“Holistic” Low-Effort Model for Damage Tolerance Analysis in Preliminary Design

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Abstract:

New aircraft concepts, which make use of new, sustainable energy types, will all require low structural mass, owing to density problems in energy storage or energy cost. Such questions have to be checked already in the preliminary design phase to prove feasibility. One of the obstacles in preliminary design optimization is the computational effort needed to find reliable results. Therefore, damage tolerance issues are often neglected, although a larger part of the primary structure is sized according to damage tolerance criteria.

This paper shows a way to provide low-effort damage tolerance results for complex structural items. The basic scenarios are all dedicated to stiffened structures, as this is firstly one of the most relevant in aircraft and secondly, the effort to calculate residual strength and inspection intervals is considerable. Therefore, reduced effort models are required in preliminary design. The low-effort model allows variation of many parameters relevant for aircraft design, e.g., stringer pitch, fastener pitch, fastener diameter, stringer and skin thickness, etc. and can therefore be applied to many aircraft regions. Three different typical locations of such structural element are taken into account, namely the upper fuselage panel, a fuselage side panel and a lower wing panel (see Figure 1). All cases show very different design parameters, as e.g. stiffener design and pitch, as well as typical load sequences.

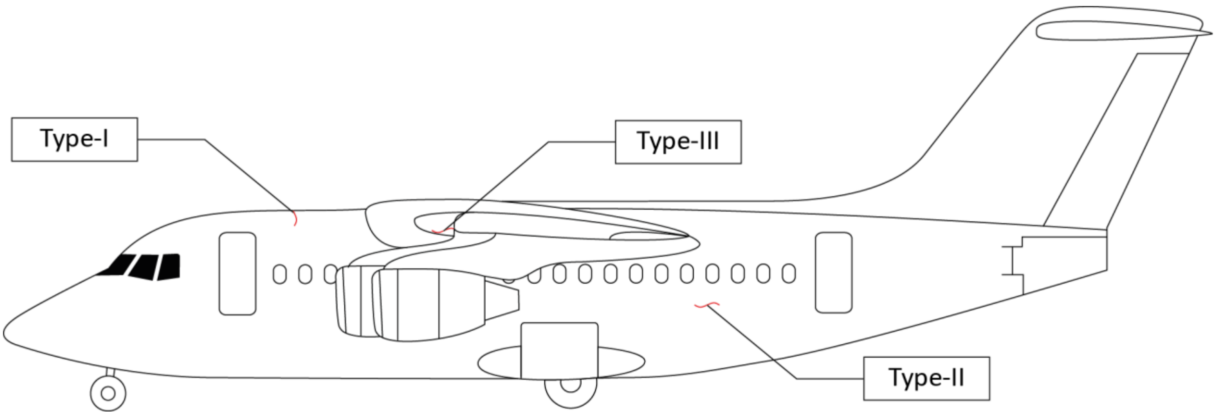

Figure 1: Typical structural elements, crack position and orientation[1]

The basis of the model is a semi-numerical simulation of cracks in a stiffened structure to evaluate stress intensity factors. Based on these factors crack growth and residual strength may be determined, taking into account sequence effects via the wheeler retardation model[2]. Where necessary, the effect of bulging is considered as well. Based on this model many scenarios are

[1] adapted from https://www.norebbo.com/wp-content/uploads/2018/11/BAe_146-200_Avro_RJ85_line_drawing.jpg, Visited on 10.05.21

[2] O. E. Wheeler (1972) Spectrum loading and crack growth, J. Bas. Engng, 94, 181–186.

calculated, where many design parameters are systematically varied. This includes material parameters, too. It is still an open point, whether it is possible to jointly model different material results. Several criteria, as e.g. 1-bay- and 2-bay-cracks are taken into account. In total a multi-dimensional matrix of results is found, which may be used to assess damage tolerance behaviour of structures in preliminary design.

The modelling of the result matrices via Response Surface and/or Artificial Neural Network is an ongoing task; where some results are shown by means of examples. The crack location has strong impact on crack growth. Response surfaces are therefore calculated separately for 1- and 2-bay cracks. In preliminary design, the response surfaces can be used as shown in Figure 2 (left) for a 1-bay Type-II crack with an initial half crack length of $a_{detectable}$ = 37.5 mm: For each skin thickness - fuselage radius combination the flight cycles until unstable crack growth occurs is calculated. Furthermore, it is determined whether the configuration is in-/admissible by criteria such as crack length or endured cycles. In Figure 2 a configuration is deemed inadmissible if the crack does not reach the next frame before growing uncontrollably - a typical requirement in damage tolerance. It can be seen, that for this case small sized aircraft such as the BAe 146 can be built with skin thicknesses between 1.0 and 1.5 mm, whereas long range aircraft need skin thicknesses between 1.7 and 2.0 mm. Via the endured cycles the endured maintenance intervals can be obtained and used accordingly. In Figure 2 (right) the response surface due to ground air ground cycles (peak to peak, here referred to as type I loading) with an initial half crack length of $a_{detectable}$ = 37.5 mm at the upper fuselage panel behind the center wing box is shown for a fuselage radius of 1800 mm. It can be observed that for stringer pitch greater than 180 mm the crack does not reach the stringers which results in an inadmissible stringer configuration. AL2024T3 has been used as material in Figure 2.

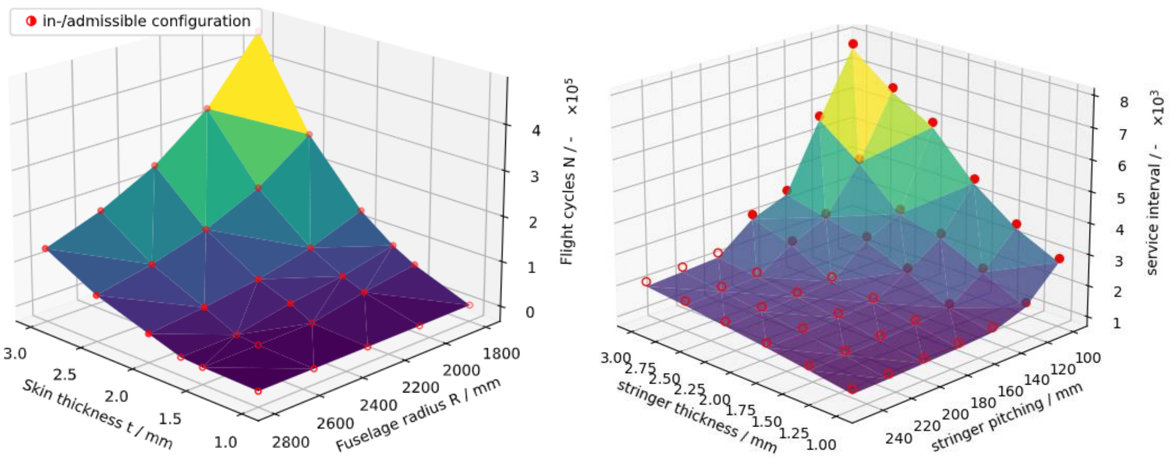

Figure 2: Flight cycle response surface for skin thickness and fuselage radius variation for type II loading (left) and service interval reponse surface for stringer thickness and stringer spacing variation for type I loading (right)

Utilizing the low-effort model in combination with artificial neural networks as mentioned above leads to the idea of the digital twin of a real aircraft to provide specific maintenance tailored to the real aircraft. In addition, the models may be used to assess the impact of different load sequences, which may result from new flight control laws in the attempt to reduce loads and therefore mass. This may be an additional benefit to be utilized for sustainable flights. Furthermore, the influence of increased airport traffic and new flight routes may be investigated.