CERTIFICATION OF ENGINE USAGE MONITORING SYSTEMS.

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ABSTRACT

Airworthiness Authorities around the world sponsor certification codes for aero gas turbine engines with an aim to ensure an adequate level of safety is designed into these engines. Importantly, the lifing of safety critical components forms a significant element of all gas turbine certification codes. Once the safety critical lives are set the Original Equipment Manufactures (OEMs) provide advice to operators on processes that can be used to track the life usage of these components. However, formal certification of these usage monitoring systems and regular and rigorous review of operator engine usage does not form an element of the current certification requirements.

A variety of engine usage monitoring programs have been developed for aero gas turbine engines, ranging from simple hourly life recording to full on-board usage monitoring equipment. The accuracy of these systems while not impacting on immediate aircraft safety is critical in supporting the continued airworthiness of the aircraft they power. The Australian Defence Force has taken particular interest in the formal review and certification of these usage monitoring systems for its gas turbine engines. Certification of the engine usage monitoring equipment forms an equally important requirement to critical component lifing in the certification of new engines.

This paper overviews current certification code requirements and identifies validation requirements for engine usage monitoring equipment. Australian Defence Force processes for engine certification and management of engine structural integrity are detailed.

1. INTRODUCTION

Airworthiness Authorities (AAs) around the world sponsor certification codes for aero gas turbine engines with an aim to ensure an adequate level of safety is designed into these engines. Importantly, the lifing of safety critical components forms a significant element of all gas turbine certification codes. Once the safety critical lives are set the OEMs provide advice to operators on processes that can be used to track the life usage of these components. However, formal certification of these usage monitoring systems and regular and rigorous review of operator engine usage does not form an element of the current certification requirements.

A variety of engine usage monitoring programs have been developed for aero gas turbine engines, ranging from simple hourly life recording to full on-board usage monitoring equipment. The accuracy of these systems while not impacting on immediate aircraft safety is critical in supporting the continued airworthiness of the aircraft they power. The Australian Defence Force has taken particular interest in the formal review and certification of these usage monitoring systems for its gas turbine engines. Certification of the engine usage monitoring equipment forms an equally important requirement to critical component lifing in the certification of new engines.

This paper overviews current certification code requirements and identifies validation requirements for engine usage monitoring equipment. Australian Defence Force processes for engine certification and management of engine structural integrity are detailed.

1.1 ENGINE USAGE MONITORING SYSTEMS

The operational requirements of aero gas turbine users drive the design requirements of the engine manufacturer. The civil operators' requirement is for an engine which powers the aircraft safely, consistently and economically. The military operator requires the delivery of thrust when required, to generate aircraft missions. Importantly, however, the military operator is now required to balance this desire for instant thrust, with the long-term asset preservation requirements of safety and Life Cycle Costs (LCC). An understanding of engine usage allows the operator to become confident in the safety of the engine, ensures effective and efficient maintenance to increase availability and retains the costly critical components in-service as long as possible reducing LCC.

This paper focuses on the application of engine usage monitoring systems to ensure safety. It is considered that certification of the usage monitoring equipment is as important as the substantiation of the lives of the critical components. An appropriately certified usage monitoring system provides the operator with more confidence in the safety of the engine, better ability use of all the remaining available life saving money and better ability to plan the maintenance, thus increasing availability.

2. AERO GAS TURBINE CERTIFICATION

This section provides an overview of the airworthiness certification requirements applicable to aero gas turbine engines. It is these requirements which define the method that must be followed when initially setting the engine life and the process of ensuring safe operation of the engine during its operation.

The energy possessed by rotating engine components is beyond the containment capability of the engine case and has the potential for serious damage to personnel and other aircraft components. The consequence of such a failure has meant that the Airworthiness Authorities impose the strictest rules on reducing these risks. The strategy to prevent disc failures has been to define regulations on the setting of a safe-life and then to ensure that the usage is monitored to ensure the component is retired prior to the safe-life limit.

As with the aircraft itself, all gas turbines fitted to aircraft must meet minimum airworthiness standards in order to be certified as "fit for flight". Depending on the application and country of origin of the engine, a particular Airworthiness Authority is responsible for defining the certification code that the engine must meet. Figure 1 below provides a list of some better known Airworthiness Authorities, the Certification Codes they sponsor and the engines they are applicable to.

Airworthiness Authority	**Certification Code**	**Application**
Joint Airworthiness Authority (JAA)	JAR – E [1]	European Civil Aircraft Engines
UK Civil Aviation Authority (UK CAA)	BCAR [2]	UK Civil Aircraft Engines
Federal Aviation Authority (US FAA)	FAR 33 [3]	United States Civil Aircraft Engines
UK Ministry of Defence (UK MoD)	DEF STAN 00-971 [4][1]	UK Military Aircraft Engines
United States Air Force / Navy (USAF/USN)	JSSG-2007[5][2], MIL-STD-1783 [6]	USAF/USN Aircraft Engines
Australian Defence Force (ADF)	DEF STAN 00-971 and US Military Standards	Australian Military Aircraft Engines

Figure 1 - Airworthiness Authorities and Certification Codes

The certification code is a comprehensive list of the design standards and qualification requirements that must be met in order to gain certification. The specific requirements of the codes can be found by a review of the identified references. An excellent historical overview of engine certification codes and their application is covered by Holmes [7]. Most certification codes are developed along similar lines with sections typically covering:

- Description and Use,
- Functional Characteristics,
- Environmental Conditions,
- Interfaces,
- Physical Characteristics,
- Design and Construction, including:
  - Fire prevention,
  - Engine Cooling,
  - Engine Mounting Attachments,
  - Rotor Overspeed,
  - Surge Stall Characteristics,
  - Fuel Systems,
  - Lubrication System,
  - Power Response,
  - Foreign Object Damage,
  - Endurance Test,
  - Engine Overtemperature,

[1] DEF STAN 00-971 is currently under review and will be republished as part 11 to a new formatted aircraft standard DEF STAN 00-970.

[2] JSSG 2007 replaces the US MIL-E-5007E and provides additional guidance and lessons learned from US Navy and Air Force experience.

    - Initial Maintenance Inspection (Engine Life),
    - Engine Component Tests, and
    - Blade Containment,
- Engine Systems,
- Reliability,
- Maintainability, and
- Engine Qualification.

The two basic applications of aero gas turbine certification are military and civil. As these organisations have different roles they both have a different approach to certification. As well as the Airworthiness Authority, the military is the customer and operator of the engine. As such the military requires assurance that the engine bought will perform the desired functions safely and reliably over its service life, will have the specified performance, can be economically maintained, is efficient and simple to operate, has good growth potential and has low LCC [8]. The civil Airworthiness Authority, on the other hand, is not the customer but acts in the public interest in terms of assuring safety. The military frequently participate in funding the development of improvements, which does not happen in the commercial business. Historically, the military has performed engine overhaul themselves, while commercial operators are only required to meet the minimum maintenance requirements established by the Airworthiness Authority [9].

In the military certification code DEF STAN 00-971 for example, the Design and Construction section covers Engine Life. The standard defines the requirements upon the manufacturer, in terms of development of procedures for predicting and substantiating the safe cyclic life of major rotating and non-rotating components. DEF STAN 00-971 also includes an Annex that provides a model lifing procedure that has been deemed to meet the airworthiness requirements. Of note however, is the fact that the standard allows for the procedure to "be modified to suit the parts to which it will apply … in the light of current knowledge". Thus the standard recognises the various approaches to lifing but requires the manufacturer to verify the procedures they plan to use for lifing during the certification process. DEF STAN 971 requires the engine OEM to prepare and agree with the Certifying Authority and the operator a "programme of life evaluation". This programme is required before entry into service, and should include some or all of the following [4]:

- Monitoring of sortie patterns and distributions by pilots' observations and records.
- Continuous in-flight recording of engine parameters.
- Fitted counters recording parameters which can be related to life usage.
- Inspection of parts at prescribed intervals.
- Cyclic rig testing of ex-service parts.
- Cyclic rig testing of ex-service engines.

The civil code JAR-E in comparison, details the regulatory requirements in a broad sense in Section 1 of the Standard and provides further details including an accepted means of meeting the requirements and advisory material in Sections 2 and 3 (the ACJs and AMJs) of the standard. Again a proposed lifing procedure is provided. The standard also requires a formal Life Management Plan (LMP) detailing the extent of ex-service inspections, requirement for destructive tests and timing of technical life reviews. In addition, the engine OEM is required to define the Reference Flight Cycle used for component lifing and define an acceptable means of monitoring the actual flight profiles within the engine manual. Significant variations from the Reference Flight Cycle are to be reported to the Authority [1].

The USAF and USN generally develop a new Military Specification (MIL-SPEC) for any new aircraft and its engine. These MIL-SPECs have previously been based upon MIL-E-5007 and define the qualification requirements for the equipment referring to established MIL-STDs for certain design and process requirements. MIL-STD-1783 Engine Structural Integrity Program (ENSIP) is one of these MIL-STDs which forms the basis of US military aircraft engine certification requirements. The ENSIP standard defines the Damage Tolerance approach to engine component lifing and covers [6]:

- Structural design,
- Analysis,
- Development,
- Production, and
- Life Management.

Rather than rely on usage monitoring practices, ENSIP ensures safety by inspection.

The appropriate Airworthiness Authority and certification codes define the requirements upon which the approach to engine life prediction is established. The Airworthiness Authority is rarely involved in-service unless a specific incident has occurred. Once the type certificate is issued the OEMs take responsibility to ensure usage appropriately monitored to ensure the continued airworthiness of the engine.

3. THE NEED FOR USAGE MONITORING

As indicated by Thamburaj [10] and others [11], the task of life prediction is not complete unless utilisation scenarios are considered. The usage rate of the engine during its service life is generally based upon an estimate of the type and mix of missions to be flown. Low cycle fatigue lives of critical components are set by the number and severity of the RPM cycles imposed on the material. The creep life of turbine blades is determined by the time the blades spend within the creep range of temperature of the material. An early and accurate definition of the service usage is essential in meeting engine performance parameters and ensuring cost effective durable components [12]. Service usage and mission analysis is a critical task that must be accomplished to accurately model and predict fleet engine activity and duty cycles [13].

Service usage can be estimated from operations of comparable aircraft in the same or similar roles. If the operator already has an aircraft fulfilling the role, and is purchasing a new aircraft or re-engining, data from existing operations can assist in determining the engine usage. Usage for new missions or new roles may be more difficult to determine, but can be based on anticipated usage. If available, engine health or usage monitoring data provides an extremely valuable insight into the mission parameters required for service usage determinations.

3.1 MISSION PROFILE ANALYSIS

Each stage of the aircraft mission poses varying stresses on the engine and thus varies the life usage rates. Life usage rates should be determined for each mission stage, eg. taxi, take-off, climb, cruise and landing. The mission analysis determines the time spent at each of these mission stages for varying mission types. Missions should be defined in terms of altitude and Mach number, preferably with details of the Power Lever Angle (PLA) or percentage spool speed (PCN) as a function of time.

For commercial aircraft a standard profile may be readily established. However, for military aircraft, much in-service knowledge is required to determine a reasonable set of basic mission profiles. Engine manufacturers must develop a flexible methodology for determining the life of particular components, accounting for the variation in engine usage and mission profiles for each customer.

3.2 VARIATION OF USAGE

It is appropriate to maintain clear details of the basis for the initial life limits with reference to the initial assumed mission profiles. A structured and rigorous approach to review of the actual usage is required in-service to ensure that the basis for the initial life limits remains valid. A consistent aspect of military aircraft operation is the variation in role or training objectives, which varies the mission profile and engine usage [11]. Unchecked, this can have significant impact on the actual usage rates of the fleet. Examples of the CF-18 usage, included 60% more time spent at maximum power and 60% greater usage of afterburner than initially predicted, resulting in variations to several component lives [14]. The assessment of variations to mission profiles must also assess the full logistics impact of changes in usage that will impact on maintenance timings and spare part requirements.

As described by Pomfret [15], the initial assumptions of the mission profiles may vary widely from the actual missions flown in-service, and thus the initial life can only be considered as an estimate at best. Additionally, two aircraft flying nominally the same mission, can experience vastly different operation conditions and thus different life usage. The famous example of the variation in engine usage between two Red Arrows aircraft flying the same profile [16] demonstrated factors of up to 40 times the usage. Figure 2 below shows the difference in RPM variation during the mission of the lead aircraft compared to one of the other aircraft in the formation.

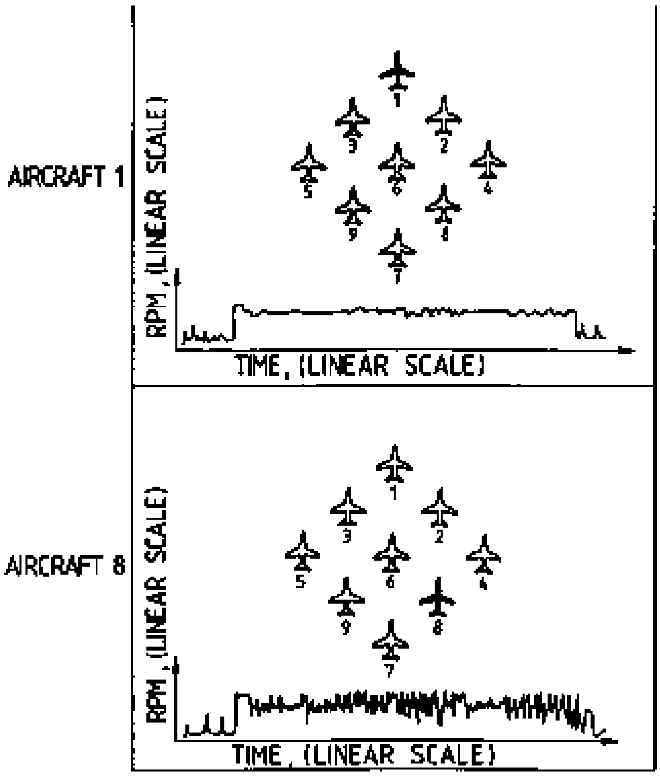

Figure 2 – Variation in RPM for Red Arrows

Esposito and Pettigrew add that from US navy experience, two engines on the same aircraft can experience very different LCF usage levels [17]. The significant point from these examples is that it is essential to monitor engines in-service to determine the actual engine usage.

As well as manufacturer involvement, user groups for particular engines can provide assistance in the development of usage management plans. While larger users can provide good general data, smaller operators provide data on the consequences and usage parameters associated with particular flight profiles.

3.3 MILITARY ENGINE LIFING

Modern military fast jet aircraft are designed for high Specific Excess Power (SEP) to increase their combat capability. These design requirements have been matched by lightweight aircraft that are required to perform multi-role operations and thus must be highly manoeuverable. To obtain the maximum benefit from these features, the pilots often use the throttle vigorously with frequent excursions into and out of maximum power [18].

At the same time the engine materials have been required to be lighter and operate at higher temperatures, resulting in the development of the nickel based superalloys. These materials have greater strength at elevated temperature but have a reduced fracture toughness and are therefore more susceptible to fatigue failure.

The demanding usage and new materials has led to LCF becoming the major failure mode of military jet engines. The costs involved in retiring components that potentially have significant life remaining, led the USAF to develop the Retirement for Cause (RFC) concept [19]. The demands placed on modern military engines has also been the main driver to the development of more complex usage monitoring equipment.

4. LIFE USAGE MONITORING

There has been a growing realisation by major gas turbine operators that an effective life usage management program can have a significant input into understanding life usage and providing appropriate data which can be used to justify increasing component lives. Previous reliance on the manufacturer's recommendation for life extension resulted in time delays and an over-conservative approach to lifing. This often resulted in expensive parts replacement or redesign programs. User initiated usage monitoring programs and manufacturer developed advanced engine lifing systems, provide effective tools to reduce costs, increase availability and improve the overall fleet safety. In the military field, the durability problems experience by the USAF were found to be significantly contributed to by poor definition of service usage during the design stage of the engine [20] [21]. In order to gain a better understanding of engine usage considerable effort was put into the development of usage monitoring systems.

4.1 INTRODUCTION TO LIFE USAGE MONITORING SYSTEMS

The initial life assigned to engine components is generally conservative to assure integrity, and will depend upon the severity of the proposed operating conditions and the amount of in-service experience. The initial lifing assumptions are re-evaluated using data provided from in-service monitoring programs. Life Usage Monitoring Systems (LUMSs) are used to monitor the actual in-flight engine speeds, pressures and temperatures from real missions. This data is used to determine the actual life usage rate of the components [23] and thereby adjust the initial life estimations.

The initial safe life is generally determined using complex design algorithms on a mainframe computer. However, for in-flight life usage measurement and calculation, a simplified model is normally incorporated to meet on-board computing time and space requirements. Critical parts form the basis of the components whose lives are monitored by a LUMS. In order to assign the recorded lives to these components they must be uniquely identified.

LUMSs range from basic engine hour counters to complex on-board real-time computers which use sophisticated algorithms to calculate various types of life limiting failure damage to multiple sites within many components. LUMS can be characterised in two types; General Life Monitoring and Individual Life Monitoring. These types of systems are discussed below.

4.2 GENERAL LIFE MONITORING

General life monitoring is where the LUMS is fitted to a sample of the aircraft fleet to record actual engine parameters. The data collected is then used to determine the life usage for the components for the range of missions flown by the aircraft. The data recorded from this subset of engines is then statically combined to estimate the fleet usage. This requires a necessary level of conservatism to ensure that fleet usage is not underpredicted for any particular operations. A cyclic exchange rate is then determined to calculate the average number of cycles per hour for the fleet.

General life monitoring systems are relatively cheap to install and can provide substantial benefit to the user. USAF and RAF experiences with such systems have shown significant reductions in maintenance costs and increases in aircraft availability. The RAF Engine Usage Monitoring System has been in operation since 1975 and is fitted to 12 aircraft types. For the Hawk it has allowed a reduction in cyclic exchange rates of 50% [14].

However general life monitoring systems are unable to account for:

- variations in mission type and mission mix,
- temperature and other environmental changes due to operations from different bases, and
- individual aircraft usage due to pilot response and engine condition variations.

Additionally, as each engine is not monitored individually, large safety factors are applied to the average usage. This results in an over-estimation of the life used for most sorties, with the possibility that some severe flight profiles can have the life used under estimated. These significant shortcomings of general life monitoring systems result in the full benefit of life monitoring not being achieved.

4.3 INDIVIDUAL LIFE MONITORING

In individual life monitoring each engine in the fleet is fitted with a LUMS and the life usage on each engine is recorded against that engine. Additionally, individual identified components within these engines can be tracked and their life history and usage recorded. This allows the maximum safe-life usage of the engine and its components, while reducing the risk of exceeding the approved limits [22]. Figure 3 below identifies the benefits of engine monitoring systems.

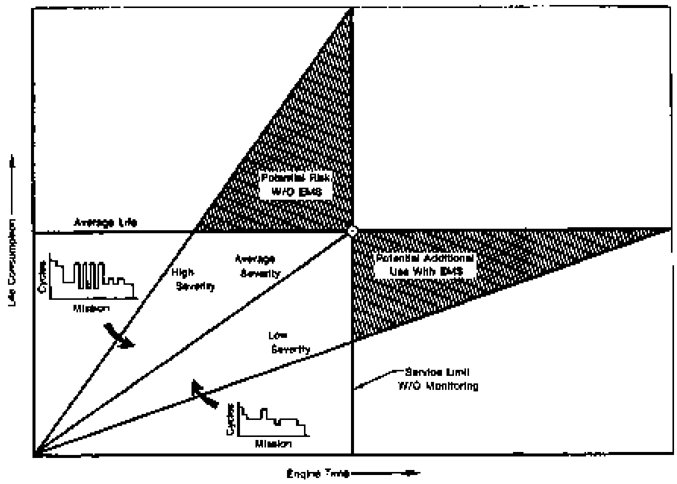

Figure 3 – Benefits of Life Usage Monitoring [23]

An additional benefit of individual life monitoring is that it allows the comparison of individual engine data against fleet averages. Such comparative analysis can provide an indication of the variations in the condition of individual engines. It also improves safety by indicating possible component deterioration prior to failure and can also show the specific damage caused as a result of certain mission profiles or pilot response [23].

While the benefits are numerous, the obvious drawback to individual life monitoring systems is the cost involved. Substantial commitment is required by the user in terms of funds and resources to efficiently manage an engine with an individual life monitoring system. The user needs to be involved from the design of the system to ensure the information generated is appropriately recorded, processed and stored [24]. However, the benefits of an advanced and integrated usage monitoring systems have been clearly demonstrated with the German Air Force On-Board Life Monitoring System (OLMOS) showing 3 times less component removals than without the system, and flow on benefits in reduced spare part usage and maintenance manhours [25].

5. CERTIFICATION OF USAGE MONITORING PROGRAMS

With an understanding of the certification codes and usage monitoring systems in general, it is possible to develop a generic strategy for the certification of an engine usage monitoring system (EUMS). As explained by Harrison [26], qualification of the engine requires that sufficient testing has been completed to demonstrate that the regulatory requirements have been met. Once the safety critical lives are set the in-service life consumption is monitored in accordance with the OEMs recommendations. Certification of this life usage monitoring system is critical to ensure the continued airworthiness of the engine. The level of validation required for the EUMS depends on the monitoring method used and the level of complexity of the system.

The usage monitoring systems whether Individual or General will be based upon the following two types of systems:

- Conversion Factor system, or
- Usage Algorithm system.

5.1 CONVERSION FACTOR SYSTEM

With a conversion factor system a number events are recorded and the usage estimated as a function of the number of events, eg:

- Total running time,
- Number of flights, or
- Number of engine starts.

While it is difficult to directly translate these events in the life usage data, it is relatively simple to identify and record the events. A mission analysis is undertaken to estimate the amount of usage consumed per event. A conversion factor is then used to convert this usage back into the same units as those which the critical components are lifed. Different conversion factors may apply to different parts within the engine. As usage may vary significantly during any of these specific events for different missions, the conversion factor must necessarily remain sufficient conservative to ensure no component will overfly its life limit [3].

Certification of conversion factor systems will ensure that the EUMS is formally promulgated within maintenance documentation and is strictly controlled. The aircraft managers must ensure that flight line operators are aware of the criticality of the usage monitoring program to the continued airworthiness of the aircraft. This requires regular audit of operator procedures to ensure the continued effectiveness of the program and ensure that usage records are accurately processed and stored. Ideally the usage data should be regularly reviewed by the OEM to ensure that any changes in usage have not impacted any initial lifing assumptions. When required, new conversion factors may need to be implemented; appropriately stored data allows for retrospective application of conversion factors. The key requirement for certification of these systems is ensuring that an in-service plan is established which controls the critical component life limits and identifies the requirement for regular review of the conversion factor.

The conversion factor system is simple and if appropriately validated, will remain conservatively safe. However, the variability of engine usage per record event has led to the development of more complex analytical techniques to more accurately calculate usage via lifing algorithms.

5.2 USAGE ALGORITHM SYSTEM

The failure of gas turbine engine components is a result of stresses resulting from temperatures, pressure changes and high-speed rotation [27]. Thus event based usage monitoring systems are very rough estimates of the actual usage experienced by the engine. In the usage algorithm system, the engine operating parameters are measured and life usage is computed based upon Reduced Order Algorithms (ROAs). The engine parameters will be recorded and the lifing calculations either carried out on-board in real time or stored for download to a ground system for processing. The complexity of these ROAs generally varies with the age of the engine and its EUMS. Early algorithms were based upon engine speeds alone, while new thermal transient algorithms provide more accurate life assessments by calculation of combined centrifugal and transient thermal stresses.

The usage algorithm system EUMS consist of components which are fitted to the aircraft and other essential ground support equipment to complete the “system” of recording, calculating, monitoring and reporting [28]. The functional elements include:

- data recording – acquisition of data necessary for life calculations,
- damage calculation – calculation of life used at each critical location,
- life management – storage and presentation of lifing information to support engine fleet management.

These functions will be performed on either hardware or software components fitted to the aircraft or as part of a ground system. Each of the system elements must be validated as part of the certification process.

5.2.1 Fitted or Air Segment

The fitted or air segment hardware generally consists of monitoring sensors or transducers, processors, recorders and storage devices, and displays. All hardware equipment fitted to the aircraft must meet its own certification requirements to ensure it doesn’t impact on the airworthiness of the aircraft itself. FAR 25.1309 covers these systems issues which must be addressed. However, it is the ability of the equipment to accurately and consistently provide life usage data that is the key focus of this certification discussion.

Engine parameter and aircraft operating data acquisition equipment whether analogue or digital must be independently verified. Both signal source and recording equipment must be tested in all possible states and modes to ensure data is correctly recorded. Functionality tests should include Electromagnetic Compatibility (EMC) to a suitable standard such as MIL-STD-464 and other environmental tests covering temperature, vibration, humidity, salt spray, dust and sand conditions as defined within standards such as MIL-STD-810.

On-board software must be designed and approved to meet minimum safety levels such as those defined within RTCA/DO-178B. Data sampling rates must be such that aliasing errors are avoided and data generated is not excessive. Where multiple location temperatures are deduced from single sensors, the algorithms must be tested for all possible operational scenarios to ensure the validity of the results produced. Accurate identification of peak rotational speeds and temperatures at critical locations is vital to ensuring a suitable lifing algorithm can be produced. The key focus of the validation is to ensure that the implemented system provides the same results as the OEMs full engineering model within defined limits [29]. Testing should include synthetic missions exercising the extremes of the flight envelope and real missions to ensure satisfactory operation with transient operational data.

5.2.2 Data Transfer Segment

The data transfer hardware should be suitable for flight line operations. Sufficient robustness, ease of operation and ample storage capacity are key requirements. The data transfer procedures for download and upload must ensure the integrity of the data is maintained and system failures are flagged to the operator.

5.2.3 Ground Segment

The ground segment will vary from a single device to a set of computers that fulfil individual roles. In order for the ground station to be most effective, it should be developed at the same time as the airborne system [30]. The ground system hardware and software will normally be commercially available equipment. Validation testing should ensure integrity of data, correct implementation of algorithms and appropriate information display.

The usage data must be carefully matched to the individual components to which they relate. This often requires a parts life tracking system. The initial design assessment of the engine should indicate those components whose lives will be usage limited and therefore require their service histories to be managed. If the engine is new and a current system established, a lower level (ie. a higher number) of components may be able to be tracked. If the EUMS is fitted after the aircraft has been in-service for some time, only selected components may be tracked. If the component is moved from one engine to another its service history must follow it.

5.2.4 Overall System Certification

The final step of the certification process should be end to end system testing to demonstrate that the total in-service system provides a satisfactory representation of the full design model and process. Laboratory tests should ensure correct system operation over the full range of input data variables exercising all logic loops and switches. Dynamic testing should include full mock-up ground running of the system and flight testing to ensure representative data is input [29]. Service environment testing or Operational Test and Evaluation (OT&E) should cover actual operations of equipment in the normal service environment with appropriately trained personnel.

As for the conversion factor system, the usage algorithm system requires on-going review to ensure the system continues to contribute to the airworthiness of the engine. The complete EUMS should be managed via an engineering plan to control the critical component life limits, define the usage monitoring program and identify the requirement for regular review of each element of the system. Participation by the OEM in this plan is highly desirable and Airworthiness Authority audit of the system should be expected regularly.

6. ADF's ROLE AS AN AIRWORTHINESS AUTHORITY

Under the Chicago Convention of 1944, the Australian Defence Force (ADF) is a recognised AA charged with ensuring an adequate level of safety is designed into existing and new aircraft (including engines and systems) to be used by Royal Australian Navy (RAN), Australian Army and Royal Australian Air Force (RAAF). The ADF has equivalent responsibilities to US FAA, European JAA, CASA and other international military AA's such as the USAF, USN and UK MoD. The ADF is responsible for issue of an Australian Military Type Certificate (AMTC) to all state operated aircraft.

The ADF recognises its limitations in size to develop its own standards and therefore relies on standards developed by other reputable AAs. The ADF has set the UK MoD DEF STAN 00-970 as its comparative standard for aircraft and DEF STAN 00-971 for gas turbine engines. This does not mean that they have been judged as any safer or more complete than other standards, rather they provide an accessible comprehensive military airworthiness standard [31].

The ADF recognise a range of standards as new aircraft are developed initially to meet many different requirements. For new engines the ADF recognised standards include FAR 33, JAR-E and US DoD JSSG-2007. The ADF's approach to certification of new aircraft is to have the prime contractor provide details of existing certification. If the aircraft is design and certified to an acceptable standard by a recognised AA, then the ADF applies criteria looking at changes since certification which impact the aircraft's configuration, role and the operating environment. This process may identify additional certification requirements.

The ADF has defined its technical airworthiness requirements within AAP 7001.054 [31]. This publication overviews recognised standards and the typical certification process. The manual describes the process for evaluating the suitability of the equipment to perform defined operations with a certain level of safety. Significant airworthiness issues are the focus of ADF certification activities; aircraft and engine structural integrity, software certification and avionics system safety form the primary focus of ADF reviews. For engine certification, activities focus on safety critical component identification, life substantiation and validation of in-service usage monitoring systems.

6.1 ADF CERTIFICATION OF ENGINES

The ADF certification review of the safety critical component identification and life substantiation will follow those procedures defined within the appropriate airworthiness standard. To ensure the continued airworthiness of all ADF aero gas turbine engines an Engine Structural Integrity Management Plan (ESIMP) is required prior to formal issue of the AMTC. The ESIMP is similar to programme of life evaluation required by DEF STAN 971 and the JAR-E LMP. The ESIMP covers the following topics:

- general engine description;
- definition of life limited components;
- definition of the usage monitoring requirement; and
- identification of the technical life review requirements.

The ESIMP requires the nomination of an Engine Structural Integrity Manager (ESIM) and identified the authoritative source of lifing details. It is generally the OEM requirements which are promulgated, however the ESIMP will also identify specific ADF lifing if appropriate for operational or logistics requirements. The ESIMP is approved by the ADF Technical

Airworthiness Regulator (TAR) and is subject to regular audit to ensure the continued airworthiness of the engine.

Engine structural integrity management systems have been established for the majority of in-service ADF engines and are mandatory for all new acquisitions. Effective initial certification, including validation of usage monitoring systems and implementation of ESIMPs will ensure the continued airworthiness of all ADF engines.

7. CONCLUSION

Airworthiness Authorities sponsor certification codes for aero gas turbine engines to ensure an adequate safety of critical components. While certain standards require management plans to control safety critical parts, certification of the usage monitoring systems is not formally required.

A variety of engine usage monitoring programs have been developed for aero gas turbine engines. Operators currently monitoring their engine usage with either conversion factor based systems or systems using more complex usage algorithms. The accuracy of these systems while not impacting on immediate aircraft safety is critical in supporting the continued airworthiness of the aircraft they power. The ADF has taken particular interest in the formal review and certification of these usage monitoring systems for its gas turbine engines. Certification of the engine usage monitoring equipment forms an equal requirement to critical component lifing in the certification of new engines. Effective initial certification, including validation of usage monitoring systems and implementation of ESIMPs will ensure the continued airworthiness of all ADF engines.

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Aircraft engines produce the power needed for aircraft. For this reason, aircraft engines are very important for flight safety [1]. Todayâ€™s complex and advanced technology systems require advanced and expensive maintenance strategies [2]. Maintenance services are costly for airline companies. For manufacturers, maintenance is a source of revenue. According to Dennis and Kambil, though after-sales service and parts sales constitute 25% of the manufacturerâ€™s income, it makes up 40â€“50% of company profits [3].Â There are many electronic indicators and systems that help pilots on board during flight. The pilots monitor the indicators, have knowledge of the current status of the aircraft systems, and carry out the flight. Matchett, R.A. (2001). Certification of Engine Usage Monitoring Systems. HUMS2001 -DSTO International Conference on Health and Usage Monitoring. Recommended publications. Discover more about: Gas Turbines. Article. Sustainment of commercial aircraft gas turbine engines : an organizational and cognitive engineering December 2013. Goh, Shaun Shiao Sing HUMS sensors and embedded diagnostic software monitor and communicate the health and maintenance needs of critical components.Â Your browser is not supported. For the best experience, please access this site using the latest version of the following browsers: Google Chrome. Mozilla Firefox. â€¢ Integrated Aircraft Health Monitoring (IAHM) is a general â€œumbrellaâ€ term that covers a wide variety of health management technologies. â€¢ Examples: HUMS, AHM, SHM, ECM, ACMS, etcâ€¦ â€¢ Avoids the use of proprietary terms. Federal Aviation Administration. 2.Â system starting with organizational goals and ending with system implementation. Federal Aviation Administration. 5.Â â€¢ Regardless of rulemaking, do we want a single AC that goes from certification to operator involvement or separate ACs? One for certification (AC 27-1 and 29-2) and another for operator approval. â€¢ Can we design an interim process to expedite an IAHM system certification? Special condition? Federal Aviation Administration. Health and usage monitoring systems (HUMS) is a generic term given to activities that utilize data collection and analysis techniques to help ensure availability, reliability and safety of vehicles. Activities similar to, or sometimes used interchangeably with, HUMS include condition-based maintenance (CBM) and operational data recording (ODR). This term HUMS is often used in reference to airborne craft and in particular rotor-craft â€“ the term is cited as being introduced by the offshore oil industry...