DEMOCRATIZATION OF FATIGUE EVALUATION FOR REALISTIC RIVETING CONFIGURATIONS USING STATE-OF-THE-ART SIMULATIONS

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Abstract

Advanced structural simulations are a key driver to achieve efficient and reliable aircraft structures, especially for new design configurations or applications. However, the implementation of these technologies requires very specific knowledge and expertise, which can limit the massive deployment of simulations for the development of a new aircraft. An approach for the democratization of advanced numerical simulations for fatigue life prediction in aircraft riveted joints is presented in this paper.

Keywords: simulation, fatigue, democratization, CDM

1. Introduction

The use of advanced numerical simulation technologies for aircraft structural evaluation is a key pillar in the aeronautical industry in order to achieve more efficient and reliable airframe designs.

A significant effort is being made in the industry to develop, validate and implement computational methodologies able to predict complex material and structural behaviors (for example fatigue cracking or structural collapse) with a level of credibility compatible with aircraft certification needs. These new methodologies evolve from the classical Global Finite Element Models (GFEMs) used to derive airframe load values and paths to very Detailed FEMs with embedded material constitutive models and damage laws that can reproduce material behavior at design detail point level. [1]

Even if the latest versions of commercial simulation software are becoming more user-friendly, the application of these technologies require significant expertise and practical experience to ensure the achievement of robust simulation results. This need of highly specialized engineering profiles is a limitation to massively deploy advanced simulation technologies in the development and certification processes of new aircraft.

To democratize the deployment of advanced simulation technologies for the development of the new generation of Military Aircraft Programs in Airbus, new integrated software tools are developed at Airbus [2]. One of these tools, called INFERNAL, is able to generate high-fidelity simulations for aircraft riveted joints in an automatic process. These simulations are able to predict fatigue cracking for realistic complex scenarios including rivet interference, preloading, thermal effects… An overview of software, capabilities and validation is provided in the following chapters.

2. Simulation approach

The basis for the simulation approach implemented in INFERNAL software are discussed in [2]. The physics-based solver module is able to generate high-fidelity FEM simulations for realistic riveted joint configurations including embedded damage models to predict fatigue cracking in the joint. The main Modelling & Simulation (M&S) features of the approach are described below:

- Automatized FE model generation based on user parametric inputs
- Implicit Finite Element Method simulation based on Abaqus Std software [3]
- 3D solid mesh based on hexahedral elements (C3D8) or tetrahedral (C3D10) with elastic plastic material constitutive model
- Fatigue Life obtained by Continuum Damage Mechanics (CDM) approach implemented through Abaqus Material User Subroutine (UMAT).
- Reference computational time per case in the order of minutes (for stress analysis) or hours (for CDM fatigue cracking computation).

The M&S capabilities of INFERNAL has been extended to include:

- Compatibility with metallic and composite materials
- Realistic riveting features like interference, tightening torque and countersunk
- Mechanical + Thermal loading

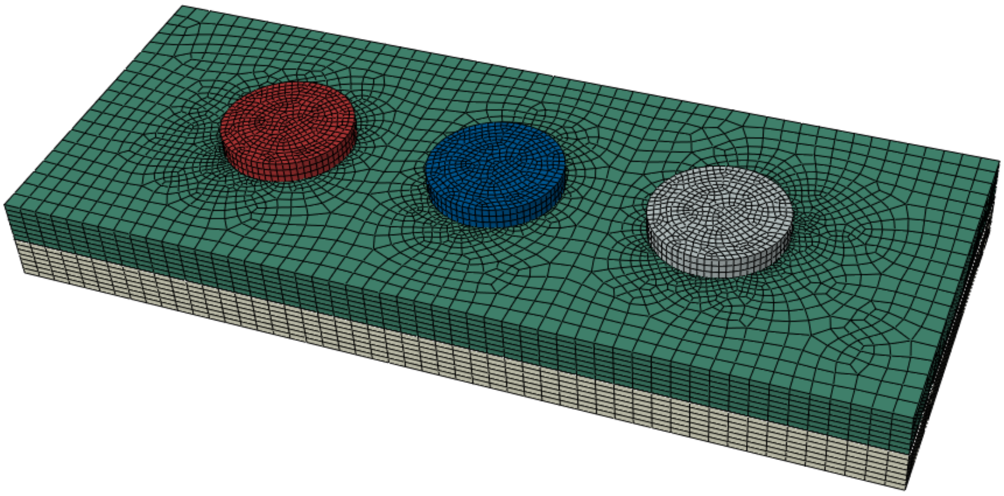

Figure 1 – Example of 3D high fidelity riveted joint modelling

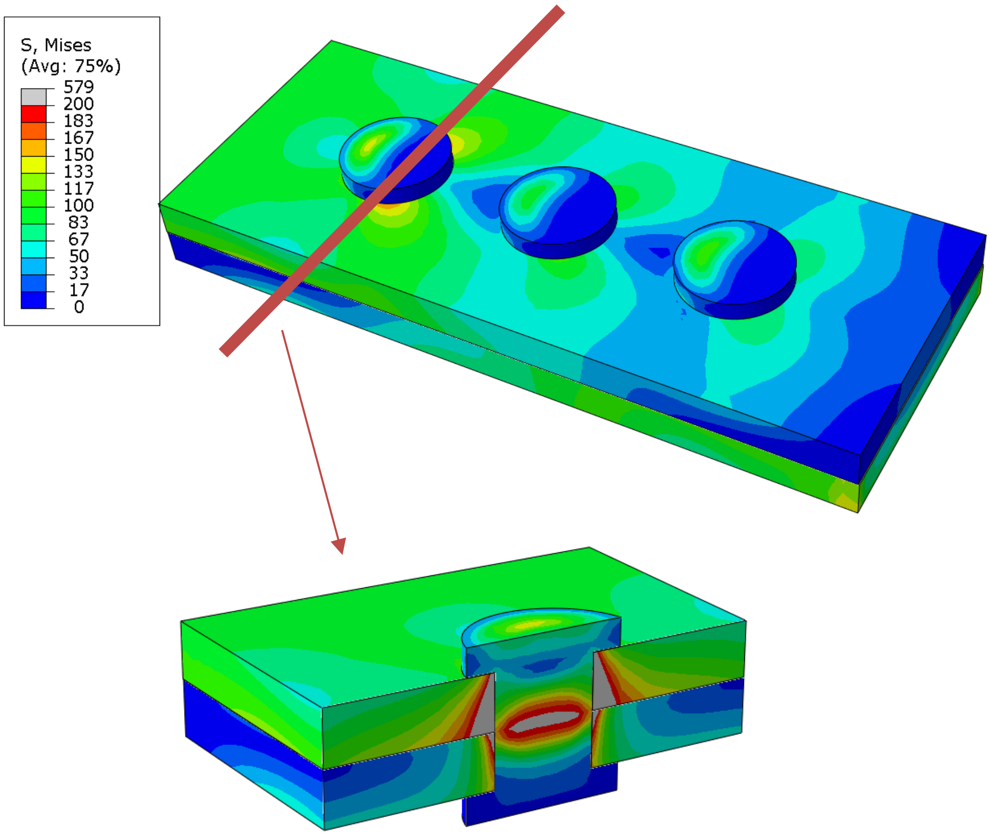

Figure 2 – Example of 3D high fidelity riveted joint simulation. Von Mises stress plot.

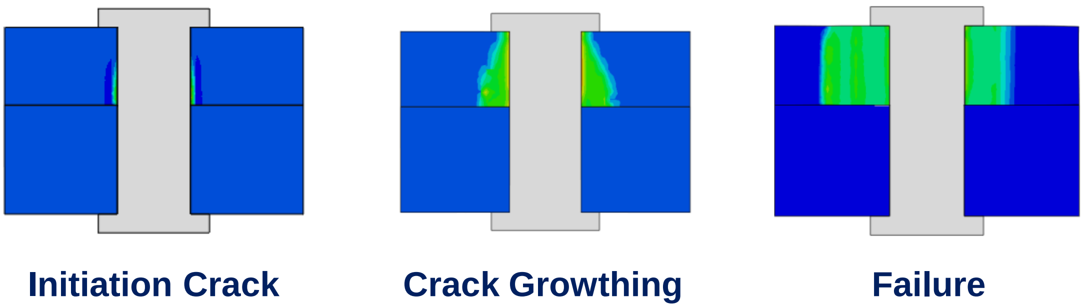

Figure 3 – Fatigue cracking prediction at riveting hole (Damage Plot)

3. Application Case Study

For demonstration of the capabilities for the Modelling & Simulation approach implemented in INFERNAL two case studies are shown. The first one is focused on determining by simulation the effect of interference level in the fatigue life of a riveted joint and the second one is focused on the effect of hole countersunk.

3.1 Effect of Interference Fit

The effect of interference fit over fatigue life will be assessed using a simple coupon configuration. This coupon consists of a single riveted hole in which axial load is cyclically applied at the end of one of the plates and reacted at the end of the other plate.

The coupon is modelled as shown in the figure below:

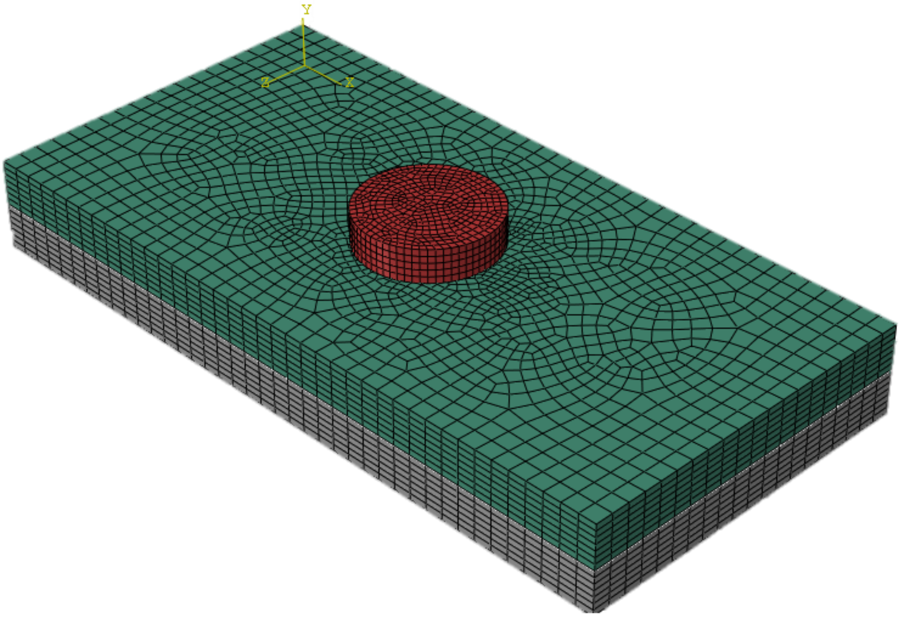

Figure 4 – Interference Coupon Model

The FEM simulation of the coupon is run for different interference levels covering low and high interference. The effect of interference level over the stress at the hole is shown in the figure below.

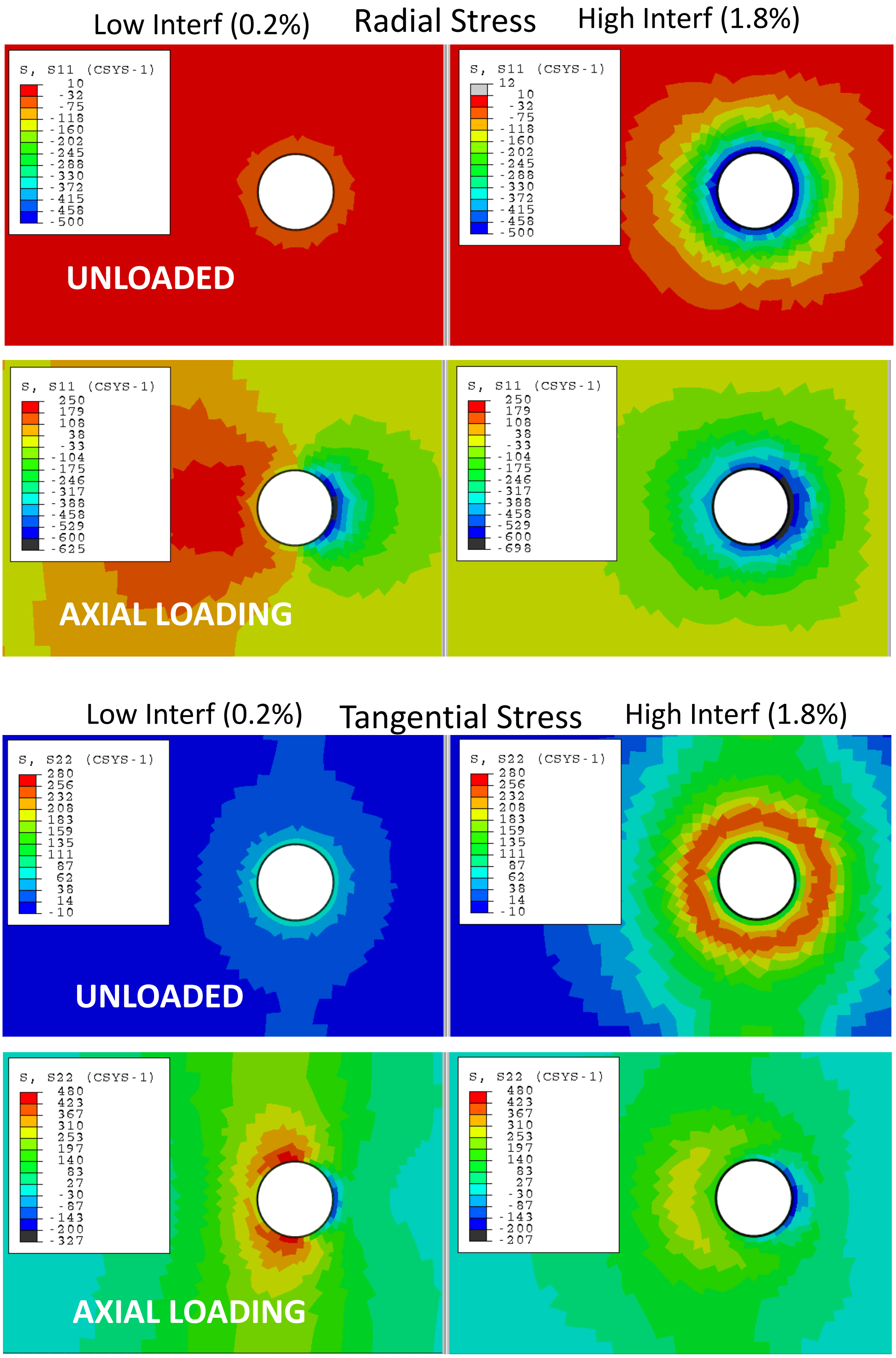

Figure 5 – Influence of interference fit over stress levels at hole

The evolution of the stress levels at the hole with the application of cyclic loading is shown in the figure below. The stiffness degradation due to the evolution of damage can be observed until final failure due to crack nucleation. It must be observed that simulation time in the X-axis does not correspond to each applied load cycle as cycle jumping scheme is applied to speed up the simulation.

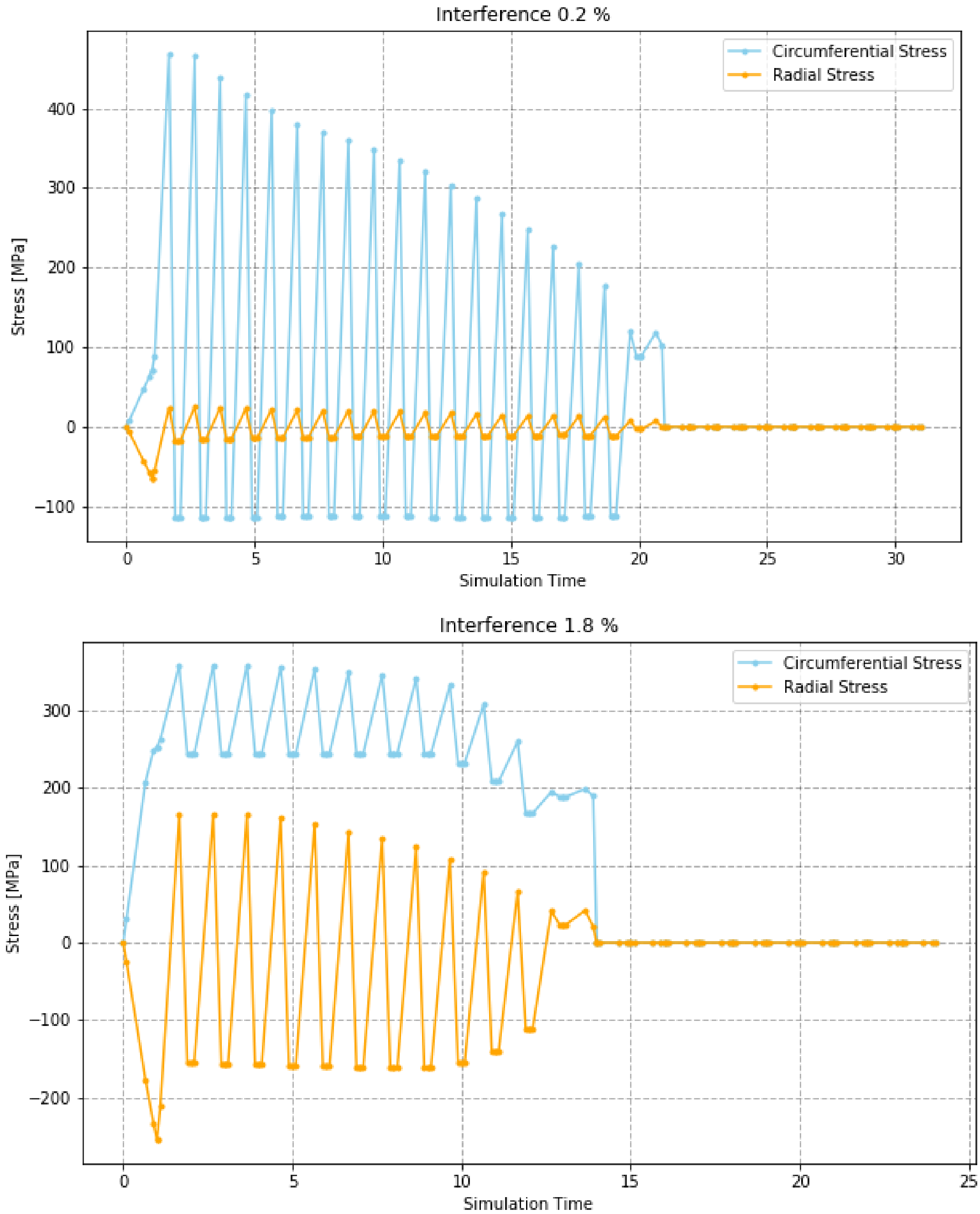

Figure 6 – Evolution of stress levels at crack nucleation sites with cyclic loading application

From the Continuum Damage Mechanics (CDM) simulation of the coupons, the influence of the interference level over the fatigue cracking at hole is obtained.

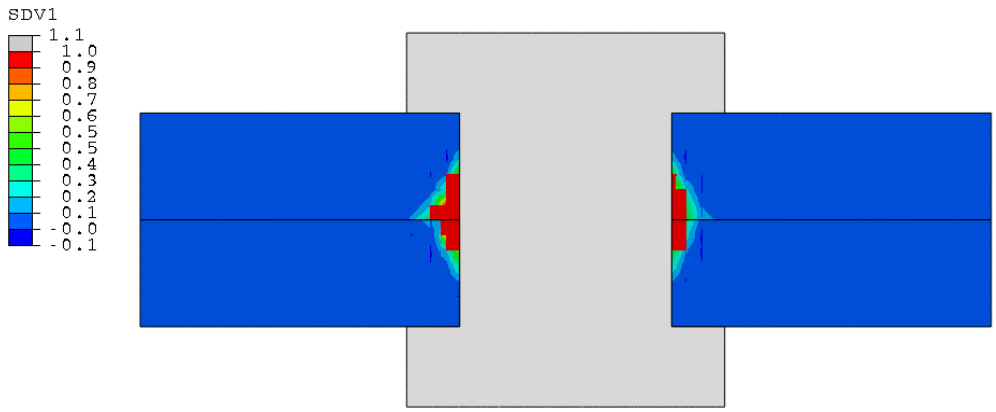

Figure 7 – Simulation of fatigue cracking at critical hole (damage variable plot)

The Fatigue Life Improvement Factor is summarized in the figure below.

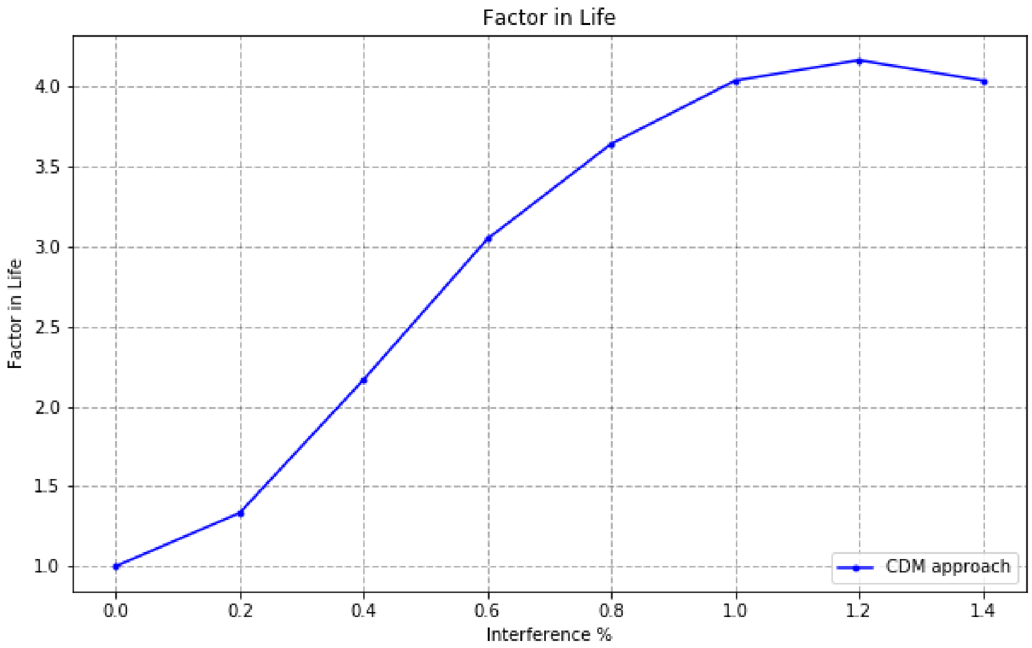

Figure 8 – Fatigue Life Improvement Factor due to interference fit

3.2 Effect of Countersunk

The effect of hole countersunk over fatigue life will be assessed using a single shear riveted coupon configuration. This coupon consists of 5 riveted holes, with countersunk in one of the sides, in which axial load is cyclically applied at the end of one of the plates and reacted at the end of the other plate.

The coupon is modelled as shown in the figure below:

Figure 9 – Countersunk Coupon Model

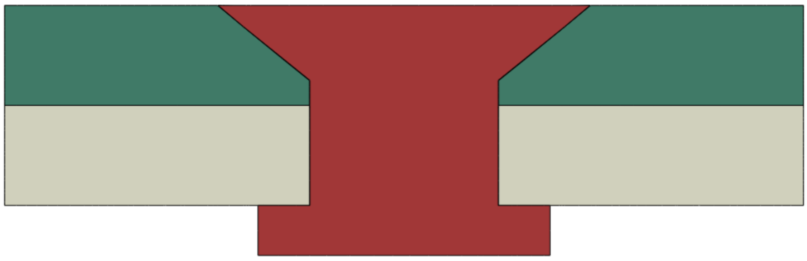

Figure 10 – Countersunk rivet detailed view

The FEM simulation of the coupon is run for different countersunk depths. One coupon without countersunk is also run to obtain the reference fatigue life for no countersunk.

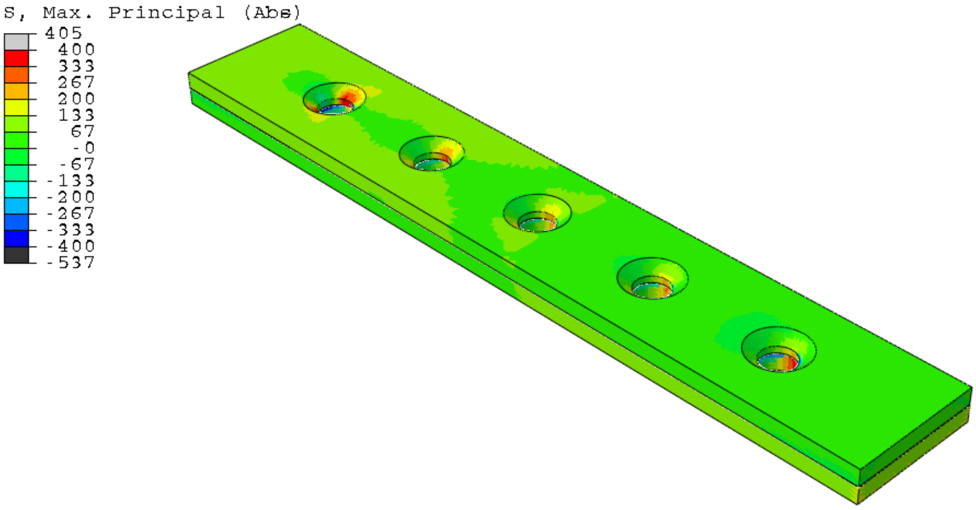

Figure 11 – Stress levels at countersunk coupon

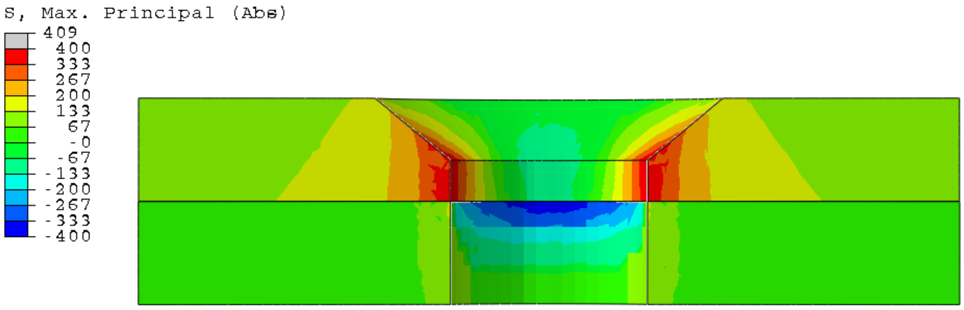

Figure 12 – Stress levels at critical hole section

From the Continuum Damage Mechanics (CDM) simulation of the coupons, the influence of the countersunk depth over the fatigue cracking at hole is obtained.

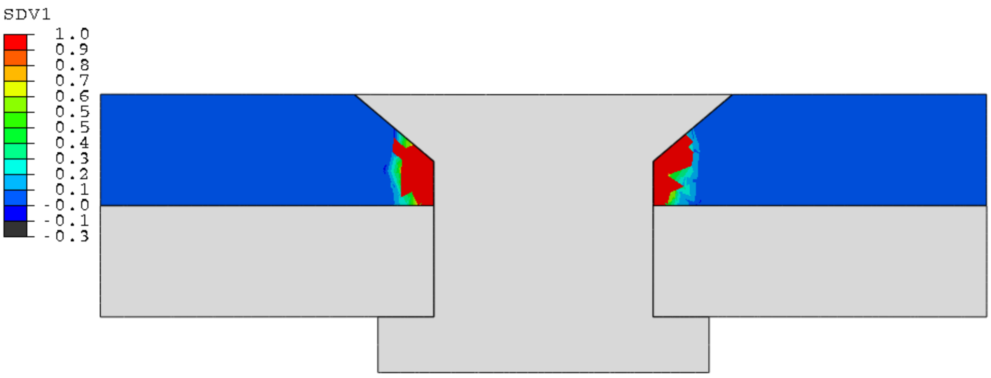

Figure 13 – Simulation of fatigue cracking at countersunk hole (damage variable plot)

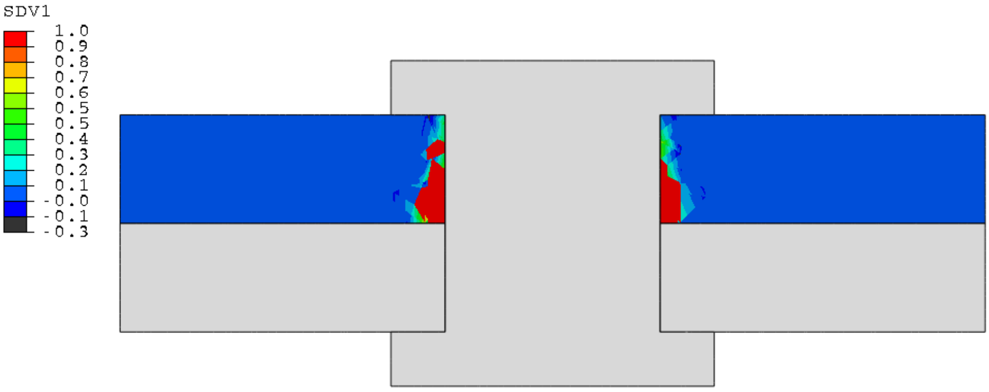

Figure 14 – Simulation of fatigue cracking at cylindrical hole (damage variable plot)

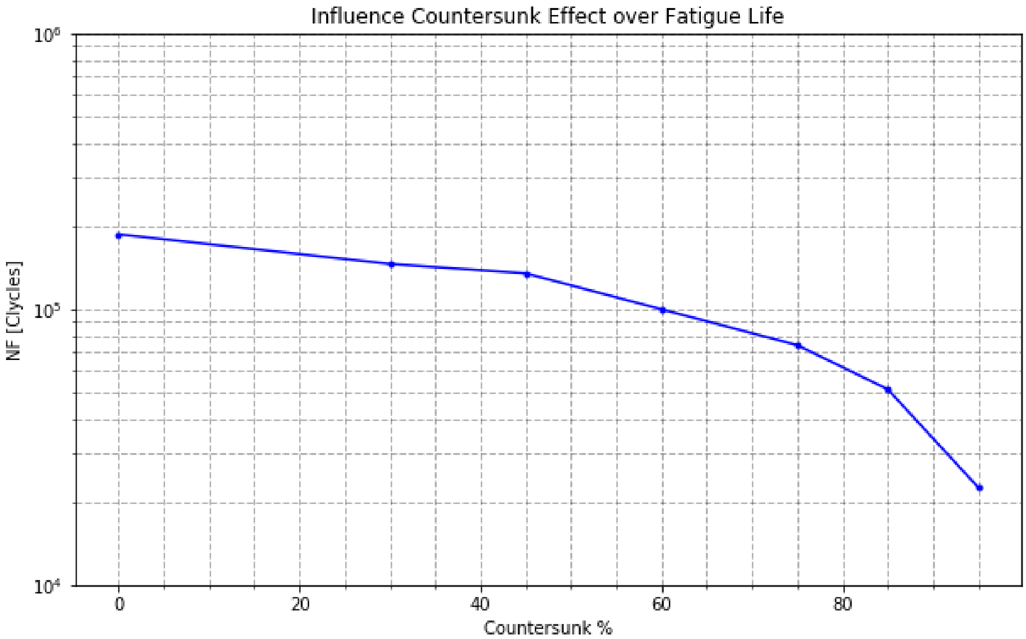

Figure 15 – Influence of countersunk depth over fatigue life

4. Verification and Validation

Verification and Validation (V&V) is key to ensure simulation credibility. This process includes the verification of the code (FE solver, user subroutines, machine learning algorithms…), modelling principles aligned with industry best-practices (geometric simplification, meshing, contacts, materials…) and checking of solution accuracy and robustness against reference validation data.

For INFERNAL software, extensive V&V process is being carried out in order to integrate this software into the current F&DT substantiation workflow for Military Aircraft Programs in Airbus.

5. Conclusions

Democratization of high-fidelity simulations for aircraft structural behavior modelling is one of the key pillars for the deployment of advanced predictive capabilities into the aircraft lifecycle. To achieve this deployment, the generation, analysis and post-processing workflows for these simulations must be integrated and automatized into a new generation of structural analysis software tools.

This democratization principle has been applied to the use case of riveted joints by creating a new software, INFERNAL, able to generate high-fidelity models of these joints including the complexity and design features that exists in the real aircraft structures.

This framework will be extended to additional airframe design details and configurations to expand agile predictive capabilities for aircraft structure design and development.

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