Demonstration of an Airframe Digital Twin Framework using a CF188 Full-Scale Component Test

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The National Research Council of Canada (NRC) is currently reviewing and assessing the Airframe Digital Twin (ADT) framework being developed by the United States Air Force (USAF) [1], for potential application for existing and future fleets of the Royal Canadian Air Forces (RCAF), in order to reduce maintenance cost and maximize availability. The USAF ADT framework is based on a Probabilistic and Prognostic Individual Aircraft Tracking (P^2IAT) approach. This approach carries out uncertainties in parameters (e.g. usage, geometry, material properties, damage state, etc.) into probabilistic fatigue life assessment for individual aircraft. As new operation and sustainment information are acquired, probabilistic distributions are updated and the uncertainty in fatigue life estimation is expected to be progressively reduced. The consistently model updating ensures that the digital twin continually mirrors the fatigue life of its corresponding physical airframe to allow pro-active, cost-effective decision-making in the fleet management.

A preliminary investigation performed by NRC [2] suggests that the USAF ADT framework can be adapted to the IAT programs currently used in some RCAF fleets. The ADT framework currently envisioned by NRC is shown in Figure 1.

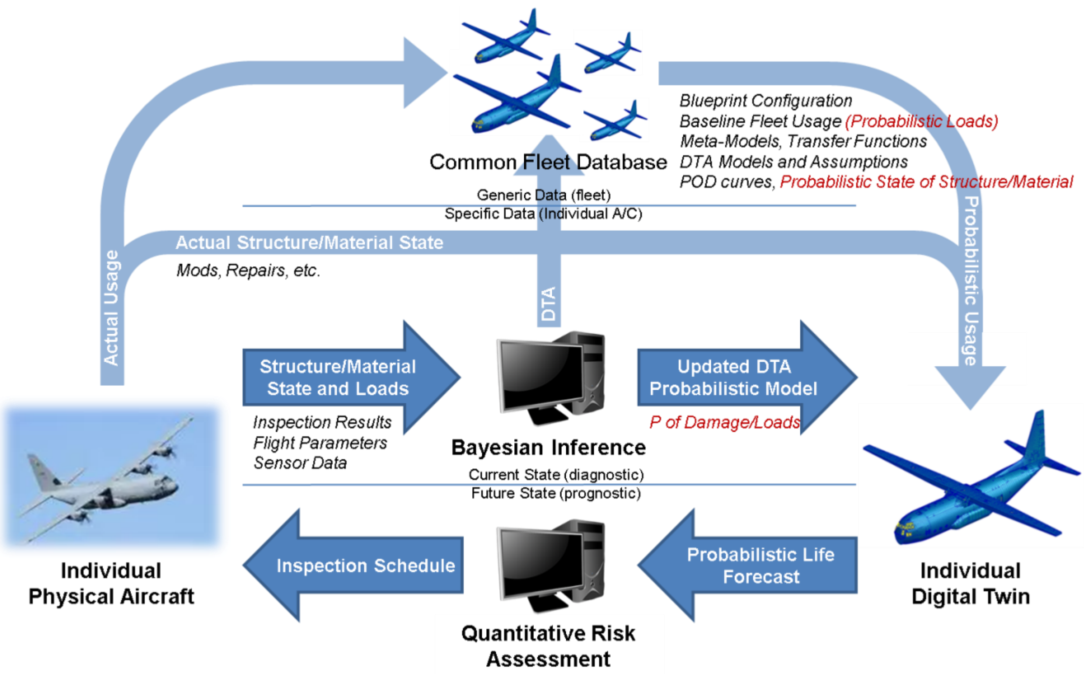

Figure 1. NRC ADT framework based on the P^2IAT concept.

In the phase 2 of the NRC project, a component test case study is planned to demonstrate the feasibility of the ADT framework on RCAF fleet management. To do so, the CF188 Inboard Leading Edge Flap (ILEF) life-extension fatigue test, currently being commissioned at NRC, is used as the physical asset of the digital twin. The tested ILEF is a retired component from the RCAF with some repair history representative of the current fleet and the test load spectra are representative of current and future usage. The ILEF transmission lugs, a life limiting item, is the main focus of this full-scale component test and of the ADT demonstration. A specific goal of the demonstration is to compare the ADT framework with the current lifing and fleet management practices, and to formulate recommendations on its improvement and potential adaptation and application.

The CF188 ILEF testing project is able to provide IAT data equivalent to that is available from the actual aircraft, including the inspection methods and results in service. Additional measurement and inspection results, using techniques such as digital image correlation, and thermoelastic stress analysis, X-rays, and thermography, will be used for initial model validation and then to assess the performance of the ADT models and framework. However, only the data that would normally be available for fleet management will be used for the remaining life estimation and the ADT framework evaluation.

In addition to the statistical methods required to perform model updating (i.e., Bayesian inference) and probabilistic life forecasting (i.e., quantitative risk assessment), the ADT framework requires input parameters and numerical models that relate IAT data to probabilistic life forecasting. For instance a prior probabilistic representation of the usage was developed based on the IAT data (ex. wing root bending moment) by limited random sampling in the test spectrum. Model updating using the IAT data is needed to progressively reduce the loading uncertainty. In this task, a global finite element (FE) model is used to formulate a joint probability distribution of the IAT data and the ILEF transmission hinge moment used to generate random ILEF lug forces. Since all the ILEF lugs used in the RCAF fleet have been shot-peened. A prior distribution of the initial material state was developed based on equivalent pre-crack size distributions developed for shot-peened 7050 aluminum alloy. Furthermore, X-ray diffraction measurements were performed at NRC to measure the compressive residual stresses present in the component. A detailed FE model of the lugs is used to obtain local stress distributions and then followed with fracture mechanics analyses using StressCheck and crack growth tools. The remaining life distributions will be used to calculate the probability of failure in a risk analysis. The major elements composing the CF188 ILEF ADT demonstrator are illustrated in Figure 2.

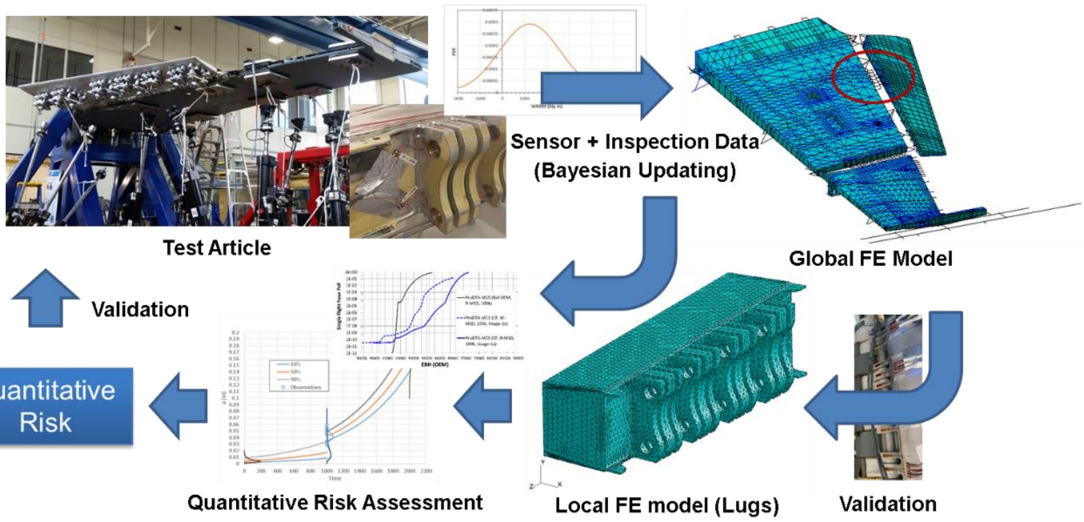

Figure 2. NRC ADT demonstration using the CF188 ILEF full-scale test.

The full paper will present the results of the CF188 ILEF ADT demonstration, including the approaches and results for various elements, including the results from the Bayesian updating and quantitative risk assessment. It should be noted that the current ADT demonstration will not interfere with the operations of the CF188 ILEF testing, i.e. no decision in the test will be made based on the digital twin analysis results. The test data will be recorded and made available for either in-situ or afterwards analysis, for what if scenarios, and will remain available for later tuning and improving of the framework. By comparing the ADT results with the existing fleet management approach, this paper will identify the gaps/challenges for the ADT technology development, and provide further recommendations on the feasibility of the ADT framework for future RCAF applications.

Keywords: Airframe Digital Twin, Individual Aircraft Tracking, Probabilistic Prognostics, Bayesian Updating, Technology Demonstrator, CF188, Aging Fleet Management, and Sustainment Engineering.

[1] Tuegel, E., Kobryn, P., and Henderson, D., “Developing the Airframe Digital Twin”, The Aircraft Airworthiness & Sustainment Conference (AA&S), March 30 – April 2 2016, Baltimore, Maryland.
[2] Liao, M., Renaud, G., and Bombardier, Y., Airframe Digital Twin (ADT) Technology Adaptability Assessment and Technology Development Roadmap, NRC Technical Report, LTR-SMM-2018-0063, March 2018.