A Prognostics and Health Management Approach for Aircraft Control Surface Free-play

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***free-play** = a loose, zero stiffness or dead zone in the structure - for example in the control surface hinge line or actuator*

Introduction

Fighter Aircraft demand high airworthiness performance to enable high speed and high-alpha manoeuvres, but with this comes more severe operating conditions and heavier maintenance burdens – impacting aircraft availability.

This research focusses on control surface free-play, an anomaly that can limit the performance of Generic Fighter Aircraft (GFA) and is closely linked to high-severity flight conditions (e.g., manoeuvres with vortex buffet).

Using an AGARD wing numerical benchmark model, a Prognostics and Health Management (PHM) approach is developed to predict free-play degradation and estimate a remaining useful life (RUL). This synthetic dataset aims to be representative of GFA in-flight regimes and the data acquisition of on-board sensor responses.

PHM is enabled by advanced aircraft sensor systems *(Fig. 1)*; to provide the rich-data source for these signal processing techniques and ultimately enable maintainers to manage free-play to increase aircraft availability and reduce labour-intensive checks *(Fig. 2)*.

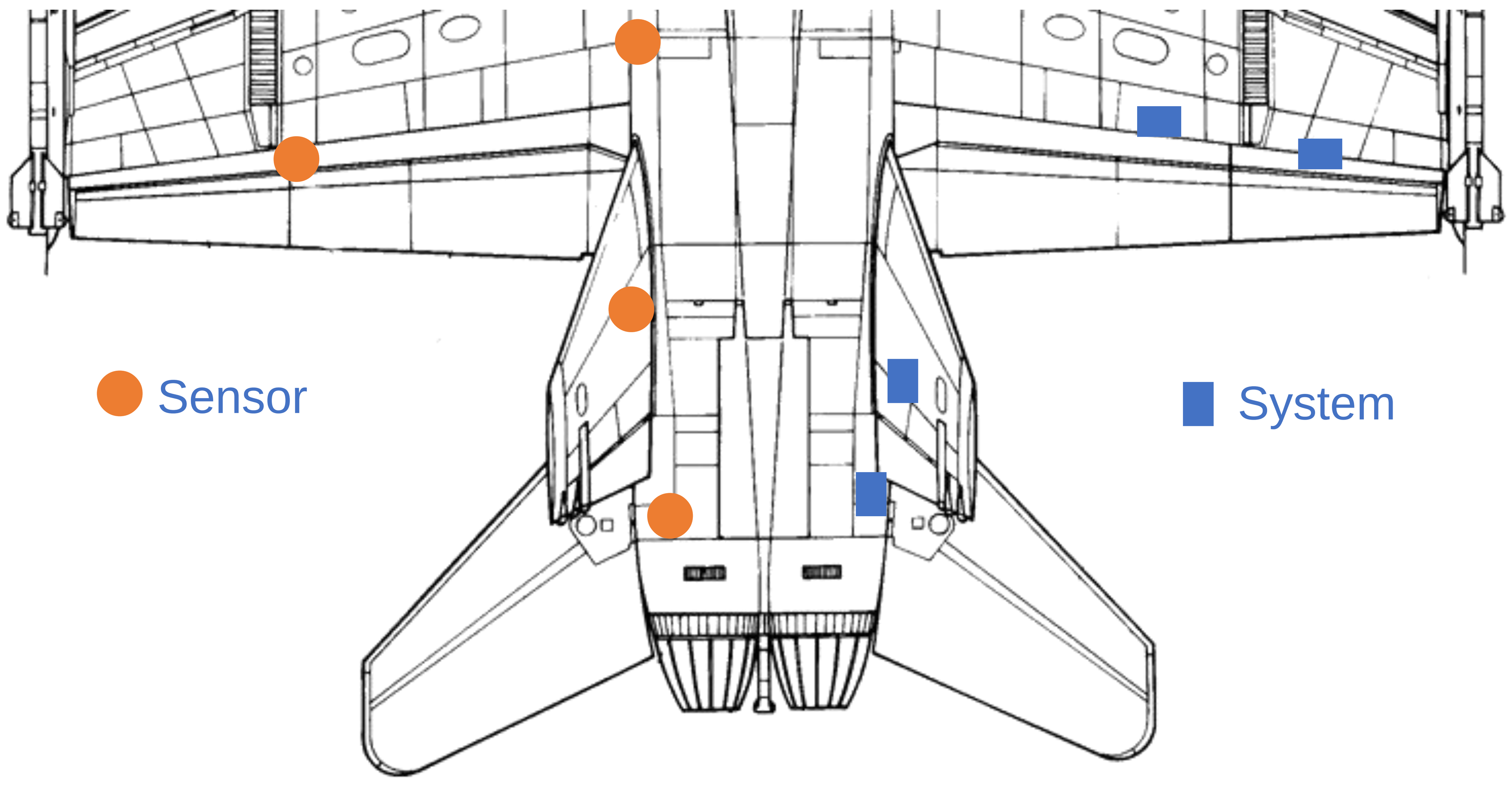


Fig. 1 – Representative PHM system *(source: the-blueprints.com)*

Significance & Motivation

Present Impact

- ▼ Restricted operational performance
- ▼ Labour-intensive manual checks
- ▼ Costly component swaps and repairs
- ▼ Reactive maintenance practices

source: F-35 Demo Team.

Future Benefit

- ▲ Higher aircraft mission readiness
- ▲ Greater aircraft structural integrity life
- ▲ Increased aircraft controllability
- ▲ Higher efficiencies and lower costs
- ▲ Proactive condition-based maintenance

Fig. 2 – Control Surface Maintenance Check *(source: RAAF)*

Approach & Results

A modified aeroelastic AGARD 445.6 wing with leading-edge (LE) and trailing-edge (TE) control surfaces is subjected to TE free-play degradation over thirty flights, with varying Mach, Alpha and Velocity index, until it reaches a threshold of 0.57 degrees maximum allowable movement according to MIL-SPEC 8870 - then signal processing is performed.

The predicted RUL results *(Fig. 3)* show that the exponential degradation model is in good agreement along the piece-wise linear actual RUL, with an overall root-mean-square-error (RMSE) value of 7.05 samples. However, the most critical stage for aircraft operations is near the nominal free-play failure threshold, which has an RMSE of 1.31 samples, enabling proactive maintenance.

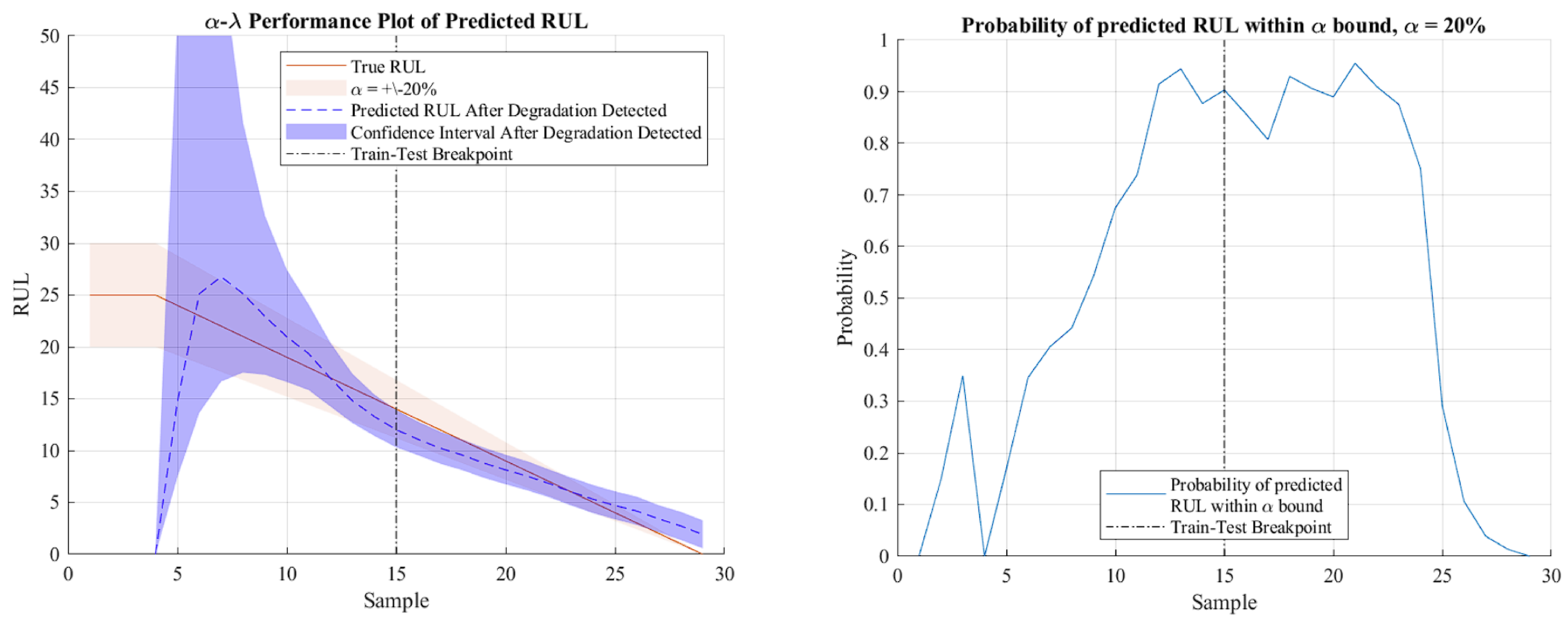


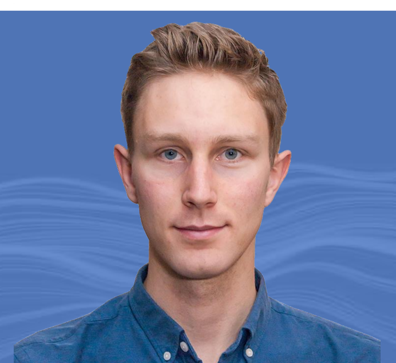
Fig. 3 – Performance plots of RUL estimation

Conclusion & Future Work

This PHM approach contributes a numerical benchmark case for aircraft control surface free-play degradation and outlines a PHM approach for the estimation of RUL, while helping to model the impact of cyclic hinge loading at high-alpha manoeuvres, which can induce large aerodynamic loading on control surfaces caused by sustained vortex buffet flow regimes. [scan QR code to see]

Future work will focus on: i) refining free-play degradation model with an all-movable stabilator configuration; and ii) representative on-board sensor responses with reduced signal response fidelity and greater spatial distance of the sensor to free-play source.

[scan QR code to connect!]



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