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A SURVEY OF HEALTH AND USAGE MONITORING SYSTEM IN CONTEMPORARY AIRCRAFT

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Abstract— **Health and usage monitoring systems (HUMS) is a generic term given to activities that utilize data collection and analysis techniques to help ensure availability, reliability and safety of vehicles. Activities similar to, or sometimes used interchangeably with, HUMS include condition-based maintenance (CBM) and operational data recording (ODR). In this paper, a Survey has been conducted on the present usage of H.U.M.S. in contemporary aircraft. The paper broadly explains the purpose, function, working principle, and the objectives of using HUMS in the Aircraft Industry.**

Index Terms— **Aircraft Recording and Monitoring System, Cockpit Voice Recorder, Flight Data Recorder, Rotor Track and Balance, Euro-fighter.**

I. NOMENCLATURE

A/C	Aircraft
ARMS	Aircraft Recording & Monitoring System
CBM	Condition-Based Maintenance
CI	Condition Indicator
CG	Center Of Gravity
COTS	Commercial Off-The-Shelf
CVR	Cockpit Voice Recorder
DAU	Data Acquisition Unit
DSC	Digital Source Collector
EF	Euro-fighter
EVM	Engine Vibration Monitoring
FAA	Federal Aviation Administration (USA)
FDR	Flight Data Recorder
HUMS	Health and Usage Monitoring Systems
IAS	Indicated Airspeed
IGB	Intermediate Gear-Box
ILS	Integrated Logistic Support
IPS	Inches Per Second
IVHM	Integrated Vibration Based Health Monitoring
MARMS	Modular Aircraft Recording and Monitoring System
MGB	Main Gear-Box
MSR	Mechanical Strain Recorder
RMS	Root Mean Square
RTB	Rotor Track and Balance
SHM	Structural Health Monitoring
SHMS	Structural Health Monitoring System
SO (*n*)	Shaft Order (*n*-1 harmonic)
TAT	Temporary Aircraft Tracking
TBM	Time-Based Maintenance
TDS	Tail Drive Shaft
TGB	Tail Gear-Box
VHM	Vibration Health Monitoring
VgH-	Recorder Velocity & altitude recorder
VMS	Vibration Monitoring System
WS	Weapon System

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II. INTRODUCTION

HUMS is a sensor-based monitoring system that enables preventative maintenance by measuring the health and performance of mission-critical components. This term **HUMS** is often used in reference to airborne craft and in particular rotor-craft – the term is cited as being introduced by the offshore oil industry after a commercial Chinook crashed in the North Sea, killing all but two passengers in 1986. By continuously monitoring aircraft flight data and vibration at numerous points throughout the drive-train and pinpointing mechanical faults before they become catastrophic failures, HUMS provides helicopter operators with actionable information that enables them to anticipate mechanical failures and make anticipatory maintenance decisions, before the issues arise. HUMS are now used not only for safety but for a number of other reasons including:

- Maintenance: reduced mission aborts, fewer aircraft on ground (AOG), simplified logistics for fleet deployment.
- Cost: "maintain as you fly" maintenance flights are not required. Performing repairs when the damage is minor increases the aircraft mean time before failure (MTBF) and decreases the mean time to repair (MTTR).
- Operational Requirements: improved flight safety, mission reliability and effectiveness.
- Performance: improved aircraft performance and reduced fuel consumption.

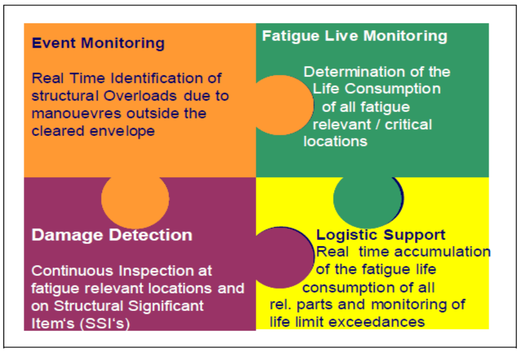

Figure 1: Purpose of S.H.M.

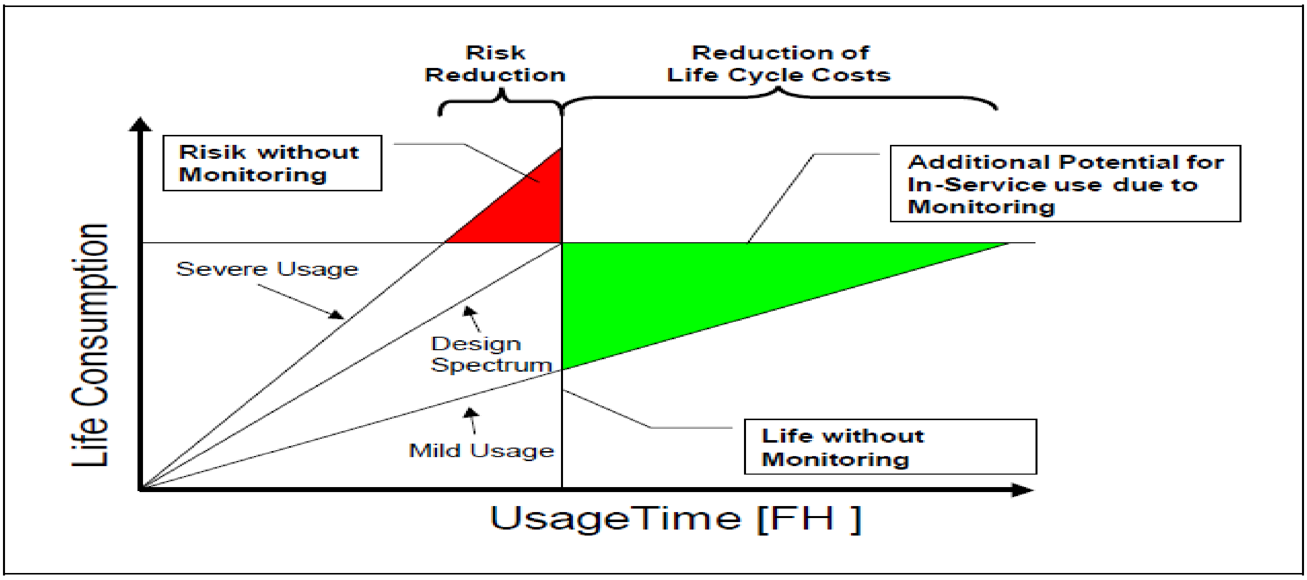

Figure 2: Benefit of Structural Health Monitoring.

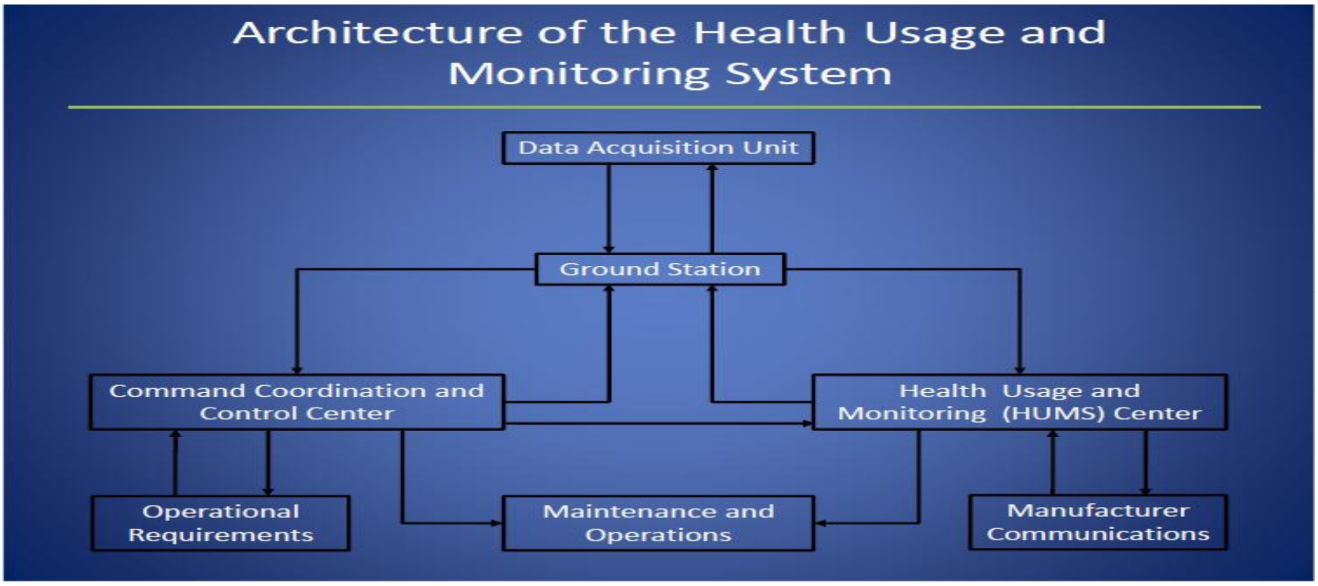

Figure 3:- Architecture Of H.U.M.S.

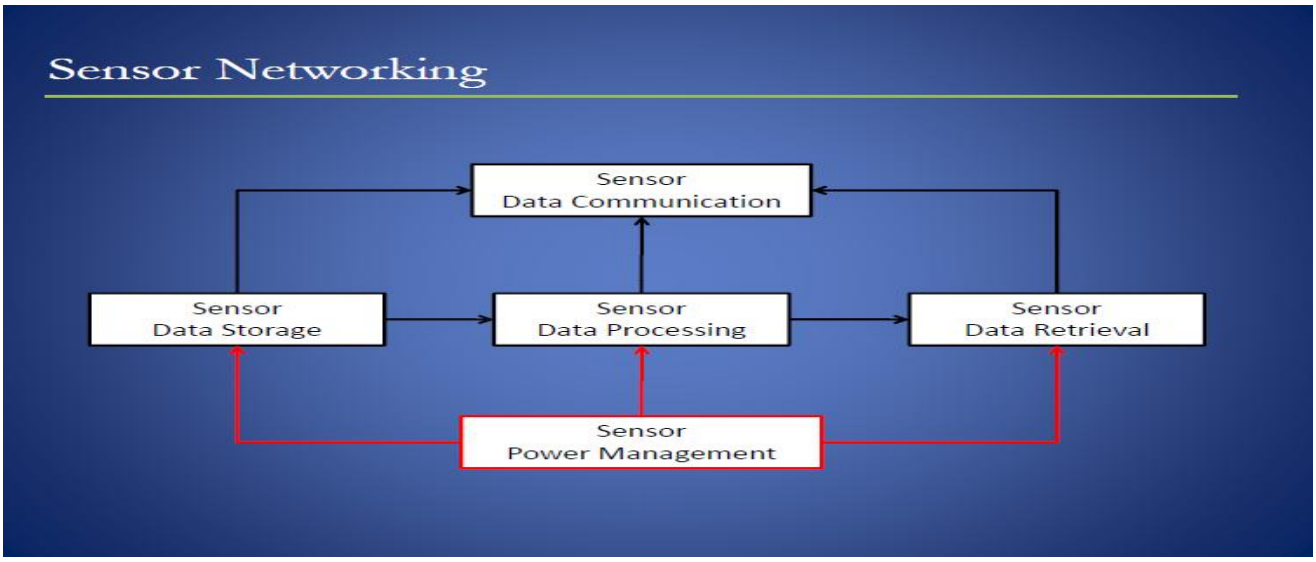

Figure 4:- Sensor Networking involved in H.U.MS.

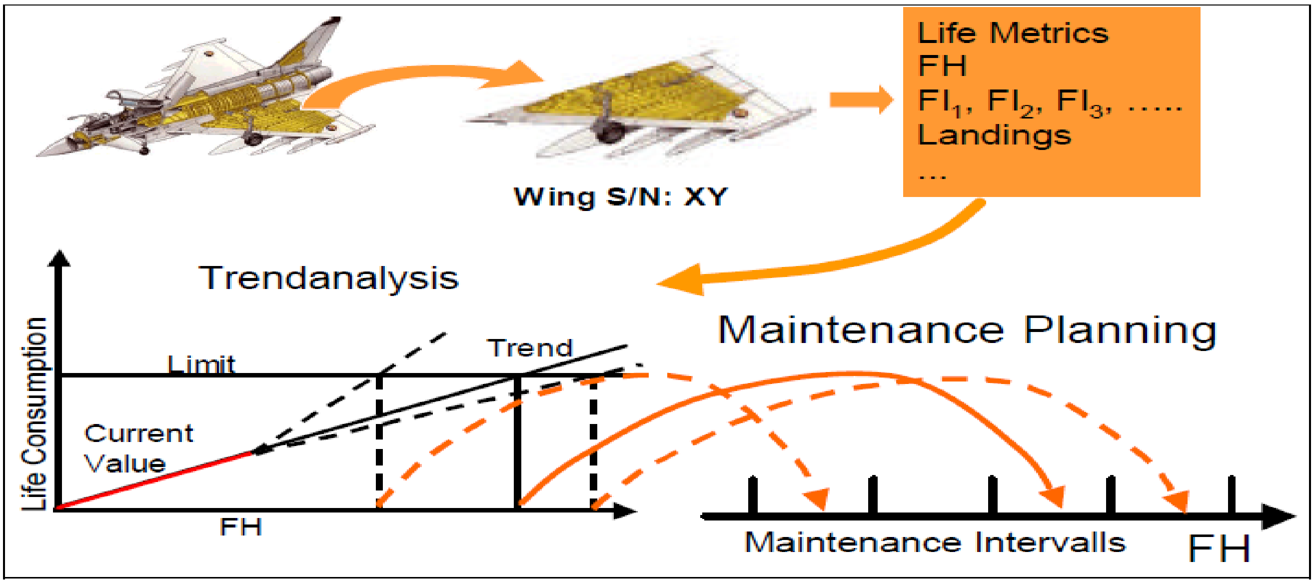

Figure 5 - Maintenance Planning.

III APPLICATIONS IN CIVILIAN AIRCRAFT

A. Application Examples

ENGINE MONITORING SYSTEMS: To accomplish the demanding task of monitoring fuel and oil status, indicators for quantity, pressure, and temperature are used. In addition to these crucial parameters, vibration is constantly monitored during engine operation to detect possible unbalance from failure of rotating parts, or loss of a blade, engine monitoring systems (EMS) have become increasingly standard in the last two decades. Any of these parameters can serve as an early indicator to prevent costly component damage and/or catastrophic failure, and thus help reduce the number of incidents and the cost of maintaining aircraft engines.

AIRCRAFT BLEED AIR CONTROL SYSTEM:
Current State Of Practice: Engine performance monitoring, a current trend in monitoring the gas turbine engine's day-to-day condition, is proving to be very effective in providing early warning information of ongoing or impending failures, thus reducing unscheduled delays and more serious engine failures. The goal is to have these performance parameters as a reliable indicator of developing defects and impending failures that are detected and repaired during inspection and overhaul.

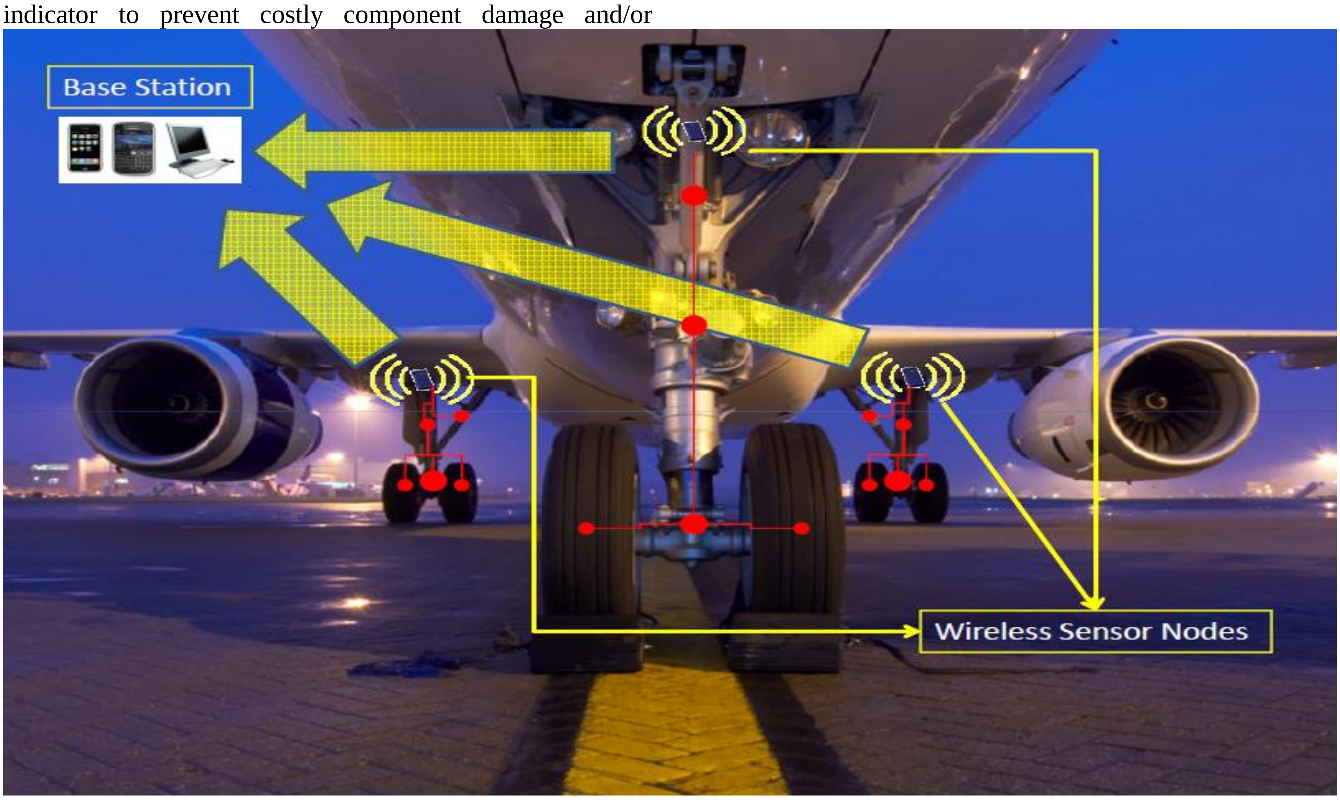

Figure 6: H.U.M.S. Sensor Positions in Landing Gear.

The Boeing approach to IVHM includes four analytical areas of concentration:

- diagnostics (identifying the root cause of a problem).
- prognostics (predicting system health with current and historical data).
- condition-based maintenance (basing maintenance on the material condition of the aircraft components rather than on flight time or worst-case scenarios).
- adaptive control (providing the means to complete a mission despite battle damage or system failures).

IV APPLICATIONS IN MILITARY AIRCRAFT

The Structural Health Monitoring (SHM) is an important requirement to handle military aircraft safety. In contrast with civil aircraft, the missions, configurations and environments changing frequently and therefore also the load spectra, which lead to a various life consumption. With structural health monitoring the actual life consumption of each individual aircraft based on the real loads will be determined. This is the basis for an economic and safety in-service operation of a flying weapon system.

This paper shows the current structural health monitoring systems and additional support systems, which are integrated within the German Air Force and discuss the benefits of these systems based on in-service experience.
HUMS technology has helped the U.S. military increase the availability and reduce maintenance costs of its rotorcraft fleet including the following:

- **A 66 percent reduction** of U.S. Air Force mission aborts due to vibration over five years.
- **71 CH-47 Chinook** helicopters avoided 2,957 maintenance man-hours from 2007 to 2008.
- **30 percent reduction** in mission aborts on AH-64 Apaches.

V NAVY

With 90% of the Total Life Cycle (TLC) cost occurring after aircraft delivery, achieving and sustaining this objective presents a great challenge to the entire Aviation Team, especially the engineering community. Better tools to accurately assess structural health and recommend appropriate maintenance actions at the proper time are essential to meet this technical challenge, while ensuring airworthiness for continued operations. The Structural Health and Usage Monitoring (SHUM) program is the cornerstone of our efforts to exploit the full fatigue life of our rotary wing aircraft while minimizing cost.

Navy SHUMS Roadmap:
Bell-Boeing also implemented the Vibration/Structural Life and Engine Diagnostics (VSLED) system on the V-22 tilt-rotor aircraft during production. In addition, the Navy has decided to incorporate newer and more capable usage monitoring systems on all CH-53E, UH-1Y, AH-1Z, and MH-60R/S aircraft.

It is the Navy's intent to install similar systems on all future aircraft as well.

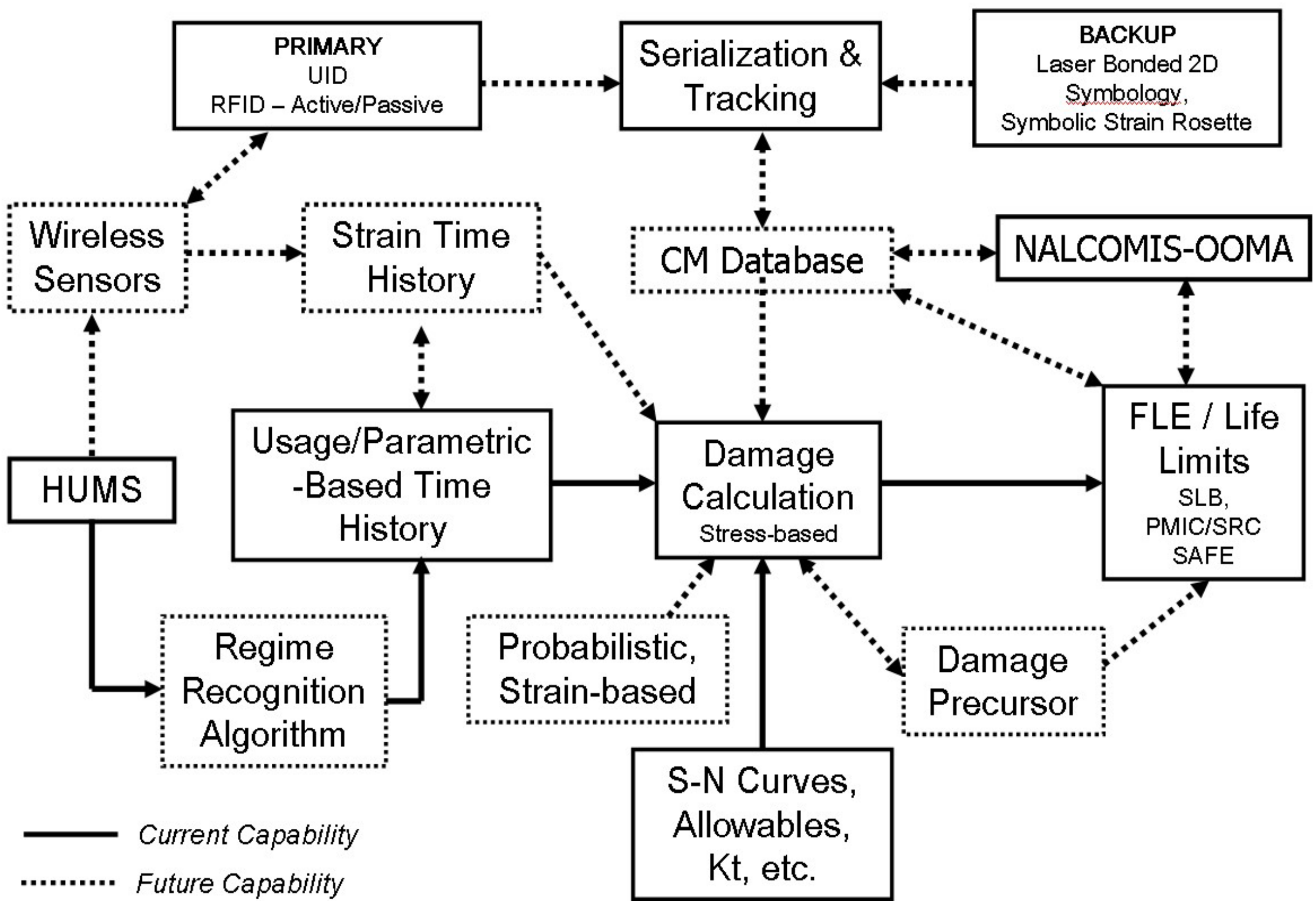

Figure 7: Navy SHUMS Roadmap.

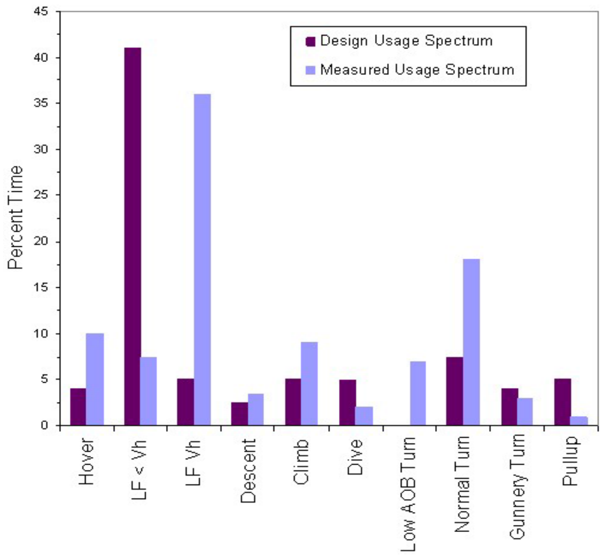

Figure 8: AH-1W Usage Comparison.

In the long term, coupled with the ability of tracking each aircraft and its components in near/real time, we also need better diagnostic and prognostic tools to assess the health of the aircraft's structural integrity and enhance our capability to determine what and when maintenance action is required. Figure 2 shows our proposed implementation concept for SHUM in order to achieve our long-term goal of Conditional Based Maintenance (CBM).

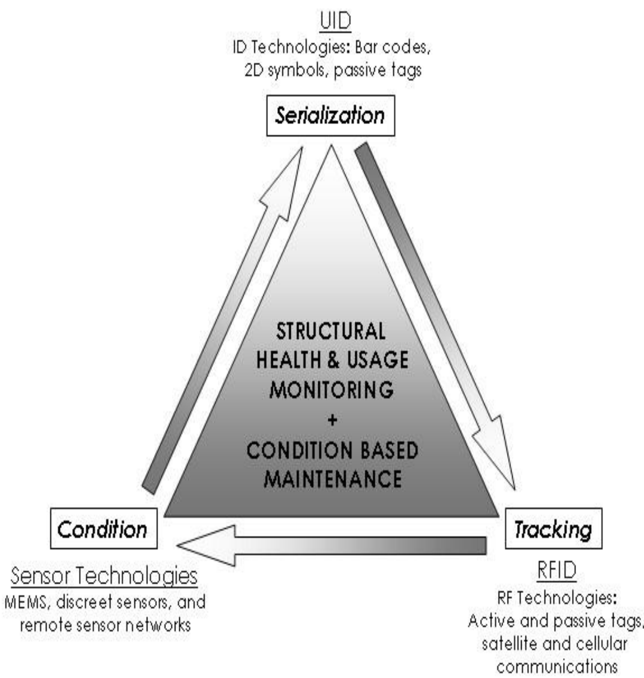

Figure 9: SHUM Implementation Concept.

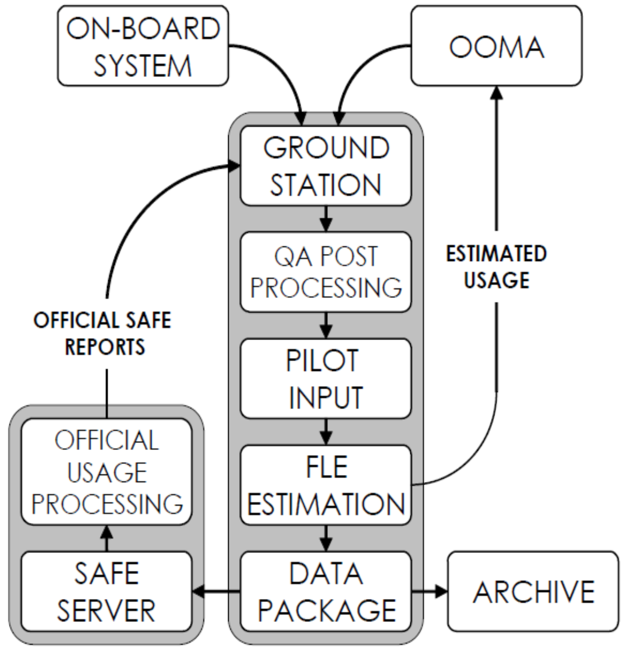

Figure 10: Data Flow for Structural Usage Monitoring.

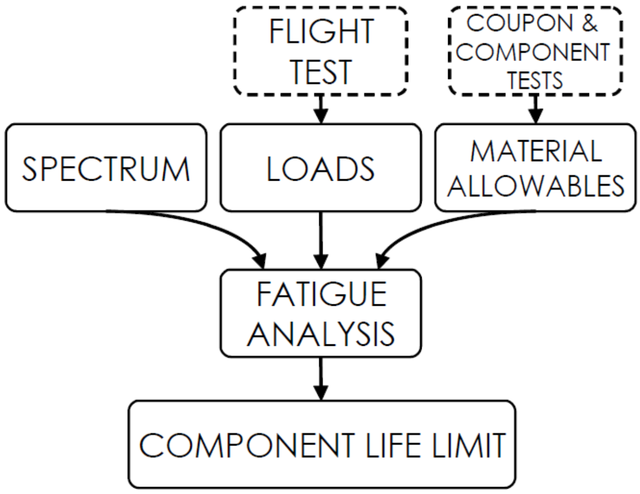

Figure 11: Basic Fatigue Life Methodology.

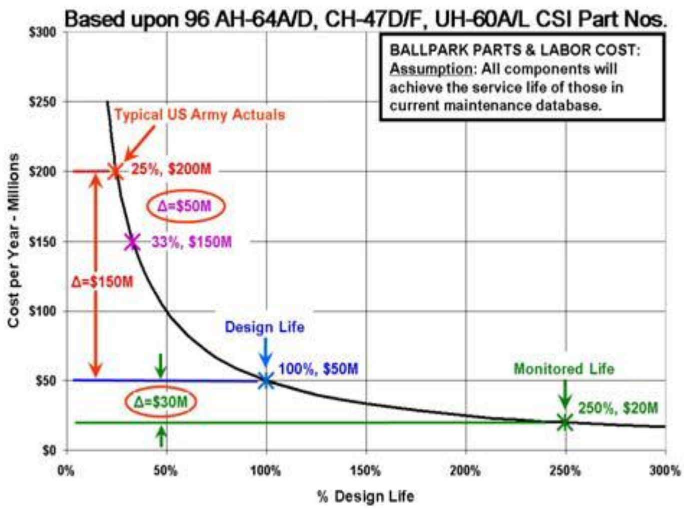

Figure 12: US Army Cost vs. Design Life

VI CONCLUSIONS

The Navy is proceeding full steam ahead with the implementation of structural usage monitoring for rotary wing aircraft and their dynamic components. The short-term plan includes tracking implementation on V-22 and CH- 53E aircraft, with the MH-60R/S and H-1Y/Z to follow. All future Naval rotorcraft will have structural usage monitoring of airframes and dynamic components. The Navy plans to compile a toolbox of capabilities to support future condition based maintenance.

VII AIRFORCE

EXISTING SHMS IN THE AIRFORCE:

Three military aircraft have been surveyed. Beginning with the C-160, a carrier, which has a very simple loads monitoring system, followed by the F-4F with a simple load counting system at each individual A/C and a more complex system at selected A/C, coming to the TORNADO with an intelligent load counting system at each individual aircraft and an intelligent and complex flight parameter and strain gauge data acquisition unit used at selected aircraft.

C-160 Transall:

Figure 13: C-160.

Description:

- Mechanical Strain Recorder (MSR) at inner wing main spar.
- Digitizing of cycle sequence into engineering units using an optical system.
- Synchronization with mission form sheets.
- Calculation of stress spectrum.
- Calculation of fatigue life using a relative Miner calculation against test spectrum.
- Event monitoring is based on pilot debrief.

F-4F Phantom:

Figure 14: F-4F.

Description:

- G-counter in each individual aircraft - manual reading.
- VgH-recorder in 15% of fleet with mission form sheets.
- Manual digitizing of mission data and synchronizing with VgH.
- Evaluation of VgH-recorder data and calculation of BigN data.
- Calculation of Damage Index (DI) for one pilot location (LTBS BL44).
- The operational limits for all fatigue critical areas are related to the DI of this pilot location.
- Modification management is based on the operational limits.
- Event Monitoring is based on g-meter and pilot debrief.

PA200 – TORNADO

Figure 15: PA-200.

Description: The S.H.M includes:

- FDR for all relevant flight parameters and strain gauges.
- DAU for simplified recording of main flight parameter.
- Event monitoring for structural overloads.
- Three sectors of data acquisition.
- Individual Aircraft Tracking IAT (g, weight, stores, WSA).
- Selected Aircraft Tracking SAT.
- Temporary Aircraft Tracking TAT.

- Relative Miner fatigue calculation against test for fatigue critical areas based on IAT data, using transfer functions from SAT and TAT.
  - Modification management is based on operational limits for different fatigue critical areas based on test results.

EURO-FIGHTER

Figure 16: Euro-Fighter.

The SHM-System of the Euro-fighter was developed to reduce the amount of evaluation and data storage on ground. Most of the fatigue life consumption will be done onboard. Only a reduced data set will be stored and transferred to the Ground Support System. A powerful Ground Support System is available for:

- data evaluation.
- managing of inspections and modifications.
- trend analysis and fleet management.

Until now no relevant in-service experiences are available within the GAF, because this system is in the last phase of development.

VIII ASSESSMENT OF EXPERIENCES

In contrast to the Euro-fighter, the Structural Health Monitoring Systems for the C-160, the F-4F and the TORNADO are in-service for a long period. Thus the following assessment includes only the SHMS of these three aircraft types. Only the SHMS of the TORNADO has been modified during this period for several times.

HELICOPTERS

Figure 17: S-70i.

Health and Usage Monitoring Systems (HUMS) are gaining wide acceptance as an effective predictive maintenance strategy in helicopters and some fixed wing aircraft. Due to the large number of critical flight safety systems on aircraft, particularly rotating systems on helicopters, vibration monitoring technology is effective in detecting and thus preventing catastrophic mechanical failures.

A STUDY OF HUMS ON AH-64 APACHES FOUND:

1: **5 – 10%** REDUCTION IN SCHEDULED MAINTENANCE.

2: **30%** REDUCTION IN MISSION ABORTS.

3: **20%** REDUCTION IN MAINTENANCE TEST FLIGHTS.

The HUMS on-board system constantly monitors component health from tip to tail by tapping into hundreds of aircraft flight-control signals and specialized accelerometers distributed throughout the aircraft. By synthesizing performance information including speed, torque, temperature and pressure data as well as comprehensive vibration and rotor track and balance data, the system executes real-time diagnostics without pilot involvement. The system provides “go” or “no-go” status on the flight deck display or more detailed health assessments and recommended maintenance actions on the ground station.

In addition to automatic data recording, the system provides:
• Aircraft flight manual limit and exceedance monitoring.
• Aircraft and engine usage hours and cycles.
• Engine performance monitoring.
• Traditional gearbox and drive train monitoring as well as advanced diagnostics.

Regime recognition.

The primary components monitored by HUMS in helicopters are:

- Gear Condition Monitoring.
- Bearing Condition Monitoring.
- Shaft Condition Monitoring.

Below is a Case Study of HUMS early fault detection in a Helicopter:

Case Study: Gear Fault Detection

Title: Identification of an AH-64 Nose Gearbox Gear Fault

Date: January 2009

Problem: The subject gearbox was removed from service due to a review of the HUMS data by the aircraft crew revealing a ‘red’ condition indicator. The AH-64 is equipped with a Honeywell Modernized Signal Processing Unit (MSPU). The nose gearbox is outfitted with a triply redundant diagnostic system, which includes a chip detector, a temperature sensor, and an accelerometer tied to the MSPU. A teardown analysis of the gearbox revealed severe damage to both the input pinion and output bevel gears. Neither the chip detector nor the temperature sensor revealed a fault in the gearbox.

Approach: The condition indicators successfully identified and classified the fault. No other action was required to improve the diagnostics of the HUMS.

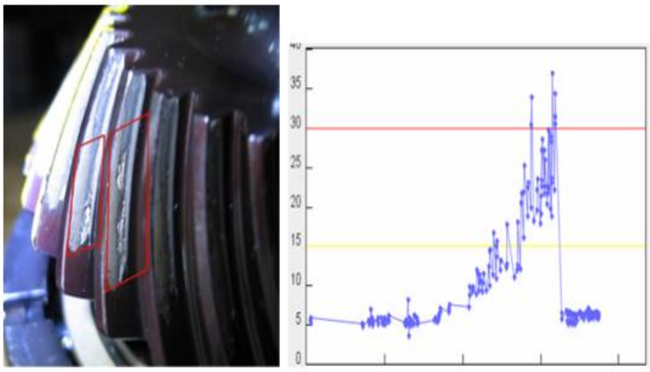

Figure 18: Gear Fault Detection.

Results: The significance of the subject case is the fact that neither the chip detector nor the temperature sensor detected the severe fault. If the HUMS data had been ignored, it is likely that the helicopter would have eventually experienced a chip indication or suffered a catastrophic loss of the gearbox, which, in either case, would have resulted in a precautionary landing or accident. Because the HUMS were able to correctly identify the fault, a precautionary landing was avoided, along with the subsequent recovery effort. The aircraft crew was also able to avoid unnecessary aircraft unavailability by performing proactive maintenance.

IX IMPORVEMENTS AND OUTLOOK TO FUTURE SHMS

Currently available structural health monitoring technologies still have a high potential for cost and performance benefits by improving the integration of structural health monitoring in the overall operational concept of a weapon system platform, taking into account logistics and fleet management.

On the technological development axes today's available loads and usage monitoring technologies will be enhanced in the future by technologies and philosophies being capable to introduce more flexibility within the monitoring of fatigue relevant locations considering also new areas like role equipment, landing gear, systems and areas affected from dynamic loads. This can be supported by new technologies.

From an Industrial assessment point of view parameters such as acceptance by aviation authorities, inspection cost reduction potential, aircraft availability, false alarm rate, reliability, ease of operation will play an important role on decisions about future fleet-wide applications.

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