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Definition of 'best modeling practice' for the propagation of 3D cracks with level sets and the XFEM. Application to multi-site crack propagation in an aeroengine component

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ABSTRACT

This contribution presents a procedure for the analysis of 3D cracks with the XFEM, ensuring accuracy, quality and robustness of the solution both for static and propagating cracks. This procedure can be considered as 'state-of-the-art' modeling practice.

The structure of interest is a stator blade containing two cracks (one at the leading edge, the other at the trailing edge) which propagate in 3D out of their initial planes, starting from a 0.1mm length up to about 4mm. The blade is subjected to a distributed pressure (static plus oscillating), a temperature gradient (transient or steady) and kinematic conditions under the form of fixed displacements and periodicity. The crack advance is related to the variation of the Stress Intensity Factors and the number of loading cycles using a standard Paris fatigue crack propagation law.

The approach used in this contribution combines the classical FEM and the XFEM through a substructuring approach (the S-FE/XFE method). In this case, the structure is decomposed into cracked and uncracked domains which are treated by an in-house XFE-code called Morfeo (developed by Cenaero) and the commercial FE software Samcef^{TM}, respectively. The interface problem between the two domains is solved using the Finite Element Tearing and Interconnecting method.

So-called 'best modeling practice' include considerations about the following issues (note that the list is far from being exhaustive):

- **Mesh refinement.** In 3D, the XFEM must be coupled with selective mesh refinement in the vicinity of the crack in order to capture the sharp variation of the fields. It must be noted that, even though the mesh does not need to be conformal, it has to be fine enough in the sense of global and local convergence of the solution. The use of the level sets helps defining size maps that are particularly suited for fracture mechanics problems.

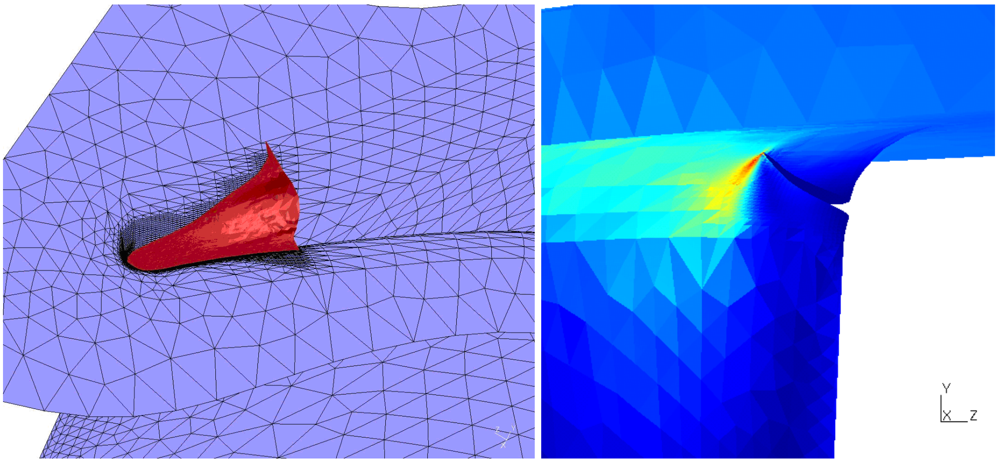

Figure 1: Left: level sets of the crack at the trailing edge after 3.5mm of propagation (inner view) - note the significant mesh refinement needed for high quality SIFs. Right, Von Mises stress on the blade surface at the trailing edge.

- **Crack positioning.** Cracks are generally placed at the locus of -and perpendicular to the direction of- maximum principal stress. Nevertheless, in a damage tolerant approach using the LEFM, the initial crack has a finite length (surface) and this procedure might not be conservative, i.e. might not lead to a maximum mode I SIF. XFEM is here very useful for iteratively finding with minimal operator interventions the orientation of the initial crack with maximum mode I SIF.
- **Enrichment strategies.** The quality of the solution depends on the size of the zone in which the approximation space is enhanced with the a priori knowledge of the solution.
- **Reliable stress intensity factors.** As with any FE method based on unstructured meshes, numerical oscillations in the stress intensity factors can be observed. At minimum smoothing operations are necessary. Other methods suggest for solving the stress intensity factors as a specific finite element field with proper interpolation.
- **Robust level set propagation algorithms.** The level set representation of cracks requires specific update algorithms when dealing with propagation, which can be either fully numerical, fully geometrical or mixed. Knowing that the level sets are used in the definition of the local coordinates systems at the crack tip and in the definition of the virtual crack extension vector field in the evaluation of the J-integral, they must be carefully evaluated, updated and orthogonalized.
- **Multi-physics applications.** Most fracture mechanics problems involve complex boundary conditions and loads. For instance, it happens quite often that mechanical loads, thermal loads, residual stresses and other body forces interact and influence significantly the stress concentration and the stress intensity factors. The XFEM must be adapted accordingly, as well as all the post-processing operations such as the interaction integral.
- **Intermediate 3D validation.** While numerous 2D validation cases are available in the literature, it is only recently that 3D applications with both verification and validation have been published. It is of utmost importance to propose exhaustive validation of the method in order to promote its use in the industrial software environment and crack analysis procedure.