

A Framework for Developing an EPS Health Management System

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ABSTRACT

This paper describes a framework for developing an Integrated Electrical Power System (EPS) Health Management System. The framework is based on the perspective that health management, unlike other capabilities, is not a self-contained, stand-alone system, but is rather an integral part of every aircraft subsystem, system, and the entire platform. Ultimately, the objective is to improve the entire maintenance, logistics and fleet operations support processes. This perspective requires a new mindset when applying systems engineering design principles. The paper provides an overview description of the framework, the potential benefits of the approach and some critical design and implementation issues based on current development efforts.

INTRODUCTION

One of the most critical systems in military and commercial aircraft is the electrical power system (EPS). All critical aircraft systems - propulsion, guidance, navigation, communications, and mission systems - depend on a reliable source of electrical power. EPS is comprised of power generation, conversion, storage, power distribution, and power management components. Advanced power system technologies, including health management systems, will enable higher levels of reliability, safety and operational availability of new aircraft, including unmanned air systems. Health management systems enable Condition Based Maintenance (CBM) by providing capabilities for early detection and management of incipient faults in EPS subsystems and components. Current advances include efforts to develop health monitoring technologies for power

generation, storage and wiring, with a lesser emphasis on power management and power distribution subsystems [1]. Application of these advances to actual operational programs could be accelerated by using a common framework for developing integrated EPS health management solutions.

A significant amount of resources has been invested in developing science and technology (S&T) to enable the development of EPS health management systems. Programs such as the Aircraft Electrical Power Systems Prognostics and Health Management (AEPHM) [2] demonstrated the application and benefits of advanced health management technologies in this critical domain. Many other government sponsored S&T initiatives have also demonstrated the value of health management technologies in specific EPS components (e.g., generators, batteries) [3, 4]. In this paper, we present a framework for developing an integrated EPS Health Management System. The proposed framework uses the health management principles and holistic systems view presented by Dabney et al., [5] as they apply to a particular aircraft subsystem. That is, where the authors of this work address the enterprise, we apply the same principles to the aircraft electrical power system. The paper discusses some critical system design and implementation considerations to ensure that the health management capability is transitioned to operational programs.

SYSTEM HEALTH MANAGEMENT PRINCIPLES

Health management of engineered systems requires a new perspective in order to deal with the different engineering disciplines and complexities involved. Without the right perspective, most researchers in the field migrate toward

complex physics of failure diagnostic models as they attempt to look for *deterministic solutions* to inherently complex systems. This approach results in technology (more hardware) and techniques (complex models/algorithms) that essentially have little chance of transitioning into the engineered system or platform. The authors observe that we ought to model health management of engineered systems after another science, *medicine*. As in the human body, there are doubtless hundreds of (if not endless) different failure mechanisms in an engineered system. Add to this the anomalies due to failed interconnected systems in a highly complex system-of-systems structure. The tendency toward employing data mining, neural networks, complex logical theories and genetic algorithms is symptomatic of this puzzling, widespread belief that health management applications require capturing every possible failure mechanism [6] in the system-instead of focusing on understanding the system's degradation characteristics [7]. That is, it is more important to manage the fault progression in a particular component or subsystem, prior to an actual failure, by monitoring the subsystem's "heart beat signals" as opposed to dealing with the failure after the fact (a heart attack).

Using this perspective, there are four key health management principles that form the foundation for the proposed framework:

- **First-Health Management** is not a "self contained, stand-alone system."
- **Second-Health Management** is both a Function and a Process.
- **Third-Health Management** can be performed on a subsystem, a system, an aircraft, a vehicle, a ship, an entire fleet or an industrial plant.
- **Fourth-Health Management** information enhances the entire "enterprise" which includes business, fleet operations and sustainment infrastructures.

The first principle is based on the notion that, unlike other platform capabilities, health management is inherently designed within a system. That is, as in the case of the human body, an engineered system has self-monitoring and safety mechanisms (e.g., BIT, redundant functions) to monitor its health (functional performance). What is needed is a way to extend these self-monitoring capabilities so that health state indications are continuous as opposed to discrete [8].

Health management can be described as both a *function* and a *process*. In the space and commercial aviation sectors, the term is used to describe the automated systems used to manage the health state information across systems and subsystems. In this context, health management can be defined as *the function that provides users with an integrated view of the health state of the overall system* [9]. This is

followed by the set of activities, systems, resources, and *processes* used to identify, mitigate and resolve actual and impending faults within the vehicle [11].

The notion behind the third principle is that health management must be viewed as an incremental (layered) capability that requires insertion and maturation over time. That is, since health management involves multiple technology layers (sensors, data acquisition, feature extraction, prognostics, etc.), these layers can be incrementally integrated and matured over time. The idea is to start with highly critical components or subsystems on the aircraft. An example that supports this notion is to recognize that the health and usage monitoring systems (HUMS) only cover the data acquisition, manipulation and presentation layers, and only for certain life limited mechanical components on rotary aircraft. It has been, however, a step in the right direction. If there is one drawback to the HUMS approach is the fact that HUMS becomes "another stand-alone system" to worry about.

Finally, in the Defense sector, health management is defined as the capabilities that maximize system effectiveness in the presence of system anomalies, provide decision support to optimally plan missions or defer maintenance, and manage component life [11]. It is clear from this definition that health management is an integral *function* that ultimately enables decision support *processes* across the enterprise. *This is ultimately the value that health management delivers to operational programs.*

AN EPS HEALTH MANAGEMENT SYSTEM DEVELOPMENT FRAMEWORK

This section discusses the application of the principles discussed in the previous section as they relate to aircraft electrical power systems. As described in [Figure 1](#), in this framework each aircraft subsystem (propulsion, EPS, mission systems, avionics, structures, etc.) has its own subsystem health management (SHM) function (Layer 1). Ideally, each subsystem SHM function should produce a health state determination or the data to produce one for its health enabled components. The integrated health state determination is then derived from the health state data produced by the individual subsystems in an aircraft (Layer 2). Once obtained, the integrated health state can be used by a variety of decision support applications throughout the enterprise, including crew alerting, vehicle maintenance and logistics systems, mission planning, and fleet operations to name a few (Layer 3). It is in this way that health management truly enhances the enterprise operations. As shown in [Figure 1](#), the idea is to group aircraft subsystems into functional groups. The EPS group (circled) includes the

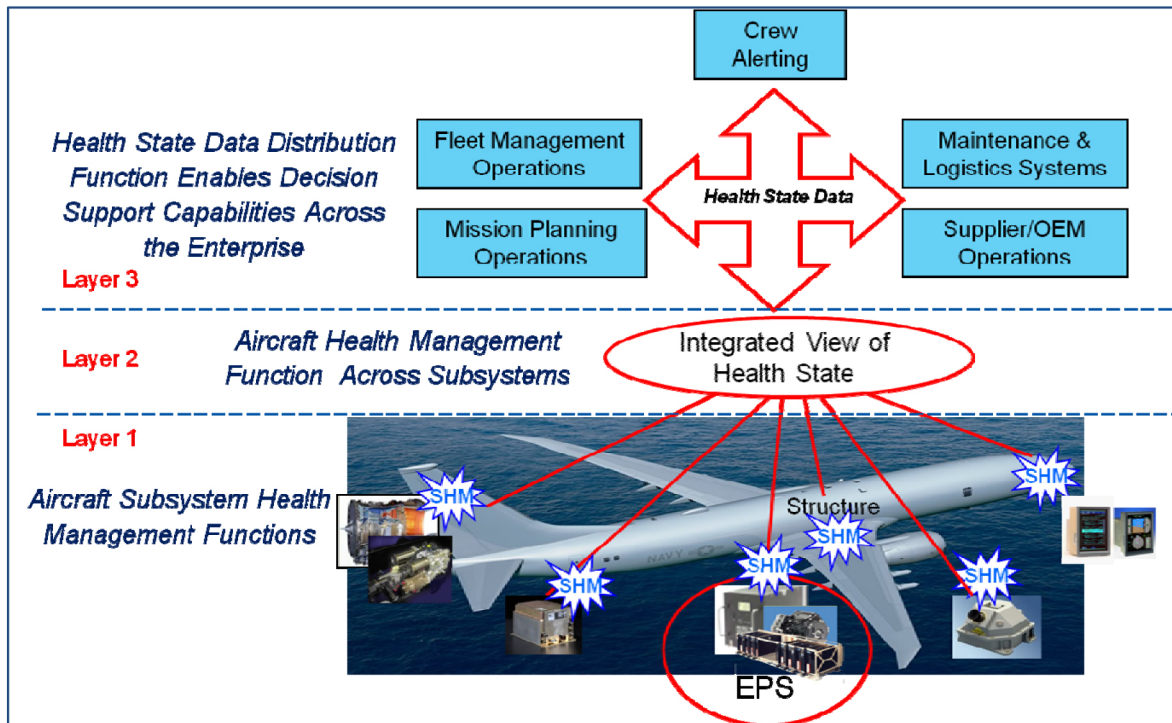


Figure 1. Integrated Vehicle Health Management Framework Functional Overview

power generation, conversion, storage, power distribution, and power management components.

Figure 2 shows the application of the framework to the EPS. This functional application layer (Layer 0) can be viewed as the lower functional layer for each of the aircraft subsystems. The idea here is to note that in both figures there is a common link to the upper layers 2 and 3 from all the subsystems. To define this link, it requires taking a systems engineering approach when developing the EPS health management capability. This systems approach prevents the development of health management capabilities for certain components from becoming “orphans” looking for a place in the aircraft health management infrastructure (data bus, storage, processing, etc.).

As shown in Figure 2, as it was the case when grouping aircraft subsystems, the idea is to group the EPS components into related functional line replaceable units in order to provide functional granularity in determining the health condition of the specific EPS component. As far as what specific EPS health management functions (layers) are part of an on-board or off-board capability, it all depends on the inherent capabilities of the EPS components, the aircraft infrastructure and the objectives of each program. The objective here is to develop a solution aiming at striking the proper balance between on-board and off-board capabilities, memory, data storage, processing, network throughput and software required, without affecting safety critical aircraft functions.

As shown in Figure 2, the health state data distribution function (Layer 3) resident in the P-8A aircraft Digital Flight Data Acquisition Unit (DFDAU) could drive (trigger) key decision support capabilities:

- **Mission Planning Operations** - EPS health state data works in concert with mission planning systems to enable assessment and/or adjustment of mission scenarios to alternate mission plans that account for the health state of EPS components and their estimated performance life remaining (PLR).
- **Fleet Management Operations** - the EPS health state of individual aircraft is used to determine fleet health, suitability, and availability for the desired mission.
- **Crew Alerting** - the health state data is used to generate appropriate crew alerting messages based on the EPS health.
- **Maintenance and Logistics** - health state data enables *condition based maintenance* of EPS components and works in concert with maintenance and logistic systems to schedule needed maintenance activities, order necessary parts and perform guided troubleshooting to assist mechanics in EPS repair activities.
- **Supplier/OEM Operations** - EPS health state data enables suppliers to execute performance based logistics strategies and service level agreements with platform integrators. Engineering support organizations are able to investigate and