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A flexible aircraft maintenance scheme based on predictive maintenance allows a higher structural utilization. This leads to reduced mass for new aircraft designs or longer maintenance intervals for existing aircraft. Current aircraft are designed to endure predefined operating load and to fulfil standard maintenance requirements with fixed intervals for damage inspection. For a predictive maintenance, the utilization the actual load history of an aircraft as well as evaluating the development of a damage will be analysed. The workflow in figure 1 uses the concept of a digital twin by evaluating data from on-board sensors. The Operational Loads Monitoring System (OLMS) transforms this data into operating global loads. These are converted to local strain spectra and fed into a damage tolerance calculation estimating the remaining useful life (RUL) of a structure.

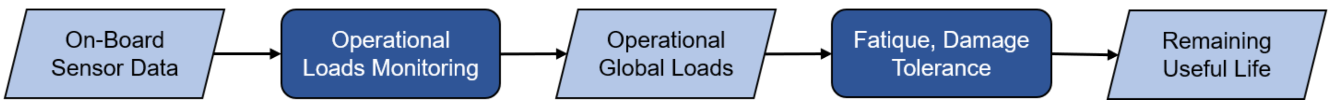

Figure 1: Proposed workflow from sensor data to remaining useful life

The OLMS provides the global loads, hence the loads acting within the aircraft structure during the whole flight mission. These loads consist of shear and axial forces as well as bending moments and torque [4]. In order to estimate the loads during real flight missions, the OLMS requires recorded data from the mission consisting of flight parameters as well as data representing control surface movement and engine thrust. The flight parameter data includes attitude angles, velocities, angular rates as well as load factors. Next to the data from the flight mission, a physical model, which is derived using the framework VARLOADS [3], is required to determine the global loads. It consists of a dynamic aircraft model which represents the rigid body dynamics of the aircraft as well as the flexible dynamics of the aircraft structure. The aerodynamics are model by a panel method, which is based on potential flow assumptions. The aeroelastic effects are considered by coupling the aerodynamic model with the rigid body and flexible dynamics of the aircraft structure. Additionally, disturbances like the one minus cosine gust, are included in the model. The recorded data and the physical model are combined by using an observer-based approach, the Kalman filter. This enables to estimate the global loads during operation.

Using the given global loads in a linear static FEM analysis, the operating load of a CFRP structure can be described by a 2D strain spectrum obtained by rainflow counting. The spectrum is a 2D histogram, mapping the load level at the beginning to the end of a half-cycle. The structure under investigation is a CFRP skin, where the largest damages of category 2 according to FAA AC 20-107B [2] are considered. This is the largest damage size the structure must withstand limit loads until the next inspection. Damages, CFRP layup and load spectrum are input to the analytical damage tolerance method by Bogenfeld et. al [1] for compression dominated structures using a no-growth approach. For each load levels of the spectrum, the method calculates energy release rates. With the use of the Palmgren Miner rule, the accumulated damage is calculated, which can be extrapolated up to the delamination growth onset. The flight cycles up to the delamination growth onset can be interpreted as the RUL.

The described workflow is a building block for predictive maintenance optimization. Since it uses already existing sensors, it can be used for existing aircraft as well. Additionally, it allows the extension of inspection intervals when the aircraft experiences lower loads in its history as assumed in the aircraft design. Furthermore, with this type of structural health monitoring, revealed former category 2 damages may stay within the structure up to consecutive inspection intervals or until the end of the aircraft's life cycle as long it does not reach its delamination growth onset.

References

[1] Raffael Marius Bogenfeld, Sebastian Freund, and Andreas Schuster. An analytical damage tolerance method accounting for delamination in compression-loaded composites. *Engineering Failure Analysis*, (118), 2020.

[2] Federal Aviation Administration. Advisory Circular: 20-107B - Composite Aircraft Structure. 2009.

[3] T. Kier and J. Hofstee, editors. *VARLOADS - Eine Simulationsumgebung zur Lastenberechnung eines voll flexiblen, freifliegenden Flugzeugs*, volume I & II, 2004.

[4] Jan R. Wright and Jonathan E. Cooper. *Introduction to aircraft aeroelasticity and loads.* Aerospace series. Wiley, Chichester, West Sussex, United Kingdom, second edition edition, 2015.