Lessons Learned from the Structural Life Tracking of Rotorcraft Dynamic Components

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ABSTRACT

Over the last two years, TDA developed a framework for the rotorcraft dynamic component structural life tracking. The framework addressed three key important areas in dynamic component life tracking: accurate component tracking, reliable fatigue life assessment using HUMS and other sensor data, and dissemination of required information to stakeholders for decision making via an enterprise Web application. This paper discusses the key areas of framework and lessons learned for future implementation and adaptation.

INTRODUCTION

Recent studies [1] have shown that, on average, components are retired at 25% of their design fatigue lives because of inaccurate monitoring of part histories. Analysis of monitored structural usage data estimates that the usage-based fatigue life limits of dynamic structural components is about two-and-one-half times greater than the design flight hour life limits. Therefore, tracking part histories has the potential to extend the fatigue life of the dynamic components. However, program offices and other agencies have struggled with rotorcraft component history tracking to obtain accurate component history and maintenance information. This is mainly due to records that are kept manually through paperwork systems such as hand-written SRC and ASR cards, which are prone to human errors and frequently misplaced or lost. Inability to reconstruct the usage history of components exposes the fleet to risk which must be mitigated with the application of conservative life penalties, effectively shortening the useful life of components which are still serviceable. Because of the ongoing safety, readiness, and cost concerns, the issue of component tracking has been consistently listed as a priority project.

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TDA has been working for the past two years to address problems associated with part tracking of rotorcraft dynamic components, and lessons learned from this project are discussed in this paper.

As part of our solution to the rotorcraft part and life tracking, we envisioned a framework called '**HeloTrack**' in which component information is collected via a RFID system, rotorcraft usage data (such as HUMS) is processed to make reliable life predictions, and right information is made available to different stake holders to make appropriate decisions for fleet management. Component information as gleaned from the tags will support rotorcraft configuration management, maintenance, repair and overhaul shop optimization and life-limited parts monitoring. Consequently, the fast maintenance turnaround facilitated by RFID can translate into improved aircraft availability.

HeloTrack has been designed considering the current data collection and analysis processes, while at the same time looking forward to consider component tracking via RFID system and direct loads monitoring. The system consists of three modules: component tracking using pRFID technology while allowing legacy methods for ease of transition, reliable fatigue life assessment using HUMS and other sensor data, and dissemination of required information to stakeholders for decision making via an enterprise Web application. All the three subsystems share the data with one another which is processed and quality controlled at each level before being made available to the stakeholders via the web interface. Reference [2,3] gives a detailed description of this architecture.

Figure 1 below shows a notional pRFID network to be used for component tracking. It consists of pRFID tags, gateway node and pRFID reader.

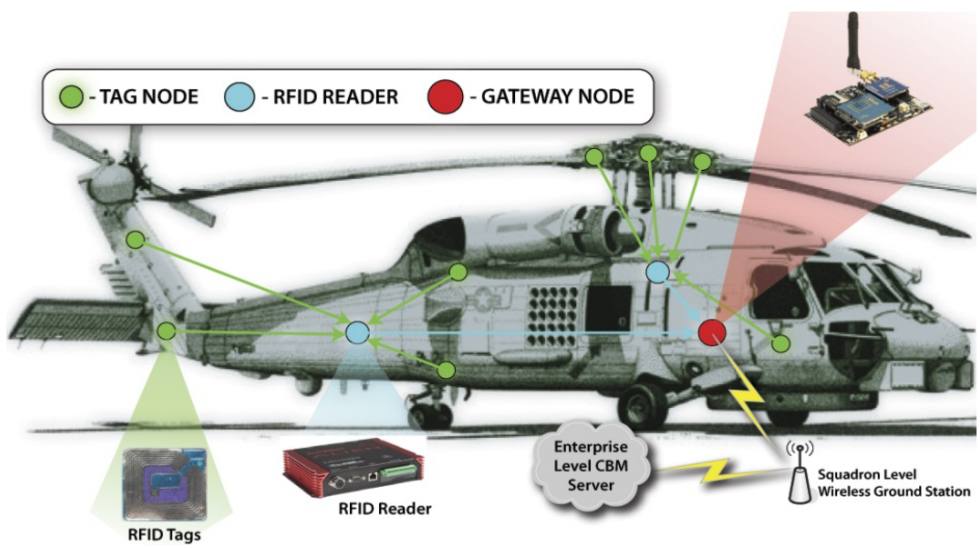

Figure 1. Notional RFID Network.

ASSESSMENT OF pRFID SYSTEM

In order to incorporate pRFID technology for tracking dynamic components near the rotorhub, the system component, including reader/antenna and tag, must be capable of functioning in a densely-packed metallic environment. Moreover, since pRFID tag performance is susceptible to relative orientation to the reader antenna, and local EM interference. Therefore, TDA conducted onboard and in lab performance tests to establish the current state of the art and a baseline of functionality for COTS pRFID systems, and characterize their ability to function in this challenging environment.

Testing took place in two phases. First, control field tests were conducted in an isolated environment, away from potential influences of ambient signal noise or reflections. During the second phase of testing, the RFID systems were tested within aircraft rotor heads. The sections below describe the testing program procedures and results in detail. All tests were performed with 915 MHz equipment. Equipment which operates on other frequencies may be subject to different sources of interference, or react differently within rotor head environments. Further testing is required for operation at other frequencies.

Control Tests – System Baseline

First phase of testing was designed to establish the baseline performance of the COTS RFID systems, while maintaining control over environmental factors such as ambient RF interference and the influence of metallic obstructions. A test matrix was created and tests were designed to characterize the effects of introducing metallic obstructions and surroundings into the RF transmission functionality.

There were several variables evaluated in the control tests. As mentioned previously, the influence of the presence and location of a metallic obstacle was tested. Secondly, the effects of metallic surroundings were simulated by building an open-ended housing which was alternately placed around the RFID tags, and the transceiver antenna. Finally, tag and antenna orientation were varied to determine the effects on tag readability.

The pRFID tags used were specifically designed to be mounted on metallic components. During these field tests the tags used in the study were mounted on sheets of aluminium in order to simulate their functionality in the field.

Six different types/brands of pRFID tags were evaluated during these tests. A total of 12 tags were used, two of each type. One tag of each of those pairs was mounted in a horizontal orientation, and the other was mounted vertically. In this way, the effect of the orthogonally oriented RF field could be determined.

Table 1 summarizes the overall performance of the different types of passive tags. The column labelled “Orientation” refers to the mounting orientation of the tag. The column labelled “Readability” describes the percentage of the 354 configurations in which that tag could be read.

The large Confidex Ironside tag, oriented horizontally, was the best performer. However, the smaller 0000 Mini Metal RFID tag from GAO RFID also performed well, considering its dimensions.

Tests were conducted with different permutations of tag orientation, tag inside a metal housing, antenna inside metal housing, metallic obstruction in front of the tag and metallic obstruction in front of the antenna. We observed that the tag performance can be unpredictable at times. Sometimes, we could read tags from a larger distance, while we were unsuccessful in reading at shorter distances. We also noticed that tag orientation has a big influence in the tag’s readability (See tag 067F in Figure 2 below)

Table 1. Tag Test Results.

Tag ID	Tag Name	Orientation	Readability
0649	Ironside	Vertical	29%
067F	Ironside	Horizontal	45%
0B8D	MetalTag Flex	Vertical	15%
D086	MetalTag Flex	Horizontal	11%
7332	MetalTag with Core	Vertical	13%
8611	MetalTag with Core	Horizontal	9%
8BBF	MetalTag Foam	Vertical	8%
8A20	MetalTag Foam	Horizontal	8%
A000233	Universal RFID Asset Tag	Vertical	41%
A000232	Universal RFID Asset Tag	Horizontal	18%
0000	Mini Metal RFID	Both	30%

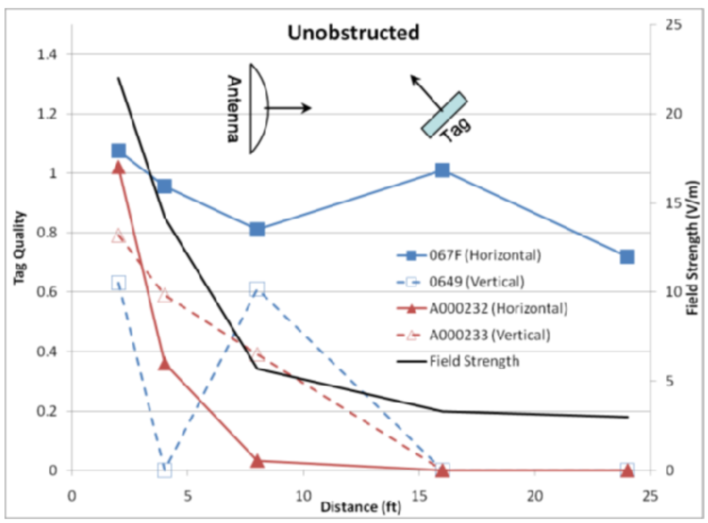

Figure 2. Unobstructed, Inclined Tag Results.

On-Aircraft Testing

In this phase of pRFID performance testing, the COTS Alien passive system was tested in and around the rotor head on three different types of rotorcraft. All the aircraft were at different locations which provided an array of varying environments and weather conditions and helped characterize the performance for the COTS RFID systems.

The same sheet-mounted tags used in the control field tests mentioned above were used during the aircraft-based testing. The sheets were inserted into the rotor head of the aircraft, facing away from the shaft. This allowed the metal-mount tags to be tested without having to apply the tags to actual dynamic components. See Figure 3 below.

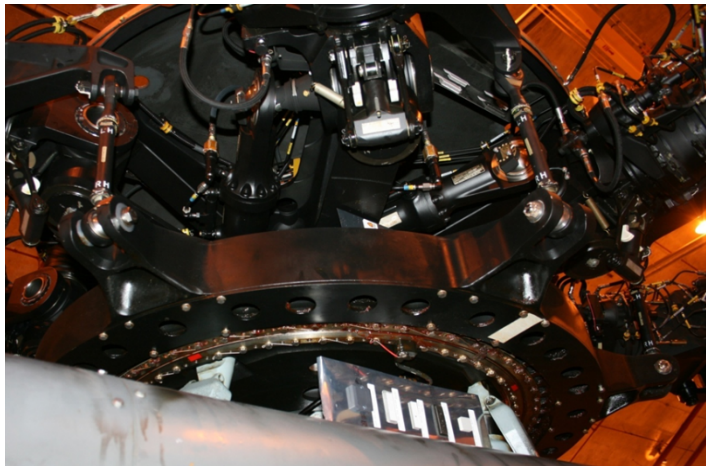

Figure 3. pRFID Tag Sheets in a Rotor Head.

These tests were conducted in two phases. First, the pRFID antennas were mounted on extension poles, and positioned facing the rotor head. This allowed for the evaluation of RF signal transmission from various locations around the aircraft, simulating the possibility of off-aircraft RFID readers.

Alien linear, Alien circular, and Motorola circular antennas were all used in individual tests. Additionally, the tests were repeated with two Alien circular antennas, positioned 180° apart, as well as 90° apart.

In the next round of tests, the Alien linear and circular antennas were positioned individually at various locations onboard the aircraft. This was done to simulate the possibility of aircraft-mounted pRFID readers and antennas. The tag sheets remained in the rotor head, and the tag read and RF field measurement procedure remained the same.

The result of these tests showed that tag construction is the most important driver of overall performance. Small form factors are available, but most of the smaller tags are poor performers. Bigger seems to be better. In terms of cost, the more expensive tag is not always the best option. The Universal RFID tag with a vertical orientation we tested was the second least expensive tag, with the second highest readability of all the tags tested. Tag orientation with respect to antenna is critical. Antenna (linear vs. circular) – Linear antennas may be slightly better, at one known location. However, circular antennas provide better, more consistent, and broader coverage. At close distances, it's possible to read high-quality tags even within a metallic environment.

DISCUSSION - LESSONS LEARNED

As discussed before, the overall architecture consists of three main subsystems. These subsystems constantly share data with each other. In order to ensure data consistency and accuracy, quality control checks have to be put in place at every stage of data collection and manipulation. Every subsystem has its own set of data repository so it is imperative to provide data visibility into the locally stored data for the stakeholders via web in a secure manner. Reliable means of data transfer is required in order to transfer data between subsystems at high speed. For example, in order to transfer component data from the aircraft to the ground station, Gateway nodes need to be installed on the aircraft which can transfer data securely over the air even in remote locations. Since, WAN or GPRS is not available in all parts of the world, private networks like XBee can be used to transfer data.

TDA used passive instead of active RFID technology because of obvious electro-magnetic interference associated with active RFID in aircraft environment. Besides, the active tags that are available are also bulky, and require batteries. It is a logistics burden to maintain and replace batteries throughout the fleet aircraft over entire service life.

However, pRFID system has its own challenges as it has a restrictive range and is highly dependent on the tags used, antenna orientation, line of sight and the environment in which it's installed. Its range greatly reduces in heavy metal rich environment. In order to counter that, more than one tag with different orientation and location were installed and tested on a single component. This greatly increased the readability of the tags by the reader. Furthermore, optimal tag placement position needs to be determined for each component.

Additional studies needs to be done by equipping one aircraft with an RFID system and carrying out flight tests. Results will need to be evaluated to see how the complete system performs during flight. Optimal positions for tagging critical components at suitable exposed surfaces, reader placements, antenna placement, and gateway based on the directivity, enclosure, and RF strength parameters have to be established. However, finding optimum pRFID system configuration without a physics-based model would include numerous trial-and-error measurements involving different positions of reader antenna and tag configurations, which can vary significantly with only a slight change in the relative location, position and orientation. Test asset availability can also be difficult to schedule. To determine the optimum location of the reader-antenna for a given set of pRFID mount locations on critical components, stand-alone software with a built-in optimization tool that can be run on a desktop computer is needed. Any computational models should also be tuned further to predict the performance of the pRFID system for given rotorcraft configuration, such as probable instrumentation or armament configurations. In addition, to account for dynamic scenario where people and machinery are moving in their vicinity, the above mentioned deterministic solution have to be augmented by statistical signal propagation models.

We also realized that there is a need to develop built-in performance monitoring of the RFID system to provide metrics to measure the efficacy of the system. The performance monitoring tool will analyze all data reads and event logs (such as tag read, tag list, and various vendor defined events) and conduct administrative operations including the start/stop process. This will provide system status of hardware, software, and problem resolution methods if needed. The performance monitor tool will check the tags processed, suspended, number of errors raised, amount of downtime waiting for connection, etc. This monitoring tool will be helpful in analyzing and improving the pRFID process time in field operations. We plan to implement the monitoring tool after the pRFID system demonstration is carried out at the squadron level.

We developed applications for handheld RFID readers to read tags when tags are not read by the gateway. This application can be used to read parts in the inventory or during maintenance activity also. We also had to consider situations where RFID system has been removed for some rework etc. For this, a contingency plan had to be developed to smooth data acquisition without impeding the operation of the aircraft.

TDA's current contingency plan requires that after takeoff of each flight, the RFID network will be queried for a "roll-call". At the conclusion of the flight, during the data download from the gateway to the ground station, if the system discovers that any RFID tags are not responding, the user will be prompted to verify that the corresponding part has not been swapped out from the aircraft. If an undocumented part swap has occurred, it can be properly recorded at that time. If there has been no part swap, it will indicate that the tag is malfunctioning. The usage data will continue to be tracked for the part, and an alert will be generated to repair or replace the malfunctioning tag at the next convenient opportunity. These steps will guarantee part identification and data correlation, even if the RFID node is not present or non-functional. Note that during the phase-in period of this technology, there will be existing components, aircraft, and squadrons that are not equipped with RFID tags or readers.

Maintainers and logisticians will revert to standard paper records via Assembly Service Record (ASR) and SRC cards when the RFID system is not in place or inactive. In these situations, we let information be entered manually into the ground station or at the enterprise-level server for dissemination to the other active ground stations. In order to mitigate the risk of data loss, procedures will have to be implemented further to ensure accurate tracking and correlation of logistics and usage information for tracked components.

In order to ensure that the integrity of the RFID system is maintained throughout the maintenance, repair, and overhaul (MRO) procedures, component needs to be tracked during these operations in order to capture service history. The service history records need to be maintained in the architecture during these processes when the old tag is removed, part is overhauled, and new tag is affixed after overhaul.

Importantly, the data stored in pRFID has to be minimal for security reasons. Therefore, we retained only the birth record of the component and stored all other information regarding the component such as service history and usage information within a central database.

Some of the other issues and possible solutions that have been identified while performing this study have been summarized in Table 2.

CONCLUSIONS

We found that passive RFID system can be implemented to track rotorcraft components with further improvements in design of metal-mountable tag design for its from factor and readability. Since tag readability is sensitive to many factors, multiple tags and antennas need to be considered. Component data integrity has to be ensured throughout the maintenance, repair and overhaul activity for realizing the full benefits of the RFID system.

Table 2. Issues and Solutions.

Issues	Solutions
Difficulty mounting tags, form factor too large.	Metal-mount tag systems with small footprints solve this problem
Tag malfunction.	An alert will be generated at ground station in case of tag malfunction. The tag will then be replaced during the next maintenance.
Difficulty mounting antenna, antenna form factor too large.	For efficient RF communication, antenna with appropriate polarization can be selected. A combination of these antennas will be used depending on RF strength and tag detection capabilities.
Reader malfunction.	In case there is a reader malfunction on board the aircraft, the gateway node will detect it and send the alert to ground station system diagnostic tool.
Gateway placement and fixture design problem.	A gateway with wireless capabilities so that it can be placed anywhere on the aircraft will offer the best solution.
Uncommanded broadcasting due to EMI.	To prevent spurious signals or inadvertent broadcasting, the gateway will be put into sleep mode after it has captured the data from the reader.
Gateway malfunction.	Any gateway malfunction will trigger an alert to the ground station.
No internet connection to the enterprise server at ground station.	The ground station will have its own data storage facility. In case there is no internet connection, it will continue to store data locally and pass the information over once the connection with enterprise server is established.
Ground station malfunction.	The systems diagnostic tools will detect any problems with the ground station and will send alerts notifying of the malfunction.
Antenna reader communication problem.	Antennas will be wired to the readers so that the connection is secure and reliable.
Reader gateway communication problem.	The reader will be attached to the gateway via USB port. The connection will be fast and reliable.
Gateway ground station communication problem.	A secure private wireless network will be setup between the gateway and the ground station. All the data between the gateway and ground station will be sent over this network.
Interference with RF communication aboard ship.	In situations when there is interference due to other EM sources (e.g. shipboard radar), the gateway will detect the problem and notify the ground station. Manual checks and corrective actions will be performed.
Data collection errors such as collisions.	In order to ensure clean component data, the data gathering will be performed when the aircraft is in an isolated place, away from any other aircraft with RFID tags. The gateway will have altitude sensors which will trigger component data collection as it begins it takeoff and climb.
High EM signature.	Given the operational concept of activating the RFID reader after takeoff, consideration will be given to the RF signature of the aircraft. The gateway node will be put into the sleep mode after the initial gathering of RFID data after the takeoff. If operational requirements demand minimal RF emission, the crew will be given the ability to cut power to the reader and gateway with a kill switch.

REFERENCES

1. Vaughan, et. al; “Obtaining Usage Credits from Monitoring of Helicopter Dynamic Components without Impacting Safe Life Reliability”, 2007 AHS Forum.
2. Algera D., et al; “Rotary Wing Structural Life Tracking Architecture”; Presented at 66th American Helicopter Society Forum; Virginia Beach, VA; May 2010.
3. Iyyer N., et al; “Architecture for Dynamic Component Life Tracking in an Advanced HUMS, RFID, and Direct Load Sensor Environment”; Presented at 65th American Helicopter Society Forum; Grapevine, TX; May 2009.