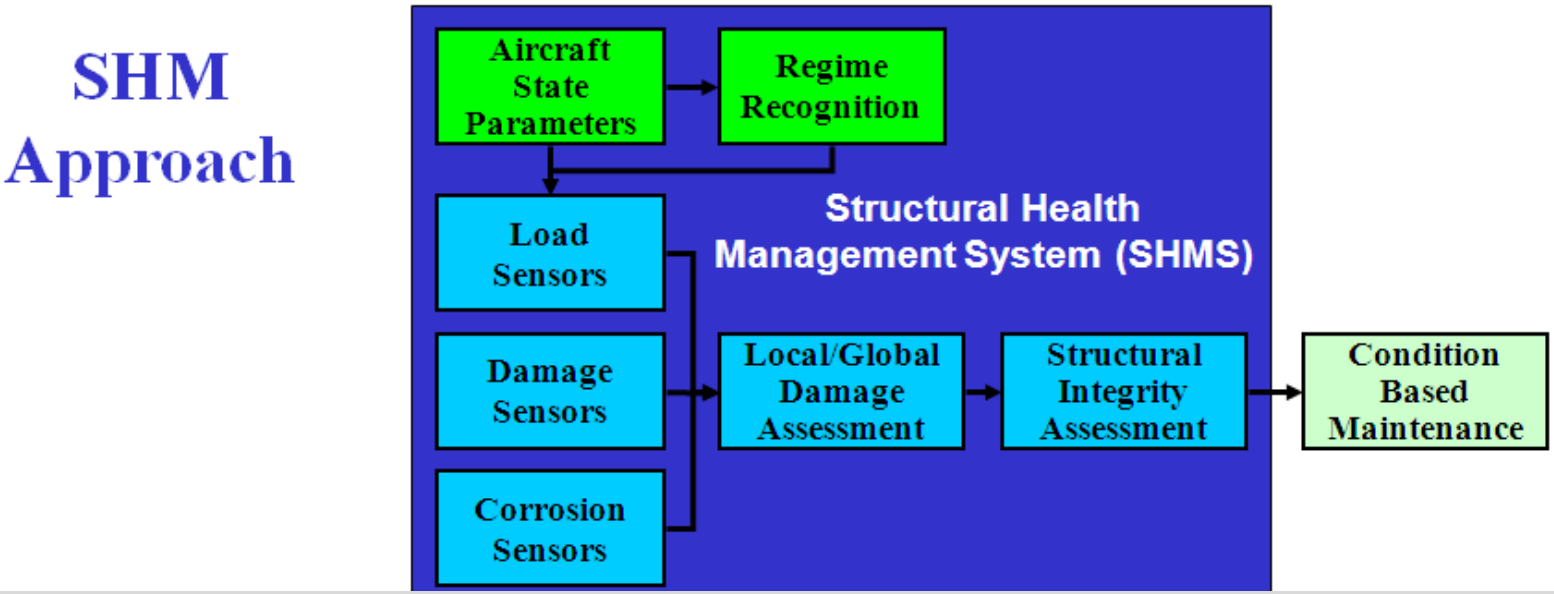


Variability of Operational Usage & Loads

Variability of Operational & Maintenance Environments

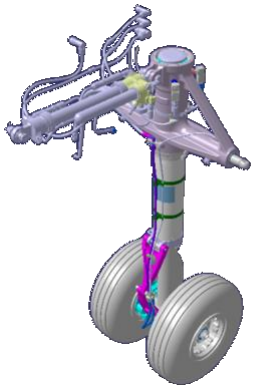
HOLISTIC SHM APPROACH





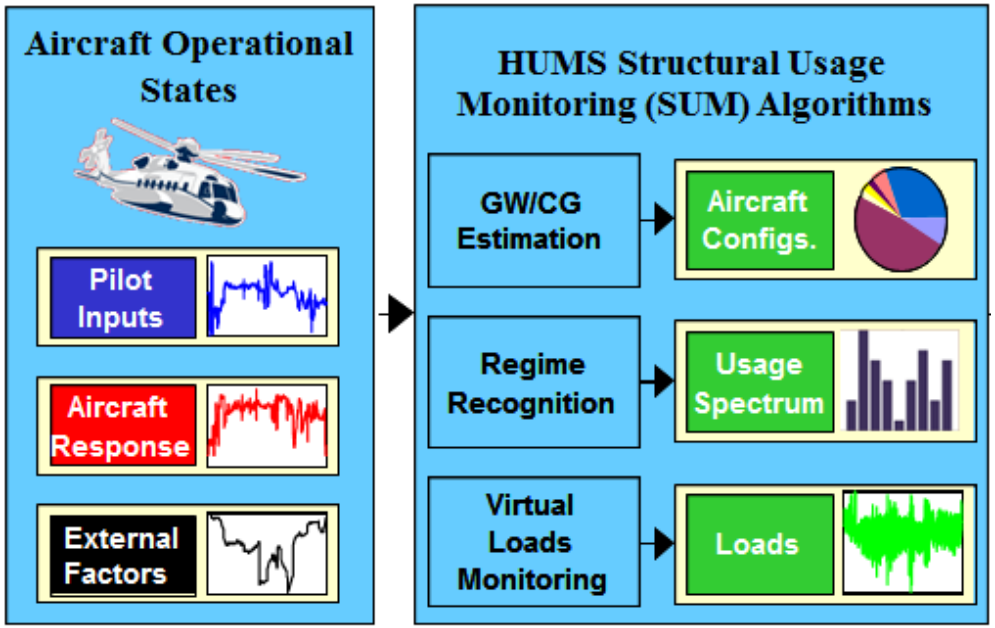
USAGE/LOADS MONITORING

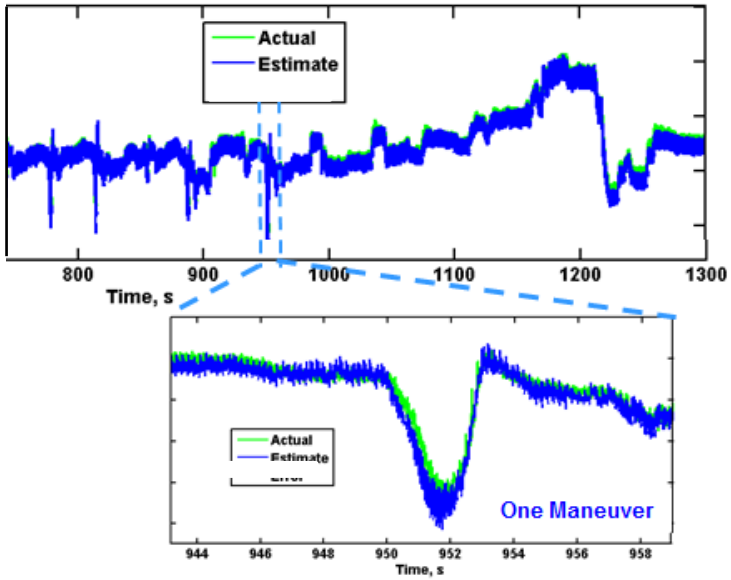
Example Key Physical Sensors





Virtual Structural Usage/Loads Monitoring

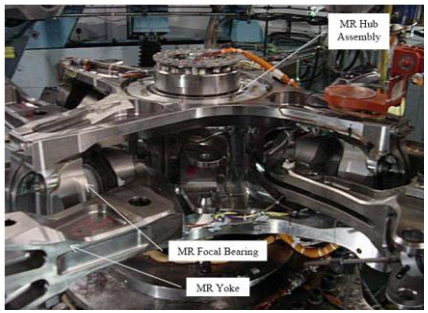


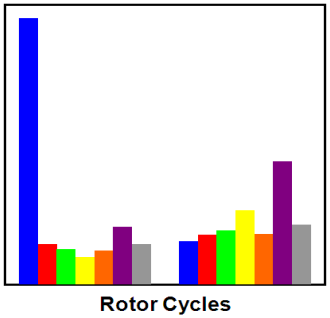


SAMPLE S-92® A/C BENEFITS

LLP Retirement Extension (Serial #)

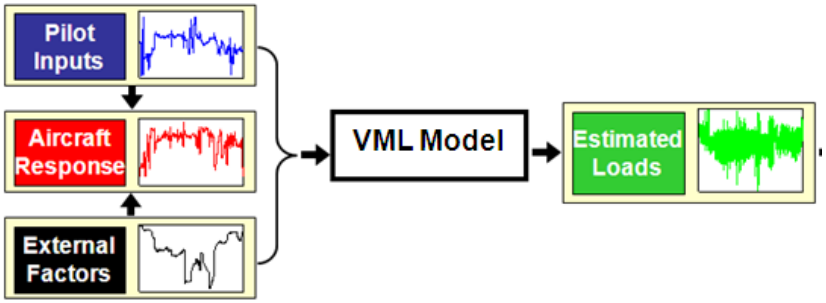
- FAA approved S-92® main rotor (MR) hub life extension based on MR rpm GAG
- Average benefit of 50% one-time CRT extension calculated from first 20 fleet hubs

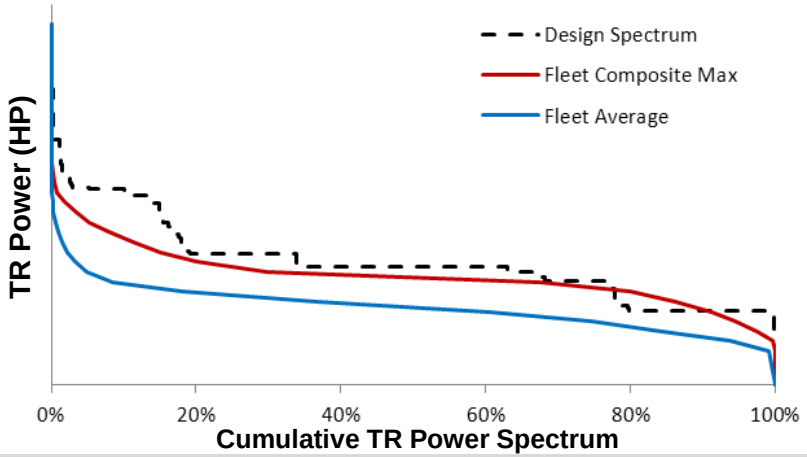




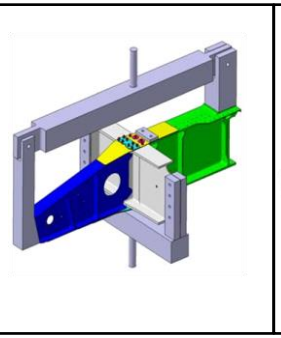
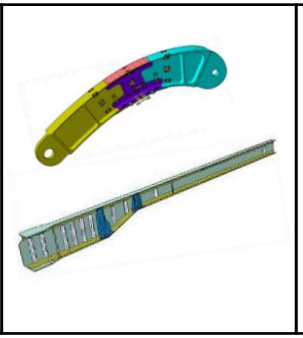
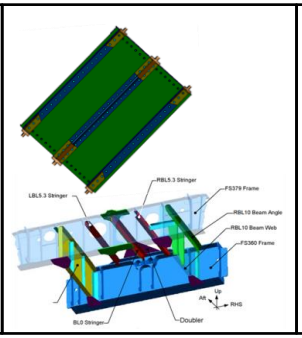
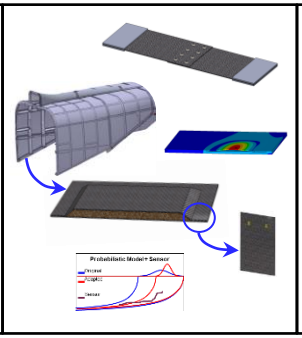
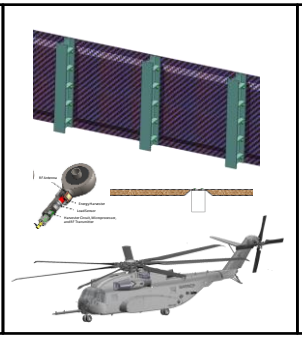
Fleet Spectrum Update (Part #)

- Virtual Monitoring of Loads (VML) used to calculate TR torque from 500kFH HUMS data
- Load statistics used to revise usage spectrum ➔ 3.25X retirement time
- Same approach can be used for serial # credit





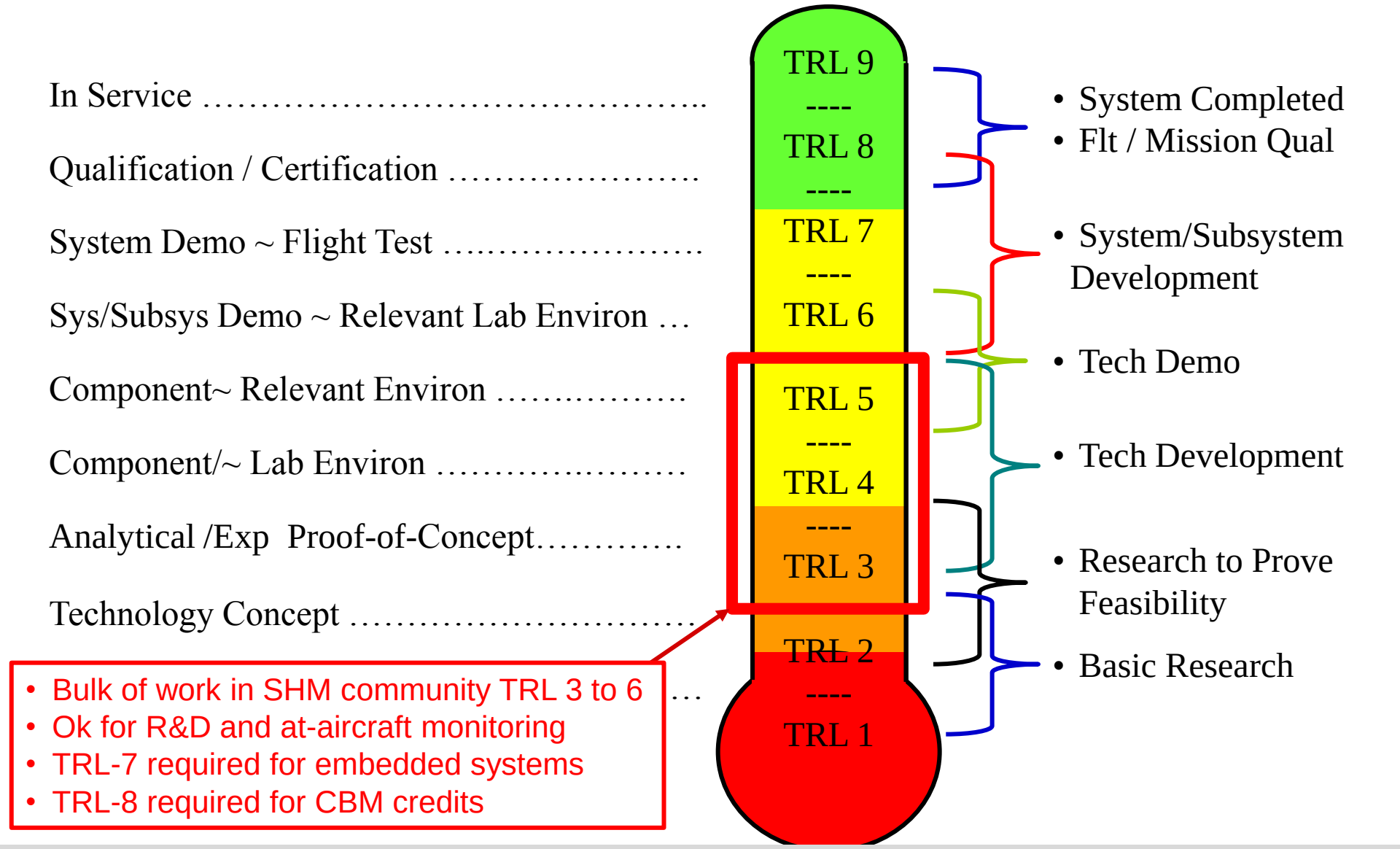
SAC SHM TECH DEVELOPMENT PROGRAMS

SIMS	IRDT	COST-A	RDDT	IHSMS	ASTRO
2006-9	2008-10	2010-14	2010-13	2012-17	2013-17
					
▪ Tech Assessment ▪ Challenge Problem Characterization ▪ Metal sub-components & PSE ▪ Damage detection sensing validation ▪ Load sensing evaluation ▪ Prognostic system architecture ▪ VML extension	▪ Metal PSE ▪ Damage detection sensing ▪ Damage growth modeling ▪ Damage tolerant design framework ▪ Limited composites ▪ VML application	▪ Focus on H-60 ▪ Metals only ▪ Damage, corrosion, & impact detection and quantification ▪ VML application ▪ Addresses structures, drives, & rotors ▪ On-board/off-board system integration	▪ Very focused on composites ▪ Local damage propagation modeling ▪ Integration of models with sensor feedback ▪ Coupon testing for correlation with models	▪ Focus on CH-53K composite aircraft ▪ Local / zonal damage monitoring ▪ Usage & loads monitoring ▪ Measure load changes on select primary structures due to damage	▪ Reduce over-maintenance of composite airframes – focus on “big damage” ▪ Estimate damage from fewer sensors ▪ Quantify effect of damage on load distribution and DT ▪ Multi-site Damage

SIMS → Structural Integrity Monitoring System
IRDT → Integrated Rotorcraft Damage Tolerance
COST-A → Capability-Based Operations Sustainment Technologies – Aviation

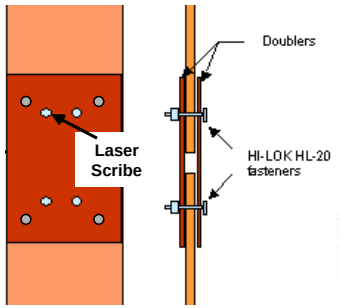
RDDT → Rotorcraft Durability and Damage Tolerance
IHSMS → Integrated Hybrid Structural Management System
ASTRO → Autonomous Sustainment Technologies for Rotorcraft Operations

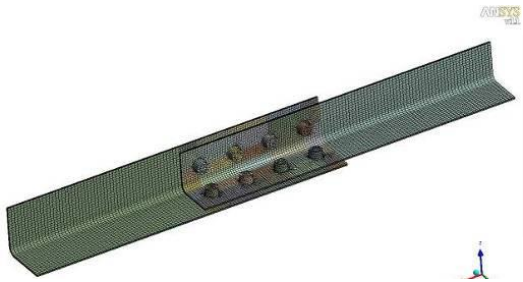
TECHNOLOGY READINESS DEFINITIONS

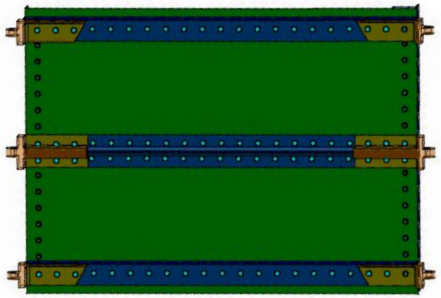


SAC SHM TRL PROGRESSION

Sub-Component (TRL 3-5)





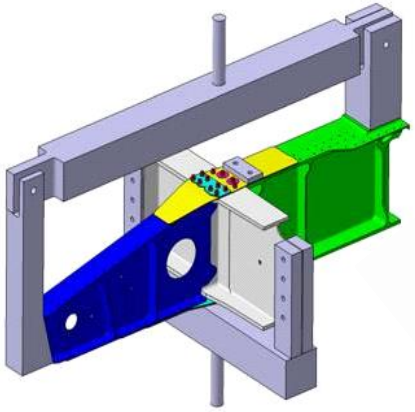


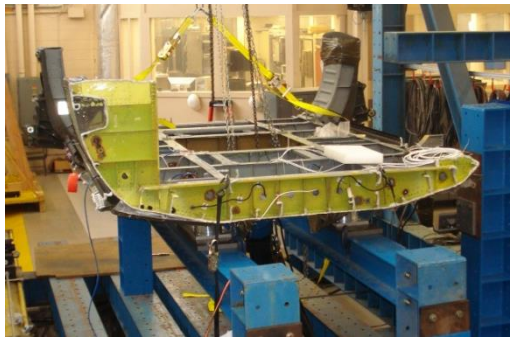
- Representative Features
- Lab transducers, DAQ, and processors

Doubler Joint **Angle Lap Joint** **Stiffened Bay Panels**

50-100 tests* **20-30 tests***

Full-Scale Primary Structural Elements (PSEs) & Sub-Assemblies (TRL 5-6)





- Full-Scale test articles
- Representative SHM hardware/software
- Software partially integrated with OBS/GBS HUMS/IVHMS

Beam/Frame Joint **Frame Splice** **Cabin Top-Deck Sub-Assembly**

1-5 tests* **1 test***

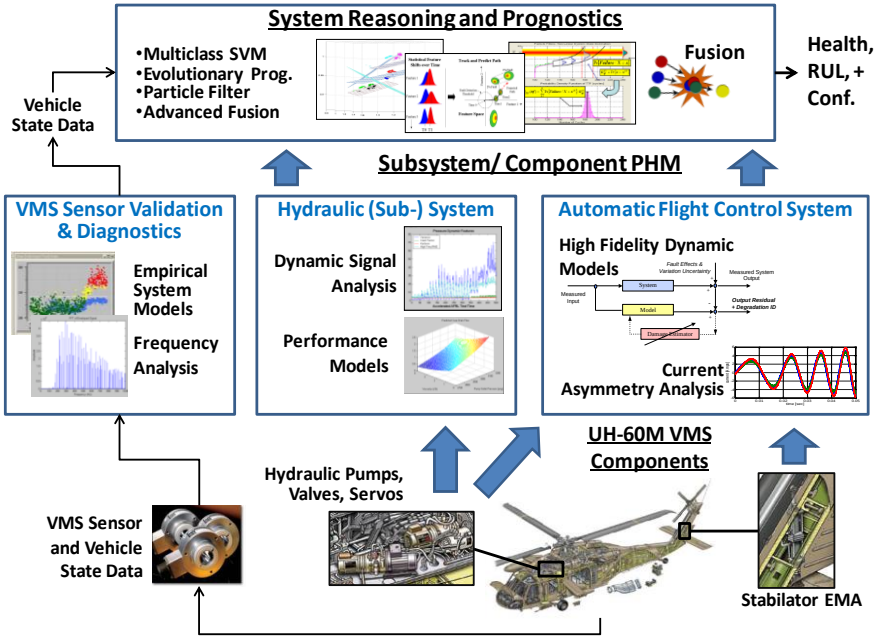
*** Rough number of tests that can be conducted for cost of one sub-assembly test**

CAPABILITY-BASED OPERATION SUSTAINMENT TECHNOLOGY – AVIATION (COST-A)

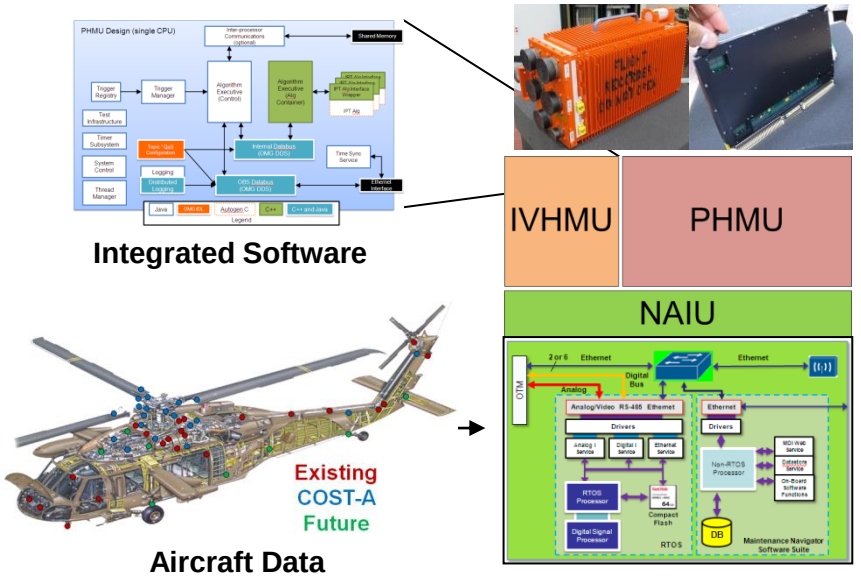
Objectives

- Mature and integrate embedded diagnostics and prognostics to decrease O&S costs by reducing maintenance and transitioning to Condition-Based Maintenance
- Demonstrate an integrated set of prognostic technologies across six focus areas: Propulsion, Drive, Structural, Rotor, Electrical, and Vehicle Management Systems

System/Sub-System-Level Reasoners



On-Aircraft Systems Integration



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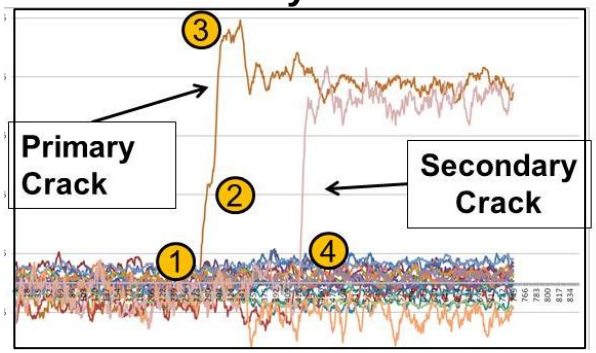
COST-A FULL-SCALE TESTING

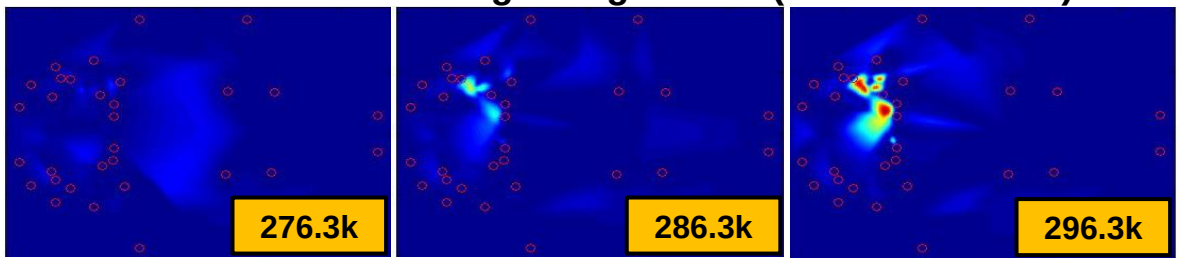
Local Eddy Current CI



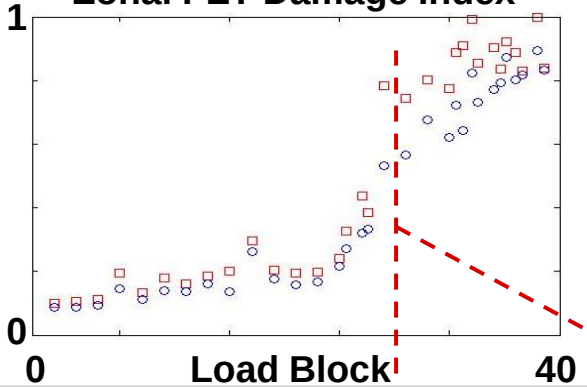
Point 1: 270k Cycles
Point 2: 276k Cycles
Point 3: 282k Cycles
Point 4: 291k Cycles

Top Deck Fatigue Test Article

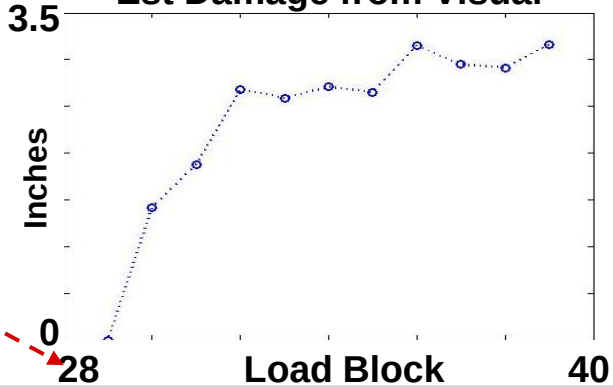
Zonal Direct Path Image Progression (20x30 inch area)



Zonal PZT Damage Index



Est Damage from Visual



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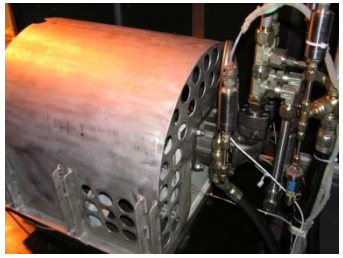
SHM MONITORING READINESS

- Individual SHM monitoring and diagnostic technologies have matured greatly over last 10 years. Leading technologies have achieved TRL-6+.
- Both local and zonal crack detection methods are ready for prime time under right circumstances.
- Significant transition challenges remain:
  - Lack of agreed upon reliability methods and certification requirements
  - Expense of validation and POD substantiation
  - Expense of integrating into legacy aircraft and/or need for new ground support equipment
  - Scalability to total aircraft monitoring
  - System productionization

MECHANICAL DIAGNOSTICS ANALOGY

- Similarities between SHM and Mechanical Diagnostics
  - Vibration is indirect, remote indication of gearbox faults
  - Cost of drive system seeded fault tests are prohibitive
  - Aircraft seeded fault tests typically not allowed
- Approach for developing condition indicators (CIs)
  - Identify CIs via physical understanding, modeling, rig test or fleet analysis
  - Substantiate feature performance via small-scale tests
  - Substantiate fault progression and feature performance via full-scale tests
  - Conduct controlled introduction to service



Component Tests

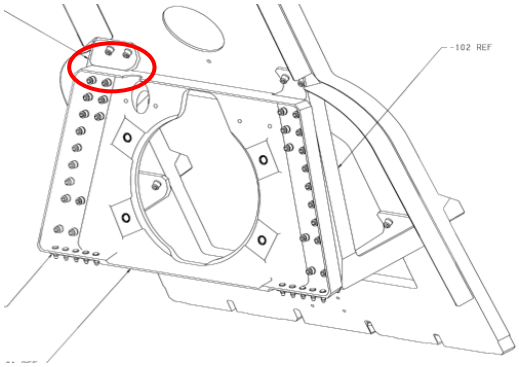
Full-Scale System Tests

Controlled Introduction to Fleet Service

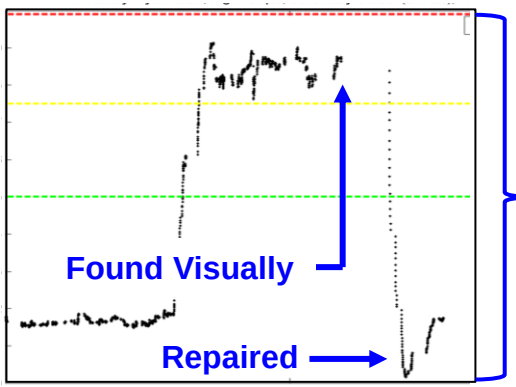
VIBRATION-BASED SHM EXAMPLES

Gearbox Support Crack Monitoring

Tail Pylon Gearbox Support Structure

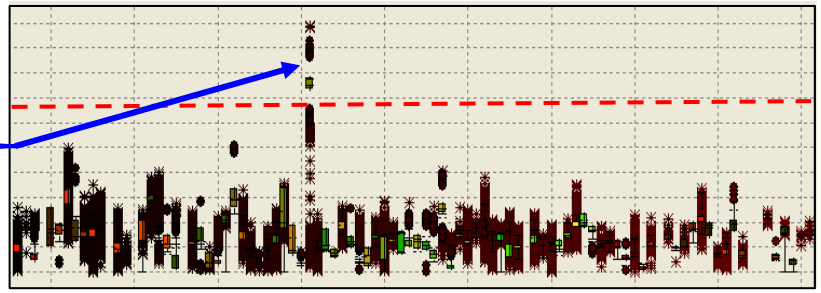


Vibration HI Trend



Time

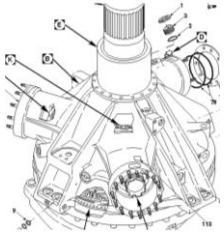
Fleet Comparison of Vibration CI



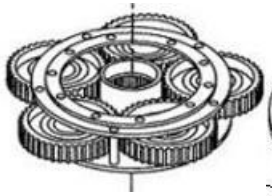
Aircraft Tail No.

Planetary Main Gearbox Carrier Plate (CP Crack Monitoring

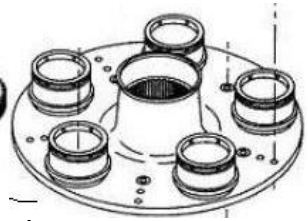
Main Gearbox



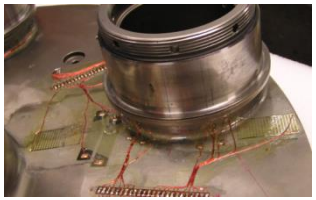
Planet Assembly



Carrier Plate

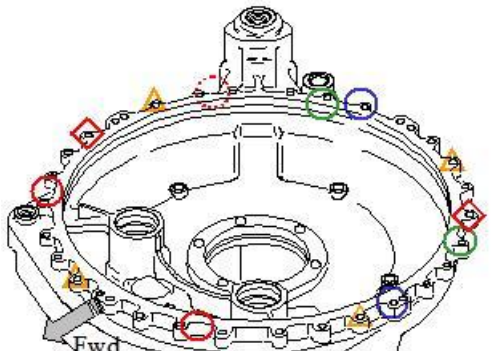


Seeded Fault Test



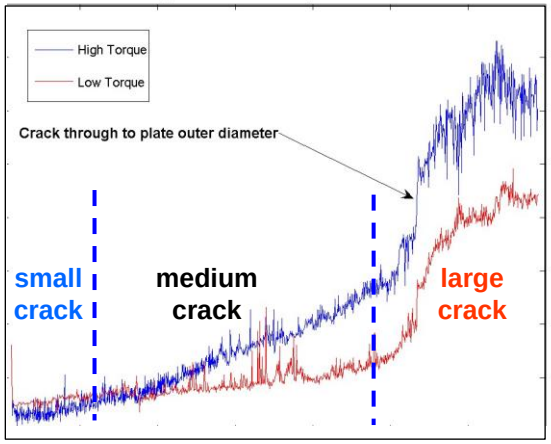
COTS Crack Gages

CP Crack Morphology



Candidate Accel Locations on Housing

Vibration HI Trend



WHAT CAN SHM COMMUNITY DO TO BE READY TO EXPLOIT NEXT TRANSITION OPPORTUNITY?

SHM Technology providers

- Leverage HUMS lessons learned
- Address technology challenges
  - Develop trendable SHM CIs and robust load/temp compensation algorithms
  - Develop methods for monitoring health of fail-safe SHM networks
  - Develop viable approach for substantiating POD and CI performance
  - Develop turnkey solutions that provides actionable info
- Develop list of applications for which technologies are truly transition ready

Aircraft OEMs

- Provide clear guidance on viable architectures and CONOPS
- Develop application specific approach(es) for certification
- Support SAE and regulatory agency efforts to develop unified guidance

HUMS OEMs

- Develop robust SHM interface(s) that can support multiple technologies

Regulatory Agencies and Airworthiness Authorities

- Support SAE efforts to develop unified guidance
- Solicit SHM community input into airworthiness guidelines

CONCLUDING REMARKS

- HUMS lessons learned and infrastructure are a solid foundation for SHM
- Most likely transition opportunity is fleet issue requiring frequent inspections during long design/dev/qual/retrofit deployment cycle
- SHM community must be positioned to respond quickly to next opportunity
- Once confidence is gained by OEM & airworthiness community, SHM will be powerful tool for reducing operator burden while resolving fleet issues
- Close collaboration between tech developers and OEMs on specific applications is required

CHANGING THE O&S PARADIGM