DEVELOPMENT OF AN INTEGRATED INFORMATION MANAGEMENT SYSTEM FOR AIRCRAFT STRUCTURAL TEST PROGRAMS

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Abstract

The Defence Science and Technology Organisation (DSTO) have developed an integrated information management system for aircraft structural test programs, designated IMSst. This paper outlines the development rationale and process for this system, and using the Royal Air Force (RAF)/Royal Australian Air Force (RAAF) C-130J Wing Fatigue Test Program (WFTP) as a case study, highlights the potential benefits that can be achieved through adoption of an integrated approach to information management. This paper also explores the concept of developing a broader information management system for management of aircraft structural integrity information, and how it could assist in ensuring continued airworthiness.

1 Introduction

Structural test programs form an integral part of an aircraft's design and certification process. These programs are critical in providing the physical evidence to support the engineering analysis which underpins a design, and are typically a requirement of many certification structural design standards [1,2,3]. They are also critical for providing the data required to develop an Aircraft Structural Integrity Program (ASIP) which will support continued airworthiness of an aircraft through to its Life of Type (LOT).

Aircraft structural tests are technically complex programs, relying on input from a wide range of engineering disciplines, and have a number of unique characteristics which present several issues and challenges:

- Run for significant lengths of time (typically 2 to 10+ years);
- Whilst running, are constantly evolving (both from a test system and test article perspective);
- Involve processes and activities which need to be monitored and performed in a controlled manner;
- Have a large number of stakeholders and contributors to the test program who require visibility of test data and information;
- Generate significant amounts of information and data which need to be readily interrogated;
- Provide information which is used for aircraft certification and to support airworthiness advice;
- Have information and data that are required to be stored for significant lengths of time and be available for future interrogation and re-interpretation.

The success of a structural test program is not solely attributable to the output from the test itself, but in how these outputs are subsequently interpreted to firstly demonstrate compliance of the structural design against a certification standard, and secondly for defining suitable management strategies for ensuring continued airworthiness throughout the LOT. Given the significance of structural test programs in the design and certification process, it is inconsistent that the control and management of the data and information generated by the test is often neglected, such that value of this data is unable to be fully exploited in the context of ongoing airworthiness management. This is often because there is disconnect between the process of conducting a test and that of interpreting and applying the knowledge generated from the test results. Any certification and ongoing airworthiness advice must have sufficient supporting evidence from programs such as structural tests [4], and when assessing this evidence, it is critically important to understand the fidelity and limitations that are associated with using this evidence.

2 The C-130J Wing Fatigue Test Program

In 1999, the Royal Australian Air Force (RAAF) introduced the C-130J-30 Hercules into service. In accordance with the requirement to achieve military type certification, an extensive program of work was conducted to demonstrate compliance against a certification structural design standard. Despite the established service and structural test history associated with the C-130 Hercules, a finding of non-compliance against the durability and life of type certification basis elements was found for the RAAF C-130J-30. The Royal Air Force (RAF) had concurrently arrived at a similar conclusion and as a result of the shared concerns, both parties subsequently entered into a collaborative program to conduct the C-130J Wing Fatigue Test Program (WFTP).

In summary, the fundamental aims of the WFTP, from an RAAF perspective, are to resolve the identified structural certification shortfalls and to:

1. Provide a basis of certification for fatigue management of the RAAF fleet;
2. Determine structural/economic LOT of the C-130J-30 wing in accordance with the adopted certification standard(s);
3. Obtain test data to support aircraft structural integrity management via a Safety-By-Inspection (SBI) philosophy, including the ability to pursue fail-safe management options; and
4. Validate repairs and SBI inspection procedures.

The C-130J WFT is being run under contract by Marshall Aerospace in Cambridge, UK. The WFT is now in a relatively mature state, having commenced fatigue cycling in early 2009 and accumulated in excess of 30,000 hours of average representative usage to date, with completion of an estimated 62,500 hours of testing by mid 2014. As anticipated, the test program is generating a significant amount of data and information which requires an efficient and effective data management strategy.

3 Information management

There is no generic strategy for the development of an efficient and effective information management system (IMS). This is largely because what is defined as being information is contextual. However, there are a number of general principles which require consideration. The purpose of an IMS should be to assist the generation of information from the data [5]. As a result, rather than simplistically assuming that all an IMS needs to do is manage data, an IMS should be designed such that it meets a set of objectives which consider how the information managed by the system will ultimately be used and applied.

3.1 Defining data, information and knowledge

There are fundamental differences between what constitutes data, information, knowledge and wisdom. Data typically consists of discrete items which in isolation, often have no particular meaning beyond the item to which the data pertains. Information is drawn from developing an understanding of the relationships that exist between pieces of data. Knowledge is derived from understanding the patterns that exist between pieces of information and the implications of these relationships. And finally, wisdom comes from understanding the underlying principles and their potential impact, which can be derived from integrating knowledge.

In the context of an aircraft structural test program, the following definitions have been adopted:

- Data are discrete items which are artifacts of the process of conducting the test program, or the test system itself;
- Information is derived from forming relationships between these pieces of data, such as the test configuration and activity logs, which can be used to determine information like who, what, where, when things happened during the test program;
- Knowledge will be derived from the information collected from the test program, and is applicable to all aircraft of this type; and
- Wisdom will be derived from the knowledge acquired about this aircraft type, but is applicable to all aircraft designs.

Figure 1 shows a diagram representing the hierarchical nature of these definitions, and their relationship to both level of understanding and context independence.

Fig. 1. The hierarchy of data, information, knowledge and wisdom [6], overlaid with the definitions adopted in the context of an aircraft structural test program.

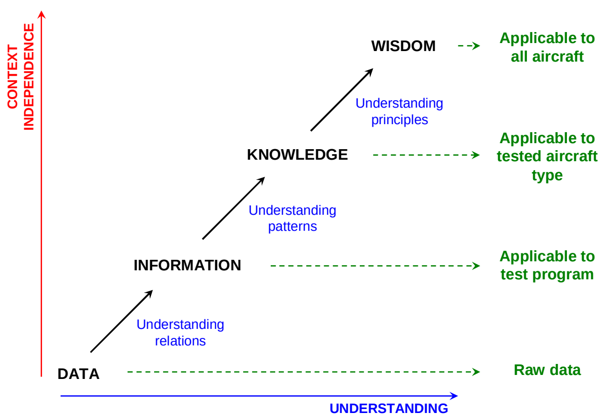


Figure 1 also highlights that a key goal of any IMS should be to encourage and facilitate the generation of knowledge. This reinforces the requirement for having an effective IMS for aircraft structural test programs, because in this context, the ultimate goal is to generate knowledge about how a particular type of aircraft structure performs in operational conditions rather than the mere collection and storage of data obtained from performing the test.

However, in isolation, an IMS will not automatically lead to the generation of knowledge. The act of knowing is human, and knowledge is the residual of thinking [7]. Therefore, an equally important factor in the development of a successful IMS is the human interface: how data and information is entered into the system and how it is subsequently extracted in order to create knowledge. This also reinforces the scope of the system to be developed in this case, and how it should limit itself to management of data and information, rather than attempt to manage knowledge.

3.2 System requirements

The first step in the development of an IMS for aircraft structural test programs was to define the goals for the system. The main goal of the IMS is to accurately capture the evolution of, and outputs from a test program, such that they can be readily interpreted at any time, in order to meet the broader test objectives. In order to achieve this, the main goal can be broken into a number of more specific goals:

- Define the configuration of the test (both test article and test rig), and be able to track the evolution over the duration of the test program;
- Track the process used to generate the data that is obtained from the test program;
- Capture all data that are acquired from the test program;
- Have the ability to form links between pieces of related data.

There are two options for the implementation of an IMS for aircraft structural test programs:

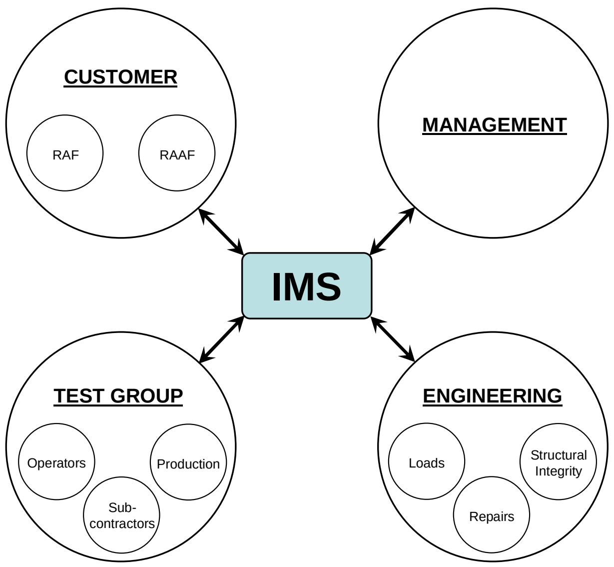
- A stand-alone system, which requires users to input and maintain the data stored in the system, and is separate to the process of conducting the test; or

- An integrated system, which is routinely used and forms an integral part of the process of conducting the test program itself.

Each option has merits, and which is more appropriate is likely to be dependent on the work environment where the system is implemented.

Another key input into the design of a suitable IMS is to analyse how the C-130J stakeholders will use the IMS to derive knowledge to satisfy their individual test requirements. Figure 2 shows the IMS stakeholders for the C-130J WFTP. Whilst these stakeholders appear quite specific to this test program, they are representative of the typical stakeholders associated with any aircraft structural test program.

Fig. 2. C-130J WFTP IMS stakeholders



Each stakeholder, whilst requiring access to the same type of information about a test program, will utilize this information in very different ways to satisfy their unique objectives. For example, the Customer will use the information from the IMS to develop knowledge about the progress of the test program, to better inform themselves in order to make program decisions, and ultimately to perform interpretation of the test outputs to meet their broader program objectives. Management will use the IMS to derive information about test progress versus program milestones, and to identify any emerging program issues. The Test Group will use the IMS to store and manage data generated by the test program, to derive knowledge about the current configuration of the test system and test article and to gain awareness of any upcoming events which may affect the test program or system. Engineering personnel will use the IMS to gather information in order to make engineering recommendations associated with the test program, and to derive knowledge about the performance of the test article to identify any emergent issues.

In this case, there are a number of advantages of making an IMS integral to the process of conducting a structural test program. An integrated IMS will provide the following additional capabilities:

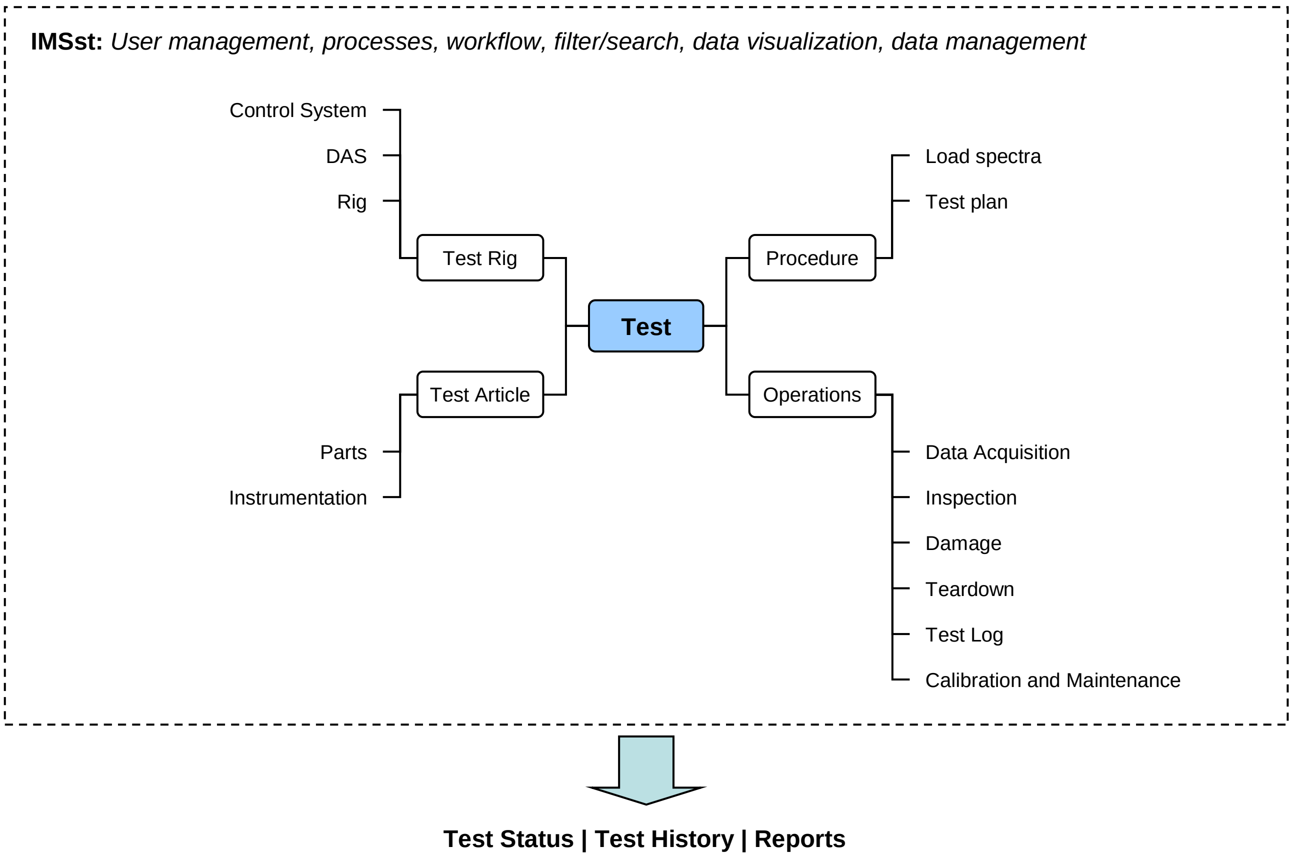
- Facilitate and standardize project communication process;
- Implementation of workflow;
- Control visibility and access to data and implement authority restrictions;
- Record of decisions.

However, it is worth noting that productivity will not necessarily be enhanced unless attention is given to assuring systems are designed for human interaction [7]. This is particularly important for integrated systems. For an IMS to be effective, people have to use it. It is hoped that implementation of an integrated IMS will result in several improvements, which are realized through both overall efficiency gains in running the test program and the development of relevant knowledge from the test program which can be effectively applied to meet the overall test objectives.

3.3 System model

A system level model of a generic aircraft structural test program was developed in order to better define what data will be captured within the IMS, and what relationships exist between various pieces of data.

Fig 3. Top level system diagram



A test program comprises of 4 main components: the test article; the test system/rig; the data acquisition system; and the activities which are conducted during the course of the test program. Each of these main components may consist of several sub-elements, which each have associated data. For example, the test rig consists of a number of control channels, each of which consists of a number of resources (rig, hydraulic, pneumatic, electronic and sensor items). These resource items also each have associated calibration and maintenance data. Figure 3 shows a top-level diagram of an aircraft structural test system.

The overall scope of the IMS to be developed is represented in Figure 3 by the dotted box surrounding the test system. As indicated, the IMS must also be capable of user management, data control, data filtering and search capabilities, data visualization and data management.

3.4 System processes

An IMS design needs to be task oriented in order to avoid unnecessary technical overload of team members [7]. As part of developing an integrated IMS, it is necessary to define the tasks, processes and workflow to be embodied into IMS. The following is a list of areas where workflow or process control shall be implemented:

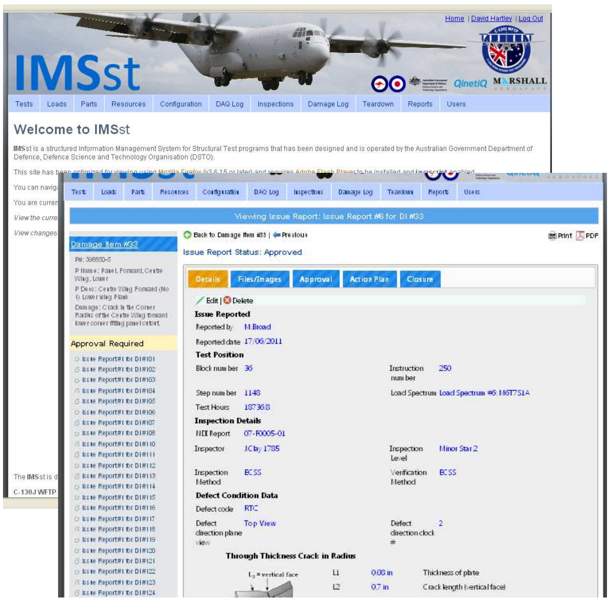
- Damage reporting and disposition;
- Teardown;
- Data acquisition;
- Configuration management.

The implementation of these processes can be achieved through the design of the IMS and the user interface. Another key aspect is designing the processes to be sufficiently generic such that they can be adapted and applied to other circumstances. For example, a standard process for approval and sign-off of items should be implemented such that a system administrator can configure the approval process to suit any situation requiring approval/sign-off within the system.

4 IMSst

DSTO has developed an integrated IMS for aircraft structural test programs, designated *IMSst*. In order to maximize accessibility to all program stakeholders whilst minimizing the cost of any specific hardware or software required by the end-user, *IMSst* has been developed as a web application (accessible via all current internet browser software packages). This also gives it the potential to make it accessible by any stakeholders with access to the internet. The web-application has been developed using the Ruby-on-Rails web application framework, which interfaces to a MySQL database to store the system data. This is implemented within a VMware virtual machine environment. This has a number of advantages, in particular for data backup, system portability and also for any future system updates. Figure 4 shows a screen capture of *IMSst* when viewed using a web-browser.

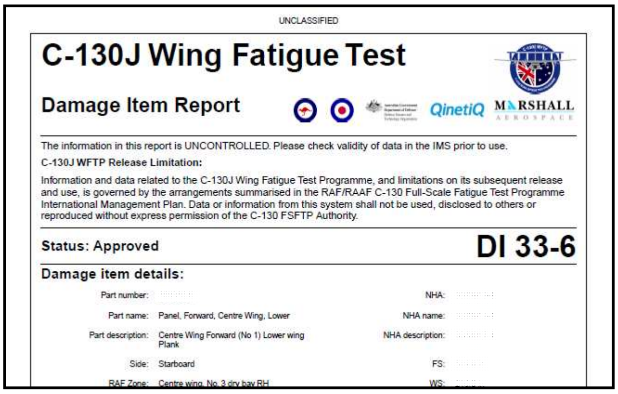
Fig 4. Example screen captures from *IMSst*



IMSst has been developed as a modular system. In other words, whilst the full system is capable of managing all aspects of data and information related to a structural test program, it is not necessary to utilize all aspects of the full system functionality for the system to operate. For example, it is possible to use the Teardown module of *IMSst* in isolation for the management of the teardown of any structural component.

IMSst is able to output a number of standard types of reports. An example of a damage item report is shown in Figure 5. In addition to this, all data that is stored in the system is able to be exported in a comma-separated file, for manipulation or use in external analysis.

Fig 5. Example report from *IMSst*



UNCLASSIFIED

C-130J Wing Fatigue Test

Damage Item Report

The information in this report is UNCONTROLLED. Please check validity of data in the IMS prior to use.

C-130J WFTP Release Limitation:

Information and data related to the C-130J Wing Fatigue Test Programme, and limitations on its subsequent release and use, is governed by the arrangements summarised in the RAF/RAAF C-130 Full-Scale Fatigue Test Programme International Management Plan. Data or information from this system shall not be used, disclosed to others or reproduced without express permission of the C-130 FSFTP Authority.

Status: Approved **DI 33-6**

Damage item details:

Part number:		NHA:	
Part name:	Panel, Forward, Centre Wing, Lower	NHA name:	
Part description:	Centre Wing Forward (No 1) Lower wing Plank	NHA description:	
Side:	Starboard	FS:	
RAF Zone:	Centre wing, No. 3 dry bay RH	WS:	

4.1 Implementation to the C-130J WFTP

Whilst applicable to any structural test program, *IMSst* was specifically developed in response to a requirement to manage data and information generated by the C-130J WFTP. As a result, this system was developed in parallel with the initial phases of testing of the C-130J WFTP, with this test program being used to trial the implementation of *IMSst*.

IMSst was implemented in a staged manner. Version 1 of the system was implemented in the early stages of the test program, with system functionality limited to the Damage Reporting module only. Once initial system training was conducted and preliminary software problems were resolved, the remaining elements of *IMSst* were progressively rolled out. It should be noted that whilst complete system functionality exists at the time of writing, full implementation of *IMSst* is yet to be achieved. This is largely due to the requirement to back-populate data from the earlier phases of testing.

4.2 Impact on the C-130J WFTP

The implementation of *IMSst* on the C-130J WFTP has had a significant positive impact on the test program itself. Although still in its infancy, *IMSst* has resulted in significant improvements in:

- Overall program awareness and knowledge of participants;
- Data accuracy and reduced mistakes/error rates;
- Information dissemination and communication;
- Data accessibility;
- Data visualization;
- Process control and workflow implementation.

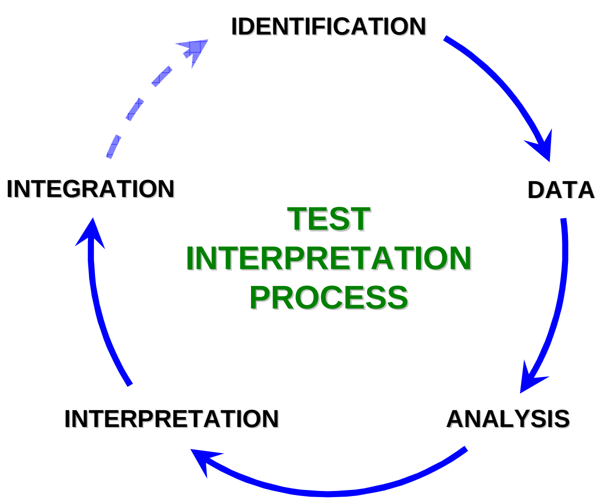
One particular example where improvements have been observed is in reporting the damage arising on the test article. Use of *IMSst* has significantly improved the consistency and the accuracy of the data reported, largely through the standardization of the data capture and disposition process, and removal of the requirement for users to refer to additional technical procedures. Using one central system to collate the damage data and implement the process of disposition and approval has reduced the amount of additional paperwork, and more efficiently communicates this information to team members, achieving a better outcome for the test program.

As remaining modules of *IMSst* are fully implemented, it is expected that further significant system benefits will be observed, in particular the management of the test rig and test article configuration (and associated calibration and maintenance activities).

4.3 Impact on Test Interpretation

A full scale structural test program is inevitably a practical and technical compromise of the real life operational scenario, and a process of interpretation is required to compensate or adjust for these factors when translating across to the fleet [8]. The objectives of structural test programs are typically to provide the evidence necessary to support certification activities and to support ongoing airworthiness of the fleet aircraft. In order to assess the impact *IMSst* will have on test interpretation, it is first necessary to understand what test interpretation involves. Test interpretation (TI) is the process of taking the outputs of a structural test program, adjusting them to account for any deficiencies between the test program and what a fleet aircraft would typically experience, and using this information to validate and update the structural design analysis which underpins the aircraft certification. [8]. Figure 6 shows a simplified diagram of the Australian TI process which will be applied to structural failure scenarios identified by the C-130J WFTP.

Fig 6. Simplified TI process



IMSst will have a significant impact on the first two phases of TI shown in Figure 6: the identification of structural failure scenarios and the compilation of data associated with these scenarios. *IMSst* will improve the ability to identify structural failure scenarios, including identification of emerging widespread fatigue damage, largely through its ability to visualize data. It will also enable more efficient identification and linkage between related failure scenarios, resulting in more robust analysis. The main potential of *IMSst* however, will be to assist with the compilation of data pertaining to a failure scenario, which is required for performing the analysis and interpretation phases of the TI process. *IMSst* will be able to provide a definitive history of the testing conducted to produce the failure scenario that was observed, including details of any significant changes during testing which may have impacted on the fidelity of the test result. In addition to this, *IMSst* will be able to readily provide details on other related items of data, including configuration of the test article in that region throughout the test, any instrumentation which may assist with the interpretation of the failure, and details of the inspections that were performed in that area.

Most importantly, for personnel conducting certification and interpretation activities, *IMSst* will provide a readily accessible, centralized and traceable source of all information and data related to the test program for performing the required analysis and assessments. This capability will not only improve efficiency, but improve the capacity, where required, for these analyses and assessments to be re-visited in the future, long after the test program is completed if required.

4.4 Future system development

Whilst full system functionality (as depicted in Figure 3) has been implemented in the current version of *IMSst* and is unlikely to change significantly, it is anticipated that further development of the system will be undertaken in the future. The focus of this development work will likely be on system process and data storage optimization, data visualization and improvements to the overall system interface. The feedback and information gained from implementation on the C-130J WFTP will be invaluable in developing a tool that has sufficient scope and flexibility for adoption on any future test program.

In addition to this, TI is unlikely to be performed until the later stages of the test program. As a result, it is anticipated that additional data interrogation capability will be developed once the process of performing TI becomes better established.

5 Concept extension to the management of Aircraft Structural Integrity Program related information

The overall concept of developing and implementing a similar well designed IMS has the potential to significantly improve the management of ASIP related information and data, and subsequently increase the overall effectiveness of an ASIP program.

Airworthiness is defined as being the property of a particular air system configuration to safely attain, sustain, and terminate flight in accordance with the approved usage and limits [9]. Safety is the state in which the risk of harm to persons or of property damage is reduced to, and maintained at or below, an acceptable level through a continuing process of hazard identification and safety risk management [10]. The safety hazards creating risk may become evident after an obvious breach of safety, such as an accident or incident, or they may be proactively identified through formal safety management programs before an actual safety event occurs [10]. No system is ever 100% safe or reliable, and as a result, it is necessary to routinely review and assess system safety to ensure the overall risk level is maintained to as low as reasonably practical (ALARP). To do this though, requires access to all relevant information and data, including the assumptions and limitations that accompany the data. Maintenance of a sufficient level of safety via misassumption effectively results in the invalidation of the original certification basis, and has been previously attributed to catastrophic aircraft losses [11,12]

Management of aircraft structural integrity is just one element that contributes to the overall safety of an air system. The RAAF Directorate General Technical Airworthiness (DGTA), as the Technical Airworthiness Regulator, ensures the structural integrity of all RAAF aircraft via the implementation of ASIPs, which are developed in accordance with the principles outlined by MIL-STD-1530C [13]. An ASIP covers the entire life of the aircraft: from initial concept and design through to retirement (the cradle-to-grave concept). This is achieved through establishing the initial airworthiness of an aircraft structural design (via certification), and implementing suitable force management programs (maintenance, condition monitoring, and usage monitoring etc.) that are required to ensure continued airworthiness.

Throughout the operational phase of an aircraft's life the most critical part of an effective ASIP in ensuring safety and continued airworthiness, is that the data and information generated by force management programs are continuously fed back and compared against the assumptions and analyses which underpin the certification process and initial safety assessment.

At present, although a number of separate processes or systems exist for management of data from individual elements of an ASIP, this data is rarely integrated and when it is, often requires additional effort to do so. Similarly, communication of relevant information across ASIP domains, particularly those with differing stakeholders, is not necessarily routine and often dependent on an ASIP Manager to coordinate. In addition to this, assumptions are often made about what information is required by various ASIP stakeholders, which impacts what data are shared, and subsequently limits the potential for knowledge development and early identification of emerging system safety or reliability issues. As with any team environment, success is dependent on effective communication and knowledge sharing among members.

As a result, knowledge about how an aircraft is performing (through recognition of patterns) is only acquired by people who have access to this information. In a military context, this problem is usually compounded by the unique circumstances where the staff posting cycle often results in regular and significant loss of knowledge associated with that particular ASIP. In addition to this, military aircraft fleets are often dispersed across many localities around the world, with ASIP related data potentially generated by any number of people associated with the operation and maintenance of these aircraft.

Recent information technology developments and the implementation of an appropriate IMS to manage aircraft structural integrity information have the potential to make significant improvements to operational safety and reliability of an aircraft, and fully realize the potential of the programs that are defined as part of an ASIP.

There are a number of specific examples where an integrated IMS could improve the efficiency and effectiveness of an ASIP, including:

- To provide aircraft inspection and maintenance staff with access to condition data which is instantly available, to improve awareness of potential or emerging structural issues during routine maintenance;
- To enable up-to-date correlation of aircraft usage data against the assumed usage which underpins the certification of the aircraft, and for which the inspection program is based;
- To enable correlation of structural condition data to either confirm the anticipated structural degradation, or identify new failure scenarios which may require additional structural management actions that invalidate the analysis assumptions in the certification basis;
- The ability to review structural configuration to determine if the certification and safety assessment is still valid.

There are a number of potential strategies for the development of an IMS for management of ASIP data. However, the most appropriate and effective solution may not be the development of an all encompassing IMS which manages data and information for all aspects of an ASIP. It may be more effective to analyze extant systems and processes which manage sub-elements of the ASIP, and develop an IMS which acts to integrate the data and information in these systems. The system design must reflect an understanding that not all teams contributing to an ASIP require access to all systems [7]. An effective IMS will not attempt to provide everyone with every piece of information; it will have the capacity to provide all stakeholders with relevant (and accurate) information. Similarly, increased system complexity often creates a number of additional development problems which limit the overall efficiency, effectiveness and functionality of the system [14].

One proposal for a similar type of system is proposed by the US Air Force Research Laboratory: the development of an Aircraft Digital Twin [15]. However this system would be considered relatively large and complex in comparison, as it attempts to not only manage information associated with an ASIP, but provide prognostic capability to predict the degradation of aircraft structural integrity.

Ideally, an ASIP IMS will not be aircraft type specific, as the principles of an ASIP are generic. Whilst challenging, the development of an effective ASIP IMS could potentially be staged and implemented in a modular fashion such that areas can be progressively utilized, with full system functionality only realized upon completion of the system. Similarly, the cost of developing an IMS could be offset against the efficiencies gained through implementing a more effective ASIP, and potential reduction in cost of ownership via early identification of issues.

More importantly, an IMS for management of ASIP data will help address the social challenge [7] of creating an ASIP community which encourages knowledge development and sharing. This will enable the focus to shift from training personnel to simply collect the necessary ASIP data, to using the data and information that is available to recognize emerging patterns and proactively identify aircraft safety or reliability issues.

6 Conclusions

DSTO has successfully developed an integrated IMS to manage and organize data from a structural test program, designated *IMSst*. This system has been implemented for the C-130J WFTP, and has had positive impacts on the efficiency of conducting the test program. To date, the system has also been shown to be effective in fulfilling the goals for which it was developed, through improving data quality and availability for subsequent test interpretation. Ongoing improvements will continue to be made, mainly focused on improving how information can be interrogated and visualized in order to develop the knowledge required by each of the program stakeholders. Ultimately however, the effectiveness of the system to help fulfill the overall RAAF test objectives will only become apparent once the process of test interpretation begins at the completion of testing.

The concepts which have been applied to the development of an integrated IMS have the potential to be extended to information management for a broader ASIP. Whilst this could be achieved by development of a single integrated IMS, this might be better achieved by focusing on improving interoperability of any IMS that already exist for sub-elements of the ASIP. In order to achieve this, a comprehensive model of the system needs to be established and stakeholders surveyed to determine the system requirements. The development of such a system would enable realization of the overall ASIP philosophy, and could significantly improve both the efficiency of implementing and operating an ASIP (through reduced cost of ownership) and effectiveness of the ASIP (through an overall reduction of risk to safety).

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