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HEALTH AND USAGE MONITORING SYSTEM FUNCTIONAL ASSESSMENT—GOODRICH HEALTH AND USAGE MANAGEMENT SYSTEM

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This report provides an assessment of the Goodrich Health and Usage Management System (GHUMS) onboard system (OBS) and ground station (GS) functional capabilities. For each identified HUMS-specific function, the role of the OBS and the GS is identified with particular emphasis on the relationship of the two subsystems and the functional partitioning between the two. This report also outlines the commercial off-the-shelf (COTS) components of all HUMS subsystems, and identifies the role that COTS plays in the overall functionality of the system.

Helicopter, Rotorcraft, Usage
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EXECUTIVE SUMMARY

Rotorcraft Health and Usage Monitoring Systems (HUMS) are transitioning from small-scale, temporarily installed research and development data collection devices to large-scale avionics systems designed for permanent installation on numerous military and commercial rotorcraft. The introduction of production HUMS equipment holds promise for increased operational safety, quantitative flight regime and component life usage measurement, accurate and timely reporting of significant flight envelope excursion and over-limit exceedances, and increased automation and interface to other maintenance management and configuration management systems.

The means for obtaining flight certification for the onboard component of a HUMS-equipped aircraft is clearly identified through the regulatory process and governing documents such as RTCA/DO-178B. However, this certification path does not extend to cover the other elements of HUMS that are implemented off the aircraft. Furthermore, the increased use of commercial off-the-shelf (COTS) hardware and software in those elements can erode confidence in the overall system, as information travels throughout multiple interfaces and is stored on multiple, disparate machines.

The Federal Aviation Administration has issued Advisory Circular (AC) 29-2C, Section Miscellaneous Guidance (MG)-15, to address a means of obtaining airworthiness approval of HUMS. However, industry has been slow to adopt the specified process, and there is considerable disagreement and/or confusion within the industry on whether the specified methods are achievable.

This report provides an overview of the Goodrich Health and Usage Management Systems hardware and software functionality and provides detailed descriptions of the various HUMS functions implemented by that system. It also includes a description of the COTS software resident within both the onboard and ground station components of the system. The report serves as a baseline description of current HUMS functionality and provides the context within which the contractor will be developing HUMS functionality consistent with the practices and methods described within AC 29-2C, Section MG-15.
1. INTRODUCTION.

1.1 PURPOSE.

This report presents an overview of the Goodrich Health and Usage Management System (HUMS) hardware and software functionality, with an emphasis on the interaction between the onboard system (OBS) and ground station (GS). In addition, the inclusion of commercial off-the-shelf (COTS) software in both the OBS and GS is identified to aid in the understanding of the role of COTS within the system.

1.2 BACKGROUND.

The GHUMS is used to provide rotor track and balance, exceedance monitoring, drive train and engine diagnostics, component health assessment, operational usage monitoring, and an open-architecture interface to maintenance and configuration management systems. Data is typically both acquired and fully processed by the OBS, with results of this processing passed to a GS via a data storage device for subsequent display and trending. The GS provides for flight crew and maintenance review of the data as well as a centralized point to interface to maintenance and configuration management systems for the transfer of maintenance instructions and/or component health and usage information.

Federal Aviation Administration (FAA) Advisory Circular (AC) 29-2C, Section Miscellaneous Guidance (MG)-15 [1], addresses airworthiness approval of Health and Usage Monitoring System (HUMS). The AC provides guidance for achieving airworthiness approval for installation, credit validation, and instructions for continued airworthiness (ICA) for a full range of HUMS applications. The AC establishes one acceptable means of certifying a rotorcraft HUMS.

Over the past decade, industry has expressed little interest in using the AC to certify a rotorcraft HUMS, as evidenced by the lack of certification activity in this area, despite the maturation of HUMS technologies and the introduction of HUMS on a wide variety of commercial and military rotorcraft platforms. To address this apparent lack of interest in the certification methods of the AC, the FAA has embarked on a multiyear research and development program with the following objectives:

- Validation of certification procedures contained in AC 29-2C, Section MG-15
- Substantiation of HUMS applications used to support rotorcraft damage tolerance approaches for continued airworthiness issues
- Advancement and demonstration of sensor technologies
• Research and demonstration on the use of HUMS to provide onboard warning to flight crew
• Flight tests with HUMS-installed helicopters

1.3 RELATED DOCUMENTATION.

This report is the first of a series of documents generated under this contract. It establishes the context in which the COTS components of the system operate; outlines the software functionality, criticality, and mitigation strategies; and examines the interaction between the OBS and the GS to achieve that functionality.

Documents developed under this contract include:

• Commercial Off-the-Shelf Validation Criteria [2]: This will document the process and specific techniques developed by the contractor under this research program, which can be used to establish the “acceptability” of the entire Ground Station System (GSS), including COTS hardware and software, using AC-29-2C, Section MG-15.

• Health and Usage Monitoring System Commercial Off-the-Shelf GSS Process Guidance [3]: This document will contain specific guidance to assist organizations with meeting the criteria found in AC-29-2C, Section MG-15. It will cover methods and guidelines for establishing a service history program for HUMS, establishing a process of indirect and/or direct evidence correlating HUMS outputs to actual component lifing issues, and providing guidelines for use by the operator of HUMS-equipped aircraft that outline the steps necessary to remain compliant with the FAA ICA program.

The other major activity under this contract is the development of a Structural Life Usage component for the GS as a means of validating the effect of GS COTS software.

2. GOODRICH HEALTH AND USAGE MANAGEMENT SYSTEM.

2.1 SYSTEM OVERVIEW.

The Goodrich HUMS (GHUMS) is currently in production in two variants: A third-generation main processor unit (MPU)-based system, and a fourth-generation Integrated Vehicle Health Management System (IVHMS). The HUMS functionality available in both systems is virtually identical, and both systems use common processor hardware, software component, and aircraft configuration data concepts. The IVHMS unit adds the capacity for additional aircraft monitoring, including a bearing monitor unit circuit card assembly, cockpit voice (CV)/flight data recorder (FDR), and a crash-survivable memory unit. Both systems share the ability to download data to a common GSS.

The Goodrich system, whether HUMS or IVHMS based, is comprised of two major subsystems. The first subsystem is the OBS comprised of either an MPU or an Integrated Vehicle Management Unit (IVHMU) and associated HUMS sensors. Also included in the OBS is a data storage unit for recording HUMS-specific data. This device is either a serial data interface data transfer unit (DTU),
or an Ethernet-based data transfer system. Both data units store OBS data in identical data formats for transmission to the GS.

The second subsystem is the HUMS GS, which is responsible for downloading data from the OBS data storage unit, processing that data as required for operations and maintenance personnel, and interfacing with other ground processing systems, such as maintenance management, configuration management, and flight data management systems.

Figure 1 provides a simplified graphical depiction of the HUMS architecture for the purpose of describing the functional partitioning of the system.

Figure 1. The HUMS Functional Partitioning

The remainder of this functional assessment will focus on the common HUMS functionality of these systems, and will exclude any non-HUMS component or function of these systems. A specific function or capability should be considered common across the two types of systems unless it is specifically tagged as being either [MPU Only] or [IVHMS Only]. The terms HUMS and OBS should be considered common across both systems.
2.1.1 Onboard System.

The OBS is responsible for the following functions and processing:

- Monitoring mechanical, electrical, hydraulic, and electronic aircraft systems
- Determining exceedances, health status, operational status, faults, rotor tuning (also known as rotor track and balance) solutions, and engine drive-shaft balance solutions
- Reporting health status, operational readiness, and exceedances of those systems to the cockpit display (as required, necessary, or directed for specific aircraft systems)
- Recording exceedances, usage, faults, advisories, cautions, warnings, aircraft state parameters, and predefined health packets and events to the data storage unit
- Transferring recorded data to the GS

The primary OBS line replacement unit (LRU) consists of the following circuit cards and assemblies:

- A primary processing unit (PPU) card, which hosts the HUMS functions and communicates to the data storage device
- A vibration processing unit (VPU) card, responsible for preprocessing accelerometer data and providing the results to the HUMS module for additional algorithmic processing
- Necessary power supply and circuit interconnection backplanes
- IVHMU Only—A maintenance data computer (MDC) card, responsible for hosting the overall aircraft built-in test (BIT) diagnostic functions
- IVHMU Only—A bearing monitor unit card, which hosts aircraft-specific, time-critical bearing monitor diagnostic functions
- IVHMU Only—A cockpit voice (CV)/flight data recorder (FDR) unit, which records necessary voice and data signals as required to assist with accident investigation flight reconstruction

The data storage unit LRU provides the data storage capability for recording data during HUMS-monitored operations for later download to the GS.

Numerous HUMS sensors are permanently installed throughout the aircraft and are identified as follows:

- Drivetrain and gearbox accelerometers
• Engine accelerometers and remote charge converter
• Rotor accelerometers
• Main rotor blade tracker
• Main and tail rotor index sensors
• High-speed shaft optical sensors
• Main rotor speed (N_r) timing reference
• IVHMU Only bearing monitor sensors
• IVHMU Only cockpit area microphone

The OBS also collects information from the various aircraft data busses that are not dedicated HUMS sensors, but which are primary sensors for other systems. This data collection occurs via numerous ARINC-429, RS-422, Military Standard (MIL-STD)-1553 (and [IVHMU Only] Ethernet) bus interfaces, as well as various analog and discrete signal sources.

The OBS can be configured to output data to one or more aircraft multifunction displays (MFD), cockpit warning and alarm panels, or a dedicated HUMS-specific display indicator.

2.1.2 Ground Station.

The HUMS GS is a software function which resides on various industry-standard Microsoft® Windows®-based personal computer (PC) hardware and is responsible for the following HUMS-based functionality:

• Downloading the recorded HUMS data from the OBS data storage unit
• Storing the recorded HUMS data for later retrieval and analysis
• Trending of aircraft captured data, health packets, and events
• Reviewing aircraft health and trend data in support of exceedances resolution and preventative maintenance actions
• Graphical presentation of aircraft parametric data collected during HUMS-monitored operations
• Performance of various rotor tuning solutions based upon the OBS-collected rotor track and balance data. This function is shared with the OBS for current-operation solutions, but also provides access to historical data and a presentation of a wider range of equivalent rotor tuning solutions.
• Transferring usage, health, and flight regime data to ground-based configuration management systems, which are responsible for accumulating operational usage and health information at the component level for the aircraft
• Transferring maintenance and health discrepancy information to ground-based maintenance management systems (MMS), which are responsible for the unit-level maintenance actions taken to resolved issues identified during HUMS-monitored operations

• Configuration of the various available HUMS processing functions that are unique to each aircraft model (or type) administered by the HUMS GS

2.1.3 Data Transfer.

Data can be transferred between the OBS and GS in a number of ways. The most common method is the physical transfer of the data card (a PC card conforming to the Personal Computer Memory Card International Association specification) from the OBS data storage unit to a compatible card reader connected to the HUMS GS system. Some IVHMU-specific aircraft installations also provide for the ability to transfer HUMS data directly from the aircraft Ethernet data bus. These installations provide for a permanent memory storage system internal to the IVHMU, which duplicates the storage format of the external data storage unit device.

Both the OBS and the GS implement a packet-based cyclic redundancy check (CRC)-32 algorithm to allow for data error detection following the transfer of data packets to the GS. Any received packet processed by the GS that fails to match the CRC generated by the OBS will result in the entire packet being rejected and a notification written to the GS download log. In addition, the GS data download function implements a state machine, which requires a minimum data packet content to be present before allowing a HUMS operation to be created. Data that passes these checks is downloaded into the GS and forms the basis for subsequent HUMS data storage and display.

2.1.4 Configuration Data.

Software found within the OBS, and data storage connections within the GS are both influenced and specified by separately controlled aircraft configuration data, which is responsible for tailoring the OBS and GS for a specific aircraft platform. As such, this configuration data is specified, developed, and verified as a separate class of software. It is formally verified during final system test to ensure that it performs according to its specifications and requirements.

2.1.5 Commercial Off-the-Shelf Software.

Unlike traditional embedded software used by many smaller in-flight systems, the HUMS-based software includes components of COTS software. For the purpose of this report, COTS software is considered to be any run-time software package purchased commercially and not generated or modified specifically by Goodrich for the purpose of providing HUMS functionality. COTS may be resident in in-flight systems as well as in ground-based systems, and is usually responsible for providing infrastructure support (file system, run-time system, input/output, display, etc.) that is not specialized for HUMS processing, but rather is required for the general functionality of the various computer systems leveraged by the HUMS functionality that is specifically developed.
2.1.5.1 The OBS COTS Software.

The OBS uses the following COTS software:

- **Real-Time Operating System (RTOS).** [IVHMU Only] The Green Hills Integrity-178B Securely Partitioned RTOS, which supports Ada, is used on the main processing cards. This system was previously certified on a wide variety of aircraft systems including equipment certified for the Sikorsky S-92 aircraft platform.

- **File System.** [IVHMU Only] The Green Hills fast file system is used on the main processing cards to provide a file storage system for those devices.

- **Data Storage Device.** [MPU Only] The DTU is a device supplied by TARGA Systems and represents both hardware and software COTS. The entire unit, including all embedded software, is COTS.

2.1.5.2 The GS COTS Software.

The GS application is HUMS-specific. However, even within the HUMS-specific application, certain third-party COTS software is either embedded within the application, or used directly via external calls to software components, which are COTS, since they were not developed specifically for HUMS functionality but are being used by the HUMS application in support roles. The following COTS software is resident in a HUMS GS:

- **Microsoft Windows Operating System.** The underlying operating system (OS) upon which the HUMS GS loads and executes relies on Windows (XP and Server 2003) to provide basic access to central processing unit (CPU), memory, display and input/output devices.

- **Oracle® Relational Database Management System (RDBMS).** The GS stores data both as binary files (Aircraft Data File and Raw Data File (ADF/RDF) formats) and as extracted during download into the Oracle RDBMS for later retrieval, trending, and display. The Oracle database is a separately installed package and is responsible for the relational database integrity of the data that resides within it, as well as for management, storage, import, and export functions.

- **Microsoft Visual Studio®/.NET™ Runtime.** The GS application is implemented in a combination of Microsoft Visual Studio 6® and Visual Studio 2005®, using the Microsoft C++® and C#™ languages. As such, the HUMS software components contain runtime dependencies on both the ‘C’ Runtime System from Visual Studio 6 and the .NET 2.06® Framework from Visual Studio 2005.

- **Database Connectivity.** Several methods of database connectivity are used by the GS software. Specifically, the open database connectivity driver for Oracle, and ActiveX Data Objects (ADO).NET database driver for Oracle are required for connections to the
HUMS-specific application code and the underlying Oracle database. Depending on the vendor required for configuration management, maintenance management, and flight management systems, other drivers from other vendors (such as Sybase, Inc.®, for example) may also be required for GS-to-third-party connectivity. Each of these drivers is implemented as COTS by installing and configuring the necessary driver software on the GS system.

- Internal GS Display Components. Two COTS packages are used for display of data internal to the GS application itself: Steema TeeChart (for graphical displays) and FarPoint Spread (for spreadsheet-like grid controls). These COTS packages are installed within the development environment, are compiled into the runtime GS application, and are distributed as internal components of the GS when it is installed on a target computer.

2.2 THE HUMS FUNCTIONAL ASSESSMENT.

The primary purpose of this report is to provide an assessment of the various HUMS functions contained within the GHUMS, the portion(s) of the system that performs that function, the interaction between the OBS and the GS (if applicable), and the effect of COTS within that function. This section provides that assessment in detail on a function-by-function basis. Where necessary, the criticality of the specific function is discussed, along with the mitigation strategies that are provided for that function.

2.2.1 Data Transfer.

Data transfer functionality is shared between the OBS and GS. The OBS generates the processed data packets along with a CRC-32 value. The GS reads each data packet (including the OBS-generated CRC-32 value) and computes a corresponding CRC-32 value itself. Any packet that fails to validate is rejected and treated as if it had never been received by the GS. An error message is recorded to the GS download log whenever a packet fails CRC validation. The CRC algorithm is common, but implemented via multiple-diverse software in both the OBS and the GS. The actual math routines called by each algorithm are COTS (runtime libraries used by the Ada OBS code and the C# GS code) and are included in the list of COTS relied upon by both the OBS and GS listed in sections 2.1.5.1 and 2.1.5.2.

Following initial packet validation, the GS processes the successful data packets via a software state machine that validates the entire assembly of packets to determine if sufficient information is available to create an aircraft operation or not. If the data is insufficient, a warning is displayed to the operator during download to indicate that an operation cannot be constructed from this download (an error message is also written to the GS download log). If the data is sufficient, an aircraft operation is created, and additional download tasks are scheduled to run to extract various data from the download packet stream for storage and subsequent display.

Failure to detect a CRC error during download is extremely unlikely. However, if sufficient multiple errors occurred in the data stream to allow a damaged packet to validate the CRC check, it remains extremely unlikely that the subsequent packet would process correctly. Individual data field checks on the packet are performed to verify overall packet identity, word length, and
data ranges. A packet identity error would result in the rejection of the packet; word length errors would result in additional data stream errors; and data range validation failures would result in no storage for the invalid data.

The implementation of multiple-dissimilar software in the generation and validation of the CRC values is therefore a valid method of ensuring valid CRC processing and data stream error detection.

2.2.2 Aircraft Parameter Monitoring

Aircraft parametric data is configured and monitored entirely within the OBS. Data is collected from various data bus or analog inputs, scaled, processed, and declared valid or invalid entirely by the OBS HUMS software and configuration data. When communicated to the GS, the data is presented in engineering units, so the GS is not required to reinterpret, rescale, or revalidate the parametric data in any way. Those parameters designated by configuration data as requiring storage in the GS database are stored at download time into the relational database system. A link to the governing configuration definition for that item is maintained internally in the database to ensure the integrity of the definition data for that aircraft parametric data item. Later changes to the definition of the data do not impact the previously stored item because the original link to the original definition is maintained even when subsequent data is downloaded against later configurations. In this manner, the GS can maintain historical data collected against older aircraft configurations without any loss of that previous data.

2.2.3 Usage Monitoring

HUMS processing centers around identifying different kinds of usage of the helicopter. This processing actually starts with the detection of HUMS events and their subsequent processing. The actual application of time- or cycle-based usage is discussed in section 2.2.7.

The OBS is configured to recognize any number of HUMS events via the configuration data. An event is anything of significance that has occurred to the aircraft. Examples include engine start, takeoff and landing, the start and end of a scheduled HUMS data collection operation, and engine diagnostics check, a vibration diagnostics data collection, the start and end of mechanical diagnostics acquisitions, etc.

The OBS is configured to detect two broad classes of events: Instantaneous and monitored events. Instantaneous events occur at a specific point in time, but whose durations are not important. Examples would include takeoff or engine start. A monitored event is a significant occurrence on the aircraft for which the HUMS system is required to monitor the length of the event. An example would be an engine over temperature or over speed event, where the system is required to monitor the total time that the engine was experiencing that condition.

The time between two occurrences of an event or the counting of specific events can be used to form the basis for Operational Usage Determination (section 2.2.7). In addition, the OBS can be configured to attach parametric data (data sets) to an event. This is done to allow specific parametric data to be attributed to an event within the system.
In the GHUMS, the detection and determination of events is performed entirely by the OBS software and configuration data. Event packets are created and written to the data storage unit once the event is detected and all parameters of the event are known. This data is then downloaded to the GS for display to the user in a variety of ways, including a tabular display available during debrief and event overlays available on the Strip Chart function.

2.2.4 Exceedance Monitoring.

Exceedances are simply a special class of HUMS events. Any event can be marked as an exceedance, as specified in the configuration data. Usually, exceedances are those instantaneous and monitored events that represent violations of operational limitations for the aircraft. Engine or rotor over speed, engine over temperature, aircraft over speed, and hard landing are examples of the types of configured events that are usually classified as exceedances by the HUMS configuration data. Since they are also events, the HUMS OBS software and configuration data are the sole source for identifying these exceedances, and they are written by the OBS to the data storage card in the same manner as events.

Exceedances are displayed on the GS in their own tab during debrief and are marked prominently in bold red text so they can be easily recognized as exceedances. Exceedances usually have an associated maintenance discrepancy and are usually the source for maintenance actions written to the maintenance management system if one is available during download. The GS can be configured to warn the operator if any exceedance has not been acknowledged during download as a means of drawing additional attention to the presence of an exceedance.

2.2.5 Regime Recognition Monitoring.

The HUMS defines a Regime as any mode of operation of the aircraft during the entire HUMS-monitored operation. Examples include: taxi, hover, straight and level flight, right/left turn, etc. Most regimes are further classified according to airspeed ranges or angles of bank and may also contain additional information in the form of prorates, which classify specific parametric data within each regime. The OBS software and configuration data are the sole source for regime recognition, which is performed entirely within the HUMS OBS. Regimes are defined such that the aircraft can only be in one regime at a time (i.e., there are no overlapping regimes). In addition to the known aircraft operating regimes, several catch-all categories are also defined, including “unrecognized” (a regime that does not satisfy any of the criteria for any other regime) and “unknown” (usually caused by missing sensor data on one or more channels). The OBS periodically generates a regime data packet to report the current regime and writes this packet to the data storage device.

The GS detects regime data packets during download and stores this information into the GS database for later review and analysis, providing both instantaneous regime display and a summarized regime spectrum display and report.
2.2.6 Health Monitoring.

Health monitoring is usually the generic term applied for detecting individual component health on the aircraft. For this report, that specific behavior is included in section 2.2.10. However, another aspect of health monitoring, applicable here, is the ability of the HUMS to self-diagnose faults and data quality errors during initial data collection. This section will discuss this aspect of usage monitoring in the GHUMS.

The GHUMS includes functionality to detect and diagnose internal system faults. The primary method is via the fault/BIT function, performed by the OBS. Fault/BIT is implemented in three separate modes: power-on, or start-up BIT (SBIT), periodic BIT (PBIT), and operator-initiated BIT (IBIT). For each BIT type, specific fault-isolating tests are run against the system, and at the conclusion of the tests, a comprehensive list of status bits are recorded for each configured test. The results of all three types of BIT checks can be available to the flight crew via the HUMS display and are communicated to the GS via the data storage device. Any sensor that fails BIT is removed from subsequent data collection routines until that sensor passes a subsequent BIT check. BIT status is available on the GS following a download. The GS reads the encoded BIT status words and decodes them via bit mask and shift operations to determine the status (pass/fail), and any maintenance discrepancy text associated with a BIT status failure. This information is available to the operator in the debrief screen displayed during download, and can also be recalled later from the HUMS database.

In addition to BIT, the OBS also performs data quality checks during the mechanical diagnostics function. Any sensor data below the minimum or above the maximum allowable reading for a specific diagnostics test is considered to have failed the data quality check, and its data is removed from consideration during the mechanical diagnostics function. This processing ensures that sensors that are reporting out-of-range limits (even though they may have passed the BIT check) do not introduce error during mechanical diagnostics processing.

2.2.7 Operational Usage Determination.

The GHUMS provides for two methods of operational usage determination. The first method has the GS determine usage based upon the presence of configuration-specified OBS-generated events. The second method performs this function entirely on the OBS through the use of counters and timers maintained in real time for each operation. Each method is discussed in more detail below.

2.2.7.1 The GS-Based Operational Usage.

In the SH-60B and CH-53E initial integrated mechanical diagnostics (IMD)-HUMS implementations, operational usage for MPU-based systems was based on computations performed by the GS. Counter-based operational usage values (such as landings and engine starts) were configured to count the number of times in a given operation that each configured Event was recorded by the OBS. Time-based operational usage values (such as aircraft flying hours or engine operating time) were computed by designating both a start and end event, and
having the GS compute the time difference between the start and end event for the designated usage type.

Aircraft platforms using this type of operational usage determination, therefore, were reliant on both the generation of events (by the OBS), and the specific computations performed by the GS. Due to the nature of this design, only “incremental” usages could be computed by the GS. Over time, a defect in this type of processing began to emerge anytime a single aircraft operation had been recorded into more than one fragment. With multiple operation fragments, the possibility of mismatched start and end events within the fragments can cause an under-computation of usage across the fragments. In addition, operational usage hours were not available within a given operation, making it difficult to correlate operational usage and events within HUMS. As a result, the operational usage task was moved from the GS to the OBS for later aircraft platforms.

2.2.7.2 The OBS-Based Operational Usage.

The current method is to use the OBS software and configuration data to track time and counts for each type of defined operational usage metric being tracked for a specific aircraft platform. For count-based usages (landings, engine starts), a counter is maintained in the OBS data repository and is incremented each time the corresponding usage event occurs. The counter is reset to zero at the completion of an operation. For time-based usages, the OBS maintains a clock for each usage that is incremented in real time following a start event, and that is halted whenever the corresponding end event occurs. The clock is reset at the completion of an operation. In addition, any usage type can be configured as either an “incremental” or “cumulative” usage. Ending times can be stored in nonvolatile memory for re-initialization at the next operation start even if the system is powered off.

Systems configured for this type of operational usage therefore use the OBS to compute both cycle- and time-based usages. The usages are written periodically to the data storage unit, and are transferred to the GS during a download. The GS reads the final usage packet in the data stream for each operation and stores the resulting values in to the database for confirmation by the crew at download time, transfer (as necessary) to configuration management systems, and for trending and analysis.

2.2.8 Rotor Tuning.

The rotor tuning (also known as rotor track and balance) function can be performed by both the OBS and the GS, with some differences as noted below. Both systems use the identical Ada code to perform the balance algorithm (native in the OBS and cross-compiled into a .dll file for execution on the GS), and therefore will provide the same results given that they are provided the same input data.

On the OBS, the input data to rotor tuning is initialized anytime an initial power-up of the system is performed. As rotor tuning acquisitions are collected (either automatically according to detected “capture windows” or manually via crew-commanded collections), data is stored for use by the rotor tuning function. The crew can use the provided on-board display to initiate a rotor
tuning solution anytime sufficient data for a balance is available. The rotor tuning function can be performed with or without actual blade track data, and is optimized to provide a single best-fit solution. The crew can designate what type of adjustments are desired and can view a single solution provided on the display for implementation in the field.

The preferred method, however, is to allow the OBS to collect the necessary rotor tuning acquisitions, and then download this information into the GS prior to running the rotor tuning solution on the GS. In this manner, a better overall picture of the aircraft’s rotor balancing can be viewed on the larger GS display. Also, the operator of the rotor tuning function has a large degree of flexibility in selecting which operations, and even which acquisitions, within those operations are to be supplied as input to the balance algorithm. Additional information detailing the exact state of both vibration and track data is provided in both tabular and graphical formats. Once the desired input criteria are selected, the operator can request a solution and view a full list of equivalent solutions available (as opposed to the single solution presented by the OBS).

Regardless of which method is chosen, the HUMS rotor tuning function uses the identical (Ada) software to perform the actual balance function. Therefore, whether performed on the aircraft or at the GS, the same solution process is executed.

The rotor tuning display itself can be used to compare the current rotor balance state between the GS data collection and the data provided by the rotor tuning balance algorithm. Any discrepancies can be investigated, as can any differences reported between the GS and the OBS when both types of solutions are performed and compared.

In this case, the COTS used for both types of solutions are limited to the Ada run-time routines contained within the rotor tuning balance algorithm. Additional COTS software on the GS is employed for display purposes only: TeeChart to present graphical indications of measured and predicted vibration and track data, and spread to provide spreadsheet-like tabular display of that same information.

2.2.9 Vibration Diagnostics.

Vibration diagnostics is the process of using traditional vibration frequency spectrum measurements to determine out-of-limit vibration and to help diagnose potentially faulty components. In the case of the Goodrich HUMS, the OBS software and configuration data are used exclusively to collect the necessary data and process it (in real-time via the VPU) into its corresponding frequency domain. The PPU identifies the vibration levels at the specified frequencies of interest, and packages both the vibration level data and the graphical frequency data for transfer to the data storage device. The OBS can be configured to generate and store exceedances based upon the vibration levels at the various frequencies of interest.

The GS processes this vibration data into the ADF file generated during download, and also collects the associated data set data for storage into the HUMS database for later trending. Subsequently, the operator can bring up the vibration diagnostics window to view the vibration levels, fast Fourier transform graphs, and trend the specific vibration levels for a given test over time.
2.2.10 Mechanical Diagnostics.

All mechanical diagnostics (MD) data processing is computed by the OBS. A series of MD acquisitions is configured for automatic execution during a HUMS-monitored operation. The VPU is commanded to perform a sequence of data collections and analysis and reports this information within its data packets at the completion of the acquisition. The collected acquisition data is reported as various condition indicators attributed to each component in the drive train. The VPU also computes a single health indicator (HI) for each component, packaging this information into VPU private data packets, which are then transferred via the PPU to the data storage device.

Upon download, the GS detects the presence of the VPU packets and decodes them to obtain the HIs (no CIs are collected) for storage into the HUMS database. The GS MD function presents the HI data collected in the form of a tree view showing each installed component for all aircraft in the system. Each component’s HI is displayed along with a color code to aid in the identification of healthy, marginal, and unhealthy components, as determined by the aircraft platform’s configuration data. Therefore, the GS is responsible only for the display of component HIs, while the OBS is responsible for the computation of the indicator values. The GS is also able to show the trend of HI values by showing a specific component’s value as it was recorded over time.

2.2.11 Engine Performance Assessment.

Engine performance data are collected by the OBS during user-prompted acquisitions. The process of collecting engine performance data requires that the crew perform specific actions not normally conducted during normal operations. The crew is usually prompted via the HUMS onboard display during each step during engine performance data acquisition procedures. The OBS collects the necessary parametric data and also issues the necessary pass/fail criteria for immediate feedback to the crew. All data collected is written to the data storage unit for subsequent download to the GS.

The GS collects and stores the engine performance data during download to the HUMS database for subsequent display. On the GS, the operator can view all collected engine performance data in both tabular and graphical format and sequence through the various collections on a per-engine and per-collection basis.

2.2.12 Engine Shaft Balance.

Engine shaft balance functions are performed on the aircraft when it is in maintenance and ground maintainers have physical access to the engine shafts themselves. As such, it is also a data collection procedure that requires prompted acquisitions and immediate feedback in the form of onboard display. Each balance evolution consists of a prompted data acquisition, processing by the OBS to produce a suggested balance adjustment, and a prediction of the resulting vibration levels that should result from a given solution. This process is iterative, and completes when no additional balance suggestions are available from the collected vibration data.
data, or an acceptable vibration level is achieved. All prompted acquisition data and balance suggestions are stored to the data collection device for later display and trending on the GS.

The GS receives all collected engine shaft balance data acquisitions during download and stores this data to the HUMS database. The data can be viewed in an engine shaft balance report, one for each engine on the aircraft. There are no user interactions with this data outside of generating the report for a specific date range on a specific engine.

2.2.13 Airframe Absorber Tuning.

Aircraft models that incorporate airframe absorbers can be configured to perform prompted data acquisitions to assess the airframe absorbers and suggest changes to the absorber settings to optimize their performance. This type of data collection requires very specific rotor speed settings and must be made using the prompted procedures provided by the OBS. Vibration data is collected by the OBS across a range of nominal rotor speed settings, and that data is written to the data storage device for transmission to the GS.

The GS receives the absorber tuning data in the form of data sets during download. The GS user selects the Operation(s) in which the absorber tuning data was collected, and is given a tabular and graphical presentation of the vibration signature at the various rotor speeds as collected by the OBS. Based upon the local minima, the user is instructed via fixed text on the adjustment(s) to perform, which will result in minimizing airframe vibrations at the nominal rotor speed. The GS does not perform any additional computations on the data, but merely presents it in a convenient graphical form to allow for easier interpretation by the maintenance crew.

2.2.14 Flight Data Recorder Interface.

[IVHMS Only] The IVHMS contains an integral CV and FDR capability. This function is usually referred to as the CV/FDR function. This capability is an extension of functionality on IVHMS-equipped aircraft only, and is not considered a primary HUMS function. However, since HUMS contains the subset of data usually proscribed for a stand-alone CV/FDR unit, IVHMS-equipped aircraft can benefit from having this functionality integrated into the IVHMU directly, rather than requiring an additional LRU.

The primary impact to HUMS when this interface is integrated into the IVHMS is the raising of the criticality level of the entire LRU when CV/FDR functionality is required. The impact usually is that the IVHMS is added to the Mandatory Minimum Equipment List for the airframe, requires that redundant power busses be routed to the IVHMU for operation of the CV/FDR, and the DO-178B criticality level of the embedded OBS software responsible for the CV/FDR function may be elevated beyond that required for pure HUMS functionality.

In the Goodrich IVHMS, the CV/FDR function is implemented by an integral, repackaged Penny + Giles CV/FDR. Data received by the HUMS functions is collected and transmitted via an internal ARINC 717 data bus interface from the PPU to the CV/FDR, which also accepts separate audio input(s). The CV/FDR is qualified to ED-112 specifications. Configuration of
the CV/FDR and data extraction from the physically separate CV/FDR memory device is supported via an Ethernet port.

On the GS, a separate software package created by Penny + Giles is used to extract and examine the CV/FDR data, which is pulled directly from the internal memory of the device via an Ethernet connection. The HUMS GS software application does not have access to the CV/FDR data, which is normally not transferred from the unit unless a mishap investigation is in progress.

2.2.15 The MDC Interface.

The MDC functionality is also not considered to be a primary HUMS function (i.e., it does not attempt to diagnose engine, drivetrain, or rotor component health), but rather provides a single point of collection for various aircraft electronic system to report fault and BIT status. Traditionally, a separate LRU performs this function by collecting fault and BIT data from a variety of onboard electronic systems, and displaying this status information on a centralized MFD. As with the CV/FDR functionality, collocating this functionality within the IVHMS LRU provides the operator with a savings in LRU space and power. Unlike the CV/FDR, inclusion of this function within the IVHMS rarely requires any increase in power or DO-178B criticality levels. This is due to the less-critical nature of the MDC function itself.

2.2.16 Aircraft Maintenance Management System Interface.

Aircraft MMS, also known as Maintenance Management Information Systems (MMIS), usually consist of additional ground-based computer systems that have been developed to help automate the process of maintaining the aircraft and its many complex mechanical, electrical, and hydraulic systems. The extent and complexity of these systems can vary from the very small and simple to the very large and complex. Some systems serve as the authoritative source for all maintenance, part removal and replacement, hour- and cycle-based usage records. Some include the ability to automatically perform scheduled and even unscheduled maintenance actions, including recording the necessary sign-off and inspection/quality assurance authorizations to prove that required maintenance has been performed. Others extend this capability to include on-line Integrated Electronic Technical Manuals (IETM) and even to assist with fault tree and maintenance troubleshooting activities.

The HUMS GS application is designed to assist the operator and maintainer of HUMS-equipped aircraft with the collection and display of HUMS-specific information generated during monitored operations and to identify flight manual exceedances, vibration anomalies, component health, operational usage, and trends occurring primarily within the rotor system and drive train. In doing so, the HUMS GS can be the source of significant operational data, which can, in turn, be used to “feed” such information directly to an automated MMS.

The GS provides an interface capability that can be exploited by the MMS to extract relevant data from each HUMS-monitored operation. The following MMS-specific information is
available from the GS during download, and can be transferred to a configured MMS via the MMIS interface:

- Operation identity (aircraft identity, operation start time, operation duration)
- Event-based maintenance discrepancies
- Fault-BIT maintenance discrepancies
- Operational usage values
- HI values (by component/slot)
- Accepted rotor tuning solutions

2.2.17 Information Management.

Within the context of a complete HUMS implementation, information management can cover a large number of categories, technologies, and tools. The GHUMS provides a number of tools to manage the configuration and operation of HUMS-specific information. In addition, third-party COTS tools are employed in the general management of data found in the various hardware and software components of the complete system. The following sections provide detailed information on these two aspects of information management.

2.2.17.1 The HUMS-Specific Information Management Tools.

The following HUMS-specific tools are provided by the Goodrich system for information management:

- CDTM. The Configuration/Data Table Manager tool is used by Systems Engineering to generate the Aircraft Configuration Data, which controls how an aircraft-specific HUMS implementation is to operate. This tool provides export controls to generate both a binary image for use by the OBS, and a text-export mode for use by the GS.

- MSLV. The MPU Software Loader/Verifier is a software tool used to load both the MPU-based and IVHUMU-based OBS LRUs with the necessary flight software and configuration data needed to configure the system for normal operation.

- CDIU. The Configuration/Definition Import Utility is a software tool used to load aircraft configuration data into the GS.

- ATU. The Aircraft Transfer Utility is a software tool used by the GS to package aircraft data for transfer from one GS database system to another. This tool supports data archive, temporary transfer (deployment) and permanent transfer (reassignment) of the data associated with one or more specified aircraft.

- Other utilities are embedded in the GS application and are used to perform GS-specific information management functions. Refer to section 2.2.18 and associated subsections for specific functionality.
2.2.17.2 General Information Management Tools.

Certain COTS software employed on the GSS include tools for managing information associated with the HUMS, as indicated below:

- File Management. The Windows Operating System (OS) supplies both the Microsoft Windows Explorer® and command-line utilities, which can be used to copy, move, backup, and delete files stored on the PC associated with HUMS data. ADF and RDF file pairs represent the most significant amount of file storage consumed by HUMS data storage. These files can be managed by system administrators when necessary to perform backup, archive, and file movement operations as needed to support HUMS-equipped aircraft and organizations.

- Database Management. The Oracle RDBMS is installed on HUMS GS servers to host and support relational database storage of HUMS data downloaded by connected GS client computers. Oracle provides a number of information management utilities to support database backup and restore, database engine performance management, and file storage and management functions necessary for the proper operation and administration of the RDBMS and associated files.

- Computer Management. The Microsoft Windows OS also supplies a number of administration and management utilities to keep the OS up-to-date and to manage the various peripheral equipment (disk drives, printers, input and output devices, etc.) attached to the computer. These utilities include the various software tools found in the Microsoft Windows Control Panel (Administrative Tools, Add or Remove Programs, Automatic Updates, Network Connections, Printers and Faxes, User Accounts, etc.), and other tools throughout the OS that control and manage the computer and its resources.

- MMIS Systems. Organizations that include other automation systems in their HUMS environments will also use such systems as MMIS or other third-party systems that include information management utilities to support the configuration and operation of those systems within their organization. Such utilities usually mirror the functionality discussed above, providing administration, configuration, and management of user accounts, aircraft configuration, and data management utilities similar to those discussed above.

2.2.18 Ground Station Administration.

The Goodrich GS application supports a number of HUMS-specific administrative options that can be manipulated by qualified GS administrators. Each section below describes a particular major administrative function.

2.2.18.1 User Security and Access Control.

By far, the most extensive administrative function is the management of the various GS Users and Group privileges. Each function within the GS can be allocated to be allowed or rejected
based upon a user’s specific group membership and permission level. In addition, each function can also be set to require re-authentication (the re-entering of the user’s password) if deemed necessary by the administrator. Administrators are provided with a user, group, and privilege management window under the “Configure…Security” main menu, which is used to create user accounts and groups, assign users to one or more groups, and administer the available group privileges. In addition, a number of default groups and users are created automatically when the GS application is installed and configured for first use.

2.2.18.2 User Audit Log.

The GS application maintains an audit log that records major actions performed by any user of the system. This audit log can be configured to record logon/logoff activity, individual operation downloads, significant data events or errors discovered during the download session, and modifications to the general GS application environment (changes to the log itself, changes to user security settings, updates or changes to loaded aircraft configuration data). Administrators can manage this log file for archival purposes and to support audits of data generated by the GS during normal operation.

2.2.18.3 Aircraft Configuration Data.

Since the HUMS OBS is a highly data-driven system, the GS requires certain information to be loaded into it before it can download data from any specific OBS. This information is known by the term configuration data, which is used by both the OBS and the GS to interpret the HUMS data that has been collected. The Administrator is required to load the specific aircraft Configuration Data into the GS prior to downloading data from a corresponding OBS. The GS provides the CDIU, which handles the loading of aircraft configuration data for use by the GS when downloading OBS data. When the OBS records HUMS data, it includes a record of the part number and revision of configuration data used to create that HUMS data, and this information is verified against the loaded configurations in the GS. If a mismatch occurs, the missing configuration data identity is displayed to the operator and the download is aborted.

2.2.18.4 Database Installation/Refresh.

A GS installation includes the necessary Oracle Structured Query Language (SQL) scripts required to create the Oracle database structures used to store HUMS data during the download process. In addition, refresh scripts are also provided to allow for the updating of the database structure as necessary when upgrades to the GS are provided. These scripts are executed by command files that the administrator runs as directed by the GS installation instructions and other directives.

2.2.18.5 Database Export/Import.

Administrators are responsible for the periodic backup and archiving of GS data stored in the HUMS database. The “Tools…” menu provides convenient access to the Oracle database export and import commands, customized to generate valid Oracle dump (.dmp) files that hold the full contents of the HUMS database at any given point in time. These dump files can be used to
restore the HUMS database in the event of data corruption or hardware storage device failures and can also be used to transport the contents of the HUMS database from one machine to another when necessary.

2.2.18.6 Database Replication.

The GS installation includes SQL scripts and command files that support the installation of Oracle Database Replication for use throughout an organization’s data center. By implementing database replication an operator can ensure that data in the HUMS database can be centrally administered but remain up-to-date with changes made at remote (or outlying) sites. Replication is an advanced feature of the HUMS GS that can be implemented to reduce the need for periodic file transfer and re-downloading of Operations when implementing a centralized server/decentralized workstation environment.

2.2.18.7 Aircraft/Customer-Specific Settings.

Command files are provided during GS installations to help support the different settings implemented for various aircraft and customer combinations. These files are used by the Administrator to customize the appearance and behavior of the GS when implemented for a specific aircraft and customer installation. They control the installation and registration of optional components, the default functionality and download task configurations, and various user-specific aspects of a functioning GS.

2.2.18.8 Aircraft Model Configuration Files.

In addition to aircraft/customer settings, some low-level information that is specific to each aircraft model supported by the GS is maintained in model-specific eXtensible Markup Language (XML) files and can be modified by the Administrator as necessary during a specific GS installation. This information is used to identify the specific directories used for certain types of file storage and also the mapping of template files for strip chart and trending functions. These files can also contain detailed configuration data updates that have not yet been expressed within the aircraft configuration data.

2.2.18.9 Download Task Configuration.

The GS “Configure…” menu includes a selection to allow the administrator to activate, deactivate, and install additional download tasks. These tasks are Component Object Model-compliant components that are executed during download and are provided as a means of creating an extensible, open-architecture system capable of supporting third-party download tasks as necessary for a given HUMS-equipped aircraft. All Goodrich-supplied download tasks are created in conformance to this open-architecture design and can therefore be installed, removed, activated, and deactivated from within this configuration menu.

2.2.18.10 Technical Manual Configuration.

The Administrator can specify the appropriate mapping files used by the GS application to link into aircraft electronic technical manuals supported by the GS-IETM link. The Administrator
can also generate technical manual mapping file shells in XML format for the purpose of creating those links to technical manuals under development.

2.2.18.11 Debrief Tab Configuration.

The Administrator can modify the order that Debrief Tabs are displayed to the user from within the “Configure… Debrief Tab” menu selection.

2.2.18.12 Report Configuration.

The Administrator can modify the location used by the GS for obtaining available reports. In addition, using Microsoft Windows Explorer®, the Administrator can modify, delete, or add to the available GS Crystal Report Query and Report files available for display.

2.2.18.13 Operation Management.

Within the GS application, authorized users can manage the current operations by using the Operations Explorer to either “purge” or “delete” listed operations. The “purge” option is used to remove older operations that have since been downloaded again into the GS. Purging deletes these “invalid” operations to reclaim database space. The “delete” option is used to completely remove the selected operation from the HUMS database. Neither of these selections affects the underlying RDF, which can be used to re-download the operation later if desired.

In addition, authorized users can run the Aircraft Transfer Utility (ATU). The ATU was designed as a means of easily migrating data for a specific aircraft (or set of aircraft) from one GS database to another. The ATU allows the authorized user to specify the aircraft and date range, and also to indicate whether the user desires to just copy, move (delete from the current database), or “deploy” (move without deleting) the resulting operations. When run, the ATU creates an XML file containing all the HUMS database data for the specified Operations, which can then be imported to the gaining GS database or used for offline storage.

2.2.18.14 Other Administrative Tasks.

In addition to the HUMS-data specific administration tasks, there are numerous COTS-specific administrative tasks that are routinely performed on the GS computer. These include User Administration (managing users, passwords, file access and permissions, etc.), Operating System Updates (normally performed via Microsoft Windows Update® and responsible for updating operating system components and patching operating system vulnerabilities), file and disk maintenance (periodic permanent file deletions, disk defragmentation, etc.), data backup (periodic backups to preserve existing data in the event of hardware failure), data archive (periodic collection and removal of older data removed from online storage from the system and archived to offline media), update and management of installed software applications (both HUMS-specific and non-HUMS software application installation, update, and removal), hardware repair and update (replacing defective components such as disk drives, memory modules, peripheral components; installation of additional components such as printers, monitors, card readers, etc.), and other activities associated with the configuration, operation,
and maintenance of the COTS computer hardware and software upon which the HUMS-specific application runs.

3. SUMMARY.

This report provides an assessment of the HUMS functions performed by the third- and fourth-generation GHUMS currently in production and flying on a wide range of commercial and military rotorcraft. The majority of HUMS processing performed in these systems is accomplished by the onboard component of the system, including data acquisition, data analysis, and fault detection. The processed data is written to a data storage device, which is then used to download the HUMS data to a GS for subsequent retrieval, analysis, trending, and interfacing to other systems, including maintenance management and configuration management systems.

Components of both the OBS and the GS are implemented using COTS hardware and software. These components provide for certain standard functionality, which is integrated into the HUMS-specific hardware and software to create a complete system to support the operations and maintenance of HUMS-equipped aircraft.

This assessment provided a detailed list of the various functions implemented by the GHUMS, including which portion of the system performs the function, the interaction within that function between the OBS and GS, the effects of COTS on the function (if any), and applicable criticality and mitigation strategies involved.

4. REFERENCES.

