Application of data analytics to support structural life of type extension of the RAAF KC-30A MRTT

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Abstract

This paper details the application of data analytics to support the structural life of type extension of the Royal Australian Air Force (RAAF) KC-30A Multi Role Tanker Transport (MRTT). Descriptive analytics of historical data was synthesised with MAO future intent to characterise many sub-mission types and flight manoeuvres that were only broadly encompassed within the Statement of Operating Intent and Usage (SOIU). A detailed analysis was provided to the Original Equipment Manufacturer (OEM) to inform fatigue and damage tolerance analysis assumptions. Opportunities are identified to apply data science to usage data routinely to validate the SOIU and perform periodic assessments to inform the need for future life extensions. These opportunities are particularly relevant for sustainment constructs where access to fatigue and damage tolerance analysis is impeded by OEM IP constraints.

Keywords: data science and analytics applications, structures, life extension.

Introduction

A Military Air Operator's (MAO) Statement of Operating Intent and Usage (SOIU) often does not contain the level of engineering detail required to support a structural life of type extension program. This can result in costly programs that ultimately fail to cover the MAO's intended usage. Data analytics can be applied to this problem to effectively characterise in-service usage and provide insights into future usage scenarios. This paper details the application of data analytics to support the structural life of type extension of the Royal Australian Air Force (RAAF) KC-30A Multi Role Tanker Transport (MRTT).

Methodology

This project combined data science techniques with aeronautical engineering domain expertise and MAO future intentions. This is displayed schematically in Fig. 1, where Health and Usage Monitoring System (HUMS) data is combined with the SOIU and pilot interviews as inputs to the engineering analysis and data analytics. In the context of a Structural Life Extension Program (SLEP) it was important not to solely rely on the HUMS data is this only reflects historical usage. The detailed mission definition analysis holistically captures historic and future intended usage which is described within the SOIU. Pilot interviews were also used as a method to supplement stated future intentions in the SOIU and to clarify detailed observations of flying behaviour identified during the analysis. For example, historic usage was not representative of intended future usage for Air to Air Refuelling (AAR) missions due to the change in anticipated frequency of receiver aircraft and the future inclusion of novel receiver aircraft.

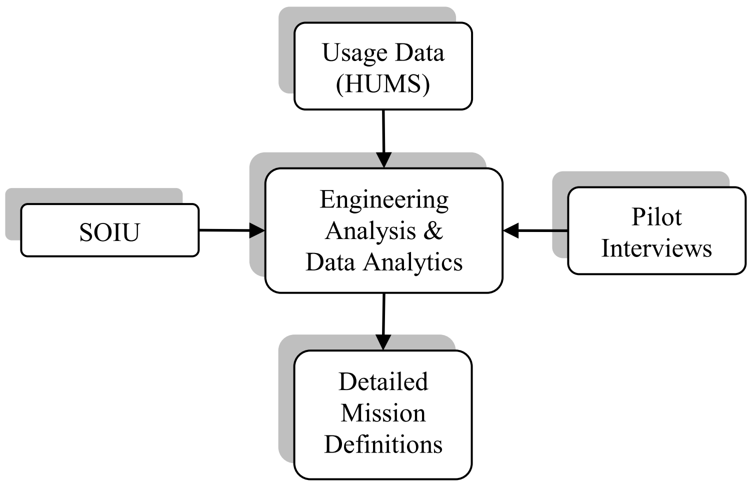

Fig 1: Methodology

The existing aircraft usage monitoring system as part of the Aircraft Structural Integrity Program (ASIP) was leveraged and modified to include additional flight parameters of interest. Due to the large amount of flight data, the map-reduce (Dean et. al., 2004) programming paradigm was applied. This allowed for parallel processing of two years of flight data files which were on the order of 100's MB – 1GB each. Optimisation of the processing algorithm to reduce the number of passes over the file allowed for the use of commodity computing infrastructure (ie: standard engineering laptops).

Descriptive analytics of historical data was synthesised with MAO future intent and presented to the aircraft OEM in an engineering report to inform SLEP analysis assumptions for fatigue and damage tolerance analysis.

Discussion

The analysis identified many sub-mission types which were only broadly encompassed within the SOIU[1]. Additionally, specific flight manoeuvres that drive fatigue damage to critical structure were characterised by severity and frequency. For example, Fig. 2 shows the distribution of flight duration for a mission type specified in the SOIU. A typical approach of someone unfamiliar with the intricacies of platform usage may be tempted to simply take an average flight duration of this mission type to characterise it. This is clearly inadequate in this scenario as taking the average of a bi-modal distribution implies the most common duration is one which is almost never flown! This underscores the importance of investigating usage in detail.

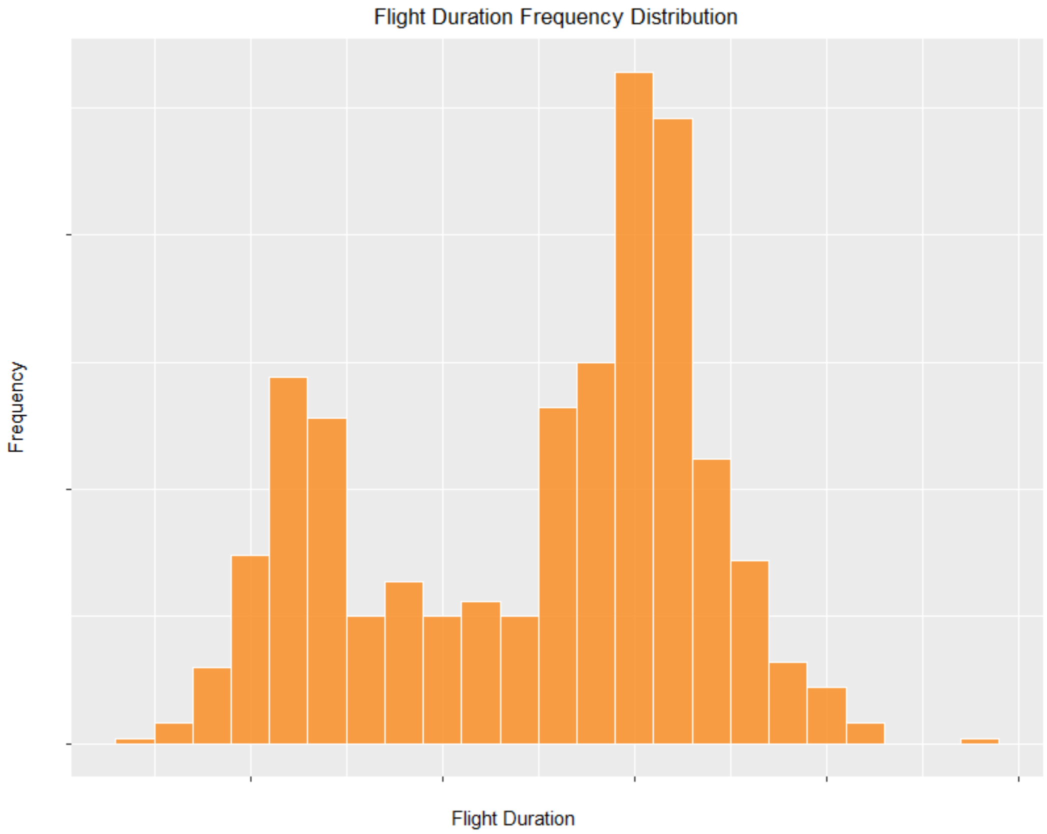

Fig 2: Histogram of flight duration for a single mission type (Kaveri, 2019)

Fig. 3 shows the same missions from Fig. 2 but decomposed into three sub-mission types. This decomposition results in a more detailed understanding of RAAF usage. Additionally the usage is more predictable as the underlying drivers of each sub-mission type can be identified and understood.

[1] The detail provided in the SOIU on mission profiles was considered insufficient to accurately inform engineering analysis required of a SLEP without significant risk of the SLEP analysis not fully reflecting RAAF intended usage.

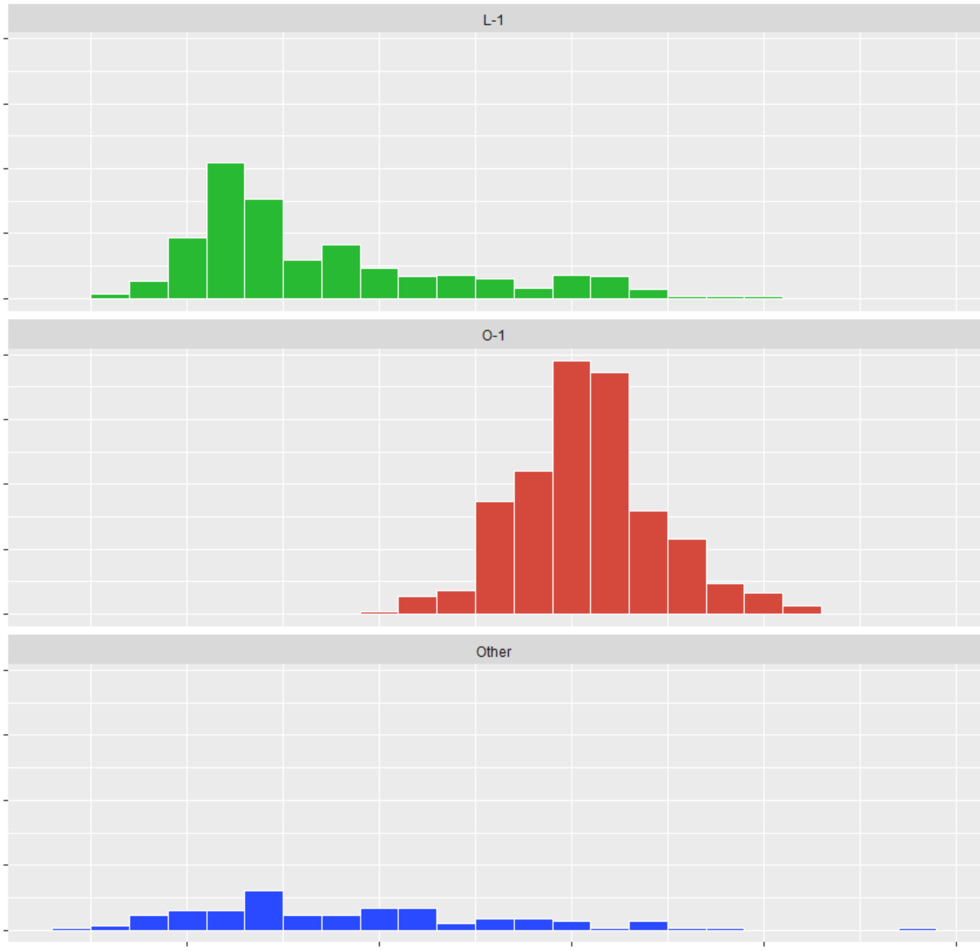

Fig 3: Histograms of flight duration after decomposition into sub-mission types (Kaveri, 2019)

Fig. 4 shows the interaction between take-off weight and flight duration with points coloured by sub-mission type. Clusters by sub-mission type can be visually identified. Additionally, variance in take-off weight can be characterised as a function of the sub-mission type. For example, Air Logistics Support (ALS) missions may be expected to have a lower variance of fuel weights relative to AAR missions.

The analysis produced for the detailed mission definitions highlighted in Fig. 1 required a multi-disciplinary analysis by combining aerospace engineering domain expertise with data science skills. Familiarity with software coding, analytics and techniques to deal with large volumes of data (i.e. big data) are skillsets rarely possessed by, or available to, structures engineers within the defence sustainment construct[2]. Given the high cost of SLEPs (i.e. 10's of millions of dollars) the ability to thoroughly understand usage and be able to forecast the future need for life extensions (or the ability to proactively manage fleet usage to avoid the need for life extensions) should be a priority in defence sustainment. As the volumes of available data grow the need for data science skills will only increase. Systems Program Offices (SPO's) and Through Life Support (TLS) contractors need to identify mechanisms of accessing these capabilities efficiently when needed. The most obvious need for these capabilities is within System Integrity Programs[3] (SIPs) due to the existing requirement for these programs to collect large volumes of HUMS or other Condition Based Maintenance (CBM) data (eg: to monitor engine condition).

[2] Engineers involved in the analysis for this project had an existing interest in the topic

[3] Collectively encompassing Aircraft Structural Integrity Programs (ASIPs) and Propulsion System Integrity Programs (PSIPs)

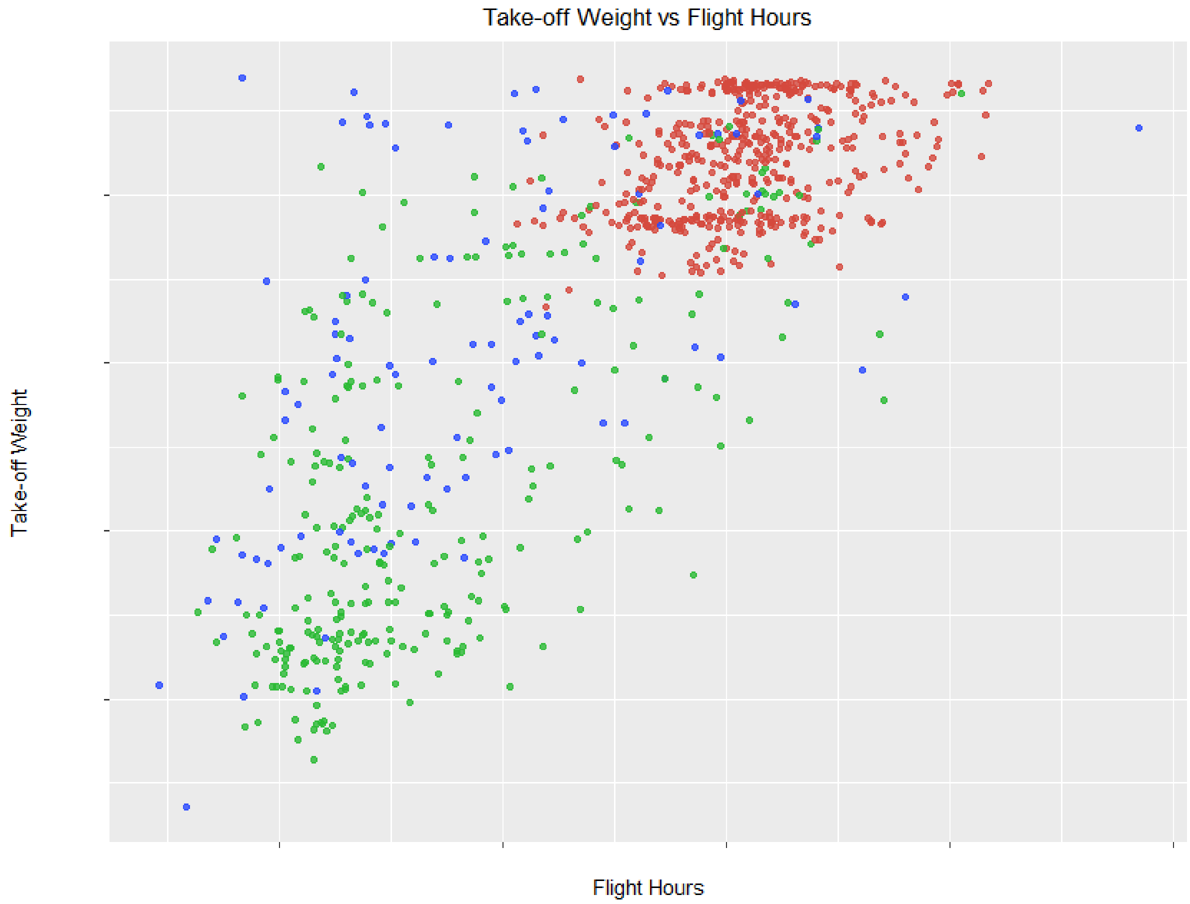

Fig 4: Scatterplot of take-off weight vs. flight duration coloured by sub-mission type (Kaveri, 2019)

The computing infrastructure used for this project was commodity engineering laptops which required multiple days to return a result on two years of flight data. This was after optimising the analysis code to run in O(n) with a single pass over the flight data file. For future applications the use of cluster computing infrastructure with the map reduce framework should be considered to allow faster processing of data. This would allow the processing of greater volumes of data, the use of more complex algorithms and the ability to return results in interactive timeframes (ie: seconds).

The application of data analytics to usage data has applications beyond a SLEP. For example, this concept could be applied:

- To routinely validating the MAO SOIU as is mandated in the UK by the Military Aviation Authority (MAA)[4];
- To performing ongoing monitoring and periodic assessment obligations of the Military Type Certificate Holder (MTCH) per Defence Aviation Safety Regulations (DASR) 21.A.44; and
- To forecasting and/or establishing the need for an updated propulsion system mission analysis per the Airworthiness Design Requirements Manual (ADRM) Section 3 Chapter 13.

These applications are particularly relevant for sustainment constructs where Intellectual Property (IP) constraints impede the sharing of detailed fatigue & damage tolerance assumptions by the OEM.

[4] The UK MAA Manual of Air System Integrity (MASIM) Chapter 8 describes an Air System Usage and Validation Programme (AUVP) whereby an SOI only becomes an SOIU once it has been validated by in-service usage data.

Conclusion

Data science and analytics techniques were applied to characterise in-service usage and provide insights into future usage scenarios to support the structural life of type extension of the RAAF KC-30A MRTT. The aircraft usage monitoring system as part of the ASIP was leveraged and modified to include additional flight parameters. Due to the large amount of flight data, the map-reduce programming paradigm was applied. Descriptive analytics of historical data was synthesised with MAO future intent through pilot interviews and consideration of future RAAF receiver aircraft. The analysis identified many sub-mission types which were only broadly encompassed within the SOIU. Future usage scenarios shaped by MAO intent were also included in a detailed analysis provided to the OEM to inform fatigue and damage tolerance analysis assumptions. Subsequently, the SLEP of the RAAF KC-30A MRTT has been successfully certified. Opportunities are identified to extend the application of data science to usage data to routinely validate the SOIU, perform ongoing monitoring and inform the need for future structural or propulsion system life extensions/mission analyses. These opportunities are particularly relevant for sustainment constructs where access to fatigue and damage tolerance analysis is impeded by OEM IP constraints.

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