Visitor Research Report

Visitor Name: **Mr. Victor Feret**
McGill University, Canada

Area of Research: **Damage Mapping of Fatigued Skin-Stringer Debond Specimens in Three Dimensions**

Period of Visit: **March 3, 2008 – May 30, 2008**

Goal:
This goal of this research was to characterize and explain the three dimensional fatigue damage observed in two skin-stringer debond specimens subjected to distinct fatigue cycles.

Understanding how fatigue damage propagates across a skin-stringer configuration will provide necessary guidance in order to later build an accurate finite element model using the Virtual Crack Closure Technique implemented in Abaqus® – a technique based on the principles of fracture mechanics that requires the delamination planes to be pre-defined.

Strategy:
In previous work[1] two fatigued skin-stringer specimens were dissected and micrographs of selected polished section edges were taken to reveal internal damage. This research builds on the micrographs to characterize the internal damage in three dimensions. As a first step, an appropriate scale was obtained by comparing the thickness of skin layers measured from the micrographs to both the nominal thickness and the actual thickness of these same layers. The actual thickness was obtained by measuring the total thickness of the skin and then dividing this value by the number of layers in the skin. A reference point common to all micrographs was then selected, which became the origin to all measurements. Relevant crack lengths were then extracted directly from the micrographs.

A three dimensional model of the two specimens was built in a finite element software (Abaqus). The micrographs present the state of internal damage at specific cross-sections in two dimensions. The data extracted from these micrographs was therefore introduced into the model, at the appropriate locations, as planar wires with no depth. The final damaged models were obtained by connecting matching planar wires, creating distinct surfaces. A conservative approach was used in creating the surface; planer wires were therefore connected linearly. The outlines of the resulting surfaces were then cross-checked with those obtained using dye penetrant X-ray radiography[1].

[1] I. Paris, M. Cvitkovich and R. Krueger, *Characterization of Fatigue Damage for Bonded Composite Skin/Stringer Configurations*, NASA/TM-2008-215308

Accomplishments:

The entire internal damage sustained by two skin-stringer debond specimens was mapped in three dimensions. Both specimens, although subjected to distinct fatigue cycles and load levels, revealed similar damage patterns and identical damage propagation mechanisms. The damage mechanism initiated in most part by a 45 degree crack at the tip of the bond line between the skin and stringer flange, which then propagated through the bond line to create the first of two delaminations. Damage at the outer edges was identical at diagonally opposite corners of the stringer flange and was dominated by the presence of a single delamination. Damage was most complex in the center of the specimens where delaminations were observed to grow along two distinct planes. Results further revealed an almost systematic transition between the two delaminations, stemmed by a series of 45 degree transverse matrix cracks, occurring between the fibers in the top skin ply. The second delamination originated from this transverse crack and propagated in both directions along the length of the specimen.

The damage observed in these specimens is identical to the damage observed in full scale stiffened panels that are used in the design of composite aircraft fuselages. These panels are traditionally manufactured by bonding the stringers onto a thin skin, and the entire assembly is then co-cured. It is therefore imperative to validate the integrity of the bond line. The results of this research indicate that the dominant damage is a delamination that occurs between the top two skin layers, and not in the bond line. A graphic representation of this is shown in Figure 1, were the surface area of the delamination running between the top two skin layers (red) is much larger than that of the delamination running through the bond line (blue).

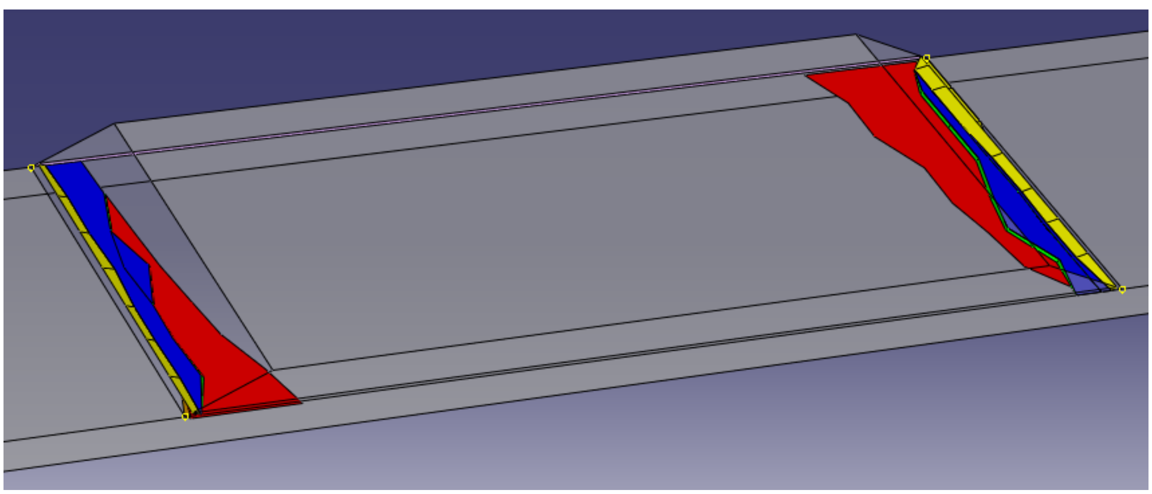

Figure 1: Isoperimetric view of a skin-stringer debond specimen revealing the internal damage. Yellow surfaces represent the damage initiation sites. Blue surfaces represent delaminations growing in the bond line. Red surfaces represent delaminations growing between the top two skin layers. Green surfaces are an artistic presentation of the transition between the two surfaces – the actual transition occurs through a series of transverse matrix cracks between fibers of the top skin layer.

Future Work:
A finite element model of the skin-stringer configuration, leveraging the Virtual Crack Closure Technique implemented in Abaqus®, will be built in the near future. This technique is based on the principles of fracture mechanics and requires the delamination planes to be pre-defined. Two delamination planes will be pre-defined in the finite element model, as per the results of this research. The goal of the future work will be to obtain a similar damage pattern computationally as was observed experimentally. If successful, this will be a giant leap forward towards decreasing the time and costs involved in designed primary composite aerospace structures, as more damage-prediction work will be performed with confidence through analysis methods.

Pending Publications:
A NASA contractor report will be published by the end of 2008, which will include the results of the future work.

Seminar Presented:
A 45 minutes technical seminar was presented on May 27th, 2008.