An Ultrafast Crack Growth Lifing Model to Support Digital Twin, Virtual Testing, and Probabilistic Damage Tolerance Applications

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New aeronautical technologies such as the Airframe Digital Twin (ADT), Virtual Fatigue Testing (VFT), and Probabilistic Damage Tolerance Analysis (PDTA); require a large number of crack growth evaluations with a comprehensive number of random variables in order to accurately predict the fatigue life, the structural risk, or the remaining useful life of the structure. Current state-of-the-art crack growth methodologies and probabilistic methods inhibit practical use of these new technologies due to limitations on computational speed and number of random variables considered.

Under Federal Aviation Administration (FAA) funding, a new computational strategy was developed and demonstrated such that random variables directly affecting the crack growth analysis can be considered. This methodology focused on the development of an ultrafast numerical crack growth algorithm that consists of: a) the development of a constant amplitude equivalent stress derived from a variable amplitude loading spectrum, and b) an adaptive step-size Runge-Kutta ordinary differential equation (ODE) solver.

Figure 1 shows a summary of the methodology used in the Ultrafast Crack Growth algorithm. The methodology was also embedded within the SMART|DT probabilistic software as shown in Figure 2 to generate the necessary inputs for multiple fracture mechanics evaluations. This approach provides the opportunity for a more comprehensive and accurate digital twin evaluation, virtual testing prediction, and risk assessment; hence, improving aircraft design, safety, and reliability

In this paper, several examples with ADT, VFT, and PDTA applications will be demonstrated using through, corner, and surface cracks at a hole under representative loading spectra using the new crack growth algorithm. The crack size versus cycles results from this new approach will be compared against results obtained from commercial lifing software codes. All results to date indicate that the life comparison is within a few percent while performing 7,000 complete crack growth analyses per second on a single processor, whereas traditional crack growth methods can take several seconds to complete a single crack growth analysis. The probabilistic crack growth analysis has been parallelized within the SMART|DT software using OpenMP and MPI in order to fully utilize multi-core computers. Due to the computational speed up, using this approach enables these new technologies with more random variables and samples while maintaining crack growth life accuracy. This all results in improved aircraft safety.

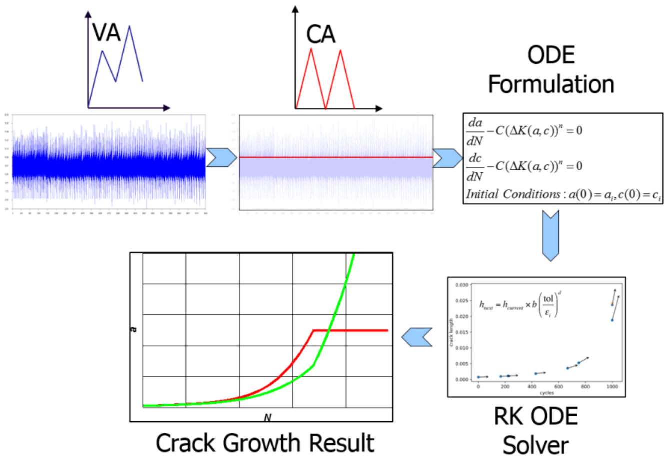

Figure 1. Ultrafast Crack Growth Methodology.

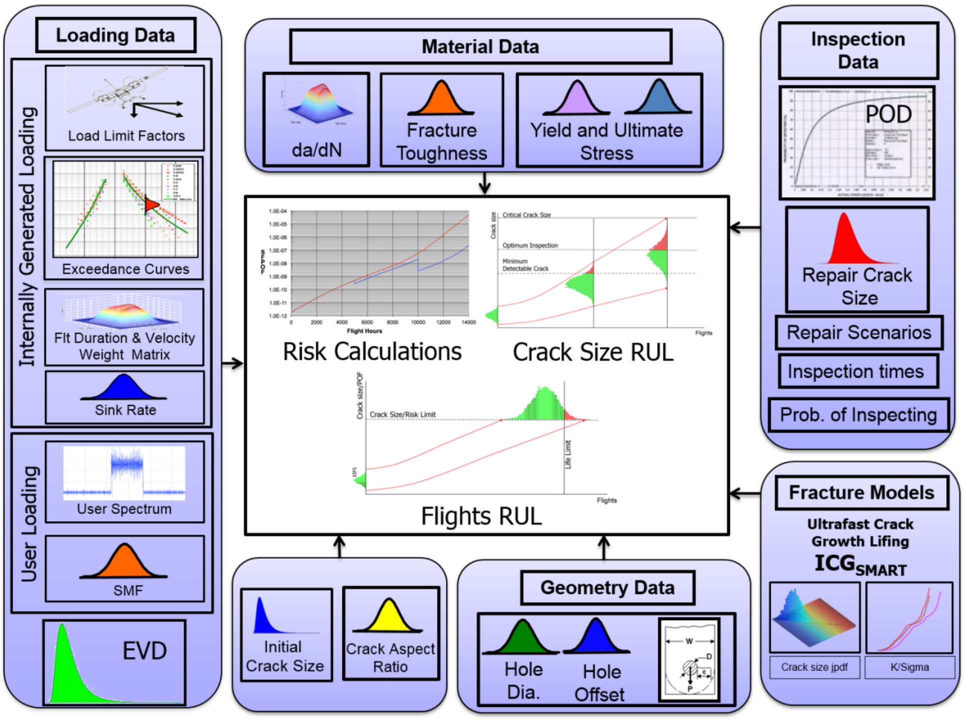

Figure 2. Probabilistic Framework.

Keywords: Fatigue Crack Growth, Airframe Digital Twin, Probabilistic Damage Tolerance Analysis, Virtual Testing.