Title: RAAF P-3C Fatigue Tracking System to Support Safety by Inspection Program

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Abstract

The RAAF P-3C fleet is approaching the end of its existing structural clearance. In order to extend the life of the airframe beyond the current safe life limits, a decision has been made to change the fatigue management philosophy from the current fatigue safe life clearance to a structural safety-by inspection (SBI) program. The adoption of the SBI program requires transitioning to a new certification structural design standard (CSDSTD) based on FAR 25.571 for fatigue management. With this aim the Australian Defence Force (ADF) became a partner in the P-3 Service Life Assessment Program (SLAP), which is a collaborative program between the United States, Canada, the Netherlands and Australia. The results of the program are being used to develop the SBI program.

Starting with an overview of the current CSDSTD basis and the transition to the new CSDSTD, this paper will give an outline of the components required to support the transition, including the P-3 Service Life Assessment Program (SLAP) and the post SLAP activities.

One of the key components of an effective SBI program is the fatigue tracking system (FTS). The FTS proposed for the P-3 applies Unit Damage Matrices (UDM) to the usage of individual aircraft to determine the fatigue life accrued by the airframe for an assumed average fleet usage (AFU) spectrum. The system also calculates Severity Factors (SEF) to track individual aircraft usage against the fleet mean in order to assess the adequacy of inspection intervals calculated using the AFU spectrum. This paper will focus on the concepts that have been used to develop the FTS for the RAAF P-3 Fleet for supporting the SBI program.

Acronyms

AFU	Average Fleet Usage	MSV	Mission Severity Value
AMP	Average Mission Profile	OLM	Operations Load Measurement
COps	Concept of Operations	PWD	Planned Withdrawal Date
CSDSTD	Certification Structural Design Standard	RD	Recorded Damage
DBI/SST	DataBase Interface/Spectra Sequencing Tool	RH	Right Hand
DGTA	Director General Technical Airworthiness	SBI	Safety-by-Inspection
DSTO	Defence Science and Technology Organisation	SEF	Severity Factor
FID	Fill-in-Damage	SLAP	Service Life Assessment Program
FLI	Fatigue Life Index	SLEP	Service Life Evaluation Program
FLM	Fatigue Life Measure	SRP	Sustained Readiness Program
FltHr	Flight Hour	SUM	Service Usage Matrix
FSFT	Full Scale Fatigue Test	TAG	Touch and Go
FTS	Fatigue Tracking System	TFID	Total Fill-In Damage
GAG	Ground Air Ground	TRD	Total Recorded Damage
LH	Left Hand	UDM	Unit Damage Matrix
L-M	Lockheed Martin	UF	Uncertainty Factor
LOT	Life of Type	MSV	Mission Severity Value

1. Introduction

1.1 Background

The P-3 Orion aircraft is approaching 25 years of service with the Royal Australian Air Force (RAAF). A number of aircraft in the current fleet are fast approaching the P3-C certified Life of Type (LOT), and thus will not reach their planned withdrawal date (PWD) of 2015, without an appropriate structural safety-by-inspection (SBI) program beyond the current maintenance requirements. The current Certification Structural Design Standard (CSDSTD), CAR 4b.270 does not provide an adequate basis for managing the P-3 fleet via SBI program. Thus in order to develop an inspection program a new CSDSTD is required. This will be based on FAR 25.571.

A key component of a SBI program is a Fatigue Tracking System (FTS), which allows the operators to monitor the fatigue life expended on structure of interest via service usage parameters collected for each respective aircraft in the RAAF P-3 fleet. A new FTS to support the requirements of the P-3 SBI program is currently under development by the Defence Science and Technology Organisation (DSTO). The system is being validated by Aerostructures and is based on methodologies that are reliant on fleet usage data and data gathered by a collaborative program of testing and analysis, involving the Commonwealth of Australia, known as Service Life Assessment Program (SLAP).

Starting with a brief background on the P-3 aircraft this paper provides an outline of the current and the new CSDSTD, and the SLAP. Description of the new FTS and the methodologies that lie behind it is presented, and where possible data is provided to support the discussions.

1.2 Brief History of the P-3

The P-3 Orion maritime patrol aircraft (Figure 1) is a low wing, land based monoplane powered by four turbo-prop powerplants. The general aircraft configuration is conventional, consisting of a fully pressurised semi-monocoque fuselage; cantilevered low wing equipped with ailerons and flaps; four wing mounted engine nacelles; a single vertical tail equipped with a rudder and trim tab; horizontal stabilisers equipped with elevators and trim tabs and a tricycle landing gear. The fuselage contains provisions for the crew and mission equipment. Stores are carried in the non-pressurised bomb bay forward of the wing in the lower fuselage and on wing pylons. The wing serves as an integral fuel tank in addition to its function as a flying surface.

Figure 1: The P-3 Aircraft

The first prototype test model Orion, based on the Lockheed L-188 Electra passenger aircraft, flew in August 1958. The initial series of aircraft was designated P3V-1. These were redesignated to P-3A in November 1962, and in 1964 Lockheed derived an improved version of the P3 which was designated the P-3B. The RAAF selected the lighter version of the P-3B to replace the aging Neptune. Ten were initially ordered and these began flying with 11 SQN at RAAF Edinburgh in 1968. In 1972 when the 10 SQN Neptune aircraft were finally due for replacement, 10 Orion P-3C Update II's were ordered. The P-3Bs of 11 SQN were replaced in 1981 with improved P-3C Update II.5's. These aircraft were redesignated P-3Ws and the P-3B aircraft were traded back in to Lockheed.

In August 1997, the RAAF took delivery of three training aircraft, designated TAP-3 although produced as P-3B(L)s. The intention of these aircraft was that they would relieve the operational fleet of the severe (in terms of structural fatigue) training missions. The TAP-3 aircraft are no longer in service with the RAAF.

Since acquisition, the RAAF Orion's have been upgraded by two major projects, both of which have added secondary structure to the aircraft as well as substantially rearranging their internal configuration. The second upgrade reclassified each modified aircraft as an AP-3C.

2. Structural Design Philosophy of the P-3 and Certification Structural Design Standards (CSDSTD)

The basic design philosophy applied to the Electra design was used throughout for the Orion. Emphasis was placed on the fail safe and long fatigue life characteristics. The P-3 Orion design program was required to conform to the fatigue and fail safe requirements set down in US CAR 4b.270 as used for the Electra design. Design loads were required to conform to the flight, landing and ground conditions of the Military Specification for Airplane Strength and Rigidity, MIL-A-8629 (Aer). Accordingly, these two aircraft design standards form the basis of the original CSDSTD.

Fail Safe Strength Criteria. The structure of the P-3C was designed to satisfy the CAR4b.270(b) fail safe strength requirements. The fail safe requirements of CAR4b.270 (b) required that by analysis and/or test, catastrophic failure or excessive structural deformation, which could adversely affect the flight characteristics of the aircraft, would not be probable after fatigue failure or obvious partial failure of a single principal structural element.

Damage Tolerance (Fatigue) Aside from the fail safe requirements, the P-3C was not designed to a damage tolerance philosophy. Subsequent analyses have established crack growth characteristics and inspection intervals for critical locations.

3. Overview of the Current Fatigue Life Management Philosophy

The P-3 is currently operated on a safe life philosophy based on the outputs from the current fatigue tracking system (FTS). This system, the Service Life Evaluation Program (SLEP), was developed by Lockheed to track the fatigue degradation on the P-3 at a number of critical locations. In addition to the information provided via the SLEP program the following activities form part of the strategies to manage fatigue on the P-3:

1. inspection programs,
2. modification/repair, and
3. replacement.

The current FTS was developed as part of SLEP II. This system is based on the fatigue tracking program developed for the United States Navy (USN) P-3 fleet and has been updated for the RAAF usage (last done in 1989). The program expresses the portion of the certified safe life expended as a Fatigue Life Index (FLI) which is based on aircraft usage and original fatigue test information. At a FLI of 110, which represents the certified fatigue life of the P-3, the fatigue life of the airframe would be consumed and the current management philosophy would require revision.

Fatigue tracking on the P-3 is based on the mission profiles used in the SLEP program and the current usage data. As such the FLI accrual will remain valid provided that these basic mission profiles do not change. To account for differences between the actual profiles flown and those assumed by the SLEP, other important parameters are recorded and analysed. These include the number of landings, duration, pressurisation data etc. and the analysis seeks to ensure that operations are not deviating significantly from the SLEP profile assumptions. When significant deviations occur, revised profiles and re-calculation of the unit damage matrices (UDM) within SLEP is required. At present only Lockheed Martin (L-M) are able to make changes to the fixed assumptions within the SLEP i.e. mission profiles, normal acceleration factors (Nz) curves etc.

Further, SLEP-II FLI calculations are limited in use as they are based on mission profile data representative of RAAF P-3 usage dating to the mid 1980s. The RAAF does not have the ability to revise the SLEP-II FLI calculations to reflect reductions in P-3 usage severity that have occurred since 1992 because it does not have access to the external loads database used by L-M.

4. Change to the Certification Basis

A number of aircraft in the RAAF P-3 fleet are already approaching the FLI limit of 110, and in order to ensure that the current planned withdrawal date (PWD) objective of 2015 is achieved it is necessary to establish the airworthiness basis of the structural life extension.

The RAAF P-3 fleet will achieve the PWD by implementing an appropriate structural SBI program to replace the fatigue safe life clearance. The current P-3 CSDSTD for fatigue strength (CAR 4b.270) does not provide a basis for management of the P-3 fleet via a SBI programme, and transition to a new CSDSTD for fatigue management of the P-3 is therefore required. Accordingly, FAR 25.571 has been approved as a suitable new P-3 CSDSTD.

5. Service Life Assessment Program (SLAP)

To effect the CSDSTD transition and obtain the necessary information to substantiate the SBI programme, the Royal Australian Air Force (RAAF) joined the United States Navy (USN), the Canadian Forces (CF) and The Royal Netherlands Navy (RNLN) to undertake a series of full-scale fatigue tests (FSFTs) and analysis on the P-3C Orion airframe within what is known as the P-3 Service Life Assessment Program (SLAP) in 1999. The main objective of the SLAP was to assess the service life of the P-3C. The SLAP was divided into three phases: Phase I – usage characterisation and spectrum development; Phase II – full scale fatigue testing; and Phase III – post test analysis and test interpretation. Within the SLAP, each country has undertaken to conduct a component of the work program. The division of technical work within SLAP was as follows:

a. USN:	Landing Loads and Taxi Flight Tests Centre Wing test article Teardown and Fractography
b. Lockheed Martin (L-M):	Test spectra development Loads Development Conduct of the Wing/Fuselage FSFT Conduct of the Empennage test on USN modified structure Conduct of the Landing Gear FSFT Test Interpretation for the USN Development of an updated individual aircraft tracking program for the USN Empennage test article teardown Fuselage test article teardown
c. Australia:	Conduct of Flight Loads Test Program Conduct of In-service wing Teardown Conduct of Empennage FSFT on un-modified structure
d. Canada:	Wind Tunnel Testing Right wing test article teardown CFD Analysis Component Testing
e. Netherlands:	Coupon testing and spectra comparison Left wing test article teardown

There were five FSFTs associated with the SLAP, which were as follows:

1. Wing/Fuselage (at Lockheed-Martin (L-M) in Marietta, USA), Figure 2,

2. Sustained Readiness Program Empennage (at L-M in Marietta, GA, USA),
3. Defence Secince and Technology (DSTO) Empennage (at DSTO in Melbourne, VIC, Australia), Figure 3,
4. Main Landing Gear (at Vought in Grand Prairie, TX, USA) and
5. Nose Landing Gear (at Vought in Grand Prairie, TX, USA)

The major wing/fuselage and USN modified empennage fatigue tests were conducted at L-M, Marietta, GA. In that test the left hand wing had been through the USN Sustained Readiness Program (SRP) in which certain primary components such as wing spars were replaced with new items. The right hand wing, which had accumulated approximately 11,000 flying hours in USN service, remained in the original 'ex-service' condition. L-M also conducted a separate fatigue test of the empennage from the same aircraft that was being used for the wing/fuselage test. The empennage had also undergone SRP (the horizontal stabiliser was replaced). Landing gear testing was subcontracted to Vought Ltd. The other SLAP partners also contributed to the technical content of the overall program. Australia conducted flight loads testing, the teardown of a retired (Kestrel program) wing and the fatigue test at DSTO of a retired USN empennage that was representative of RAAF aircraft from a structural and service usage point of view. Canada conducted wind tunnel testing and the teardown of the RH wing from the L-M fatigue test. The Netherlands conducted material testing and is presently conducting the teardown of the LH wing from the L-M fatigue test.

The RAAF primary objective within SLAP is to determine structural inspections, modifications, replacements and redesigns required to extend the RAAF P-3C operational life to at least 2015. The assessment of the fatigue life of the P-3C wing, fuselage, landing gear and empennage will be a primary consideration related to achieving the RAAF objectives. A second RAAF requirement is to obtain the data necessary to determine what are the structural modifications or repairs that are required to keep aircraft flying post 2015. They can also be used to assess when the repairs or modifications have to be applied to RAAF aircraft and how long the new, repaired or modified structure can last.

The SLAP testing and teardown activities were completed in 2004 and were followed by test interpretation conducted by L-M and the SLAP partners. DSTO conducted test interpretation activities, for the RAAF, to convert the significant numbers of test findings into location based crack initiation times and crack growth rates under RAAF P-3C and AP-3C average usage spectra. From these results inspection thresholds and recurring intervals have been calculated using a FAR 25.571 compliant test interpretation methodology developed by DSTO and approved by the RAAF Director General Technical Airworthiness (DGTA).

Figure 2: USN P-3C Wing/Fuselage Full Scale Fatigue Test Article at Lockheed Martin

Figure 3: DSTO P-3C Empennage Full Scale Fatigue Test

6. New Approach for Individual Aircraft Fatigue Tracking

The limitations inherent in the SLEP II based FTS has led to identifying an alternative approach for both tracking fatigue life of the aircraft, and for supporting the SBI program.

Prior to the commencement of the SLAP, an alternative system to the SLEP-II, known as the Structural Life Monitoring Program (SLMP) was developed. This system allowed for damage rates to be calculated based on measured Nz data and actual flight durations and landing rates. The SLMP has been partially independently verified but has not been accepted by the RAAF or used as the FTS for the RAAF P-3 fleet.

Following collaboration between DSTO and Aerostructures, a Concept of Operations (COps) document was developed to address potential FTSs for the RAAF P-3C fleet. Based on material in the COps document, DSTO was tasked to design an approach to re-baseline the RAAF P-3 fleet, which would form the basis of the FTS for the fleet aircraft. This revised FTS, called the SLMP II is a result of the data and software tools gained through the SLAP, and it will supersede SLEP-II as the FTS for the RAAF P-3 fleet.

The FTS and associated P-3 SLMP-II software was required to be compliant with the recommended approach in the COps document. The following points summarise the recommendations specific to the SLMP-II methodology development made in the COps document:

a. SLMP-II to be relatively simple, yet supported by a comprehensive and robust analytical capability.

b. SLMP-II to provide both estimates of fatigue damage with respect to life limits and estimates of variations in crack growth, and therefore inspection requirements, due to changes in usage.

c. AP-3C usage to be characterised and recorded in terms of missions, and the fatigue tracking tools will be mission based.

d. The system to feature reliable characterisation and recording of Ground-Air-Ground (GAG) cycles.

e. The current RAAF data collection and management system is retained with only limited changes necessary to integrate the new system.

f. The routine fatigue tracking tools to use a UDM approach for the cumulative damage calculation, enabling the tracking of damage accumulated by individual aircraft based on simple usage statistics such as mission mix, and a SBI usage severity tracking tool that monitors individual aircraft severity about the fleet average based value used to set recurring inspection intervals.

7. SLMP II System Overview and Fatigue Tracking System Methodologies

The P-3C SLMP-II is similar to the current SLEP II in that it calculates accumulated fatigue damage based on aircraft usage parameters.

The primary functions of the SLMP-II include collection, storage, review, assessment and reporting of RAAF P-3C usage and Operational Loads Measurement (OLM) data, as well as ad hoc calculation of revised inspection intervals for RAAF P-3C aircraft.

RAAF P-3C usage data for use in SLMP-II will be characterised and recorded in terms of missions, and the fatigue damage is calculated based on the number of flights, landings and duration accrued for each mission code. SLMP-II provides additional scope for system feedback and improvement when compared to SLEP-II, as the SLMP-II methodology has been developed locally, and can thus be modified to reflect changes in RAAF P-3C usage.

The post SLAP management strategy for the RAAF P-3C aircraft features SBI structure and life limited structure. In order to accommodate this, the SLMP-II methodology makes use of two parameters to track P-3C individual aircraft usage: the Fatigue Life Measure (FLM) and the Severity Factor (SEF).

The FLM is used for assessment of life limited structures as a measure of the total fatigue damage accrued. In this regard, the FLM is similar to the FLI used in SLEP-II. The FLM relates individual aircraft fatigue damage accrual to the damage accrued by the FSFT articles at the time at which crack initiation was observed at the tracking location in question. In addition to the assessment of life limited structure, the FLM is used to determine inspection thresholds for SBI structure.

Unlike SLEP-II, the FTS methodology uses a crack growth SEF in addition to the FLM. This crack growth measure is relative to the fleet average usage. The intent is to use the SEF to determine whether individual aircraft usage has deviated sufficiently from the fleet average to warrant revision of inspection intervals.

SLMP-II also includes a means for estimating revised inspection intervals. These are estimated by making use of the fact that post SLAP P-3C inspection intervals are based on fleet average

AP-3C usage and that the SEF is a measure of the deviation of individual aircraft usage from the fleet average AP-3C usage.

The SLMP-II system can thus be split into the following functional blocks:

- Data collection, data storage and review
- Data analysis and FLM/SEF calculation
- Reporting,
- System feedback and review, and
- Estimation of revised inspection intervals.

The usage spectra needed to calculate the UDMs and SEFs is dependent upon:

1. Accurate loads in the P-3 External Loads Database;
2. Valid RAAF Usage Data;
3. Stress to Loads Ratios as calculated from the whole aircraft Finite Element Model (FEM); and
4. Fatigue test loading spectra and test results.

The data described above is entered into a spectrum sequencing software program called the DataBase Interface/Spectra Sequencing Tool (DBI/SST), to produce RAAF usage spectra for the P-3 locations to be analysed. The process of obtaining the spectra is summarised in Figure 4.

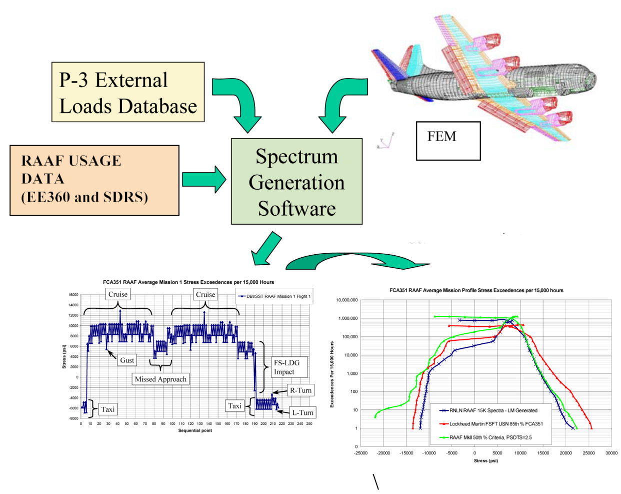

Figure 4: Process of Generating the Load Spectra need to Calculate UDMs and SEFs

The underlying methodology for monitoring the fatigue accrual and assessing the relative severity of the RAAF P-3 fleet usage has been developed by DSTO and validated by Aerostructures.

Figures 5 and 6 depict a general overview of how the processes listed above complement each other as part of the FTS methodology.

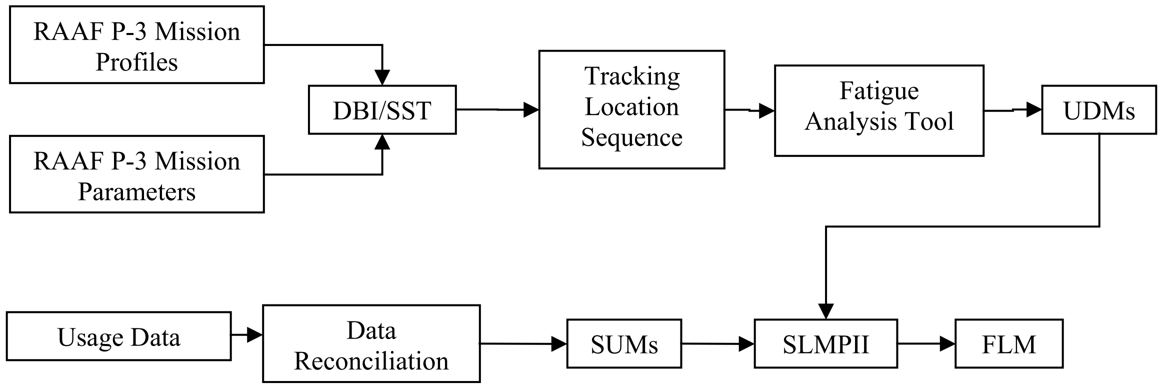

Figure 5: Process for Rebaselining and Ongoing Fatigue Tracking

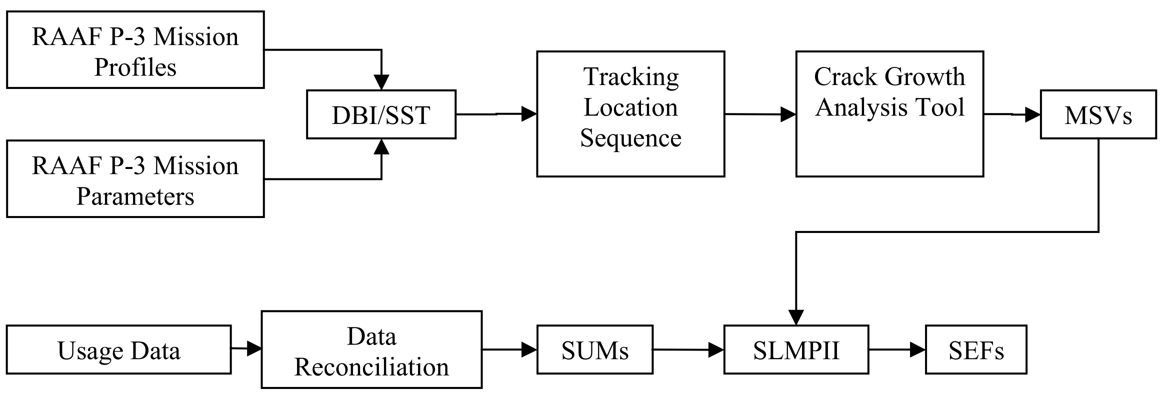

Figure 6: Process for Determining Usage Severity

It must be noted that the determination of the UDMs and mission severity values (MSVs) occurs only as required. These will only be changed if a significant variance in usage or configuration occurs within the RAAF P-3C fleet.

7.1. Calculation of the Fatigue Life Measure (FLM)

An overview of the FLM calculation process is presented below.

FLM is used to track individual aircraft usage to threshold inspection intervals and life limits. A key process in establishing the FLM is the calculation of fatigue damage, which is done for each tracking location using proprietary fatigue software. The accrued fatigue damage is established from the following:

a. A fixed amount of damage - estimated for each mission of a particular mission type (Dam_{Miss}).

a. An incremental damage rate - applied to the difference between the observed number of landings per mission for each mission type and the number of landings per mission assumed for the generation of the damage value for that mission type (ΔDam_{TAG}).

b. An incremental damage rate - applied to the difference between the observed mission duration and the assumed mission duration used for the generation of the damage value for that mission type (ΔDam_{FltHr}).

These damage rates are derived for each mission type and each tracking location, and are contained in the UDM specific to each tracking location. The UDMs for each tracking location are applied to all aircraft in the RAAF P-3C fleet. In order to calculate accrued fatigue damage the FTS methodology requires the following usage parameters:

a. the total number of missions for each mission type,

c. the total number of landings for each mission type, and

d. the total duration of each mission type.

The above usage parameters provide the service usage matrices (SUM) for each aircraft. Any unmonitored missions, flight hours or landings are attributed to each mission type based on the average mission mix percentages. These unmonitored missions, flight hours and landings are referred to as the SUMFill-In.

Equation 1 provides an expression for calculating the Recorded Damage (RD), which is from the UDM and the SUM for each mission type, tracking location and aircraft.

$$RD = \#Miss \times Dam_{Miss} + \Delta Dam_{TAG} \times \left[\#Land - (\#Miss \times Av.Land)\right] + \Delta Dam_{FltHr} \times \left[\#MissHrs - (\#Miss \times Av.Hrs)\right]$$

Equation 1.

UDM Terms (common to all aircraft in the RAAF P-3C fleet):

Dam_{Miss} = Damage per mission type for a given tracking location.

ΔDam_{TAG} = Incremental damage per touch and go (TAG) for a given mission type for a given tracking location.

ΔDam_{FltHr} = Incremental damage per flight hour (FltHr) for a given mission type for a given tracking location.

Av.Land = Average number of landings per mission for a given mission type.

Av.Hrs = Average mission duration (in hours) for a given mission type.

SUM Terms (unique to each aircraft in the RAAF P-3C fleet):

#Miss = Number of missions of a given mission type in the time period.

#Land = Number of landings of a given mission type in the time period.

#MissHrs = Total duration (in hours) of a given mission type in the time period.

Once the RD has been calculated for each mission type at each tracking location, the Total Recorded Damage (TRD) is calculated for each aircraft, for each tracking location as the sum of the RD for each mission type, i.e.:

$$TRD = \sum_{mission, m=1-n} RD_m$$

Equation 2.

The damage attributed to unmonitored usage, Fill-In Damage (FID), is calculated in exactly the same manner as the RD, only the SUMFill-In terms are substituted into Equation 2 in place of the SUM terms. The Total Fill-In Damage (TFID) is calculated in the same manner as the TRD for each aircraft, for each tracking location by summing the FID for each mission type, i.e.

$$TFID = \sum_{mission,m=1-n} FID_m \qquad \textit{Equation 3.}$$

The following procedure is used to calculate the FLM from the TRD and the TFID for each aircraft, for each tracking location:

e. A FID uncertainty factor (UF_{FID}) is applied to the TFID to account for uncertainty in the FID mission mix

f. The TRD and the factored TFID are then summed to yield the Total Damage (TD).

g. The TD is factored by an Uncertainty Factor for manoeuvre N_Z exceedances (UF_{Nz}), then multiplied by 100 to yield the FLM.

The three steps above are represented by Equation 4.

$$FLM = 100 \times UF_{Nz}\left(TRD + UF_{FID} \times TFID\right) \qquad \textit{Equation 4.}$$

Average Mission Profiles (AMP)

The FTS methodology categorises RAAF P-3C missions in terms of 7 mission types. These 7 mission types are equivalent to the SLEP-II mission types; however SLEP-II mission types 4 and 5 have been combined to represent a single mission type in the FTS methodology (see Table below).

Mission Type	Description	Number of Sub-Missions
1	Crew Training	9
2	Anti-Submarine Warfare (ASW)	12
3	Test Flight	3
4&5	Patrol, Search & Surveillance / Fisheries & Surveillance	8
6	Harpoon	1
7	Transit Ferry	4
8	Air Demonstration	1

To better align the number and types of missions flown by the P-3 SLAP partners the eight SLEP-II mission profiles were each expanded into a number of sub-mission profiles for use in the UDM development. The usage data was expanded for comparison against the 38 USN mission profiles that were used to generate the USN Full Scale Fatigue Test spectrum.

All of the DSTO SLAP test interpretation work was conducted in terms of the expanded set of sub-mission profiles. However, as the SLMP-II FTS methodology requires usage to be monitored in terms of seven SLEP-II mission types the expanded set of sub-missions had to be reduced back into the basic SLEP-II mission types.

For each SLEP-II mission type, an average mission type was derived. Each average mission profile (AMP) is a single mission profile that provides the same total damage as the set of sub-missions for that SLEP-II mission type.

To reduce all of the sub-missions into an AMP, the sub-mission profile data, which consisted of mission segment information, altitudes, airspeeds, aircraft weights, mission duration and the number of landings (both Full-Stop Landings (FSLs) and TAGs), were averaged.

The AMP profile parameters were adjusted until the fatigue damage accrued by the AMP only differed by an acceptable percentage from the total fatigue damage accrued by the sub-mission mix of the respective mission type. The approach used for this matching process is illustrated in Figure 7.

Additional Damage Per Landing: An additional term was included in the UDM (the ΔDamTAG in Equation 1) to account for differences in damage due to the fact that each individual aircraft did not necessarily accrue the same number of landings as the fleet average mission mix would suggest.

Additional Damage Per Flight Hour: To allow for differences between the total duration attributed to an individual aircraft for a particular mission type and the total duration of that mission type in the fleet AMP, the change in damage with respect to additional flight hours (the ΔDamFltHr term in Equation 1) was developed.

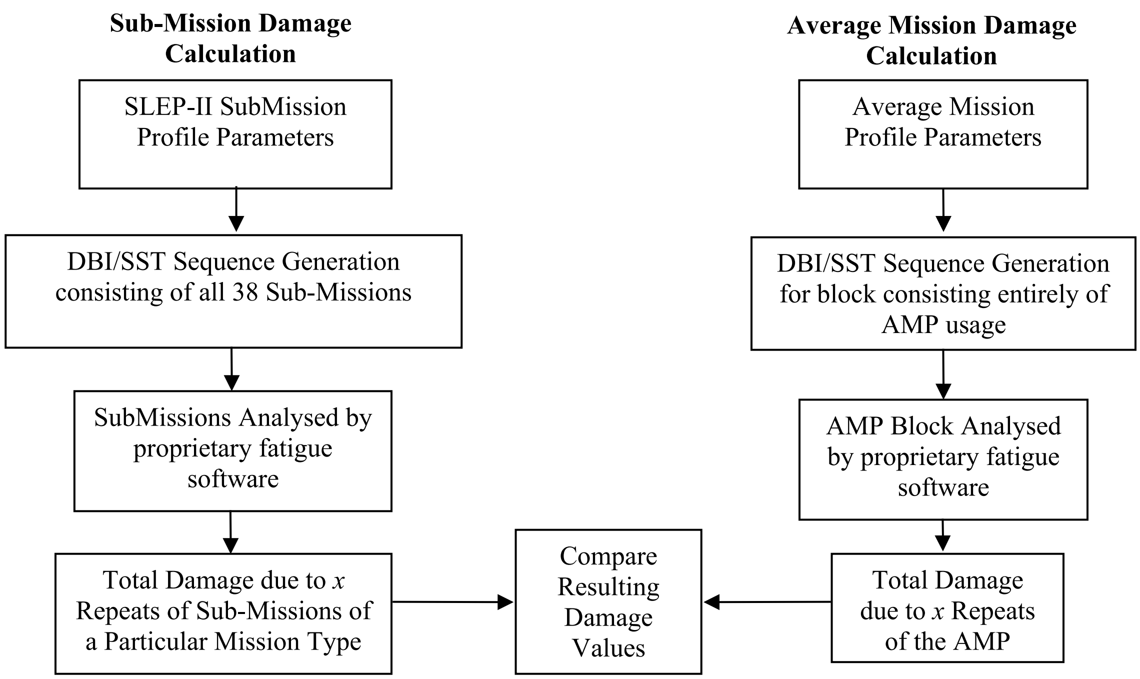

Figure 7: Total Resulting Damage Comparison Flowchart

Re-baselining

The FLM for [illegible] ntly summed to yield the total [illegible] or 18 aircraft in the RAAF P-3 [illegible]

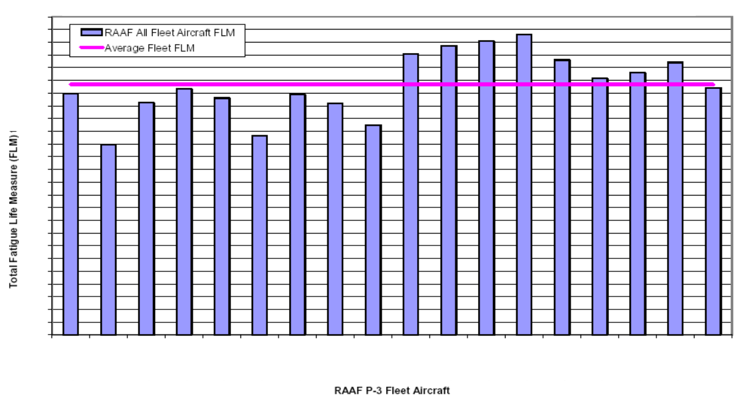

Figure 8: FLM at One FCA Location for Each RAAF P-3C Aircraft

The SLMP-II FLM accrued by each aircraft at the re-baselining date is shown compared to the SLEP-II FLI at a similar location in Figure 9. As can be seen a reasonable correlation between the FLM and the SLEP-II FLI has been achieved. This correlation lends credibility to the FLM values calculated. Note that the absolute magnitudes of the FLM and FLI are not equivalent; however, as the FLM is a relative measure to compare individual aircraft usage to the results of the SLAP test interpretation, whilst the FLI was used to assess usage relative to SLEP-II usage limits and thresholds, these magnitudes are not required to be equivalent.

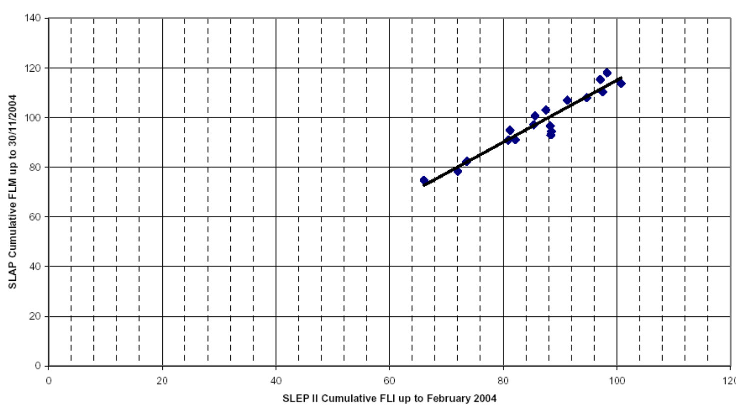

Figure 9: Comparison of the SLMP-II FLM at one FCA Location

The use of the calculated UDMs for ongoing fatigue tracking is applicable as long as RAAF AP-3C usage does not deviate significantly from the usage assumed in the derivation of these UDMs. The SLMP-II system will require routine review in order to ensure that the UDMs remain appropriate for ongoing fatigue tracking.

7.2. Calculation of Severity Factors (SEF)

The post-SLAP management strategy for the RAAF AP-3C aircraft is to set inspection intervals based on the AMP.

The SEF is a measure of crack growth rates for individual aircraft usage relative to assumed fleet average usage. It will be used to determine whether individual aircraft usage has deviated sufficiently from the fleet average to warrant revision of inspection intervals.

Calculation of the SEF uses a mission severity values (MSV) at each tracking location on the airframe for each mission type. The MSV is derived from crack growth predictions. The SEF for a given aircraft at a given tracking location is determined by combining the SUM with the MSVs for each mission type at that tracking location.

Derivation of the Mission Severity Value

To determine the MSV for each mission type, the DBI/SST was used to obtain a stress sequences consisting of repetitions of a single AMP and Average Fleet Usage (AFU). Both stress sequences were analysed by proprietary crack growth prediction software.

The MSV at each tracking location is based on a ratio of crack growth intervals. The crack growth intervals are defined from an initial flaw size of 0.05 inches to a specified final flaw size. Each tracking location will have a unique final flaw size, which is chosen such that the crack growth interval is of the same order of duration as the inspection interval for that location as defined in the DSTO test interpretation.

Figure 10 displays example of the crack growth curves predicted for one of the key FCA tracking locations.

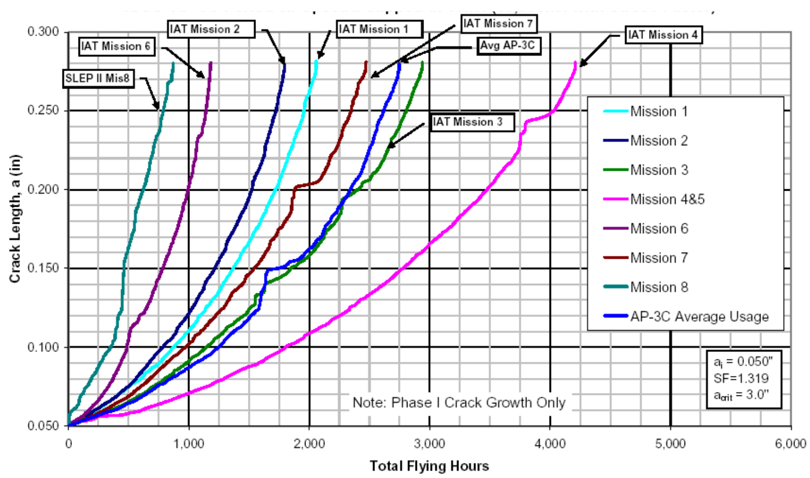

Figure 10: Example of Crack Growth Curves for Fleet Average Usage and AMP Usage

Notes:

1. ‘Avg AP-3C’ refers to crack growth predicted using the AFU stress sequence.

The MSV at each tracking location is determined by taking the ratio of the AFU crack growth interval to the crack growth interval for usage restricted to the AMP of a particular mission type. Equation 6 represents the definition of the MSV.

$$MSV = \frac{CrackGrowthInterval_{AFU}}{CrackGrowthInterval_{AMP}} \qquad \textit{Equation 6.}$$

Where:

$CrackGrowthInterval_{AFU}$ = The AFHRS required for a crack to grow from 0.05 inches to the

final crack size based on the AFU.

CrackGrowthIntervalAMP = The AFHRS required for a crack to grow from 0.05 inches to the

final crack size based on usage restricted to the AMP for a particular mission type.

Calculation of the Severity Factor

The SEF is calculated by multiplying the mission mix flown by an individual aircraft (as contained in the aircraft's SUM) by the MSV for each respective mission type, and then normalising the results by the total number of missions flown. This calculation is summarised in Equation 7.

$$SEF = \frac{\sum_{missions,1-n} (SUM_n) \times (MSV_n)}{\sum_{missions,1-n} (SUM_n)} \qquad \textit{Equation 7.}$$

For a simple example of the SEF calculation, consider an aircraft which has flown 30 mission type 1 missions, 60 mission type 4&5 missions and 10 mission type 6 missions. The respective MSVs for these missions being 1.33, 0.65 and 2.33. The SEF for this aircraft over a particular period relative to fleet average usage would be:

$$SEF = \frac{(30 \times 1.33) + (60 \times 0.65) + (10 \times 2.33)}{30 + 60 + 10} = 1.02$$

Thus in this instance the aircraft usage is 2% more severe than the fleet average. At this stage there has been no work into defining what constitutes an acceptable variation. However, this level of severity is qualitatively considered covered by the current assumptions

7.3. Current Status of the SLMP II System

The DSTO methodology for generating the UDMs and SEFs has been applied to establish the damage and severity figures for one tracking location. The methodology for this tracking location has been reviewed and validated by Aerostructures. In total there are six fatigue tracking locations on each aircraft and at present damage and severity number are being established for these tracking locations. Aerostructures will be reviewing and validating the data related to these tracking location.

Design specification for the SLMP II system has been written and the software development for the FTS has started. The aim is to have the software for the system developed and tested by the middle of 2007. The system should be implemented for use thereafter.

8. Conclusions

P-3 fleet is fast approaching its fatigue LOT limit and the fleet will not reach the PWD of 2015 with the current safe life approach. In order to ensure that the operation of the fleet can be extended to this PWD or beyond a decision was made to change the CSDSTD from the current safe life based (CAR 4b) approach to structural safety-by-inspection (SBI) clearance approach. Accordingly FAR 25.571 has been approved as a suitable new P-3 CSDSTD.

The process of transitioning from the current CSDSTD to the new standard is drawing to a conclusion. This transitioning has been possible though a major international collaborative program known as SLAP, which has been running for more than 6 years involving many organisations from the partnering countries. The partnering countries being the United States, Australia, Canada and the Netherlands.

Closely supported by Aerostructures, DSTO have been intimately involved with some of the major tasks under taken within SLAP. The combined experience of Aerostructures and DSTO in aircraft structural integrity has ensured the ADF remains a key partner for generating important and effective data that has subsequently been utilised to successfully develop a new FTS known as the SLMP II. This system is due for implementation in the middle of 2007.