Cover page

Title: *Certification Issues for a Level D HUMS Utilized for Usage Credits*

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ABSTRACT

The objective of this study is the enhancement and validation of rotorcraft structural usage monitoring and flight regime recognition (FRR). The Embry-Riddle Aeronautical University (ERAU) team project is the enhancement and validation of current technology Health and Usage Monitoring Systems (HUMS) devices, both airborne and ground, from a Technology Readiness Level (TRL) of 6 to a TRL of 8 for usage monitoring. The latter is a flight tested conformal prototype to be used for usage credit. The metric and regulatory guidance for defining this level of readiness is prototype compliance to Federal Aviation Administration (FAA) Advisory Circular (AC) 29-2C, Miscellaneous Guidance (MG) 15. Three major certification areas have been identified by the ERAU team: the HUMS assurance level, software aspects for certification, and hardware aspects for certification.

The ERAU team has determined that a Level D HUMS can safely monitor flight critical components. A statistical rationale was developed to demonstrate that the majority of lost exceedence counts may be attributed to data loss during digital conversion and quantization. The magnitude of these losses far outweighs the losses due to the HUMS assurance level. Thus, the ERAU team has chosen to complete the project with a Level D HUMS.

Software aspects for certification comprise a large portion of AC 29-2C. The certification requirements include limitations of commercial off the shelf (COTS) technology and adherence to Radio Technical Commission for Aeronautics Inc. (RTCA) DO-178B for software development. The onboard HUMS software must be capable of acquiring and storing the flight data with integrity. The ground HUMS software must be capable of downloading, processing, and storing the flight data with integrity. The ground software must also back up the data to a statistical database. The ERAU team has identified software changes which will be made to the Systems and Electronics, Inc (SEI) Structural Integrity Monitoring System (SIMS). The SIMS is the onboard unit chosen for the ERAU project.

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Hardware aspects for certification are also presented in AC 29-2C. Hardware certification requirements include installation criteria and adherence to RTCA DO-160D for hardware environment testing. The HUMS hardware must be able to support maintenance credit acquisition and validation. The hardware must also be periodically tested to ensure continued airworthiness of the HUMS device. The SIMS has no specific hardware changes. However, the hardware must support the required software changes.

INTRODUCTION

The objective of this study is the enhancement and validation of rotorcraft structural usage monitoring and flight regime recognition (FRR). The Embry-Riddle Aeronautical University (ERAU) team project is the enhancement and validation of current technology Health and Usage Monitoring System (HUMS) devices, both airborne and ground, from a Technology Readiness Level (TRL) of 6 to a TRL of 8 for usage monitoring. The latter is a flight tested conformal prototype to be used for usage credit. The metric and regulatory guidance for defining this level of readiness is prototype compliance to Federal Aviation Administration (FAA) Advisory Circular (AC) 29-2C, Miscellaneous Guidance (MG) 15. Three major certification areas have been identified by the ERAU team: the HUMS assurance level, software aspects for certification, and hardware aspects for certification.

It is conceivable that parts, for which maintenance credits may be applied, are critical components with potentially catastrophic results upon failure. Thus, there must a very high assurance that the component does not fail. The ERAU team developed a statistical rationale which demonstrated that while the HUMS assurance level contributes to lost data, it is not the largest source of lost data. A major source of data loss is digital conversion, quantization. The magnitude of these losses, at 10^{-1}, far outweighs the losses due to the HUMS assurance level, at 10^{-5} for Level D. Thus the ERAU team has determined, via this rationale, that a Level D HUMS can safely monitor flight critical components.

The HUMS chosen for this project is the Systems and Electronics Inc (SEI) Structural Integrity Monitoring System (SIMS) with a commercial off the shelf (COTS) Ground Support Station (GSS). The ERAU team has performed a detailed AC 29-2C compliance check for the SIMS and GSS. This compliance check showed no show stoppers in using the SIMS and GSS, however certain modifications are required. This document reviews the software and hardware aspects required for AC 29-2C certification. The required modifications for the SIMS and GSS to become AC 29-2C compliant are addressed in the respective hardware and software sections.

Software aspects for certification comprise a large portion of AC 29-2C. The certification requirements include limitations of commercial off the shelf (COTS) technology and adherence to Radio Technical Commission for Aeronautics Inc. (RTCA) DO-178B for software development. The onboard HUMS software must be capable of acquiring and storing the flight data with integrity. The ground HUMS software must be capable of downloading, processing, and storing the flight data with integrity. The ground software must also back up the data to a statistical database. The ERAU team has identified software changes which will be made to the Systems and

Electronics, Inc (SEI) Structural Integrity Monitoring System (SIMS). The SIMS is the onboard unit chosen for the ERAU project.

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LEVEL D HUMS JUSTIFICATION

A major concern in the use of a HUMS for maintenance credits is the individual element assurance levels within the end-to-end HUMS from a top-level perspective. It is conceivable that parts, for which maintenance credits may be applied, are critical components with potentially catastrophic results upon failure. Thus, there must be a very high assurance that the component does not fail. The Embry-Riddle Aeronautical University (ERAU) team has shown that critical parts may be monitored in an end-to-end HUMS with individual component assurances that are lower than Level A [1]. This is an important concern as FAA guidance, specifically AC 29-2C, does not allow for Level A HUMS certification [2]. This approach takes into consideration the fact that the end-to-end system includes multiple use of the airborne equipment collecting the flight data, transfer of the collected data to the ground station, and processing of the aggregated data. In addition, it is highly desirable to use Commercial off the Shelf (COTS) hardware and software in the end-to-end system, which typically cannot be approved above Level D [3].

A significant difference between the HUMS application and normal critical avionics functions is the time to failure. Most critical avionic applications are analyzed with a standard Functional Hazard Assessment (FHA). In this type of analysis, the failure is as likely to occur in hour one as it is to occur in later times. In the end-to-end HUMS system, the failure of a part is probable on at the end of its life. As this is different than previous applications a statistical theory was developed to handle the overall assurance of not exceeding a maximum life limit [1].

The derivation of the statistical analysis produced the following equation for the estimated number of maximum HUMS exceedence counts.

$$N_{MaxHUMSx} = \frac{N_{Max}}{1 + \frac{st_{\alpha}}{\sqrt{\upsilon}}} \left(1 - \sum_{1}^{M} \mu_M - \sum_{1}^{L} \mu_L \right) \quad (1)$$

Figure 1 is a graphical depiction of the top level statistics for ensuring N_{HUMS} does not exceed N_{max}. Where N_{max} is the maximum number of cycles permitted, $\widehat{N}$ is the estimated number of cycles, and N_{HUMS} is the actual number of counts accumulated by the HUMS.

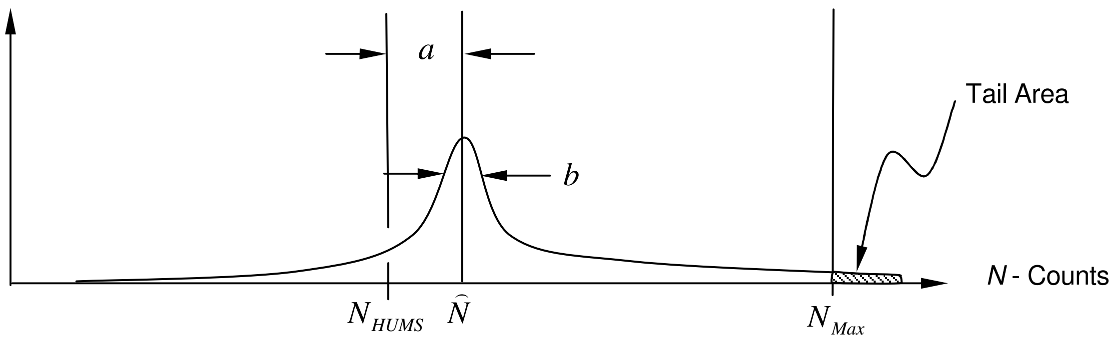

Figure 1. Graphical Depiction of N_{HUMS} Statistics

The following equations are represented in Figure 1, where s is the overall HUMS end-to-end system deviation in loss hours/hour:

$$a = \sum_{1}^{M} \mu_M N_{HUMS} + \sum_{1}^{L} \mu_L T N_{Hr} \tag{2}$$

$$b = s \tag{3}$$

The following is an example problem that was used to illustrate the sensitivity of the system to particular variables [1]. The constants chosen here are representative of a typical system with one exception. All of the deviation in the system is due to the HUMS and is specified at 1×10^{-5}, which corresponds to Level D assurance. Table III lists the values required for the example problem. $N_{maxHUMS}$ is 45,044 counts for this case. The estimate of the number of the number of actual counts is 49,998 and there are only two counts lost due to Level D assurance. Thus, the system is relatively insensitive to the assurance level of the HUMS.

Although the system is insensitive to the assurance level of the HUMS it will be important to create a statistical database to forecast a good estimate of the maximum number of HUMS counts. As the component ages, many of the required statistics needed to predict the maximum number of HUMS counts may converge. If these statistics converge then, at the maximum number of HUMS counts, the number of HUMS counts and the maximum number of HUMS counts are the same. In addition the estimated number of cycles per hour, $\widehat{N}$, will become stable and trend towards a constant. Similar to the HUMS count, the product of the average number of counts per hour and the total time on the component will approach the maximum number of HUMS counts.

$$\lim_{N_{HUMS} \to N_{MaxHUMS}} N_{HUMS} = N_{MaxHUMS} \tag{4}$$

$$\lim_{N_{HUMS} \to N_{MaxHUMS}} t_{TT} \widehat{N}_{Hr} = \widehat{N} \tag{5}$$

Example Problem	
N_{Max}	50,000
μ_M	0.10
μ_L	0.01
s	$1x10^{-5}$
t_α	2.326

TABLE III. REQUIRED VALUES FOR EXAMPLE PROBLEM

SOFTWARE CERTIFICATION ISSUES

The guidance of AC 29-2C presents certain software certification criteria. The ERAU team has performed a detailed AC 29-2C compliance check to ensure that the equipment selected for the project is compliant. The ERAU team has also established specific software requirements in order to use the SIMS to eliminate the 100 hour inspection tail rotor balance. Minimal changes are required for the SIMS to be AC 29-2C compliant and to meet the ERAU requirements.

AC 29-2C Software Certification Criteria

The AC 29-2C software specific certification criteria are: criticality, Functional Hazard Assessment (FHA), use of COTS technology, and mitigations. The first AC 29-2C criterion is to establish the HUMS criticality level. The AC states that for maintenance credit to be gained the criticality level cannot be Catastrophic, which corresponds to a Level A assurance for the system [2]. The end-to-end HUMS must be tested and verified to meet the desired criticality and assurance levels. The ERAU team has selected to use a Level D HUMS which corresponds to Minor criticality. This is important because AC 29-2C allows for a Minor criticality HUMS to be independently verified after the system has been certified, provided that a verification plan has been submitted [2].

An FHA is required to determine the possible software failures and outcomes as well as confirming the criticality level. The ERAU team performed two FHA's one standard and one augmented for the HUMS application. The standard FHA used fault tree analysis to show that the probability of exceeding the maximum number of cycles, N_{max}, could be predicted even with software failures. The augmented FHA ensured that a Level D assurance HUMS could monitor flight critical components [4]. This FHA was different from a traditional FHA because for traditional avionics applications failures are as likely in hour one as they are in later hours, for the HUMS application a failure is likely only at the end of a component's life. The augmented FHA included fault tree analysis and a probability risk assessment.

In an end-to-end HUMS application it is desirable to use COTS technology especially in the ground station. The ERAU team will be utilizing COTS software in the ground station for the operating software. The use of COTS software limits the assurance level to Level D, which has been approved in some earlier systems [3]. AC 29-2C allows for COTS software but makes certain restrictions on the use of the software. AC 29-2C states that COTS software must be limited to ground station operational software [2].

Certifying the system to Level D requires the airborne software to meet 28 of the RTCA DO-178B objectives [5]. These objectives include two in the planning process, seven in development process, three in the certification liaison process, and eight each in the verification and SQA/SCM processes. A short version of these objectives can be presented as follows [6]:

- There must be a plan
- Additional consideration must be in plan
- Plan was carried out
- Product configuration is identified, protected, and explained
- What is approved is what is flying
- Cert authority agreement up front
- Data in place to prove:
    - Plan was followed
    - Concentrate on functional testing
    - High level requirements good & trace to sys requirements
    - Executable complies and is robust with high level requirements
    - One verifies behavior of object code in target environment
    - Executable code compatible
    - High level requirements developed
    - Derived high level requirements are defined
    - SW architecture/low level requirements are developed (NV)
    - Source code is developed (NV)
    - Object code executes in target computer (NV)

NOTE: NV stands for no verification objectives to the specified activity.

Mitigating actions are permitted by AC 29-2C, however the mitigations must be consistent with the HUMS criticality level. The ERAU team included mitigations performed by the onboard and ground based software in both FHA analyses. These mitigations are important to determining if data is missing or inaccurate. The ERAU team included multi-level mitigations on both FHA analyses to ensure that all possible software failures or undercounts can be identified.

AC 29-2C Compliance Check Summary

The AC 29-2C compliance check performed by the ERAU team demonstrated that there are no show stoppers with the SIMS software. There are, however, certain items where compliance has not been met. A plan has been developed to ensure compliance of these items for the complete mock-up certification. The software algorithms must be verified for credit validation, continued airworthiness, RTCA compliance, data characteristics, and electronic tracking.

The software algorithms for credit validation are the Flight Regime Recognition (FRR) algorithms. The ERAU team has identified one flight regime of interest for the project to eliminate the 100 hour tail rotor balance. The conditions for this flight regime are: 1) Weight on wheels, 2) Full nominal RPM, 3) Collective at flat pitch, 4)

Tail rotor vibration. The tail rotor vibration level at this regime will indicate whether the tail rotor is in balance or out of balance. The algorithm for this flight regime must be tested in accordance with AC 29-2C. If additional FRR algorithms are added after the mock-up certification these algorithms must be tested and verified in accordance with AC 29-2C.

The software algorithms must be tested periodically in accordance with the AC 29-2C requirements for continued airworthiness of the HUMS device. This will involve confirmation that both onboard and ground processing algorithms are correct such as the data collection and FRR algorithms. RTCA software compliance requires that all non COTS software be DO-178B compliant for Level D software and AC 29-2C requires that all COTS software be independently verified to the software criticality level, for this case Level D. The software algorithms for data characteristics will be used with the historical statistical database to show data trending. These algorithms must be verified to ensure that the database is accurately predicting the average number of HUMS cycles and the average number of cycles allowed. Electronic tracking software algorithms will be used with the historical statistical database to track components and rotorcraft monitored using the HUMS. These algorithms will be intermittently verified with the continued airworthiness checks.

Software Requirements and Changes

The software requirements created by the ERAU team include onboard and ground based software requirements [7]. The onboard requirements include functional, performance, timing, memory, interfacing, and safety monitoring requirements. The ground requirements include functional, performance, timing, memory, interfacing, and safety monitoring requirements. These requirements are specific to the case study for elimination of the 100 hour tail rotor balance.

The onboard functional requirements detail how the software shall control the SIMS from power on and transition to initialization mode through data recording and power down. The functional requirements also include power interrupt and data integrity requirements. The onboard performance requirement is a fixed 6Hz sample rate which was determined to be sufficient to capture the commercial flight spectrum in a previous HUMS study performed by the United States Navy [8]. The onboard timing requirements ensure that each data channel is sampled and a built-in test is performed every sampling cycle. The onboard memory requirements establish the minimum memory amount for the onboard storage unit and maximum size of operational software for the SIMS. The onboard interfacing requirement establishes RS-422 protocol as the means of communication between the processing and display units. Onboard safety monitoring requirements detail status messages shown on the display unit and that built-in test results should be stored in the onboard memory.

The ground functional requirements detail how the ground station shall communicate with the onboard storage unit as well as the FRR algorithm. The ground functional requirements also include data backup criteria. The ground performance requirement establishes a data transfer rate of at least 512Kbps. The ground timing requirement enables the software to adjust to varying transfer rates. The ground interfacing requirements details the interface between the ground station and onboard storage unit. The safety detection requirements establish that onboard built-in test errors be analyzed after data download as well as detailing the status messages displayed during data download.

The ERAU team and their industry partner SEI have reviewed the requirements and determined various modifications for the SIMS [7]. The changes will be implemented prior to bench testing and flight testing the SIMS. The software changes are as follows:

1. All data shall be sampled at 6Hz
2. All sampled data shall be recorded
3. A 3 byte relative timestamp shall be used for the SIMS
4. The data storage format shall be enhanced with data integrity checking
5. The power up initialization routine shall initialize the NovAtel SPAN GPS-INS system via RS-232 communication protocol and shall display the initialization responses on the display unit.
6. The SIMS shall command the NovAtel SPAN GPS-INS system to sample the data specified by the ERAU team
7. Start/Stop recording criteria shall be established
8. Display unit and processing unit communications shall be updated
9. ARINC code in SIMS firmware shall be commented out
10. UART usage shall be enhanced on the processing and display units
11. Center of gravity and fuel weight prompts shall be eliminated from the display unit firmware
12. The display unit real-time parameter display shall be updated as required by the ERAU team
13. Engineering unit conversion factors shall be made uploadable via the display unit
14. The display unit parameter display shall be made more generic
15. The engineering unit software shall be updated to include the calibration and conversion factors required by the ERAU team
16. The ground station shall be updated to provide processed reports and data as required by the ERAU team

HARDWARE CERTIFICATION ISSUES

The guidance of AC 29-2C presents certain hardware certification criteria. The ERAU team has performed a detailed AC 29-2C compliance check to ensure that the equipment selected for the project is compliant. The ERAU team has also established specific hardware requirements to use the SIMS to eliminate the 100 hour inspection tail rotor balance. Minimal changes are required for the SIMS to be AC 29-2C compliant and to meet the ERAU requirements.

AC 29-2C Hardware Certification Criteria

There are three main sections of AC 29-2C hardware certification criteria. The three sections are installation, credit validation, and continued airworthiness. Each of these sections has onboard and ground hardware certification criteria. The HUMS installation must be approved by the FAA and "cover systems and equipment that acquire, store, process, and display HUMS data [2].” The hardware must meet the same criticality level as the software which was determined by the FHA. Any operational or hardware based mitigations must also meet the criticality level determined by the FHA. COTS hardware must be verified in accordance with AC 29-2C guidance in particular with RTCA DO-160D for environmental concerns. All airborne equipment must be qualified by Technical Standard Order (TSO) or approved with the installation approval. All ground based hardware must be qualified to the system assurance level this requires COTS hardware to be independently verified. The ground hardware must be able to support data processing, display, and communications in accordance with AC 29-2C.

The HUMS hardware must be able to support maintenance credit acquisition and validation. The hardware must be tested and verified in accordance with AC 29-2C. The use of Level D and COTS hardware allows independent verification to be performed after certification if a verification plan has been submitted to the FAA. The HUMS may be introduced to a rotorcraft fleet using controlled introduction to service techniques. This will require each level of technology to be verified with the FAA under a controlled introduction to service plan. The controlled introduction to service technique will allow the owner/operator to gather HUMS data and apply that to future HUMS modifications.

The HUMS must continually be tested and verified to ensure continued airworthiness. The hardware must pass inspections both visual and operational. Personnel must receive appropriate training to use the hardware and be made aware of any known hardware limitations. They must also receive troubleshooting training to appropriately correct HUMS hardware malfunctions. The hardware may need to be added to the Master Minimum Equipment List by the Flight Standards District Office.

Hardware Requirements and Changes

The hardware requirements include certification, onboard, and ground requirements. The certification requirements are specific to AC 29-2C certification criteria. The onboard requirements detail system equipment and operation including the type of connectors required and the messages displayed on the display unit. The ground certification requirements detail system equipment and operation including a procedure for downloading the onboard storage unit and the type of connectors required.

There are no specific hardware changes to the SEI SIMS in order to use it to eliminate the 100 hour inspection tail rotor balance [7]. However, the hardware must support the software changes listed above. For example, the real-time display messages specific to the ERAU project will be programmed into the display and processing units software and the display unit hardware must be able to properly display the messages.

CONCLUSIONS

This document shows that a Level D HUMS can be used to monitor flight critical components in a non-real time end-to-end system. The losses due to digital conversion far outweigh the losses dependant upon HUMS assurance level. The use of statistical databases is required, however, to ensure that maximum life extension can be obtained. The ERAU team will be using the SEI SIMS and a COTS GSS as a HUMS for usage credits.

AC 29-2C presents certain software requirements for a usage credit HUMS. These software aspects include: criticality, FHA, use of COTS technology, and mitigations. An underlying aspect to all portions of AC 29-2C certification is compliance to RTCA DO-178B software development standards. Level D certification requires that 28 objectives to be satisfied. These objectives include: include two in the planning process, seven in development process, three in the certification liaison process, and eight each in the verification and SQA/SCM processes.

AC 29-2C also presents certain hardware requirements for a usage credit HUMS. The hardware aspect of certification includes: installation, credit validation, and continued airworthiness. The hardware must be compliant to RTCA DO-160 for environmental testing. The hardware must be able to support maintenance credit and acquisition. The hardware must also be periodically checked for continued airworthiness, this will include visual and operational tests.

The SIMS and GSS have undergone an AC 29-2C compliance check and no show stoppers were found. Certain software changes were required to make the SIMS and GSS fully AC 29-2C compliant. These changes will improve data communications and integrity as well ensuring the SIMS communicates with other required equipment. No specific hardware changes were required, however, the hardware must support all of the software changes.

REFERENCES

1. Anderson, Dr. Richard, Kornecki, Dr. Andrew, and Rajnicek, Rachel. February 2006. "End-To-End HUMS Component Level Assurance Determination Methodology." First Intermediate Report, Embry-Riddle Aeronautical University, Daytona Beach, Florida.
2. Federal Aviation Administration. December 2003. Advisory Circular 29 Section 2C Miscellaneous Guidance 15, *Airworthiness Standards for Transport Category Rotorcraft: Airworthiness Approval of Rotorcraft Health Usage Monitoring Systems (HUMS).*
3. Federal Aviation Administration. June 2005. *Certification Authorities Software Team: Position Paper CAST-14*. available: < www.faa.gov/aircraft/air_cert/design_approvals/air_software/cast/cast_papers/media/cast-14.rtf >
4. Anderson, Dr. Richard, Kornecki, Dr. Andrew, and Rajnicek, Rachel. May 2006. "End-To-End HUMS Hardware and Software Architecture." Second Intermediate Report, Embry-Riddle Aeronautical University, Daytona Beach, Florida.
5. Radio Technical Commission for Aeronautics Inc. December 1992. DO-178B. "Software Considerations in Airborne Systems and Equipment Certification."
6. Castillo, J. 2005. "Previously Developed Software," presented at the Federal Aviation Administration National Software and Complex Electronic Hardware Standardization Conference, July 26-28, 2005.
7. Anderson, Dr. Richard, Kornecki, Dr. Andrew, and Rajnicek, Rachel. May 2007. "Rotorcraft Structural Usage Monitoring Refinement and Testing Assessment.." Fourth Intermediate Report, Embry-Riddle Aeronautical University, Daytona Beach, Florida.
8. McCool, Kelly. Barndt, Gene. April 2004. DOT/FAA/AR-04/3. "Assessment of Helicopter Structural Usage Monitoring System Requirements." Final Report, Structures Division, Air Vehicle Department, Naval Air Systems Command, Patuxent River, Maryland.

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