Development of a Flight Manoeuvre Recognition Software Application for Improved Usage Monitoring of Rotary Wing Aircraft

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Abstract

Usage monitoring systems for the majority of Australian Defence Force (ADF) Rotary Wing platforms utilise data which is manually recorded post flight. The limited number of parameters that can be reliably recalled by pilots, and the accuracy of the data recalled, are significant limiting factors for manual usage monitoring systems. These limitations have implications for the fatigue management of ADF rotary wing fleets as only a small sub-set of fatigue damaging flight regimes can be monitored. QinetiQ developed a Rotary Wing Flight Manoeuvre Recognition (FMR) software application that utilises data recorded by existing flight data recorders fitted to the Seahawk and Black Hawk fleets to allow significantly more flight regimes and manoeuvres to be identified relative to the existing manual systems. Verification and Validation (V&V) of the software was completed using data from simulated and actual test flights where prescribed manoeuvres were performed. Manoeuvre recognition algorithms were updated based on the results of the V&V activities and the software has been used to characterise and estimate their relative severity of the various different mission types flown by the Black Hawk fleet. This paper focuses on improvements that FMR software can offer over current Usage Monitoring systems.

Keywords: Usage Monitoring, Manoeuvre Recognition, Regime Recognition, Usage Severity

Introduction

Usage monitoring is a key component of any Aircraft Structural Integrity Program (ASIP) [1]. Data collected via a Usage Monitoring (UM) system is an input for Fatigue Management and Environmental Degradation Management and can be used to inform decisions that can have lifelong impacts on a fleet. Accurate data is critical for informing these decisions. Inaccurate data can increase the risk to operations by not allowing the identification of severe usage or increase the cost of operations by causing unnecessary maintenance or replacement.

Rotary Wing aircraft typically have a higher number of manoeuvres that contribute to the fatigue life consumption of their critical components than Fixed Wing aircraft. As such UM systems for Rotary Wing aircraft need to monitor a large number of manoeuvres in order to adequately monitor the total fatigue accrual of the various critical components.

QinetiQ developed Rotary Wing FMR software which uses data available from existing flight data recorders to recognise as many of the flight regimes which make up a platform's Design Usage Spectrum (DUS) as possible with the data available.

The development of the QinetiQ Rotary Wing FMR software and the improvements offered to current UM systems are described in this paper.

Extant Usage Monitoring Systems

The UM systems in place for the majority of ADF Rotary Wing fleets rely on data manually recorded after each flight. Previously data was recorded on paper forms and the data was later entered into a database to allow subsequent analysis. Recently the recording of data has been transitioned to pilots entering data directly into the CAMM2 [1] system.

Due to their nature, helicopters are capable of flying a large number of unique manoeuvres during a single flight. Ideally a helicopter's UM system would be capable of recording all of the fatigue damaging manoeuvres flown. However, it's not reasonable to expect a pilot to be able to accurately recall the number of occurrences of the many different manoeuvres flown during a mission. Try answering a similar list of questions after driving a car. How many times did you stop how many left turns did you make, how many times did you change gear, how many times did you indicate, how long did you drive faster than 70 km/h? How accurate would you expect the answers be?

The data points in Fig. 1 show the number of Black Hawk landings per flight recorded via the existing manual UM system with those recognised by the FMR software. As shown in the figure there is significant differences between the FMR recognised landings and the manually recorded landings. On average the manually recorded landings under estimate the actual landings by approximately 13 per cent. This under reporting is consistent with similar comparisons for other ADF fleets. Under reporting of a key contributor to flight damage accrual such as landings can have significant safety implications as a result of inadvertently overflying maintenance intervals or life limits.

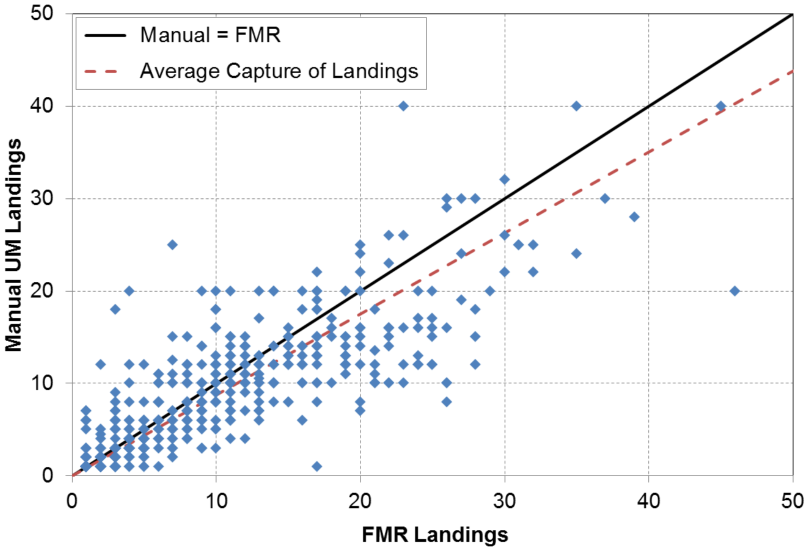

Fig. 1: Manually Recorded Landings vs FDR Landings

By increasing the number of parameters recorded by manual UM systems the already high workload on the pilot is increased and the accuracy of the data recorded is likely to decrease. As such, current manual UM systems record a small number of parameters, focusing on manoeuvres that are easier to record and have a large impact on fatigue accrual, such as landings. However, Fig. 1 shows that even for a simple parameter like landings the accuracy of the data is limited. Therefore the quality and quantity of data recorded by manual UM systems are limited.

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[1] Computer Aided Maintenance Management version 2

FMR Initial Development

The Rotary Wing FMR software was developed by QinetiQ Australia for Rotary Wing Section Directorate General Technical Airworthiness (RWS DGTA now Helicopter Structural Integrity – Defence Aviation Safety Authority HSI DASA). Regime recognition algorithms initially developed by Raytheon [2] recognise the manoeuvres and regimes of the Seahawk DUS using data available from the crash data recorder fitted to the Royal Australian Navy S-70B-2 Seahawk fleet. Parameters available from the crash data recorders include radar and pressure altitude, airspeed, heading, aircraft attitudes and accelerations, control positions, etc. The original Raytheon regime recognition algorithms were further developed and refined by QinetiQ for use in the QinetiQ Rotary Wing FMR software.

The FMR software was initially developed to recognise Seahawk DUS manoeuvres and was later expanded by developing a new set of algorithms to recognise Black Hawk DUS regimes using data from the ADF S-70A-9 Black Hawk fleet. While there are a larger number of Black Hawk DUS regimes, the Black Hawk regimes and algorithms are similar to the Seahawk algorithms. Due to data quality and serviceability issues with Seahawk crash data recorders this paper focuses on the Black Hawk side of the FMR software.

Algorithms for Regime Recognition

The manoeuvre recognition algorithms in the FMR software consist of a unique set of parameter limits and logic steps to define each manoeuvre or regime. The method used by the software to recognise manoeuvres and regimes is slightly different. The software counts the time spent in each flight regime and counts the number of occurrences of each flight manoeuvre. The parameter limits used in the algorithms and the order that they are recognised were designed so that only one regime can be recognised simultaneously, i.e. cannot recognise Level Flight and a Right Turn concurrently. However, regimes and manoeuvres can be recognised together, i.e. a Control Reversal can be performed, and recognised, during Level Flight.

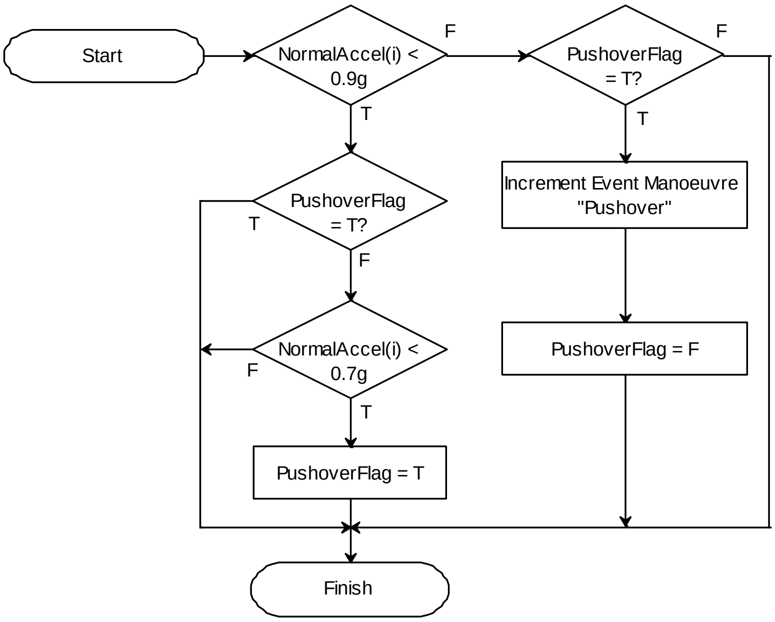

Fig. 2: Simple Algorithm Example – Pushover

Regime recognition algorithms range in complexity from simply recognising periods of level flight in different airspeed bands to identifying control reversals which require recorded parameters, derived parameters, multiple logic loops and may only last a second or less. Fig. 2 shows a relatively simple algorithm used to recognise a Pushover manoeuvre which incorporates a Flag parameter.

The Pushover algorithm aims to identify pushovers where the Normal acceleration (Nz) is less than 0.7g and then returns to greater than 0.9g, i.e. returning to a 1g level flight state. The “PushoverFlag” is initially set to False. If the Nz value is less than 0.7g the flag is changed to True, and stays True until the Nz value is greater or equal to 0.9g. At this point the flag is set to False and a Pushover manoeuvre is counted. The “PushoverFlag” parameter ensures that a pushover manoeuvre is only identified at the end of the manoeuvre rather than simply counting the amount of time flown with an Nz level less than 0.7g. A similar type of logic is applied to recognising Pull Ups and the end of turns.

Software Verification and Validation

Testing of the FMR software was carried out using manually generated “dummy” input data to perform bounds testing on the recognition algorithms; however this type of testing is not able to test how well the algorithms are able to recognise manoeuvres flown by a real aircraft. To accomplish this, test flights were flown by a Black Hawk aircraft where a predefined list of manoeuvres were performed during the flight and the start and end time of each manoeuvre was recorded by the crew. The Seahawk flight simulator at Defence Science and Technology was also used to increase the sample size and reduce the reliance on operational aircraft. The manoeuvre start and end times from the Black Hawk and Seahawk flight simulator were compared to the start and end times in the FMR outputs.

Using real life flight data rather than manually generated test data to test algorithm performance was important because the real life test data encompassed how each manoeuvre was actually flown by ADF aircrew and the test data included noise on the signals commensurate with what we could expect during actual operations. The use of actual flight data allowed the algorithms to be refined to take into account some of the peculiarities present in real world data. Typical refinements included:

a) smoothing data for parameters where the output signal was noisy or the resulting derived parameters were noisy,
b) adjusting parameter limits to move the bounds of certain parts of algorithms to more accurately match how manoeuvres were flown,
c) adjusting the duration of algorithm loops to increase or decrease the amount of time that a certain criteria needs to be satisfied to give a positive result, and
d) updating the algorithm logic to include new or remove existing parameters.

These refinements improved the correlation between the manoeuvres reported to have been flown in the test flight and those recognised by the FMR software.

Fig. 3 and show a comparison of algorithm performance before and after the algorithm refinements. Fig. 3 shows where the flight crew indicated that they performing a right turn (grey shading) and where the FMR software recognised a right turn (green shading) based on the recorded flight data. Vertical velocity, roll angle and heading rate are presented as they are the primary parameters used in the recognition of a right turn. Airspeed, collective position and throttle are also used in the level flight turn algorithm, however they aren’t presented in

Fig. 3 since they're only used to differentiate between hover, level flight, climbing and autorotation turns.

Fig. 3 shows that the test flight crew recorded a continuous right turn, but the FMR software recognised three regions where the aircraft was in a level turn regime. The recognition was interrupted by the vertical velocity values straying outside the vertical velocity parameter limits (i.e. a climbing or descending turn rather than a level turn). The heading rate data is quite noisy since this parameter is derived from the magnetic heading parameter.

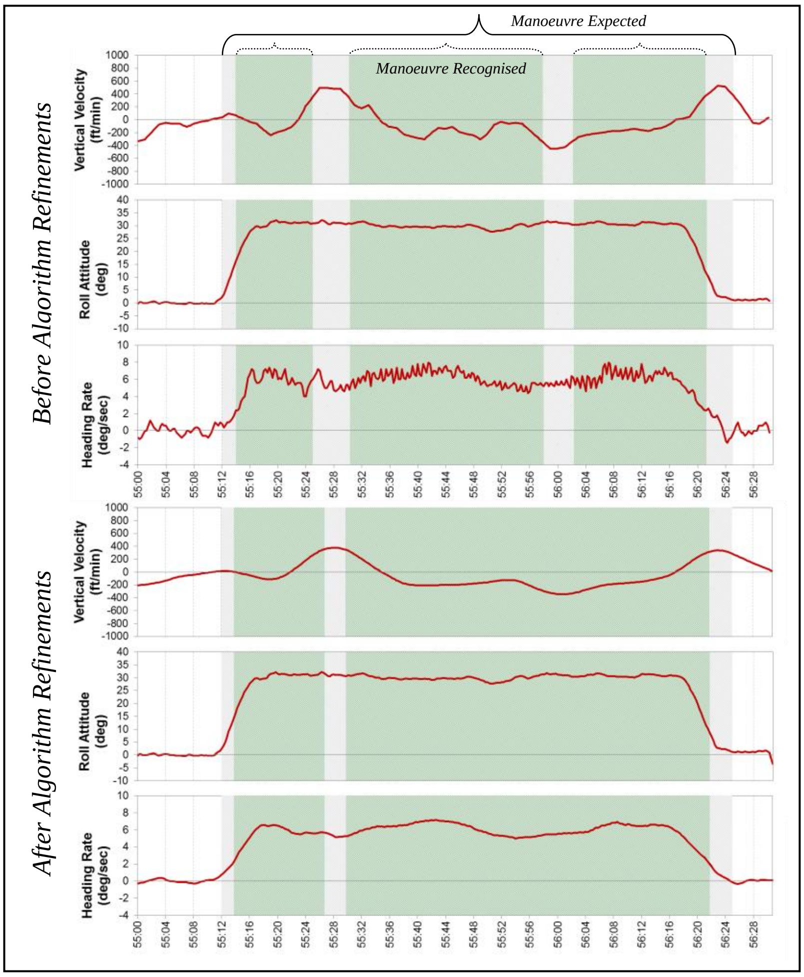

Fig. 3: V&V Test Flight, Level Flight 30 degree Right Turn

Following algorithm refinements it can be seen that the vertical velocity signal was smoothed which removed the second recognition drop out, but not the first since the climb rate (positive vertical velocity) was too high. While it didn't contribute to the recognition drop outs, the heading rate parameter was also smoothed due to smoothing of the magnetic heading parameter. Following the algorithm improvements 99.99% of the test flight could be assigned to a DUS regime or manoeuvre.

Mission Profile Development and Usage Severity

The FMR software was used to process in-service data from the S-70A-9 Black Hawk fleet. Combined with data from the extant manual UM system the manoeuvres and regimes recognised by the FMR software were used to develop representative mission profiles for each of the different mission types flown by the Black Hawk fleet. Fig. 4 presents a simplified comparison of six mission types where similar manoeuvres and regimes have been grouped together.

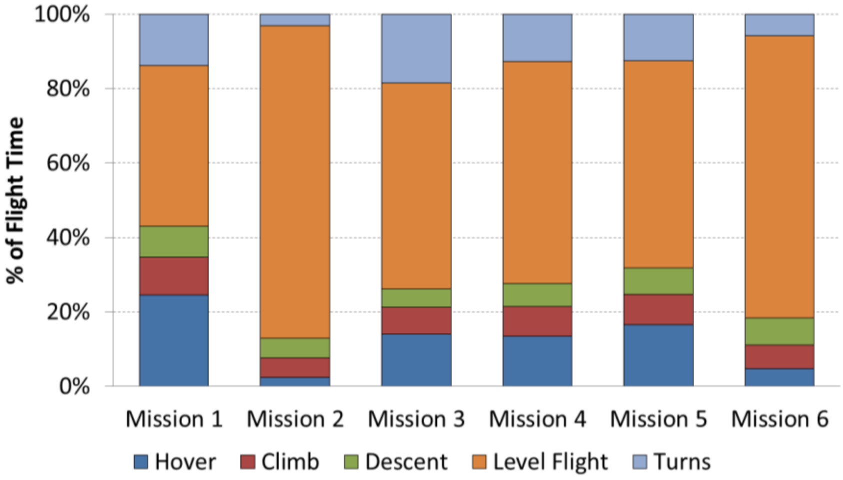

Fig. 4: Percentage of Time Flight Regimes

Using these detailed mission profiles defined in terms of OEM DUS regimes and fatigue damage rates for each of these regimes it was possible to calculate the relative severity of each mission type. The severity of each mission type was calculated for each critical component.

Conclusion

Flight Manoeuvre Recognition Software has been developed by QinetiQ which utilises data from existing flight data recorders installed on S-70B-2 Seahawk and S-70A-9 Black Hawk fleets. The software has undergone a number of testing and refinement cycles and has been used to characterise the severity of ADF Black Hawk in-service usage. The FMR software offers numerous benefits over the existing manual UM system currently in place, including:

a) significant improvement in the capture of flight regimes and manoeuvres that contribute to the fatigue damage accrual of critical components, and
b) improved confidence in the accuracy of the output data relative to the manually recorded data currently being collected.

Due to these improvements over manual UM systems, FMR software could be used to a much better understanding of the actual in-service fatigue accrual rates of critical components, and with sufficient data capture rates could be used to track or predict the fatigue damage accrual of individual components. The increased visibility and fidelity of in-service fleet usage reduces airworthiness risk by ensuring that fatigue damaging flight regimes are accurately captured and could be used to reduce cost of ownership and increase aircraft availability by optimising aircraft maintenance schedules.

References

1 Department of Defense, “Aircraft Structural Integrity Program (ASIP)”, MIL-STD-1530D, 31 August 2016.

2 Hill and S. Mitchell, “Seahawk Usage Monitoring Software Development, Flowchart Development”, SHUMS-RPT-001, 25 July 2006.