

Challenges for Costs and Benefits Evaluation of IVHM Systems

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ABSTRACT

The current pressure across the entire aerospace industry to reduce operating costs and increase efficiency has arguably never been greater. Thus the need to improve parameters such as availability and reliability, and increase the tools and services associated with more efficient aircraft operations and sustainment is now paramount. Moreover, these improvements are seen by many as important factors that define the differentiation and competitiveness of not only current but also future aircraft fleets. The paper will focus on some of the opportunities for OEMs that arise from implementing Integrated Vehicle Health Management (IVHM) systems on their platforms and the challenges associated with evaluating the costs and benefits of their implementation and operation.

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2. INTRODUCTION

Ever since the industrial era, production capacity has been one of the key competitiveness factors to a company's continued success; nowadays, a new factor, namely knowledge and innovation is prominent in companies' success [2]. An example of this is the way the outlook on aircraft maintenance has changed in recent years. It went from a corrective approach ("fix it when it's broken") to the latest version of condition-based maintenance (CBM+), where the systems requiring maintenance automatically inform its health status at a given frequency to the maintenance organization[1, 3].

Associated with this trend towards knowledge and innovation is the more rapid maturation of markets; because of modern global communications, the available products tend to be similar, as the competitors have access to equivalent technologies and manufacturing processes. Customers have become more conscientious and demanding when choosing a service, which creates an opportunity (or challenge) for differentiation for products, associated with high value services. Results of a benchmarking study conducted by SAP [19] showed that companies that manage to develop their products and services based on customer needs (along with when applicable, an excellent supply chain and spare parts stock management) were able to:

- Reduce the time taken to perform the services between 15% and 25%;

- Improve cross-selling and up-selling up to 20%;
- Increase customer loyalty between 5% and 10%; and
- Reduce service costs 10% to 15%.

Considering this context, IVHM systems brings added-value through services [4], improving customer satisfaction and improving the margins of the entire chain.

There is also a general perception that IVHM types of systems have benefits that are greater than their costs [5] and there are several approaches to measure the return that such systems provide [6, 7, 8], but solid, quantified figures have been hard to come by as there are still practical difficulties that influence this type of cost-benefit analysis.

This paper is organized as follows: section 1 presents the abstract and section 2 the introduction. Section 3 presents examples of IVHM systems showing their general characteristics, technologies and applications, including Structural Health Monitoring (SHM) and Systems Health Monitoring. Section 4 will list some practical challenges that are associated with the evaluation of the costs and benefits of such systems. Section 5 contains the paper conclusions and section 6 lists the references.

3. IVHM SYSTEMS

Health Management systems are developed by many vehicle manufacturers [20, 21, 22]. The cases explored in this section will cover some of the EMBRAER IVHM initiatives

using Structural Health Monitoring (SHM) and System Health Monitoring as particular examples.

3.1. Systems Health Management

The first EMBRAER IVHM system was released for the EJETTS (EMBRAER 170, 175, 190 and 195 models) in 2005 and was named AHEAD™ or Aircraft Health Analysis and Diagnostics. This system was a computational, web-based platform, continuously monitoring the health of the E-Jets fleet in order to provide timely maintenance information and optimize Customers' technical operations. It reduced delays and cancellations using a friendly and straightforward interface designed for the members of airlines maintenance operation/control centers (MOC/MCC). Later it was decided to create a version of AHEAD for EMBRAER business jets. At the end of 2011 EMBRAER thus developed AHEADPRO™ for E-Jets. AHEAD-PRO has all main features of its predecessor but introduced new functions related to systems and components failures prognostics.

With AHEAD-PRO, aircraft systems health condition is systematically assessed and unplanned maintenance of monitored systems is avoided by means of failure occurrence prediction. Moreover the activities of fault identification, troubleshooting and resources planning occur before the aircraft lands at its destination, thus optimizing airline turnaround-time between flights (Figure 1).

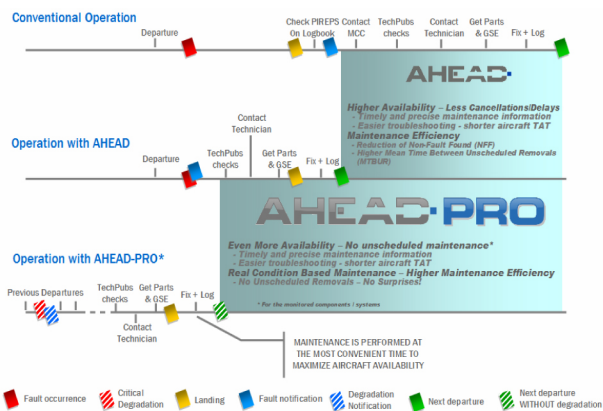


Figure 1. Enhancements of Health Management systems.

AHEAD-PRO offers functionalities to optimize all steps to execute Health Monitoring processes in the airline, from data acquisition to time-to-failure prognosis. And due to its modular architecture, new IVHM functions that are being developed can easily be incorporated in future versions.

3.2. Structural Health Management

Structural Health Monitoring / Management (SHM) is increasingly attracting the attention of aircraft OEMs. As a result, the industry made an effort to have its concept accepted as part of the Maintenance Steering Group 3 methodology (MSG-3) used as a basis for the development of

all scheduled maintenance programs (Maintenance Review Board Report - MRBR) on commercial aviation (and the majority of maintenance programs in executive and defense aviation, as well). The introduction of SHM concepts on the MSG-3 methodology occurred in April 2009, when the International Maintenance Review Board Policy Board (IMRBPB) approved the contents of the MSG-3 revision of that year [14]. Wenk [15] provided detailed information about how this was achieved and what was revised in the methodology related to SHM, which can be summarized as follows:

- **Scheduled SHM (S-SHM):** The act to use/run/read out a SHM device at an interval set by a fixed schedule;
- **NEW MAINTENANCE TASK CATEGORY:** SSHM stands separated from traditional MRBR tasks (General Visual Inspections - GV or GVI -, Detailed Inspections - DI or DET - and Special Detailed Inspection - SI or SDI), that are directly associated with qualification required for the inspector).
- **MSG-3 STRUCTURAL LOGIC REVISION:** To evaluate the use of S-SHM as a task for timely detections of Accidental Damage (AD), Fatigue Damage (FD) and Environmental Deterioration (ED) for all metallic and damage (e.g., de-lamination and disbanding) for all non-metallic Structurally Significant Items (SSIs).

Once incorporated as part of an OEM's Policy and Procedure Handbook (PPH), the A4A MSG-3 2009.1 was approved by ISC - managerial level of MRB process. The structural working group (SWG) - execution level within MRB process, can make one of three possible decisions when evaluating an MSG-3 analysis of a Structural Significant Item (SSI):

1. List the scheduled SHM (S-SHM) task as an alternative for the relevant environment damage (ED), accidental damage (AD) and/or fatigue damage (FD) inspection in the MRBR (SSHM listed together with the traditional inspections);
2. Replace a traditional inspection on the MRBR by the SSHM task and
3. Select (or maintain) a traditional inspection over the SSHM task to be listed in the MRBR.

It was also recognized that SHM can be implemented in not only the above mentioned S-SHM role but also in a mode called A-SHM, from Automated SHM, defined as "any SHM technology, which does not have a pre-determined interval at which maintenance action much takes place, but instead relies on the system to inform maintenance personnel that action must take place" [16].

One such SHM technology being studied by EMBRAER is known as Comparative Vacuum Monitoring (CVM). It is based on the differential pressure between fine galleries

containing vacuum alternating with galleries with atmospheric air.

- Vacuum is applied by a GSE
- Vacuum loss detection
- Local Monitoring (Hot Spot)

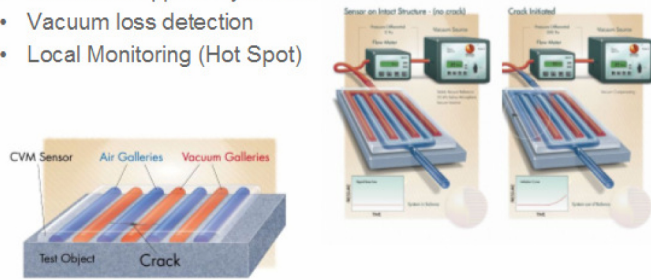


Figure 2. CVM technology for SHM applications
(adapted from [23]).

Another SHM technology is called Lamb Waves (LW), where the system looks for the changes in the structural dynamic characteristics due to structural damage. The fundamental of this technique is based on the assumption that structural damage changes the physical dynamic response of the structure, such as natural frequencies, mode shapes and damping, frequency response, etc.

- Damage detection is based on waves signatures (structure dynamic response) assessment and comparison
- Damage location and size
- Wider area when compared to CVM

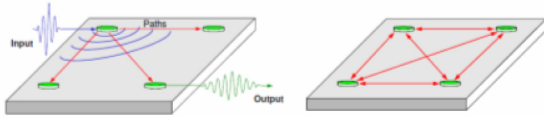


Figure 3. LW technology for SHM applications.

When applied to current and future structural maintenance programs, the benefits of S-SHM solutions would be a significant reduction in direct maintenance costs (DMC), as once installed, such systems would avoid the time consuming disassemblies to gain access to structure that must be inspected. Also, the inspection time and complexity will also be reduced, as it will be done automatically by different types of Ground Support Equipment (GSE). Finally, all data collected from the maintenance inspection may be readily available to operators and the OEM for more profound assessments of maintenance optimization.

Given such examples, some challenges that arise from IVHM systems will be explored in the next section.

4. CHALLENGES FOR IVHM COSTBENEFIT ANALYSIS

IVHM systems have a high potential to improve the maintenance processes towards a more proactive approach, minimizing unscheduled events and allowing activities to be executed at optimum moments (when all resources are

available and the operational impact is minimum). The resulting benefits are higher fleet availability and cost reduction.

Unfortunately, it is a complex task for OEMs to demonstrate that this potential can be transformed into valuable solutions to its customers.

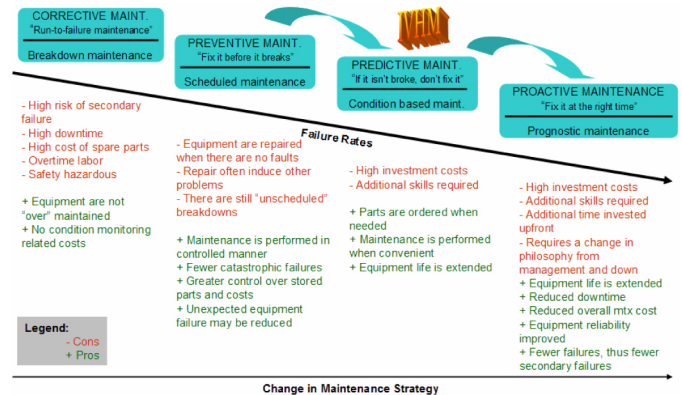


Figure 4. Maintenance Types Pros and Cons

Business case analysis relies generally on quantification of variables that have a high degree of uncertainty, such as development and certification costs, time to market, market size, acceptance by regulatory authorities and customers, price and other commercial conditions, technical risks, tangible benefits for customers and OEMs, competition level and so on. Some of these aspects are discussed in the following subsections, for Structural and System Health Management systems as well as for the application of IVHM solutions to optimize airlines' maintenance supply chains.

4.1. Structural Health Management

Several SHM technologies and techniques with potential for application in the aerospace industry are being investigated and all major aircraft manufactures are conducting their own SHM Research and Development (R&D) programs.

Regulatory Authorities (RA) and Operators are participating more and more in SHM discussions and forums, as well as in flight tests of SHM solutions. Additionally, SHM cost-benefits aspects are also being investigated, with promising indications. Nevertheless, despite the amount and quality of research and tests results on SHM, the growing question is why SHM systems are not being systematically implemented and used as part of any current commercial aviation maintenance program.

Aspects of this topic were already analyzed by Derisso et al. [11] in a paper entitled "Why Are There Few Fielded SHM Systems for Aerospace Structures?", stating that before it is possible to implement SHM solutions, a consistent business case and technical feasibility must be demonstrated. Munns et al. [12], in an earlier NASA report, proposed that the implementation of health monitoring systems will depend on how easily they will be approved in a certification process.