Architecture for Dynamic Component Life Tracking in an Advanced HUMS, RFID, and Direct Load Sensor Environment

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Abstract

The United States Navy (USN) is shifting towards condition-based maintenance (CBM) of fatigue critical dynamic components on rotorcraft, which requires more efficient methods for component identification, usage history recording, and fatigue life tracking. This paper presents a method developed by Technical Data Analysis, Inc. (TDA) to track usage and history of all uniquely serialized components throughout their lifetime, so that component life limits and applicable maintenance data are correctly and continuously assessed.

The end goal of this project is one integrated system for component tracking, fatigue lifing, and prognostics and trending, leveraging Health and Usage Monitoring System (HUMS) and direct loads sensing data to track actual component usage and loads. Presented here is a two-fold strategy for achieving this integrated component tracking system via a Radio Frequency Identification (RFID) network and a comprehensive web-based application that interfaces with the RFID network and the USN's various data management systems.

Keywords: HUMS, lifing, tracking, RFID, prognostics, data mining

Introduction

The United States Navy (USN) recognizes the importance and need to enhance health assessment capability with better prediction of fatigue life expended for rotorcraft dynamic components. To achieve this improved damage prediction capability, Ref. 1 mentions three focus areas: a) enhancing recognition accuracy for low speed regimes, b) improving individual aircraft loads/strain predictions, and c) serialization and tracking of fatigue life limited flight critical safety items (CSI). Technical Data Analysis Inc. (TDA) has concentrated on item (c) in its Phase I Small Business Innovative Research (SBIR) effort to eventually achieve the stated overall SBIR objective: "*Develop an innovative system for tracking the structural life of rotary wing dynamic components in support of condition based maintenance (CBM) and unique identification (UID) mandates.*"

The USN's current approach to component fatigue life determination for rotary wing aircraft relies on three primary sources of data: a component strength database developed during component qualification fatigue testing, a flight loads database obtained in the aircraft flight test qualification program, and the definition of a mission spectrum to reflect fleet in-service usage [2]. These three data sources are utilized to produce component replacement times

(CRT) for each aircraft fatigue critical component. These CRTs are then disseminated to the fleet in the form of the Periodic Maintenance Information Card (PMIC) deck. Additionally, all fatigue critical aircraft dynamic components have either an Assembly Service Record (ASR) or Schedule Removal of Component (SRC) cards that resides in the aircraft logbook. These component tracking cards are annotated to reflect the accumulated flight hours on each component along with the date of install or removal from the aircraft. When the accumulated flight hours on the component reaches the CRT specified on the card, the component is removed from service.

In a broad sense, the CBM concept intends to direct maintenance by predicting failures based on real-time assessment of component condition obtained from embedded sensors. This concept requires advanced sensing techniques, automated diagnostics, and prognosis models to assess component condition and system integrity in real-time (or near real-time), and schedule appropriate maintenance action upon evidence of need. With the additional requirement that parts be serialized and identified through UID mandates by the DOD, it becomes imperative to track all uniquely serialized components for their entire lifetime so that component life limits and applicable maintenance data are correctly and continuously assessed.

With the USN's intention of fleet-wide deployment of Health and Usage Monitoring Systems (HUMS), it is only natural for the USN to incorporate Condition Based Maintenance (CBM) concepts to improve rotorcraft availability and readiness at reduced operating costs. The advantage of HUMS and CBM in accurately tracking component life is illustrated in Fig. 1. However, this can only be achieved by continuously tracking usage and assessing damage throughout the life cycle of the rotorcraft's dynamic components.

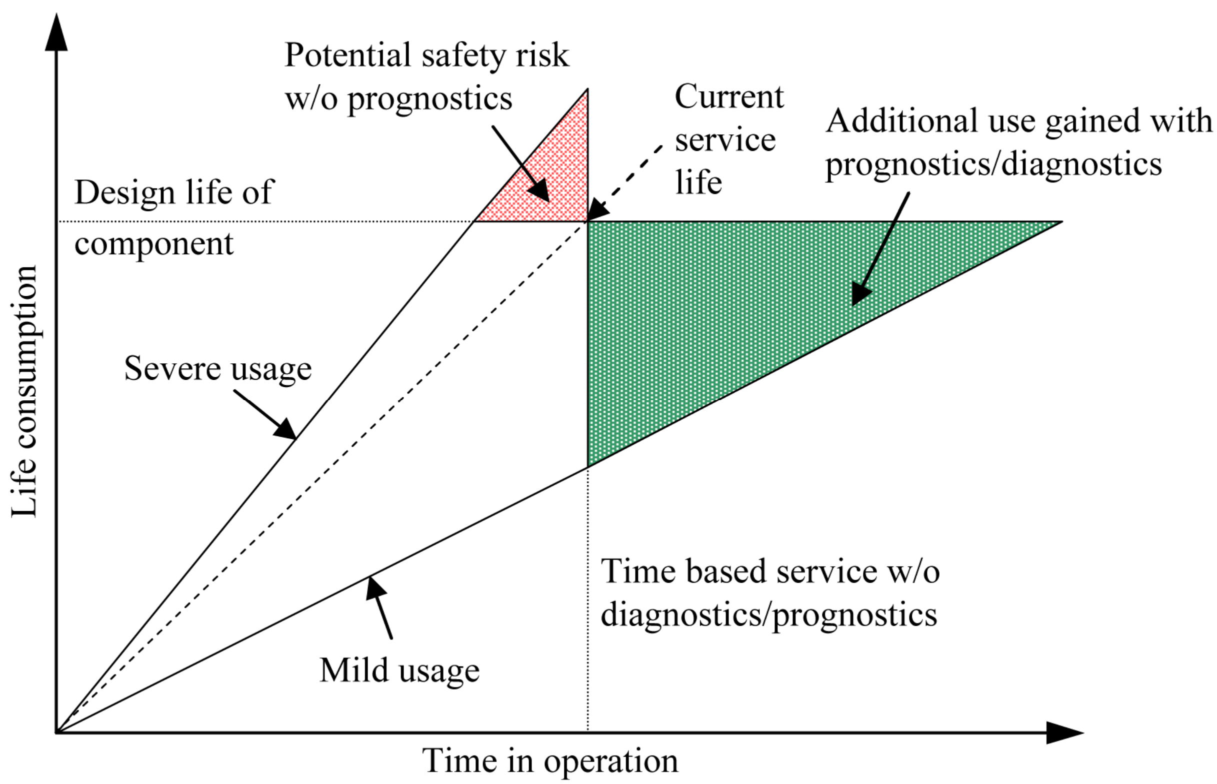


Fig. 1: Economic and Safety Benefits of Diagnostics and Prognostics [3]

This shift towards CBM requires more efficient and real-time methods for component identification, component usage history recording, and component fatigue life tracking. Current component tracking methods are limited by the accuracy of manually-maintained aircraft configuration data; a weakness that must be overcome to achieve an effective CBM implementation. This is especially critical when components are swapped from one aircraft to another, or repair/refurbishments are carried out as part of maintenance actions in the fleet. Advanced methods using state-of-the-art technology are required for component history and life tracking, which is quite cumbersome with the existing fleet data recording and logging practices. The USN correctly identifies the significance of this need in Ref. 1: "*…challenges with serialization and accurate tracking of dynamic components prevents us from taking full advantage of individual usage monitoring. Without a comprehensive system to identify and track specific parts over their life in the fleet, our ability to determine damage accrued at the component level is severely limited.*"

Overall Vision and Strategy for Dynamic Component Tracking

For effective component tracking and life assessment as part of overall CBM implementation, it is imperative that up-to-date history and remaining life of components be readily available through a sophisticated system architecture that smoothly integrates all pertinent data management systems. This satisfies the USN's end goal of tracking each aircraft and its components in near real-time, gathering complete component usage history and thereby accurately predicting the life of each component, and subsequently eliminating penalties imposed due to unknown usage histories. New technologies, commercially available to track components, can be utilized to improve this process. The technologies of specific interest to rotary wing component tracking are Radio Frequency Identification (RFID) tags.

TDA envisions one comprehensive, integrated dynamic component tracking system complementing the USN's CBM efforts for optimum fleet management to assure rotorcraft safety. This vision brings together widely differing aircraft platform data and tracking/lifing methods under one open architecture framework to provide near real-time component health and fatigue life expended (FLE) values. The fleet management tool envisioned in this framework will help the USN develop safety strategies through asset management via prognostics and trending, scheduling fleet maintenance actions, and future acquisitions.

The two-fold strategy for achieving this integrated dynamic component tracking system is to:

1. Integrate Radio Frequency Identification (RFID) tags, sensors (direct loads monitoring and diagnostic), and HUMS data streams by developing an **Integrator Application** at the ground station *(rotorcraft data extraction step)*

2. Develop a **Comprehensive Web-based Application** with the Structural Appraisal of Fatigue Effects (SAFE) system as the hub to interface with the Integrator and USN's various data management systems to provide near real-time fatigue lives and decision aid tools to optimally manage rotorcraft dynamic components (*data processing and dissemination step*)

Fig. 2 below provides an overview of the envisioned system:

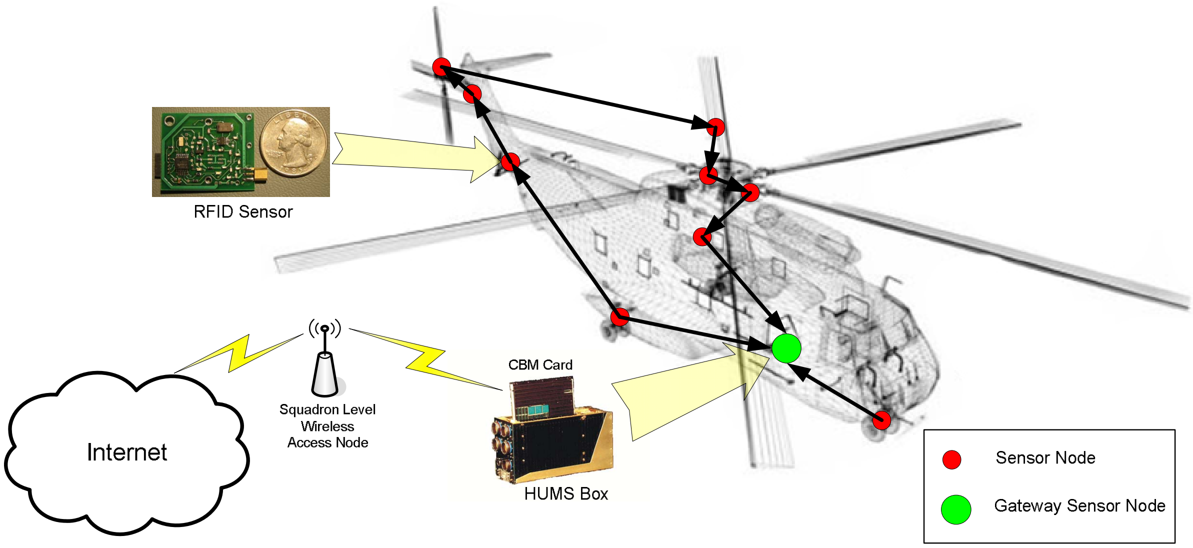


Fig. 2: Conceptual RFID-Sensor Network

Status of Current Work

To achieve the above overall SBIR objective, the Phase I effort focused on an assessment of current technology for dynamic component tracking and lifing methods, HUMS, and data management systems. This assessment led to the development of a conceptual framework for the following:

- An architecture for an RFID-based network system onboard the rotorcraft
- A strategy for dynamic component candidate selection for RFID tagging
- A method for dynamic component lifing within the RFID/CBM framework
- A web application ("***DCTSnet***") to provide tracking and near real-time life calculation for dynamic components
- Smart decision-aid tools such as data mining, prognostics and trending, and life projections for various scenarios
- A case study for implementation on the CH-53E aircraft fleet

In the Phase I SBIR effort, work also focused on developing:

- A software emulator for RFID data stream collection and processing
- A demo of the ***DCTSnet*** web application to showcase the application features

Significant conclusions made by TDA at the end of Phase I effort were:

- Use of active RFID tags with energy harvesting devices and direct load monitoring sensors for dynamic component life tracking is the most feasible option. Using the latest technologies, active tags can be placed in a "sleep" mode to save power, and efficient encryption and attestation algorithms can ensure secured data communications. TDA's review of current wireless transfer technologies indicate efficient, secure wireless data transmissions can be accomplished onboard the aircraft as well as from the aircraft to the ground station integrator application.

- Development of the integrator application (at the ground stations) and the ***DCTSnet*** comprehensive web application for dynamic component tracking will ensure smooth data flow and fast processing of FLE values. TDA indicated the software components that would be available for users within ***DCTSnet***, and discussed its advantages within an RFID/CBM framework. TDA proposed inclusion of decision-aid tools for program managers, planners, logisticians, operators, maintainers, and engineers from their respective points of view. The proposed conceptual framework would build upon TDA's Fleet Metrics web application, which is currently in wide use by the USN.

Dynamic Component Lifing within RFID/CBM Framework

The main objective of the SBIR effort is to track structural life of rotary wing dynamic components using unique identification and real usage histories. This section will focus mainly on tracking and updating of structural life of components that are installed on an aircraft. For end-to-end tracking of components over their entire lifespan, there are other tracking aspects that should be kept in consideration.

In TDA's conceptual framework, RFID tags are attached to all critical components to provide them with unique identification numbers, and their various attributes are stored in a central repository. The gateway communication nodes onboard the aircraft, which act as RFID readers as well as main communication stations, are placed at strategic locations with respect to transmissibility so that every RFID tag can be read. The readers are also equipped with wireless antennas for communicating with the centrally located CBM processor, which acts as the main coordinator of all the activities. Note that the CBM processor can be a separate unit or can be mounted inside the HUMS box. For aircraft equipped with a HUMS box, there are various sensors which measure flight parameters such as airspeed, altitude, rate of climb, pitch angle, pitch rate, lateral acceleration, sideslip, etc. The sensors transmit the measured data in real time to the HUMS box. Additionally, for cases where fatigue damage is calculated by direct load measurements, strain gauges or load sensors attached to critical components communicate with a devices known as 'aggregators', which communicate wirelessly with the HUMS box.

The identification number associated with the RFID tag uniquely identifies the component, but it is also important to know its various attributes. For example, one would be interested in knowing for any component the total hours flown, fatigue life expended, current aircraft, various installation and swap histories, and so on. Obviously, such attributes have to be stored in some central repository. However, since active tags are capable of a large amount of data storage compared to passive tags, more attributes like last official FLE, ΔFLE estimate since last official FLE, etc., can also be kept with the tags themselves.

RFID System Architecture

TDA proposes to use active RFID tags, enhanced with piezo-energy harvesting capability. Energy harvesting will be especially beneficial on tags near the main rotor assembly, and on some tags with MEMS/Capacitive systems. TDA is proposing use of MEMS/Capacitive system tags for some components because these devices can be miniaturized, which would be practical on components where access and surface area are limited.

The critical components with RFID tags in a helicopter are generally confined to a small area and hence the reader/sensor network need not be elaborate. Since distances within helicopter structure are typically of short spans, the read distances can be reduced to the order of 10-15 feet. This significantly reduces the power requirements while maintaining enough gain margins for adequate operations. Conveniently, most fatigue critical dynamic components are clustered near the main and tail rotors. Because of this, a simple sensor network, as proposed in Ref. 4, can be utilized. In this architecture, one RFID reader can be placed near the main rotor which will interrogate the RFID tags attached to critical components located in the vicinity. Similarly, one RFID reader can be located at the tail rotor to interrogate the components near that location. Both the readers will wirelessly communicate with the CBM card and transmit the information as read from the RFID tags.

A total of 100-150 RFIDs will constitute the entire RFID-network, including router nodes. One of the router nodes will also function as the main gateway node and reader, and will be located close to the HUMS unit for easy transfer of data to the data acquisition card. Fig. 3 below shows a notional RFID network aboard an H-53 aircraft.

In the proposed concept, the RFID network will be in "sleep" mode for power savings, and awaken only when interrogated by a properly encoded and validated signal transmitted through the main gateway. The data acquisition card in the HUMS unit can be used to set the triggers for status checks and data download.

A preflight scan is made of the RFID network by the main gateway node to read data stored in the tags and compare against the local database information on ground station. Missing or malfunctioning RFID tags are flagged using the algorithm built into the main gateway sensor node.

During flight, the entire RFID system remains in sleep mode, consuming very little or no power from the batteries. Only the direct load sensor units are active during flight, transferring data to the aggregator node based on a pre-set polling and recording logic.

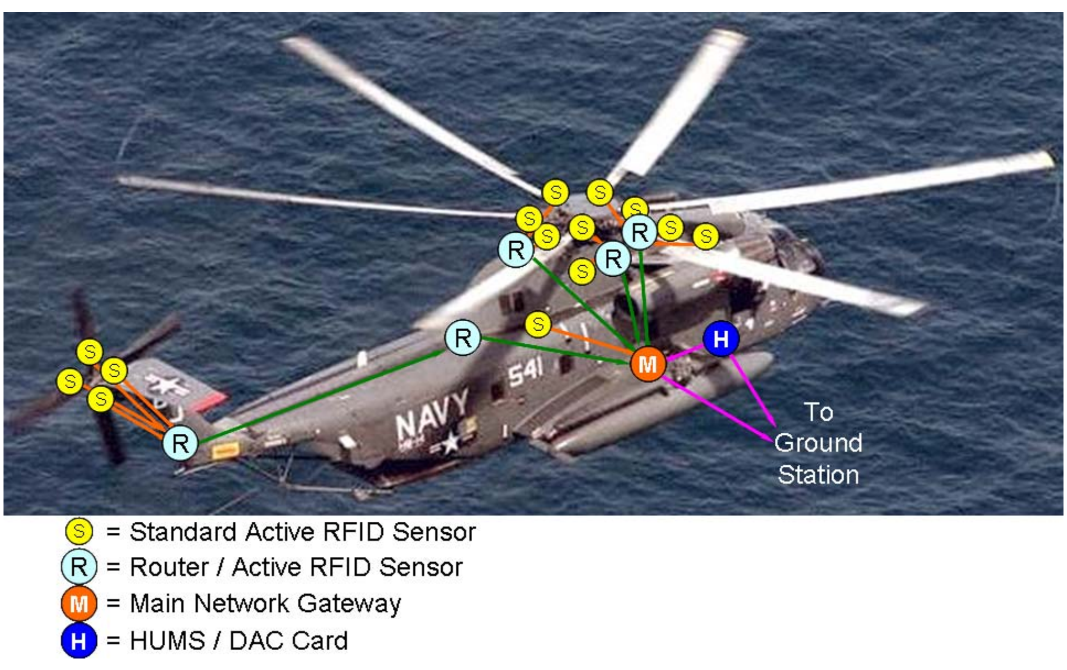


Fig. 3: Notional RFID Network Aboard an H-53

At the end of the flight, the main gateway downloads and sends RFID tag data to the data acquisition card after a trigger signal is sent. This trigger signal source can come directly from the HUMS unit, as commanded by the ground station or by an external source. The ground station can also direct the data transfer mechanism, i.e. through the DAC in the HUMS unit, or direct wireless transfer from the main gateway to the ground station.

The RFID sensor nodes will store the following data, at a minimum:

- Part Name
- Part Number
- Serial Number
- Current Host Aircraft
- Manufacture Date
- Configuration
- Last Repair Date
- Time Before Overhaul
- Estimated Time Before Inspection
- Estimated FLE Since Last SAFE Report

The following additional data are stored in the database, and can be stored in the RFID tags if required:

Serviceability Information

- Previous Maintenance Record
- Time Since Overhaul
- Time Before Inspection
- Last Safe FLE
- SAFE Data Through Date
- Current Hours
- Current FLE Estimate

Repair History

- Date and Time of Part Removed
- Time on Part at Removal
- Reason for Removal
- Repair Status
- Comments
- Service Bulletin Compliance Information

TDA's architecture for the integrator application at the ground station will include the modules necessary to process and update the RFID, HUMS, and direct load sensors data from the aggregator unit. Fig. 4 below shows the proposed ground station database schema.

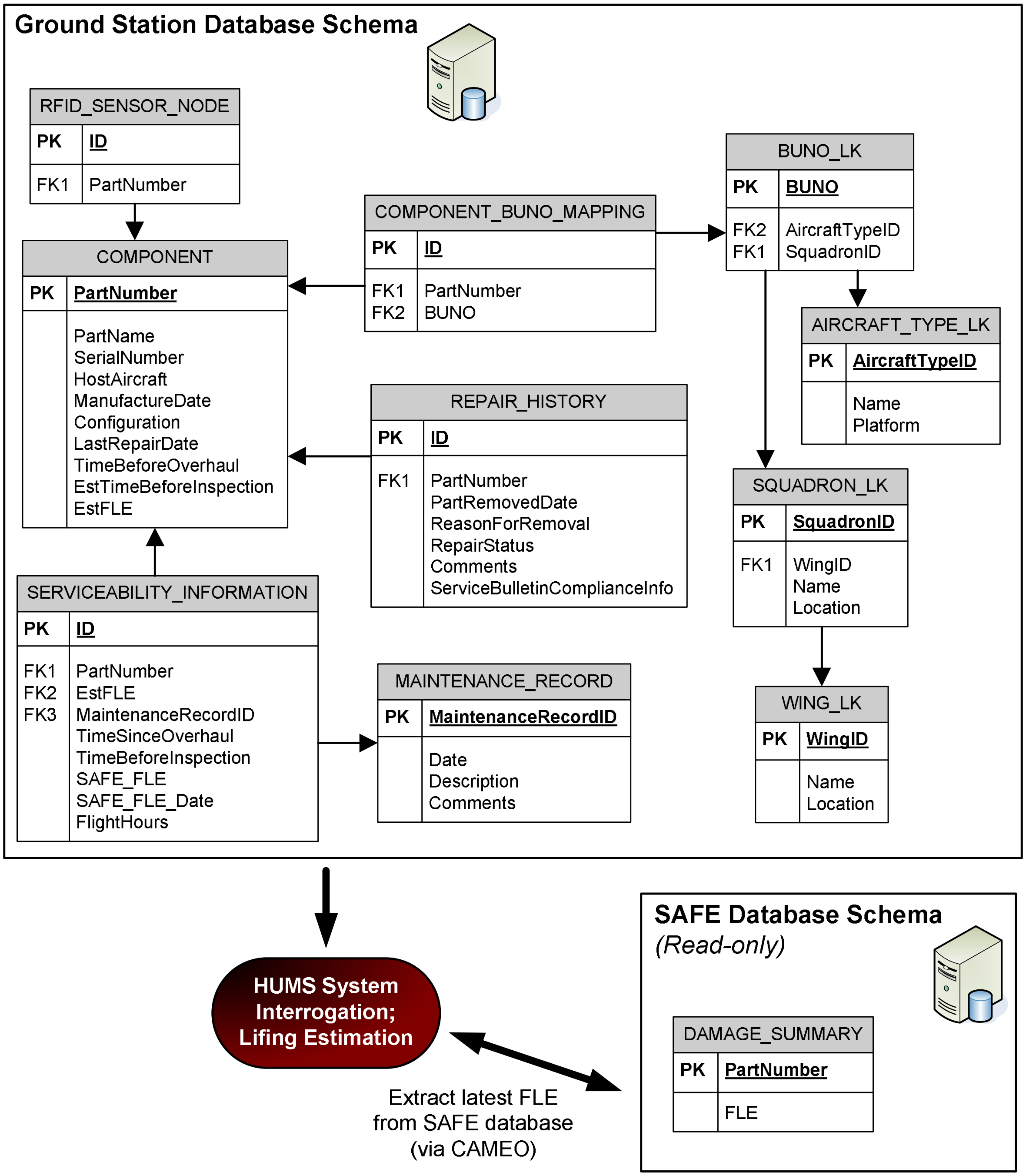


Fig. 4: Ground Station Database Schema

The integrator application database can be accessed by any squadron level computer with defined access privileges for reports on the status of different components. As shown in Fig. 5 the same or limited information can also be accessed from a 3G mobile device, using internet with proper security protocols and access privileges.

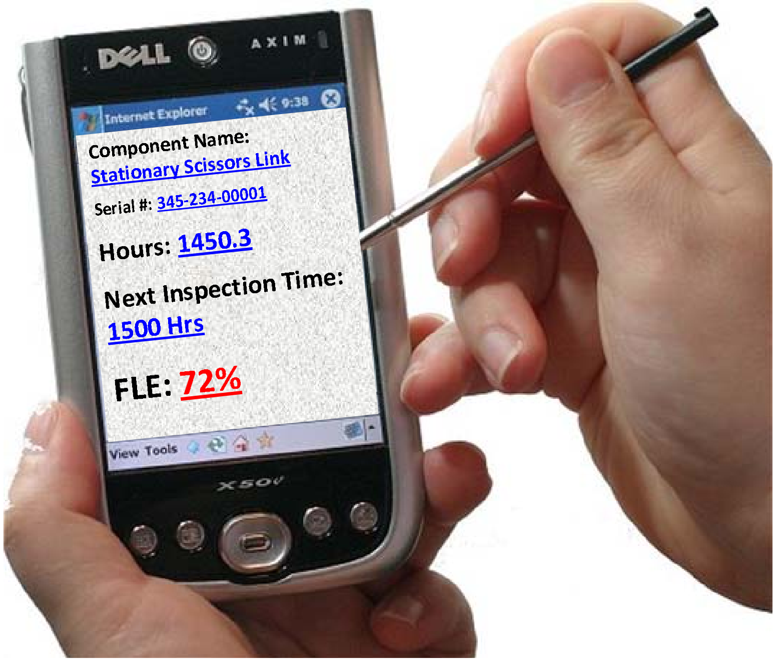


Fig. 5: Instantly Accessible Updates

TDA's Java-Based RFID Application

A working prototype application was developed to demonstrate how RFID tags can be used to automatically identify the currently installed critical components on a rotorcraft. The prototype was developed to create an approximate simulation of the component identification process, as well as to gain some familiarity in developing a software infrastructure that interacts with RFID readers and tags.

An RFID development kit created by Intensecomp Private Limited was used to create the prototype application. The kit consisted of a small desktop reader, a serial RS-232 cable, ten ICODE tags and a software library to create applications in .NET framework, C#, Java and other languages. The RFID reader could be controlled only through an electronic interface by sending commands from the serial ports. The application could be run on various Windows operating systems such as Windows XP, Windows 2000 or Windows NT.

The prototype was created to demonstrate the salient points of an actual RFID-based component identification system installed on a rotorcraft. As explained previously, in such a system RFID tags are attached to all critical components that provide them with unique identification numbers and their various attributes are stored in a central repository. The aircraft is equipped with RFID readers that are mounted at locations such that every RFID tag can be read. The attributes of all the critical components such as part name, hours flown, FLE, etc, are stored in a local database.

In the prototype application, each RFID tag supplied in the development kit was assigned to represent an aircraft part, and the fatigue calculation was carried out by an elementary module that calculated fatigue life based only on hours flown and flight severity. The basic attributes such as hours flown and FLEs were updated for each flight through a simple simulation program. For the next flight, when the tags were scanned again, the system correctly loaded the most recent values of these attributes.

Fig. 6 shows the setup for the RFID emulator program. The reader from the development kit has a limited range so the tags must be placed in direct contact for the tag ID number to be read. The reader is connected to a PC by a RS-232 serial cable on one of the serial ports, and the vendor-supplied libraries communicate with the reader. The application was developed using the Java language; a Microsoft Access database was used to store the various tag related attributes.

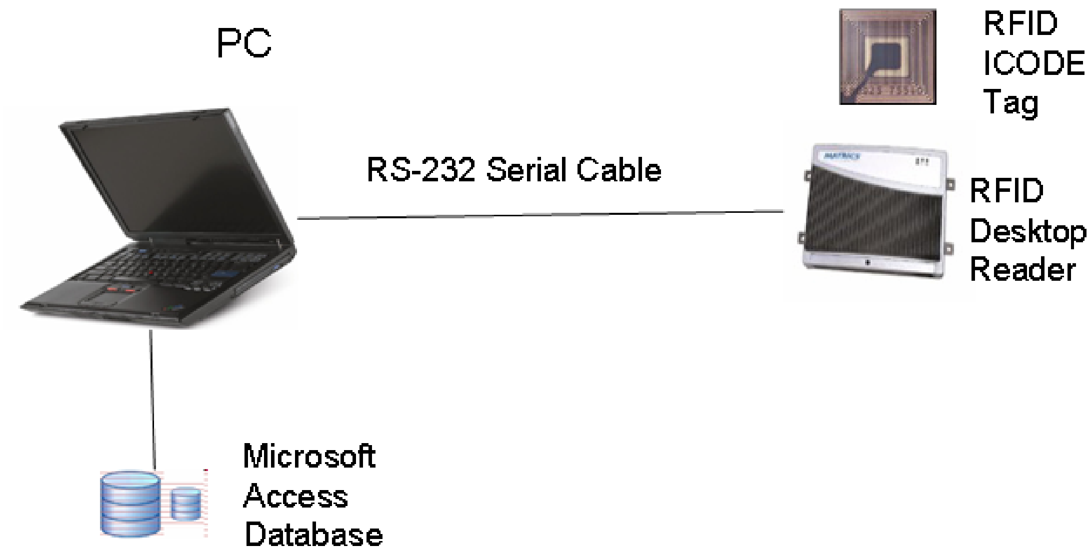


Fig. 6: Basic Setup of the RFID Emulator Program

The class library diagram of the Java based application is shown in Fig. 7. The main graphical user interface (GUI) class is *RfidAppMain* and is also the central piece of the application. The Windows operating system supplies *WinCommDriver* which is implemented in a *dll* and is used to create the *SerialPort* object as well as handle the raw byte level communication between the PC and the reader. *CommPortIdentifier* is the framework-level class that instantiates the *SerialPort* object behind the scene in a manner that is transparent to the user. The actual API (Application Programming Interface) to control the reader is provided by the vendor supplied class *SerialRFID* which uses the *SerialPort* object for actual communication with the reader. The *SerialRFID* class has many useful functions to interact with the reader. Some of the more important ones are *openConnection*(), which is used to establish the connection with the reader; *select*() which is used to instruct the reader to read a tag; and *getRecvData*() which is used to receive tag identification number from the tags. The *part* class represents the tag related attributes such as *identification number, name, hours flown* and *fle* value. The *Database* class is used to store and retrieve tag related data from the Access database. The *Flight* class contains a very basic implementation of incremental *fle* calculation based solely on hours flown and the severity level of the flight.

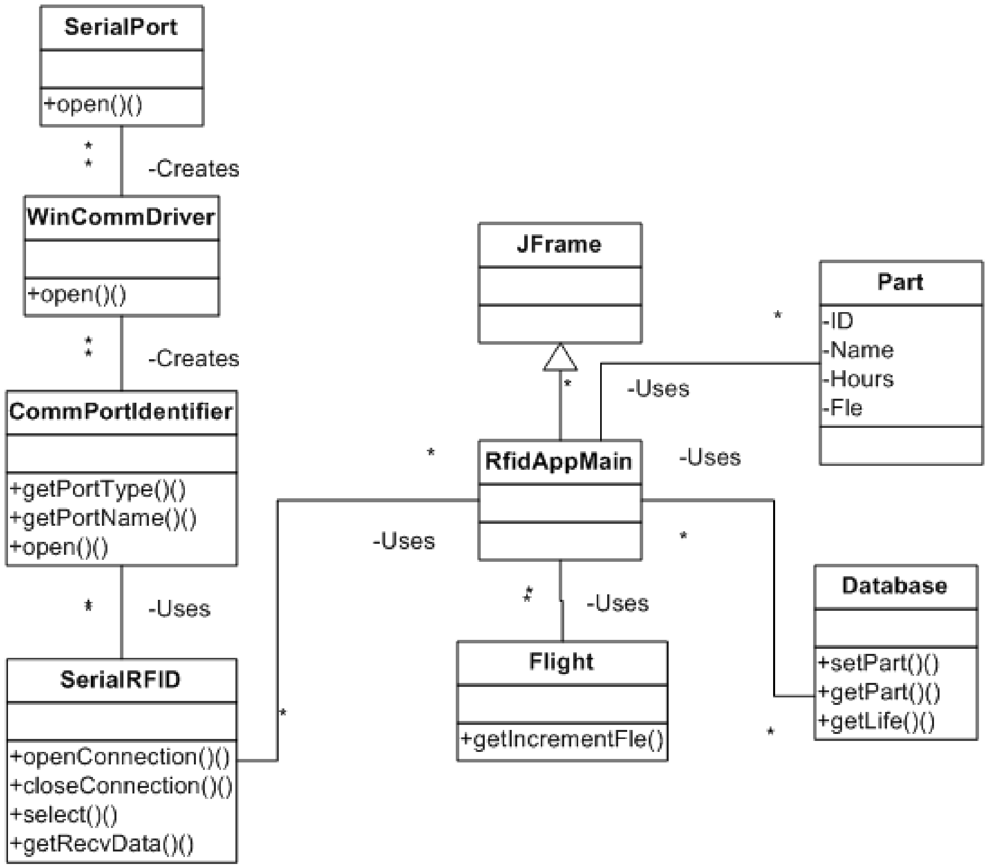


Fig. 7: Class Library Diagram of the Emulator Program

The main window of the application has three tabs to group logically related activities. The *configuration* tab is used to set the properties of the serial port connection such as *portname, baudrate, parity*, etc. Each RFID tag represents an aircraft component and its attributes are gathered by the application in the *registration* tab. The main functionality of the application is in the *Flight* tab. Before a flight, the application needs to know the critical components installed on the aircraft. In the real world application, this will be done automatically when the readers scan the tags in their vicinity and read the tag identification numbers. In this application, the tags are put on top of the reader and the Scan button is pressed. This sends a command to the RFID reader through the serial RS-232 to read the RFID tag and the resulting tag identification number is sent back to the application which loads the attributes of the relevant aircraft part from the Access database.

To simulate the update process of the component attributes before or after a flight, the user enters hours flown and the flight severity level which could be benign, normal, or severe. A simple module in the *Flight* class calculates the incremental *fle* value and the application displays the updated values when the *fly* button is pressed.

Direct Loads Sensors

In TDA's concept, a direct load sensor will be installed on at least one pitch link assembly, similar to the proof-of-concept demonstration conducted by MicroStrain on the M412 aircraft [5]. This direct load sensor system is independent of the RFID network that TDA is proposing. The data from the aggregator unit in the MicroStrain system will be acquired by TDA's proposed data acquisition card residing in the HUMS unit when required for downstream processing by the ground station software. Although the data aggregator unit in the MicroStrain system is capable of transferring wirelessly to the ground unit, it is TDA's preference that data be routed via the HUMS unit.

In the event the HUMS unit is not available or not functioning, the data from the aggregator can then be transferred directly to the ground station, similar to the way RFID system data is collected and routed by the RFID gateway node to the ground station.

Note that in addition to direct loads monitoring on a pitch link, additional loads monitoring sensors may need to be installed from other vendors (such as Insensys Ltd. or IEM), as the MicroStrain load sensor may not be feasible for other locations. Data from these sensors are sent on a continuous or periodic basis to one data aggregator node.

With the direct measurement of loads on multiple components, loads for certain other components can potentially be derived. Deducing loads for components not equipped with a direct load sensor depends upon the response characteristics of the component for a given set of loading conditions. This response function, or transfer function, can be quantified using flight test data where a more complete set of loads are directly measured for a given set of maneuvers. If there is good correlation between measured and derived load responses, then transfer functions can be created. A transformation could be developed with high confidence to derive loads for components near the main rotor assembly.

For some components, however, it will not be possible to get derived loads using transfer functions. In these instances, TDA's concept will rely on the indirect loads obtained from a combination of regime recognition algorithms and component regime loads derived by the manufacturer and confirmed by flight tests. In this instance, TDA prefers this method of indirect load measurements, as we have developed regime recognition algorithms for H-53 and H-60 rotorcraft and are able to build load sequences for some components using flight test and manufacturer data [6].

Component Lifing

In the CBM-based method described here, dynamic component load history can be constructed within the RFID/CBM framework using direct, indirect, or a combination of both techniques.

- Direct measurement of loads via flight loads monitoring through strain gage data from several key components

- Indirect measurement of loads via a combination of regime recognition and prior knowledge of regime loads. Regime recognition technique provides sequence of regimes flown in a flight to help construct the load history from regime-to-loads information.

Fatigue life values of the dynamic component are calculated using the load histories constructed from either direct or indirect measurements. Hence, the critical difference over the traditional method is the means of obtaining the real loads experienced by the components, and options of carrying out calculations either by conventional stress-life or local strain approaches. In both types of approaches, the FLE metric will be derived to provide the fatigue status of the component.

Direct Loads Monitoring

As MicroStrain has demonstrated, direct loads monitoring may be the way of the future. TDA is working closely with MicroStrain regarding data capture and delivery techniques for interfacing with the proposed dynamic component tracking system. TDA has learned that it is possible to obtain loads on some critical elements such as pitch link, but transfer functions will have to be developed to get loads on other locations. Irrespective of the direct loads monitoring sensors, indirect measurement via regime recognition is still a necessity to perform lifing calculations, since direct loads may not be available for all locations. Regime recognition is also essential as a validation check, and to help account for data gaps.

Indirect Loads Measurement via Regime Recognition

Helicopters operate in a highly complex dynamic environment involving unsteady aerodynamic effects coupled with other nonlinear phenomena such as dynamic stall, rotor-wake interaction, etc. Hence analytical techniques of obtaining loads on helicopter components are still very inaccurate. To circumvent this, flight stress surveys are conducted on specially equipped test helicopters by flying the helicopter through various regimes and measuring the loads directly on the critical components. The flight stress surveys yield an $m \times n$ transformation matrix where 'm' is the number of maneuvers or regimes and 'n' is the number of critical components. Each cell in the matrix represents the load on a critical component for a given flight regime. The number of regimes is generally kept to around 200-300 separate identifiable conditions. If, for an operational aircraft, the regime flown at every instant can be identified, then the regime to load transformation matrix can be used to obtain the load on the critical components in turn to determine the fatigue damage.

Regime recognition is essentially determination of the regime a helicopter is currently flying based on the measured flight parameters. For any regime, the relevant flight parameters are selected from helicopter flight dynamical considerations and a top-down, logical sequence of steps is carried out to identify the regimes. The flight parameters are usually measured from installed HUMS sensors that can measure forward airspeed, ground track, sideslip, roll-angle, roll rates, pitch angle, pitch rates, yaw angle, yaw rates, vertical accelerations, lateral accelerations, etc. In the regime identification process, the first step is to narrow the search to broad flying conditions. Next, for any of the above conditions, a top-down search is carried out in a systematic manner to correctly determine the regime.

Component Lifing Process

At the CBM processor aboard the aircraft, FLE can be estimated to provide real time component status updates in the field. Using direct loads sensor data and identified flight regimes, the regime-to-load transformation matrix is used to determine the loads acting on the critical components throughout the flight. Incremental fatigue damage can be calculated for a quick estimate of FLE using a stored, component-specific material and fatigue property database. At the end of the flight, the CBM unit updates attributes such as hours flown and estimated FLE values of the components and relays the information back to the RFID tags, as well as to the ground station and to central repositories and servers for a more rigorous check of FLE processing utilizing information from all data management systems and thorough quality control procedures.

Note that the FLE calculation at the CBM card mentioned above is only an estimate. A more rigorous computation, following data validation and quality control, will take place in a central database. In the overall TDA concept, the SAFE database system at Naval Air Systems Command (NAVAIR) will be the central system for component lifing calculations. Therefore, data from the local database at the ground station along with HUMS and the Naval Aviation Logistics Command Management Information System Optimized for Organizational Maintenance Activities (NALCOMIS/OOMA) data will flow via other USN infrastructure, such as the Comprehensive Automated Maintenance Environment Optimized (CAMEO) [7,8]. The main SAFE system module, designed for component lifing, will validate all incoming data from different entities by a set of quality control procedures. This quality-controlled data will be used to calculate the component life using sophisticated fatigue damage calculation algorithms developed by TDA.

Component FLE and relevant component records are sent back to the ground station to update the local database with a time stamp of the current SAFE update. The ground station can then trigger the main gateway either wirelessly or through the HUMS unit interface to update its RFID network information. The main gateway node updates its RFID network information only after asserting that there is no discrepancy. Any discrepancy found is flagged for correction and communicated to the local database, and downstream to the SAFE system if required. A concept schematic of the system is shown in Fig. 8 below. The Ground Station database schema is shown in Fig. 4.

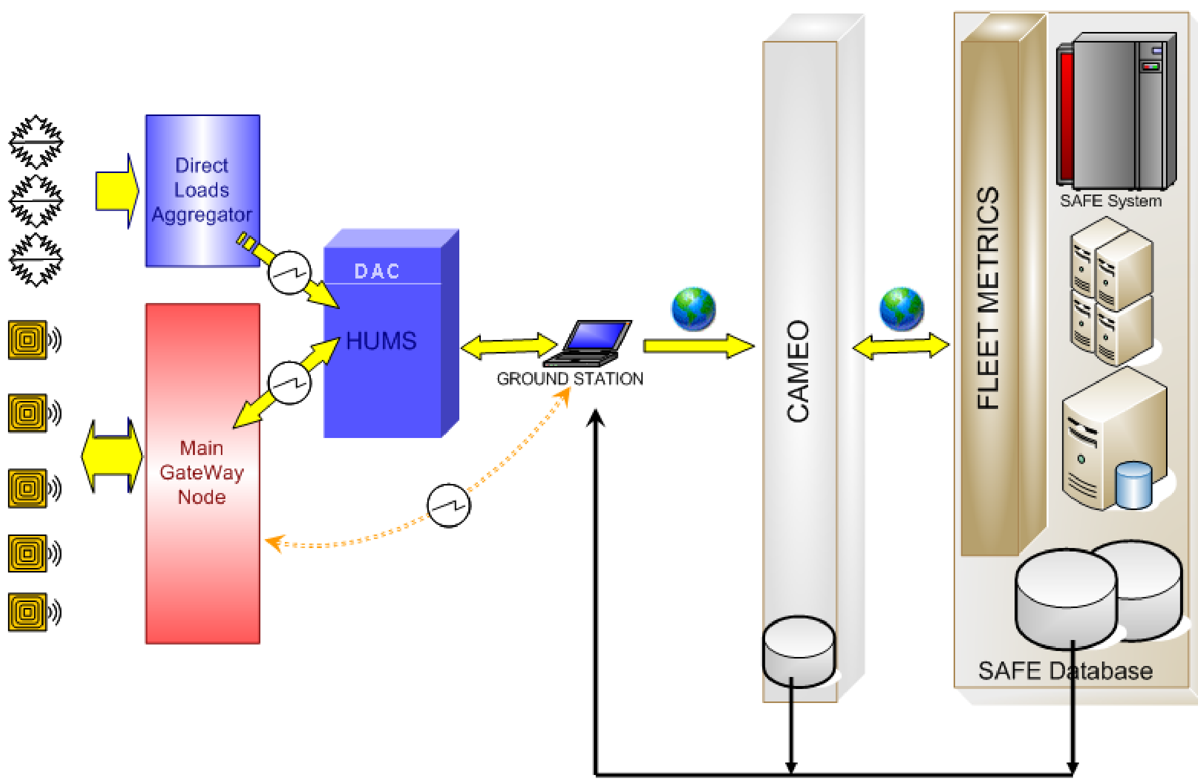


Fig. 8: Ground Station Communication with SAFE

DCTSnet – TDA's Web Application

TDA has developed the conceptual architecture of the support system and web application. Data flow and data processing schemes were conceptualized, and interfacing and support system architecture are still to be established.

The ***DCTSnet*** web application and its architecture are going be built upon the existing TDA-developed Fleet Metrics [9] web application. The salient points of the ***DCTSnet*** application are:

- Makes SAFE the hub for dynamic component life calculations, and compiles all incoming data to provide necessary statistical and visual-aid tools for decision making

- Built on the Fleet Metrics foundation, so that existing data collection, data quality control, and data monitoring and feedback procedures can be used as-is or can be customized with little effort for any particular aircraft platform

- Provides advanced dynamic component life calculation algorithms with various options within each method (safe-life, strain-life, flaw tolerant, and damage tolerant) customizable to any rotorcraft platform

- Provides elegant modules for data mining, prognostics and trending, which are independent modules that could be seamlessly integrated with any architecture

- Developed using component object model, so that it can interface with other USN application architectures such as CAMEO

To develop the architecture, TDA performed domain analysis to develop conceptual diagrams, and preliminary object models and also a sample demonstration of featured decision aid-tools in ***DCTSnet*** that shows page content and navigation schemes.

DCTSnet Conceptual Diagrams

Fig. 9 below outlines the process flow for the application. It shows the interaction between the dynamic component tracking system application, NAVAIR data management systems, and the squadron-level ground station, as well as the process from usage data measurement and collection to RFID-sensor node data transmission.

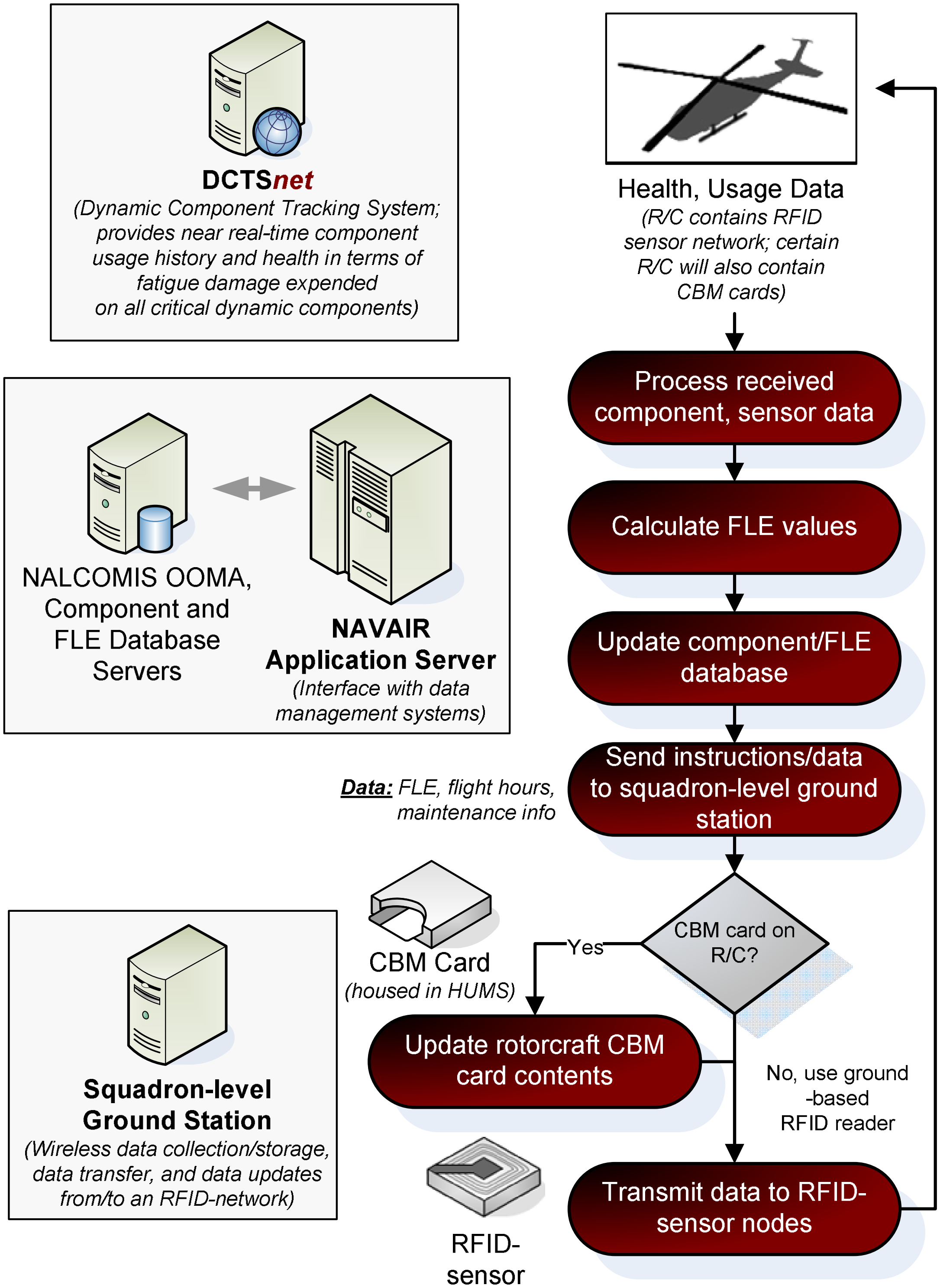


*Fig. 9: **DCTSnet** General Process Flow*

Furthermore, the overall web application will be developed considering the interests of all stakeholders (Planner, Program Manager, Engineer, Operator, Logistician, and Maintainer) in mind. This is captured schematically in Fig. 10.

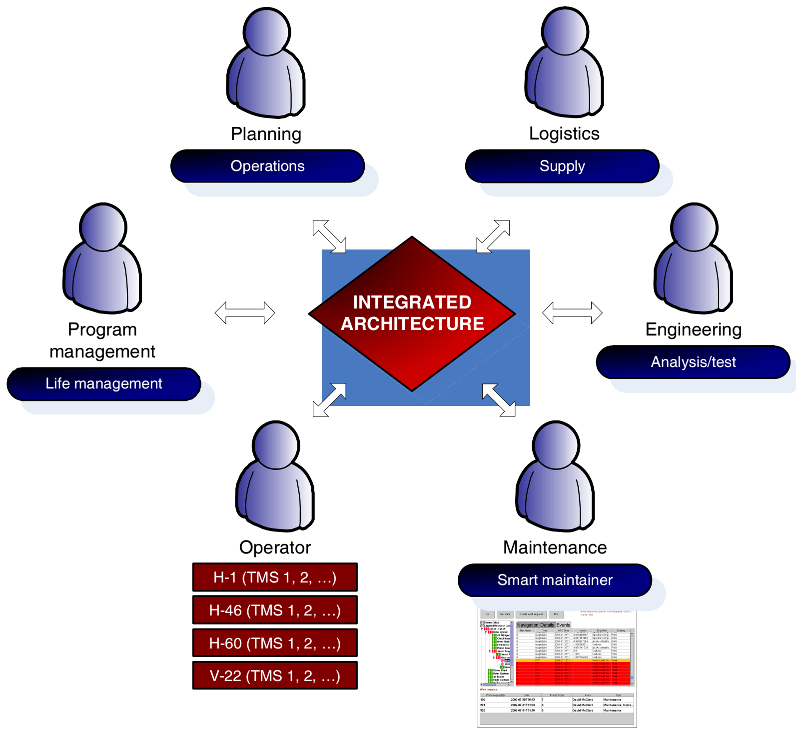


Fig. 10: DCTSnet *Stakeholders*

As examples, two software modules, the data mining and prognostics and trending modules, which will be featured in ***DCTSnet*** application are briefly discussed below.

Data Mining

Because of the growth and progress in the areas of HUMS and direct loads monitoring, the amount of data that has to be analyzed and processed for rotorcraft continues to increase significantly. These systems will generate terabytes of data for each aircraft platform. To aid in decision making, this data has to be analyzed to decipher structural patterns and trends. The value of the data in the various USN database management systems (i.e. NALCOMIS/OOMA, SAFE, CAMEO) will be greatly enhanced by employing data mining techniques. This applies to existing data, as well as data which are yet to be collected.

Data mining is often set in the broader context of analyzing large amounts of data which has these three components:

- Data preparation and cleaning (or pre-processing, QC activity)
- Hypothesis generation
- Interpretation and analysis (or post-processing)

TDA's data mining is generally used in the hypothesis generation phase. The data mining techniques developed by TDA will involve two types: Automatic data mining and visual data mining. TDA has developed these techniques in a disconnected form over several years to study various rotary and fixed wing aircraft platforms. During the development of ***DCTSnet***, these previously disparate algorithms will be integrated to form the backbone of the ***DCTSnet*** data mining capability.

Prognostics and Trending

Prognostic capability is required in order to ensure the safety of rotorcraft and provide for planning actions. The USN's prognosis capability is defined as a two-stage process [10]. First there is a model that forecasts the reliability of a component for given flight hour intervals. Second there must be a feedback capability to ensure model fidelity and robustness as the model assesses component reliability with each subsequent flight hour interval. The feedback may be a Bayesian updating loop in which the evidence comes from sensors rather than hard inspections. Nevertheless, information from a variety of sources is required to develop an effective, robust, and technically sound prognostic and diagnostic modeling system for dynamic components. As shown in Fig. 11, TDA's diagnostic and prognostic techniques will utilize:

- Damage accumulation modeling using fatigue and fracture mechanics, paying particular attention to safe-life and flaw-tolerant life approaches
- Statistical reliability assessment from a combination of HUMS and damage accumulation modeling techniques
- Available on-board sensor signal data and feature extraction
- Automated reasoning algorithms

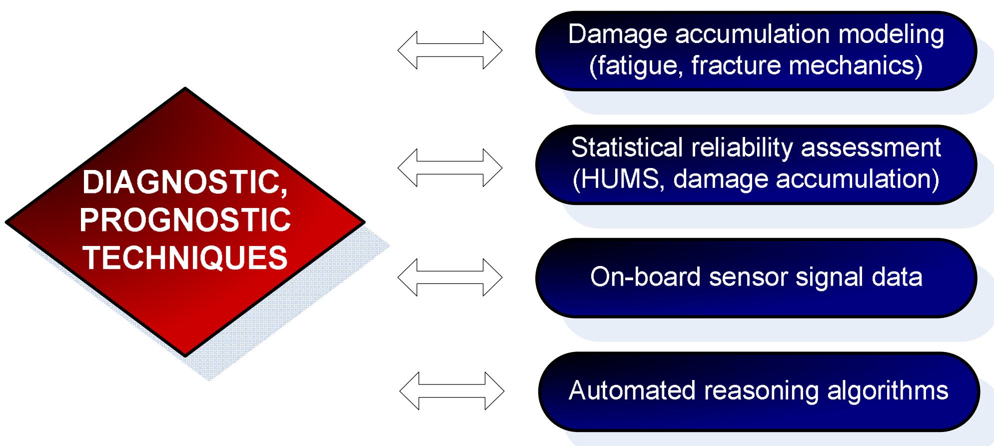


Fig. 11: TDA's Diagnostic and Prognostic Techniques

TDA's prognostic/diagnostic algorithms utilize intelligent data fusion architectures to optimally combine HUMS and sensor data with probabilistic component models to achieve the best decisions on the overall health of dynamic components. In addition, by utilizing a combination of HUMS data and reasoning algorithms, a comprehensive component prognostic capability can be achieved throughout the component's life.

Most of the current prognostic techniques utilize service data, measured features and/or models to predict the condition of the component at a future point in time. The prognostic techniques use one or a combination of the following information:

- Experience-based service data (data such as historical failure rates, MTBF, etc.)
- Advanced feature-based sensor data (acoustic emission (AE) features, peak counts, energy levels, etc)
- Physics-based damage mechanics models (environmental and operational load history, local geometry, surface conditions, etc.)

Example Object Models and Class Diagrams

TDA has started developing object models and class diagrams reviewing the domain and requirements of the overall web application. A preliminary component object model and packages are shown in the Fig. 12 below.

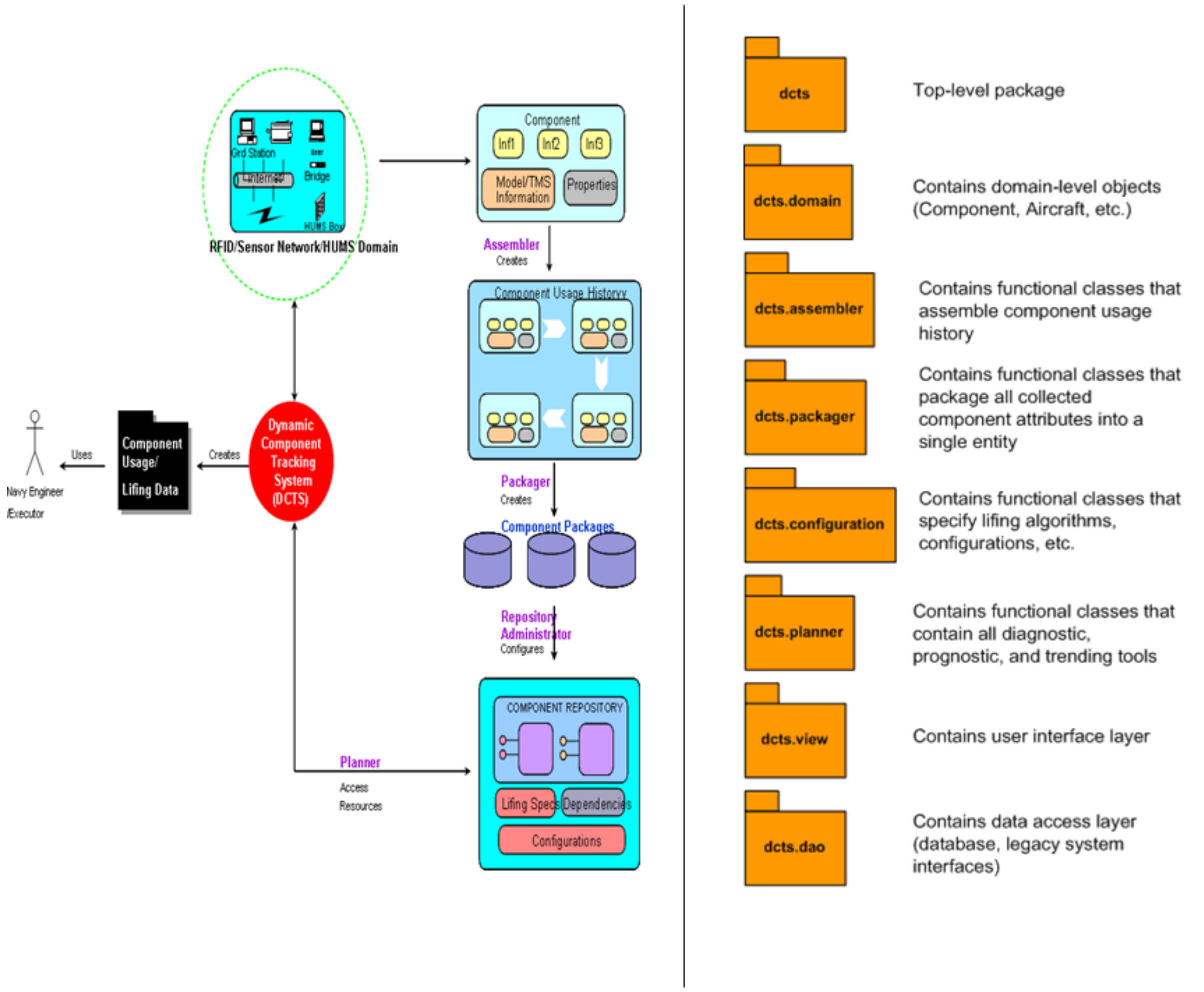


Fig. 12: DCTSnet Component Object Model

Fig. 13 below shows preliminary class diagram design for the Aircraft and Component object models, including a number of related attributes and object relationships. Note that these object models are generalized, and inclusive of all types of aircraft (i.e. fixed and rotary wing).

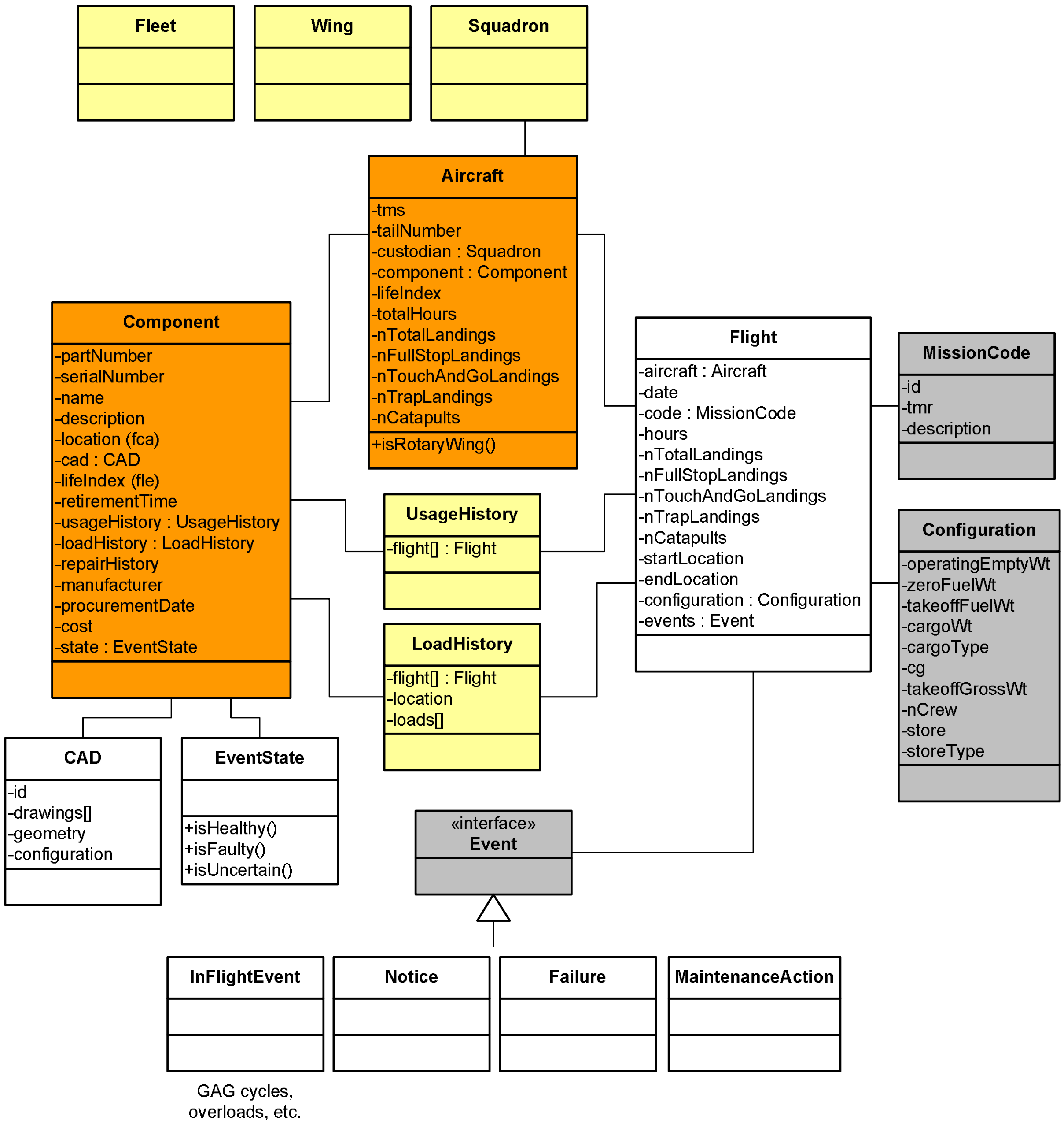
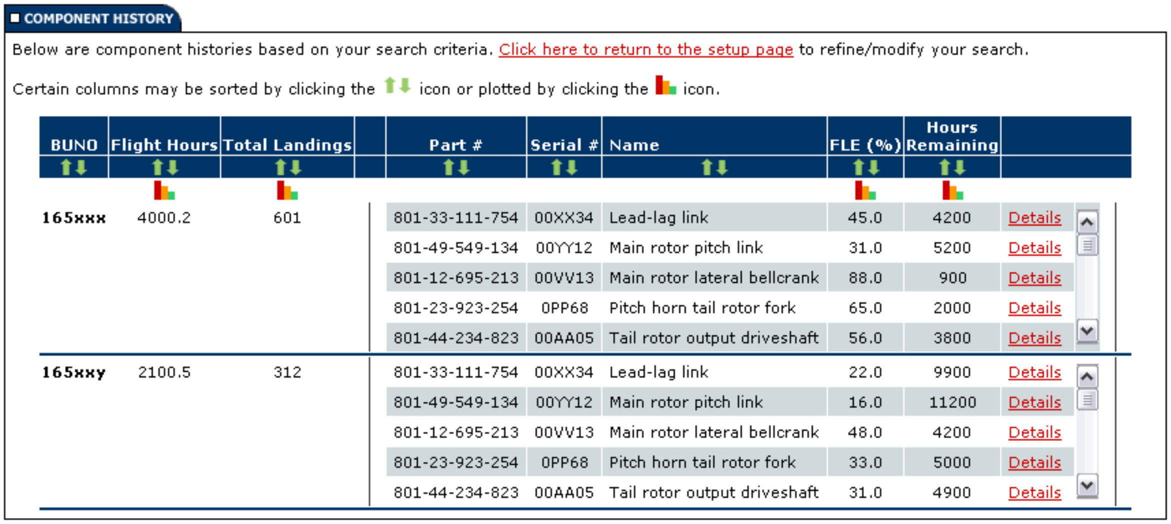


Fig. 13: Class Diagram of Aircraft and Component Object Models

DCTSnet in Fleet Metrics

TDA envisions that ***DCTSnet*** will have a foundation in the TDA-developed Fleet Metrics application. Therefore, a preliminary set of HTML pages were developed with appropriate page content and navigation scheme to illustrate the features of the planned web application. Some sample screen shots of this application are shown in Fig. 14 through Fig. 16Fig. 15.

The component history page will have a display page as shown in Fig. 14.


COMPONENT HISTORY

Below are component histories based on your search criteria. Click here to return to the setup page to refine/modify your search.

Certain columns may be sorted by clicking the icon or plotted by clicking the icon.

BUNO	Flight Hours	Total Landings	Part #	Serial #	Name	FLE (%)	Hours Remaining	
165xxx	4000.2	601	801-33-111-754	00XX34	Lead-lag link	45.0	4200	Details
			801-49-549-134	00YY12	Main rotor pitch link	31.0	5200	Details
			801-12-695-213	00VV13	Main rotor lateral bellcrank	88.0	900	Details
			801-23-923-254	0PP68	Pitch horn tail rotor fork	65.0	2000	Details
			801-44-234-823	00AA05	Tail rotor output driveshaft	56.0	3800	Details
165xxy	2100.5	312	801-33-111-754	00XX34	Lead-lag link	22.0	9900	Details
			801-49-549-134	00YY12	Main rotor pitch link	16.0	11200	Details
			801-12-695-213	00VV13	Main rotor lateral bellcrank	48.0	4200	Details
			801-23-923-254	0PP68	Pitch horn tail rotor fork	33.0	5000	Details
			801-44-234-823	00AA05	Tail rotor output driveshaft	31.0	4900	Details

Fig. 14: Component History Search

Clicking on a particular "Details" link would provide details of that component similar to that shown below. This can be explored further in a hierarchical way down to the part drawing level.

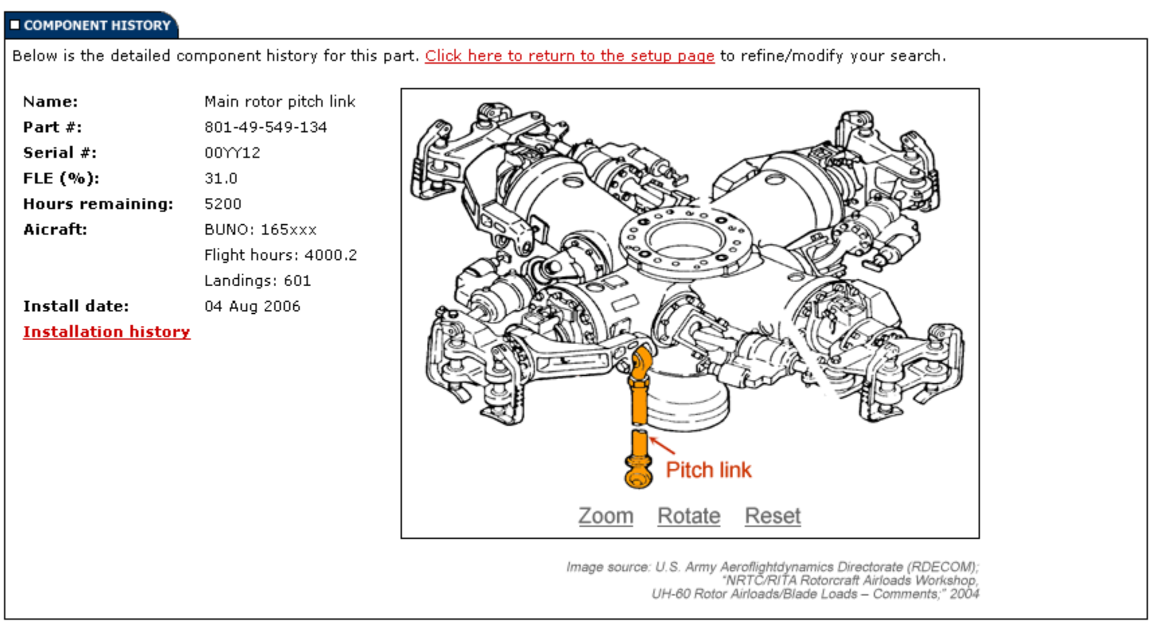
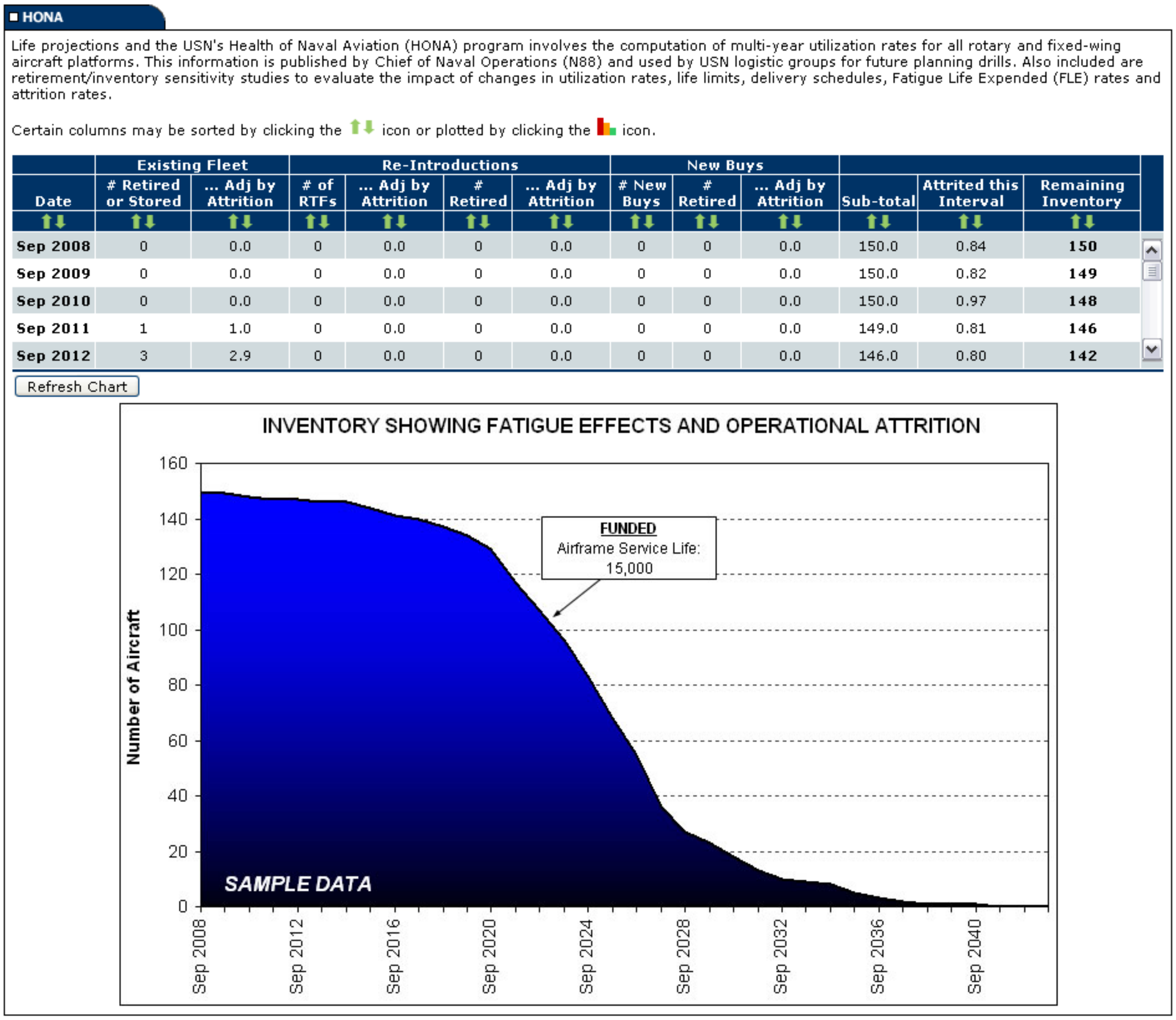


Fig. 15: Component Details

The architecture will have the scheme to show Health of Naval Aviation (HONA) charts as well, such as the one shown below in Fig. 16. This will show the inventory projections based on attrition rates and other factors that the user inputs.



	Existing Fleet		Re-Introductions				New Buys					
Date	# Retired or Stored	... Adj by Attrition	# of RTFs	... Adj by Attrition	# Retired	... Adj by Attrition	# New Buys	# Retired	... Adj by Attrition	Sub-total	Attrited this Interval	Remaining Inventory
Sep 2008	0	0.0	0	0.0	0	0.0	0	0	0.0	150.0	0.84	150
Sep 2009	0	0.0	0	0.0	0	0.0	0	0	0.0	150.0	0.82	149
Sep 2010	0	0.0	0	0.0	0	0.0	0	0	0.0	150.0	0.97	148
Sep 2011	1	1.0	0	0.0	0	0.0	0	0	0.0	149.0	0.81	146
Sep 2012	3	2.9	0	0.0	0	0.0	0	0	0.0	146.0	0.80	142

Fig. 16: Sample HONA Data

Conclusions and Future Work

TDA concludes that current methodology for calculating component retirement lives does not capture the real usage and load history. Therefore, more sophisticated algorithms are needed to utilize the direct or indirect component load history obtained from usage data. In this study, TDA has shown that RFID technology can be utilized to satisfy the USN's UID mandate when tracking the structural life of rotary wing dynamic components.

A comprehensive Web application is needed to provide real or near-real time status of dynamic components. TDA will build ***DCTSnet*** to fill this need. TDA plans to build the ***DCTSnet*** application within its Fleet Metrics framework, which has already been widely adopted in the USN, and is currently in use by several USN aircraft platforms. The web application will interface with other USN data management systems and the CAMEO infrastructure for optimum performance and throughput. The web application will feature novel tools such as data mining, and prognostics and trending applications that can be used by other management systems. The data mining will also feature both automatic and visual data mining features for end users to detect trends, patterns and rule formations for main purpose of decision-making.

TDA plans to continue its ***DCTSnet*** web application development, first focusing on its data mining, prognostics and trending modules. These programs will be built as independent modules using component model architecture, so that they can be used by other USN database management systems. The data mining module will first focus on development of generic algorithms for characterization and trend detection in rotorcraft data by improving upon existing TDA algorithms. Immediate efforts will be made to display results of data mining in simple visual forms. Similarly, the prognostics and trending module will be developed as independent modules that can be used on any rotorcraft platform. ***DCTSnet*** modules will be tested on real rotorcraft datasets as part of verification and validation of the application before release.

As part of future work, a main goal is to create a small-scale working prototype of the proposed system to test the functionality of the system before it is installed in a fully operating environment. The working prototype would simulate the actual environment of a rotorcraft as far as possible in terms of relevance and realism. A stand-alone as well as a web-based utility will also be developed to view and control the prototype application. After the system is evaluated under clean working conditions, TDA will introduce various environmental degradations such as vibrations, heat, magnetic disturbances, etc. and assess the performance.

Upon successful implementation of TDA's proposed tracking system, the USN will be poised to effectively manage the dynamic components and improve the structural life of all rotorcraft platforms, and increase the safety of the warfighter.

References

1. Maley S., Plets S., and Phan N.; "US Navy Roadmap to Structural Health and Usage Monitoring – The Present and Future;" Presented at the American Helicopter Society 63rd Annual Forum; Virginia Beach, VA; May 2007.

2. Barndt G. and Moon S.; "Development of a Fatigue Tracking Program for Navy Rotary Wing Aircraft;" American Helicopter Society 50th Annual Forum; Washington DC; 1994.

3. Romero R., Summers H., and Cronkhite J.; "Feasibility Study of a Rotorcraft Health and Usage Monitoring System (HUMS): Results of Operator's Evaluation;" NASA CR–198446; February 1996.

4. Clauberg, Rolf; "RFID and Sensor Networks"; IBM Research, Zurich Research Laboratory, Switzerland.

5. Arms S., Townsend C., Churchill D. and Phan, N.; "Tracking Pitch Link Dynamic Loads with Energy Harvesting Wireless Sensors;" Presented at American Helicopter Society 63rd Annual Forum; Virginia Beach, VA; May 2007.

6. Barndt, G, Sarkar, S, Miller, C; "Maneuver Regime Recognition Development and Verification for H-60 Structural Monitoring;" American Helicopter Society 63rd Annual Forum; Virginia Beach, VA; May 2007.

7. Maley, S; "Overview of Fatigue Life Management Enabled Through CAMEO Integration"; Post Seattle, 26 June 2007.

8. Maley, S., Lofberg, G. and Lasiter, M.; "Overview of the Comprehensive Automated Maintenance Environment Optimized (CAMEO) System"; Presented at the American Helicopter Society 64th Annual Forum, Montreal, Canada, May, 2008; CAMEO/SAFE Conops. NAVAIR Internal Document, 12 Sep 2007.

9. Connell, D.T., McColl, C.C.; "Fleet Metrics: Aircraft Flight Data Collection and Analytics"; 11th Joint NASA/FAA/DOD Conference on Aging Aircraft; Phoenix, AZ, USA; 21-24 April 2008.

10. Hoffman, Paul; "NAVAIR's Prognosis Plans: Near-term & Far-term"; NAVAIR Internal Brief, 2007.