Modelling and analysis of crack turning on aeronautical structures

Doctoral Thesis

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3 *Objectives and Methodology*

The introduction of integral structures together with new materials provides to airframe designers an increase on the design possibilities. In particular, Airbus decided to explore the utilization of the crack turning phenomenon to protect the stiffeners in front of an approaching skin crack in integral structures by means of a tailored design. The zones in the airplane which present near *Mode I* loading and where crack turning could be used as a design principle were identified by Airbus [89] to be situated in the upper fuselage, as indicated in Figure 3.1.

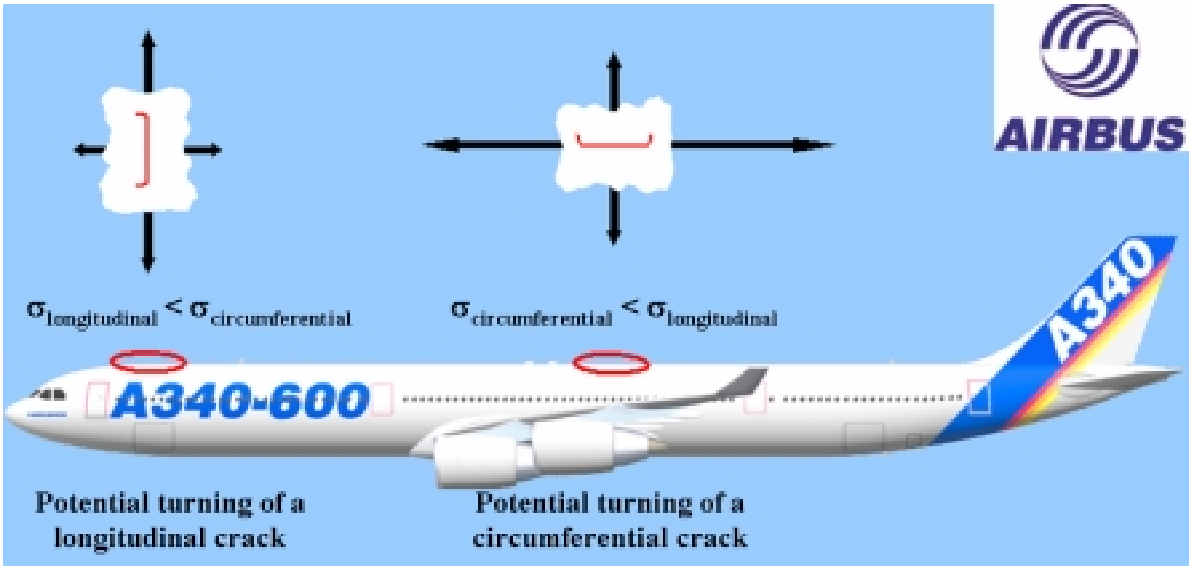

Figure 3.1. Fuselage zones and crack scenarios with turning potential [89]

But, before employing crack turning in aircraft design many of the aspects related to this phenomenon have to be investigated and understood.

Keeping in line of actual research in the aircraft industry, this doctoral thesis had as a main objective to asses and predict crack turning under nearly *Mode I* situations on structures, which reproduce actual aeronautical conditions, providing an existing modelling tool and a reliable criterion.

Due to the fact that industries are firstly interested on quick and suitable design results, the first step in this thesis has been to show the feasibility to predict crack turning by means of Linear Elastic Fracture Mechanics and Finite Element Analysis.

Figure 3.2 depicts in a flowchart the breakdown of the identified tasks necessary to achieve the above objective. These tasks are developed and explained in detail in sections 3.1 and 3.2.

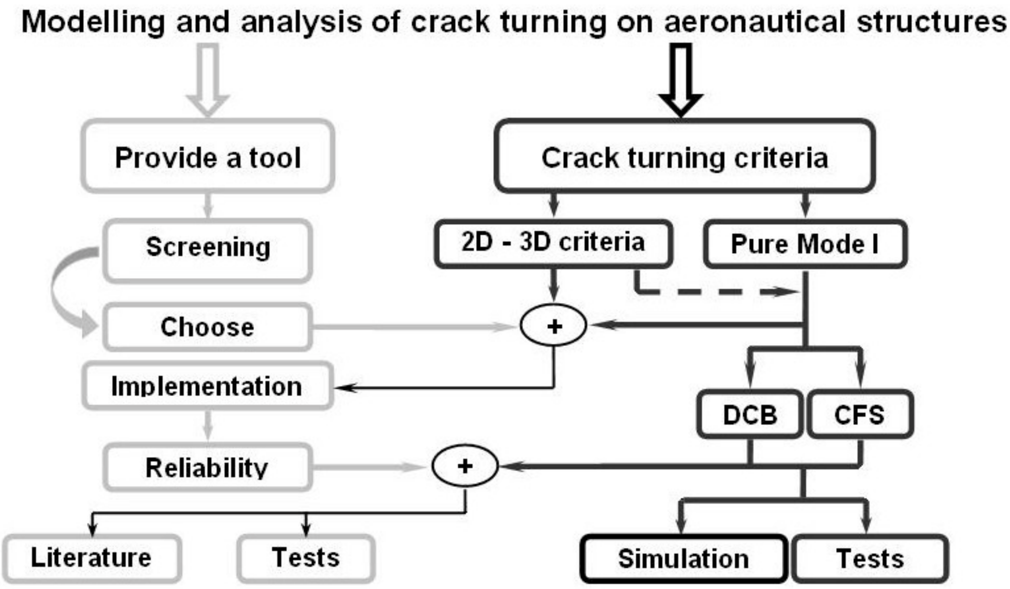

Figure 3.2. Schematic representation of the tasks involved in this work

3.1 Modelling tool for crack growth analysis

The first step, necessary to facilitate *FE*-analysis, is to have or acquire a tool. The principal requirement for the tool is that it has to be able to compute K_I and K_{II} fracture mechanics parameters. With this purpose, a screening of the existent commercial and non-commercial tools was carried out regarding their fracture mechanics capabilities on two and three dimensional models, their design abilities, implementation capacities as well as their complexity, i.e. “easy to use”. The most performing software accessible to the author, i.e. FRANC3D®, StressCheck®, ANSYS® and Crack-Kit®, were analysed. The tools which better adjust to the requirements were compared and their predictions were contrasted with experimental results. The “best” software, congruent with the pre-defined conditions, was purchased and implemented according to the need of the existent crack turning criteria near under *Mode I* conditions. To be precise, the *T*-stress calculation capability was implemented because it is indispensable to evaluate second order crack turning criteria.

Once the tool was ready to be used, a deeper check was performed to confirm its reliability by means of both literature data and experimental results.

3.2 Crack turning assessment

As already introduced, aircraft structures are principally loaded with a hoop stress due to internal pressure and bending moment. Besides, side panels are additionally charged with a shear load. These conditions generate structural parts charged under mixed mode loading while others are loaded under either near or pure *Mode I*. Crack turning under *Mode I + Mode II* loading conditions were not treated in this work because this has already been extensively studied [2, 5, 14, 22, 24, 42, 54, 57, 80, 87, 90-93].

Crack turning criteria under near *Mode I* were evaluated under both quasi-static and cyclic loading by means of two specimens: the Double Cantilever Beam and the Cruciform Specimen. The evaluation was performed using experimental data and simulations carried out with the set *FE*-software, resulting from the left block in Figure 3.2.

The *DCB* was used to evaluate different *2D* and *3D* crack turning criteria (chapters 2.4.2, 2.4.3 and annexes). As a result of the comparisons, a compilation criterion was proposed based on the work of Pettit [9] and the normalised T-stress, T_R, proposed by Pook [16]. This criterion was also evaluated by means of the tested specimens. The dimension relations of the *DCB*-specimens were the same as those used in the literature [2, 5, 7-9, 23, 49]. These dimension relations generate on the *DCB*-specimen, K_I/T-ratios similar to those on a skin crack approaching a stiffener. The *CFS* was selected due to its ability to reproduce, together with the correspondent test rig, different biaxial ratios taking place on fuselage skins. The *CFS* together with the *DCB*-specimens were used to evaluate and analyse modelling details and boundary conditions on crack turning predictions.