KC-30A Structural Health Monitoring System Verification and Validation

Ashley Tuck[1] and Vlado Kekoc[2]

[1] *QinetiQ AeroStructures, Level 3 210 Kingsway, South Melbourne, Victoria, 3205, Australia contracted to Directorate General Technical Airworthiness, Royal Australian Air Force, RAAF Base Williams.*
[2] *Air Vehicles Division, Platforms & Human Systems, Defence Science and Technology Organisation, PO Box 4331, Melbourne, Victoria, 3001, Australia.*

Abstract

The RAAF's new Air to Air Refuelling (AAR) aircraft, the KC-30A - based on the commercial A330-200, is equipped with a Structural Health Monitoring System (SHMS). The purpose of the KC-30A SHMS is to capture aircraft usage parameters significant for monitoring fatigue accrual as well as operational loads monitoring. The KC-30A SHMS employs novel features including Artificial Neural Networks (ANN) to correlate stress sequences to parametric flight data.

This paper describes the approach taken for verification and validation of the SHMS. The scope of Independent Verification and Validation (IV&V) activities considered necessary by the Australian Defence Force (ADF) to ensure that the system complied with functional requirements, was fit for purpose, and produced results of sufficient accuracy to support aircraft structural integrity management is described. The value of undertaking IV&V in parallel to the Original Equipment Manufacturer (OEM) verification activity, and the level of collaboration between the two activities to achieve best results are discussed.

Keywords: Structural Health Monitoring, Verification, Validation, Artificial Neural Networks, KC-30A

Introduction

Under Project Air 5402, the ADF is acquiring a fleet of five Air to Air Refuelling (AAR) aircraft. These aircraft, designated KC-30A, are based on the commercial Airbus A330-200 aircraft, a twin engine medium to long range aircraft. The baseline A330-200 aircraft is being modified by Airbus Military in Madrid, Spain. Major modifications made to the baseline aircraft to convert it to a KC-30A include:

a. Installation of a centreline Advanced Refuelling Boom System (ARBS) for in-flight refuelling of receptacle equipped aircraft.

b. Installation of underwing pods for refuelling of probe equipped aircraft.

c. Installation of a Universal Aerial Refuelling Receptacle Slipway Installation (UARRSI) to enable the KC-30A to take on fuel from another tanker aircraft in-flight.

d. Installation of the fuel systems necessary to support AAR.

e. Modification of flight control laws to enable more precise handling for close formation flight in order to make contact between tanker and receiver aircraft

f. Installation of military mission equipment.



Figure 1: The RAAF KC-30A demonstrating its offload capabilities via both hose-and-drogue and ARBS refuelling devices [1]

Structural Health Monitoring System

One of the important differences between civilian and military airworthiness regulations is the requirement for usage monitoring to be performed on military aircraft, as required by MIL-STD-1530C [2], DEFSTAN 00-970 [3] and incorporated in the RAAF technical airworthiness regulations [4]. To meet this requirement, each aircraft in the RAAF KC-30A fleet is fitted with a Structural Health Monitoring System (SHMS), to provide both usage monitoring and operational loads monitoring functions. The primary objective of the KC-30A SHMS is to provide a means of assessing individual aircraft usage and the implications of individual aircraft usage on inspection thresholds and repeat intervals. Key features of the SHMS installed on the RAAF KC-30A include:

a. Flight data is recorded continuously throughout the flight. Approximately 100 flight parameters are sampled at a frequency of up to 50 Hz (dependent on parameter) from the flight control system ARINC 429 data buses.

b. One aircraft in the fleet of five (termed the reference aircraft) is fitted with 57 strain gauges sampled at 200 to 400 Hz in addition to the parametric recording.

c. All flight parameters and strain gauge time histories are recorded without data reduction in binary format to an onboard memory unit, the Structural Health Monitoring Unit (SHMU) and downloaded approximately once-per-month.

d. Downloaded flight data is processed through the SHMS ground station, called the Damage Calculation Module, which performs the following functions:

   i. screens signals and performs local repair of spikes and dropouts by interpolation or replacement where possible,

   ii. calculates usage statistics from the raw data files,

   iii. estimates stress time histories at each strain gauge location based on the flight parameter inputs processed through the ANNs,

   iv. rainflow counts the predicted stress time history, and

v. calculates accrued fatigue damage and crack growth damage for each flight using software modules adapted from the same software used for initial certification of the aircraft.

Figure 2 provides a functional overview of the RAAF KC-30A SHMS.

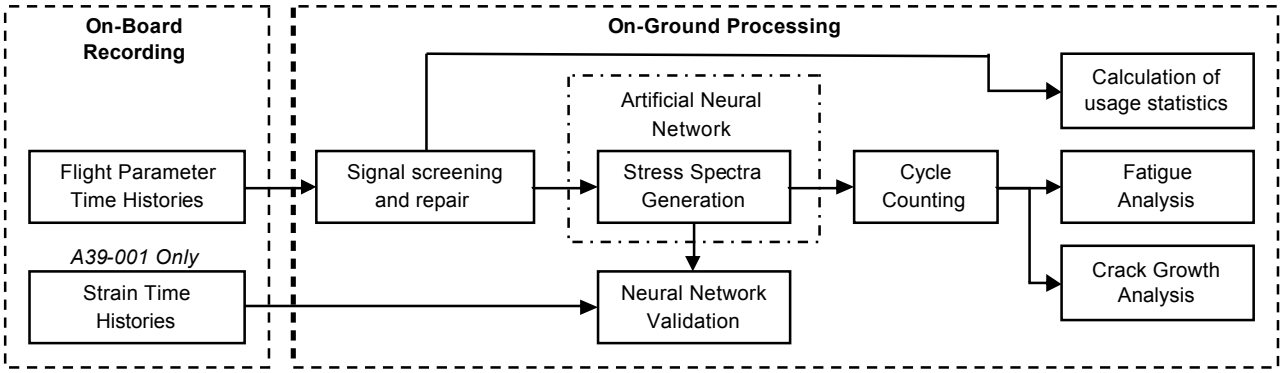


Figure 2: SHMS Functional Overview

Figure 3 shows a schematic of the ANN design used for stress spectra generation in the SHMS ground station. A separate ANN exists for each of the strain gauge locations. The ANNs incorporated in the KC-30A SHMS are feed-forward back-propagation networks trained using a supervised learning technique [5].

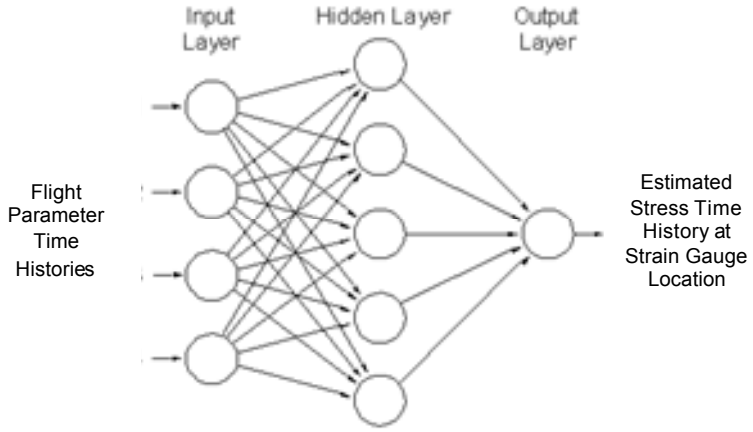


Figure 3: Artificial neural network design used for predicting stress sequences from flight parameter inputs

Flight parameters used as inputs to the ANNs include aircraft centre of gravity accelerations, aircraft configuration and control surface positions, aerodynamic measurements, aircraft attitudes, engine control settings, fuel weights, all-up-weight and AAR device operational parameters. The parameters used as inputs to the ANN are tailored for each location. The number of input flight parameters used varies between 10 and 40, dependent on the location [6].

Compared to traditional, load equations based, fatigue monitoring methods; ANNs present advantages for stress generation, as the mathematical relationships between stress response and flight parameter inputs do not need to be known a priori. Neural networks can be trained to correlate responses to various flight conditions without the need for a multitude of separate

load equations for different configuration states, and neural networks offer processing speed advantages.

The use of ANNs for operational loads monitoring has been used previously with success on the Tucano and the Dominie TMk1 as described in Refs 7, 8 and 9. Based on this work, Ref 10 proposed regulations and guidance to be incorporated into DEFSTAN 00-970 [3] for certification and qualification of ANN based aircraft fatigue monitoring systems.

The ANNs incorporated in the KC-30A SHMS are static, rather than adaptive ANNs. Static ANNs are trained during system development, following which the relationships between nodes in the ANN will be frozen. In contrast, adaptive ANNs 'learn' continuously throughout their service usage, such that the relationships between nodes are constantly changing. Adjustment of system weights post-delivery and acceptance of the SHMS will only ever be undertaken as part of a controlled system change. Attempting to verify and validate an adaptive ANN would be problematic to say the least; so much so that Ref. 3 disallows the use of adaptive ANNs in fatigue monitoring applications.

Training of the ANNs is being performed as part of the system development using a back-propagation approach as shown in Figure 4. ANN training is currently being performed by Airbus Military using significant Points In The Sky (PITS) extracted from flight data accrued during flight test campaigns. Following delivery of the aircraft to the RAAF, further ANN training will be necessary using flight data captured for representative RAAF operations. Measured strains on the reference aircraft will also be used for continued validation of the performance of the ANNs throughout the service life of the aircraft.

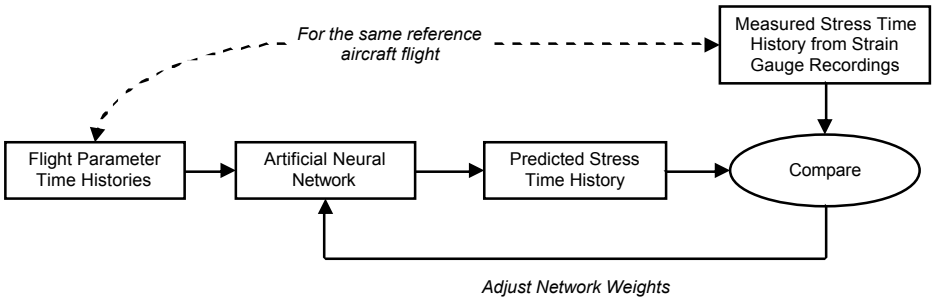


Figure 4: Artificial neural network training approach

Approach to Independent Verification and Validation

Requirement for IV&V

The baseline A330-200 was certified by the European Aviation Safety Agency (EASA) to Joint Airworthiness Regulations (JAR) 25. The KC-30A has been recertified to JAR 25 regulations under a Supplemental Type Certificate (STC) issued by EASA; but has also been certified for military operations to a set of military special conditions under a Type Certificate issued by Instituto Nacional de Técnica Aeroespacial (INTA), the Spanish military airworthiness authority. Certification of the SHMS falls outside the scope of both the EASA and INTA certification of the KC-30A. In accordance with the JAR 25 regulations, EASA and INTA will certify that the SHMS does not have any detrimental impacts on other safety-of-flight critical systems, but will not be certifying the output of the SHMS.

Ref. 11 defines certification as "the end result of a process which formally examines and documents compliance of a product against predefined standards to the satisfaction of the

certification authority." Ref. 4 Section 2 Chapter 19, states that "it is essential that certification of the structural health monitoring system forms part of the certification basis for the aircraft type." However, the remainder of the section then focuses on validation rather than certification. This is understandable as there are no accepted standards for these systems to be examined for compliance against. Thus a technical "certification" is not possible at the present due to the absence of standards associated with Health and Usage Monitoring Systems (HUMS) to which to certify to.

Without oversight from any external agencies, Aircraft Structural Integrity section of the Australian Defence Force (ADF) Directorate General Technical Airworthiness (ASI-DGTA) decided to undertake an IV&V activity led by Defence Science and Technology Organisation (DSTO). The objectives of SHMS IV&V activity were to establish compliance with contractual requirements, demonstrate that the SHMS is fit for purpose, and demonstrate that the system output is accurate and suitably conservative.

Previous Experience with IV&V Programs

The approach to KC-30A SHMS IV&V was tailored based on DSTO experience with previous HUMS certification program undertaken on the C-130J, Hawk and AEW&C platforms. One of the lessons learnt from previous programs was to ensure that the IV&V activity was performed in parallel to the OEM system development and qualification schedule. Conduct of the IV&V in this manner presents difficulties due to the ever-changing nature of systems during the development phase, and the schedule risk introduced to the IV&V activity by virtue of the fact that the activity is tied to overall program development schedule. However, it is essential to conduct the IV&V activity in parallel to the development and qualification of the system if we are to have any chance of having recommended changes and improvements incorporated in the system.

The schedule risk associated with HUMS IV&V activities is further exacerbated by the fact that HUMS development and certification is often not a prerequisite for type certification. Allocation of resources towards progressing HUMS development and certification can accordingly be a second priority to those activities that are critical to achieving a type certification.

Scope of IV&V

One of the challenges with IV&V activities is to determine what level of IV&V is required. Previous DSTO experience with the Hawk HUMS suggested that significant levels of IV&V were not warranted in that instance. Conversely, experience with the C-130J HUMS has demonstrated the need for a significant IV&V effort that has spanned many years. These contrasting experiences demonstrate that the appropriate level of IV&V is highly dependent on the particular system in question and the level of interaction with the system designer/manufacturer.

In defining an appropriate level of IV&V for the KC-30A SHMS, the usual factors of consequence of failure and probability of failure are considered. Given that the HUMS will be used to assess the applicability of structural inspection thresholds and repeat intervals, the consequence of failure of the system can be considered catastrophic. Considerations leading to a perceived increased likelihood of failure included the fact that the ADF was the launch customer for this aircraft type and this monitoring system, the SHMS was a relatively complex system relative to HUMS installed on other aircraft types, the novel features incorporated in the HUMS and the fact that limited implementation experience exists for ANN-based HUMS. Considerations leading to a perceived decreased likelihood of failure

included the fact that the aircraft has a high fatigue life relative to planned lifetime usage, and the fact that compared to other aircraft types, the expected variability of individual aircraft usage for the KC-30A is not anticipated to be overly significant (in comparison to a highly manoeuvrable fighter aircraft).

At a lower level, each of the system elements were considered separately to assess the relative likelihood and consequences of non-performance of each of the individual system elements. The level of IV&V performed for each system element was then determined based on the perceived likelihood and consequences of failure of that element.

Integration with OEM Verification

As part of the development of the SHMS, Airbus Military will deliver a Health and Usage Monitoring System Verification Plan (HUMSVP) and associated verification results. These documents will provide Airbus Military's verification evidence of the performance of the system. DSTO IV&V will not be attempted in isolation from Airbus Military's test evidence. Previous experience on the Hawk and C-130J programs has demonstrated the value of conducting IV&V in conjunction with OEM activities rather than in isolation. Wherever possible, the preferred means of verifying compliance was to witness Airbus Military testing and/or review Airbus Military test evidence. Independent testing is only being performed where considered necessary or where previous testing is considered not to encompass sufficient breadth to meet the intent of AAP 7001.054 [1].

The success or otherwise of the KC-30A SHMS IV&V program hinged on the integration of the program with the OEM verification activities. One of the strong points of the KC-30A SHMS IV&V program has been the level of open communication at a technical level between Commonwealth representatives and the Airbus Military engineers developing the SHMS. Without these direct links and the cooperation of Airbus Military, the SHMS IV&V would not have progressed to the level that it has thus far.

The SHMS IV&V activity was divided into review of raw data collection, storage and retrieval (Phase 1) and review of the ground station functionality (Phase 2). Airbus Military SHMS development and qualification is still in progress. IV&V of the SHMS by DSTO is underway, to date having mostly focussed on Phase 1 activities, with the approach to Phase 2 having been established but not yet executed.

Verification of On-Board System Elements

The first priority of the SHMS IV&V was to ensure that the data collected from the aircraft were complete, accurate and suitable for the end use of individual aircraft tracking; and that the data storage and management procedures were adequate to prevent loss of data. Raw data integrity is imperative to the performance of the system. Failure to capture and store quality raw data will undermine the performance of all subsequent SHMS functions, and therefore also the IV&V performed of these system elements. In particular, inaccuracies in the raw data could have significant and unknown impacts on the SHMS ground station outputs dependent on how the ANNs handle the inaccurate inputs.

IV&V of raw data collection, storage and retrieval was established as a pre-requisite for the issue of a special flight permit, while other IV&V elements were not considered to be critical this early in the aircraft certification program. This approach was adopted as other elements of the IV&V can be performed at a later date, and raw data reprocessed provided that

complete sets of raw data of sufficient quality is available. A summary of the Phase 1 IV&V tasks undertaken are described below.

SHMS Data Recording

These tasks range from the most basic, fundamental of activities such as checking that a readable file was created when the SHMU was activated and closed when it was deactivated, to checking that data losses would be minimised in the event that all the data storage capacity of the system is used.

The IV&V activities were designed to check that the SHMU would activate and deactivate as required, and the parametric and strain gauge data was recorded by the SHMU when activated. Witnessing these tests being performed provided the assurances required that any problems experienced during the flight test campaign had been overcome and the SHMU would perform as required in service.

In order to ensure that no fatigue cycles were omitted, the system had originally been designed to record data whenever power was applied to the aircraft. This design results in the capture of a large amount of data of little significance to fatigue tracking while consuming the finite on-board memory resources; further, the ADF do not track how much time the aircraft has power applied to it, therefore an implementable download interval could not be established. IV&V feedback resulted in system design changes such that the SHMS started and stopped recording with activation of the engine master on-off switch. While this has the potential for the system to miss some ground load cycles (for example taxiing of the aircraft when the aircraft is not operating under its own engine power), omission of these cycles was considered to have a low impact on accrued fatigue damage and be preferable relative to reduced data capture rates following the capacity of the SHMS being exceeded.

Raw Data File Integrity

Airbus Military presented verification evidence for each of the flight parameters by means of cross-correlation with independent flight test instrumentation recording of the same signals from the flight control system. Five flight data files for flights flown by the reference aircraft were subject to IV&V. The flight data files requested were from different phases of the flight test campaign and included examples of operation of both the boom and pods. For each data file extensive analysis of the files was conducted. Each of the files was examined to ensure they included all strain gauges and ARINC parameters expected. Each and every channel, strain gauge data and ARINC parametric data, of the files were visually inspected for:

a. Data Errors – such as spikes, drop-outs, etc.

b. Interference - while the INTA and EASA certifications ensured that the SHMS did not interfere with other systems, interference from other systems is the responsibility of the SHMS IV&V.

c. Synchronisation – was checked by comparing data from strongly correlated strain gauges and parameters.

d. Transposition/labelling errors – were the channels labelled correctly.

Review was undertaken primarily using the signal visualisation software provided as part of the SHMS. Initially the signal visualisation software was not considered to be in the critical data path for the SHMS (as its performance has no impact on the outputs of the SHMS ground

station), and was therefore not subject to qualification by Airbus Military. Given the potential for this tool to be used to make engineering decisions later in the life of the aircraft, it was considered necessary to subject the tool to some level of IV&V. While not considered a high likelihood of failure, given the number of signals captured by the SHMS, and previous experience with IV&V of other systems, there is always the potential for simple errors such as data being transferred on the wrong channel or incorrect signal labels, which could have significant implications if this data was used for later engineering analysis.

Data downloaded from the aircraft is saved in binary format. These files are not readily interpreted into data useful for engineering purposes. ASI-DGTA and DSTO considered it to be a valuable step in the IV&V process to develop an independent tool to decode raw data files into engineering data useful for IV&V. This tool was adapted by QinetiQ from software routines previously written to decode C-130J data files for propeller balancing. This tool was used to assist in reviewing the raw data signals stored in the binary files and was used for direct comparison with the signals displayed by signal visualisation software. Further, this tool was developed to assist in the IV&V of ANN performance as described below.

The results of these investigations, along with those conducted as part of earlier reviews of the file visualisation software, provided significant understanding of the raw data files structure, a better understanding of the evolution of the data file structure, as well as providing confidence in the integrity of the raw data files.

SHMU Download

The ability to record good data is of little use if it is not possible to download it for processing. Therefore, the download capability and robustness of the system to handle failures during the download process formed another significant section of the activities of the Phase 1 IV&V. Both the physical systems and the procedures specified for performing downloads were subject to review.

While not directly relating to the functionality of the SHMS, the human factors aspects of the system cannot be ignored or treated in isolation when conducting an IV&V, especially given that it is often the most critical element in the system. Systems that fail to consider the end user are destined to fail due to human error when they enter service.

One aspect of the SHMS that has been improved thanks to considerations of the human factors is the installation of an SHMS download point in the cockpit. Prior to this modification, SHMS downloads could only be performed from within the avionics bay. Given the dark and confined conditions within the avionics bay and the time required to download data, it was believed that such conditions were likely to lead to reluctance to perform the required download, which would ultimately lead to loss of data. Therefore, modifications were proposed and accepted to have a download point installed in the cockpit to allow the download process to be conducted in a more acceptable environment, thereby reducing the risk of loss of data.

SHMU Configuration Control

To ensure that the SHMS is able to support the changing needs of the RAAF, a degree of customisability has been included in the on-board SHMS recording unit. The primary changes possible are modification of the signals acquired and acquisition frequency. Configuration changes of the SHMU are not expected to be required often during the life of the platform, however, given the RAAF's history of life-extension programs and varying the manner in which aircraft are used during their service life, the ability to modify aspects of the

SHMU configuration is a useful feature, and one that will ensure the SHMS continues to be of use throughout the life of the platform regardless of how the aircraft's use changes over the years.

The configuration control activities of the IV&V endeavour to ensure that the changes to the configuration are reflected in the data.

Verification of Ground System Elements

Calculation of Usage Statistics

The SHMS ground station calculates usage statistics based on the parameter time histories recorded by the SHMU. IV&V of the usage statistics is relatively straightforward once the criteria for calculating the usage statistics are known (for example what the triggering methods to capture an Nz exceedance were). IV&V of this element of the system focussed on reviewing the triggering parameters for each parameter. Following this, a limited review of the statistics reported for each flight was undertaken.

Strain Gauge Calibration

Physical calibration of SHMS strain gauges using predefined input loads applied by a ground test rig has not been performed. Rather, SHMS strain gauges are being calibrated indirectly by correlation of recorded strains for specific ground and flight test points against theoretical strains as predicted using the analytical models developed as part of the initial certification of the aircraft. Calibration of strain gauges in this manner introduces further potential inaccuracies as any inaccuracy in the analytical models is inherently carried forward into the strain gauge calibration. The Commonwealth has identified this approach towards SHMS strain gauge calibration as a potential risk area. Given the potential risk identified, a relatively detailed review of the strain gauge calibration outcomes will be undertaken. However, this element of the review cannot be undertaken independently by DSTO, given the reliance of the methods on certification information not available to DSTO. Consequently, DSTO has requested that Airbus Military provide greater disclosure of the calibration results achieved. IV&V will be limited to reviewing the outcomes of the strain gauge calibration, considering factors such as the linearity of the strain gauge response and the degree of correlation achieved with the analytical models.

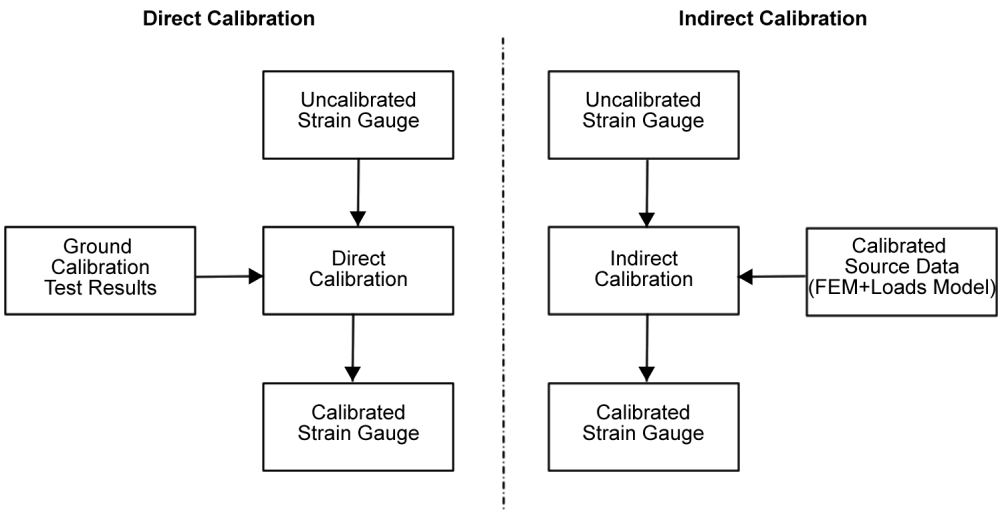


Figure 5: Comparison of Direct and Indirect Calibration Approaches

Artificial Neural Networks used for Stress Spectra Generation

IV&V Approach

In a parametric based fatigue monitoring system, stress spectra generation would typically be performed using load equations derived from the analytical models used for aircraft certification. IV&V of the stress spectrum generation element of the fatigue monitoring system would concentrate on mathematical verification of the load equations incorporated. Relative to traditional fatigue monitoring systems, there are a number of additional considerations necessary for IV&V of fatigue monitoring systems reliant on ANNs for stress spectra generation as discussed below.

In performing the IV&V of the ANN component of the ground station used for stress spectra generation, the Commonwealth had two possible options; one option was to treat the ANNs as a 'black-box,' with verification based purely on comparison of outputs against expectations. The second possible approach was to undertake verification of the system based on detailed review of the development and training of the ANNs. The approach adopted represented a combination of these two approaches. IV&V treating the system as a black-box was not undertaken as some degree of confidence in the processes for future re-training of ANNs was desirable, and there are a number of nuances relating to IV&V of ANN-based systems as described below to be considered.

One of the factors that increases confidence in the SHMS ANN output is that for every flight flown by the reference aircraft in-service, the SHMS ground station will report error magnitudes between ANN derived stress spectra and the strain gauge derived stress spectra, and error magnitudes for fatigue damage derived from the two spectra. This provides an extra level of 'insurance' that the ANNs continue to perform with sufficient accuracy once implemented in service.

The primary means by which ANN performance will be verified is through comparison of strain data recordings to ANN predictions. Airbus Military will present results of ANN verification by comparison of ANN predictions to strain gauge recordings for selected flights within the validation data set. IV&V will focus on ensuring that the validation data set is truly independent of the training data set; ensuring that the validation data set includes flights that contain more structurally severe usage than the lifetime-average mission types, while still being representative of what the aircraft could realistically be expected to encounter during its lifetime; ensuring that all different in-service aircraft configurations are considered. ANN accuracy will be assessed considering cycle peak-to-peak errors, rather than RMS error, as peak-to-peak errors are the most significant in terms of fatigue monitoring.

ANN Training Data Set

ANNs do not extrapolate data accurately if presented with inputs that fall outside of the training data set. Accordingly, the IV&V is focussing on ensuring that a sufficient quantity of training data has been used for all PITS expected to be flown in-service. Obtaining sufficient training data in the centre of the flight envelope is relatively easy, however obtaining sufficient flight data to train the ANNs at the edges of the flight envelope is significantly more difficult. Adequate training at the edges of the flight envelope (where the highest loads are typically experienced) is of particular importance given the logarithmic relationship between the magnitude of the load cycle and the corresponding fatigue damage. In this regard, the nature of the KC-30A, being a large transport-category aircraft, rather than a small and

manoeuvrable fighter aircraft, is of benefit given that a transport-category aircraft would be expected to experience high load factors rarely during in-service usage.

Further complicating the verification of the ANNs at high load factors for wing locations is the non-linearity in wing bending loads introduced by the manoeuvre loads alleviation system fitted to the A330-200. The manoeuvre loads alleviation system deploys the outer spoilers whenever 2g is exceeded, which shifts the centre of pressure of the wing inboard, alleviating wing bending. While manoeuvres of such magnitude are expected to be rare, their implications for fatigue accrual may not be insignificant. Collecting sufficient training data in this region of the flight envelope to have confidence in the ANN outputs is a challenge. One potential option to address this challenge (not currently being adopted) is to supplement the 'real-world' training data set with additional theoretical data derived from the certification loads and finite-element models.

One of the key benefits to the use of ANNs in fatigue monitoring applications is the ability of ANNs to produce a generalised solution based on the training data set presented to the ANN. ANNs also present the risk of overfitting, where the ANN maps well for data within the training data set but fails to produce similar results on previously unseen test data [10]. The implication of this for the SHMS IV&V program is that unlike traditional methods, where IV&V covering the boundaries of the flight envelope can be used to verify the performance of the load equations, the SHMS IV&V will ensure that the validation data set includes sufficient data from within the flight envelope as well as at the edges of the envelope to ensure that ANNs are not overfitting.

One of the observations to date regarding the training data set is that given that ANN training has to date been performed exclusively using flight test campaign flight data, the range of aircraft all up weights and payload configurations has not sufficiently encompassed the expected range of weights and payload configurations anticipated during in-service operations. This has introduced a schedule delay to the SHMS IV&V program that was not anticipated at the commencement of the IV&V.

Other Challenges in Verifying ANNs

The ANNs are not expected to accurately capture high frequency effects – nor were they ever intended to. This is largely a function of the fact that the flight parameters are not sampled at a high enough frequency to capture such effects. High frequency effects will be captured by means of a dynamic adjustment factor applied to calculated damage. The IV&V will review the process used to calculate dynamic adjustment factors.

One particular challenge for ANNs is to train the network to respond appropriately to step changes in the loading environment. One such change is the difference between in-flight and on-ground conditions. Two options exist to capture these step changes; firstly the neural network can be trained to capture these changes, or secondly, a logic decision can be introduced with stress predictions being derived from two separate neural networks (one for on-ground and one for in-flight conditions). The IV&V will ensure consistency and smooth transitions for any locations where multiple models are utilised.

There will be changes in the loading environment that are not captured by the neural network input flight parameters; however, these effects are likely to be of secondary importance. For example the distribution of payload within the fuselage will impact on fuselage bending stresses. In a traditional parametric system, such considerations could be accounted for by assuming a conservative distribution of payload. However, using ANNs trained with real flight data, the ANN will converge to a solution based on the training data presented to it.

Ensuring that the ANNs are conservative in this regard is very difficult, especially given that the designer is normally hamstrung by the training data set available.

ANN Verification Tools

To assist with IV&V of the ANN spectrum generation module, ASI-DGTA, supported by QinetiQ has developed a tool that enables raw SHMS data files to be modified prior to being input into the ground station. This will allow for uniform increases to input parameters or additional cycles to be included (for example uniformly increasing fuel weight or including additional Nz load cycles) and then presented to the ANNs. In doing so, care must be taken to ensure that the ANNs are not presented with unphysical scenarios (such as a change in Nz without a corresponding change in angle of attack) which are outside of the data set used to train the ANNs.

Cycle Counting, Fatigue and Crack Growth Modules

The cycle counting, fatigue and crack growth modules of the SHMS are adaptations of the software used for initial certification of the aircraft. The only changes made to these software modules are the input and output components to enable them to interface with the other elements of the SHMS ground station. Given that the performance of these software modules can be considered to have been inherently verified as part of the certification of the KC-30A, a detailed review of these modules is not planned as part of the SHMS IV&V. The primary focus of the SHMS IV&V will be to confirm that implementation of these modules within the SHMS has not negatively impacted on the performance of the analytical routines implemented.

IV&V of these elements will concentrate on ten representative locations selected from across the airframe. Data from a set of typical flights will be processed using independent tools used at DSTO for fatigue and damage tolerance assessments, and the outputs will be compared to those from the ground station for the same flights. It is expected that the results from these two assessments will show damage calculations of similar magnitude. It would be unreasonable to expect the results to be identical given the different approaches and software used, consequently the emphasis of the assessment will be to confirm that the relative differences between two flights are approximately consistent.

One of the challenges faced in undertaking this assessment is the fact that the stress spectra generated by the ANNs are not easily extractable from the ground station. Consequently, it may be necessary to feed the independent tools with strain gauge measured stress spectra rather than ANN predicted stress spectra, introducing a further element of uncertainty in the comparison.

End-to-End System Check

Previous experience with other systems has demonstrated the need to undertake an end-to-end check of system functionality. The end-to-end system functionality check will consider overall functionality, confirm that required user input is not excessive, and that processing times are not restrictive. Previous experience has also highlighted the importance of comparing the outputs of the SHMS to the original certification outcomes. For example, the IV&V undertaken for the C-130J SHMS identified damage indices several orders of magnitude greater than the fatigue damage calculated during certification – limiting the value of the SHMS for structural integrity management. Following on from this experience, the end-to-end system check for the KC-30A SHMS will confirm that SHMS outputs are comparable against the certification outcomes.

Conclusion

The SHMS developed for the KC-30A is one of the most advanced and novel approaches to structural health monitoring to be implemented on any ADF platform. IV&V of this system is being performed by ASI-DGTA and DSTO. The scope of IV&V considered necessary and the approach taken to IV&V has been described. The IV&V program is not being attempted in isolation from the OEM's own test program. Wherever possible, OEM verification evidence is being relied upon, with additional testing performed only when considered necessary.

The challenges faced by the IV&V program, in particular to verifying the ANN-based components of the SHMS are described. With cooperation between Commonwealth representatives performing the IV&V and the OEM, no impediments to the successful completion of the SHMS IV&V and implementation of the system are foreseen.

Acknowledgments

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