Development of a Composite Delamination Fatigue Life Prediction Methodology

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Abstract

Delamination is one of the most significant and unique failure modes in composite structures. Because of a lack of understanding of the consequences of delamination and the inability to predict delamination onset and growth, many composite parts are unnecessarily rejected upon inspection, both immediately after manufacture and while in service. NASA Langley is leading the efforts in the U.S. to develop a fatigue life prediction methodology for composite delamination using fracture mechanics. Research being performed to this end will be reviewed. Emphasis will be placed on the development of test standards for delamination characterization, incorporation of approaches for modeling delamination in commercial finite element codes, and efforts to mature the technology for use in design handbooks and certification documents.

1.0 Motivation, Goals and Approach

This program was originally proposed as part of the NASA Fundamental Aeronautics Program's Subsonic Rotary Wing Project in response to increased emphasis by the FAA on damage tolerance certification for composite rotorcraft structure. The requirements are described in FAA Advisory Circular (AC) 29-2C, Chapter 3 on Airworthiness Standards, Transport Category Rotorcraft, Miscellaneous Guidance (MG) 8, Amendment 29-35. However, because the results of this effort would have generic applicability to other classes of composite vehicles, it was decided to move this activity to the NASA Aviation Safety Program's Aircraft Aging and Durability (AAD) Project.

The overall goal of this activity is to improve the confidence in analytical tools available for predicting delamination onset and growth under cyclic loading to reduce the number of intermediate tests required in the building block approach used for composite design and certification (figure 1). The example shown addresses the issue of skin-stringer separation in post-buckled structure.

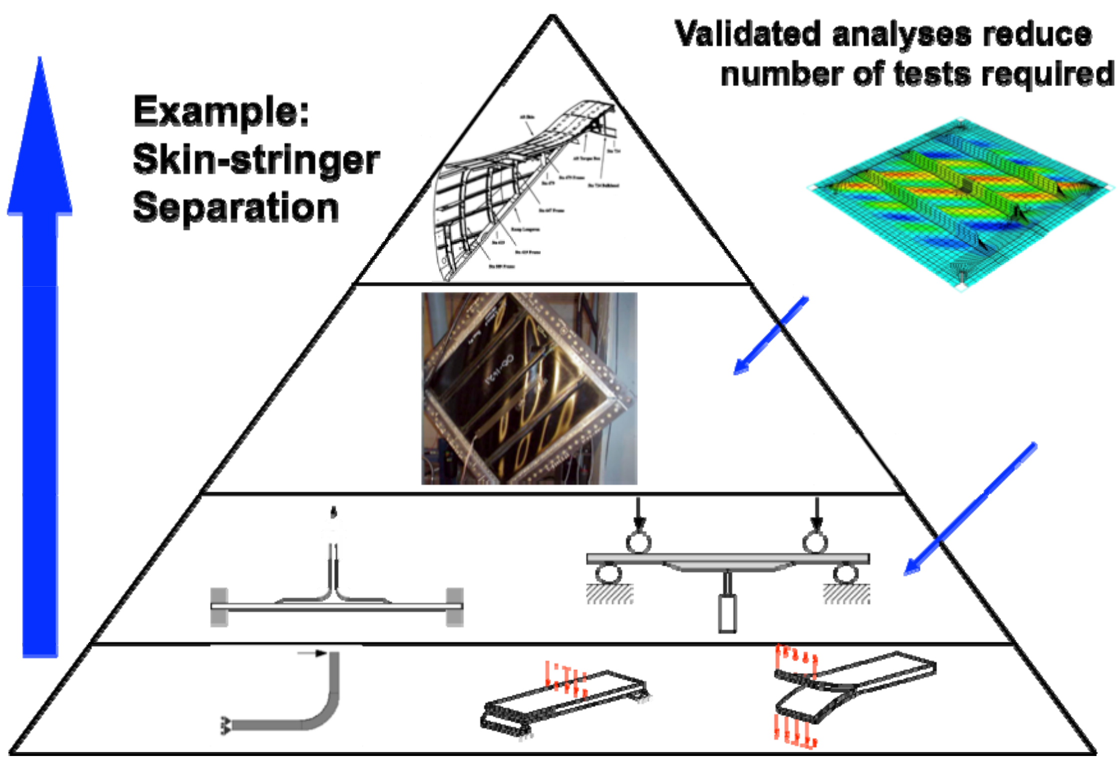

Figure 1: Building Block Approach for Composite Design and Certification

The specific program goals were to develop methodologies and validated analysis tools for fatigue life and residual strength prediction for (1) improved safety through certification by analysis (2) improved durability through reduced life cycle costs and (3) improved accept/reject criteria. The 5-Year Program deliverable is to incorporate the fatigue life prediction methodology into Composite Materials Handbook 17 (CMH-17).

The approach chosen to implement this project was to establish a collaborative research agreement between NASA and the U.S. rotorcraft companies through a NASA Space Act Agreement (SAA1-818) with the Center for Rotorcraft Innovation (CRI). CRI is a consortium of the four leading U.S. Rotorcraft companies. NASA Langley civil servants and in-house contractors will perform experimental characterization and analytical tool development and CRI will supply characterization test specimens and identify, design, and manufacture validation test articles for testing by NASA. Annual milestones were established and progress is reviewed through periodic meetings/telecoms during the 5-year period of performance. The project scope was initially reviewed at the Composite Materials Handbook 17 task group on delamination and debonding. External stakeholders will be invited to participate in selected telecoms and meetings during the course of the project.

2.0 Background

Delaminations typically form and grow in composite structures at geometric and material discontinuities such as free edges, ply drops (internal or external), and geometric details like skin/stiffener flange terminations (figure 2).

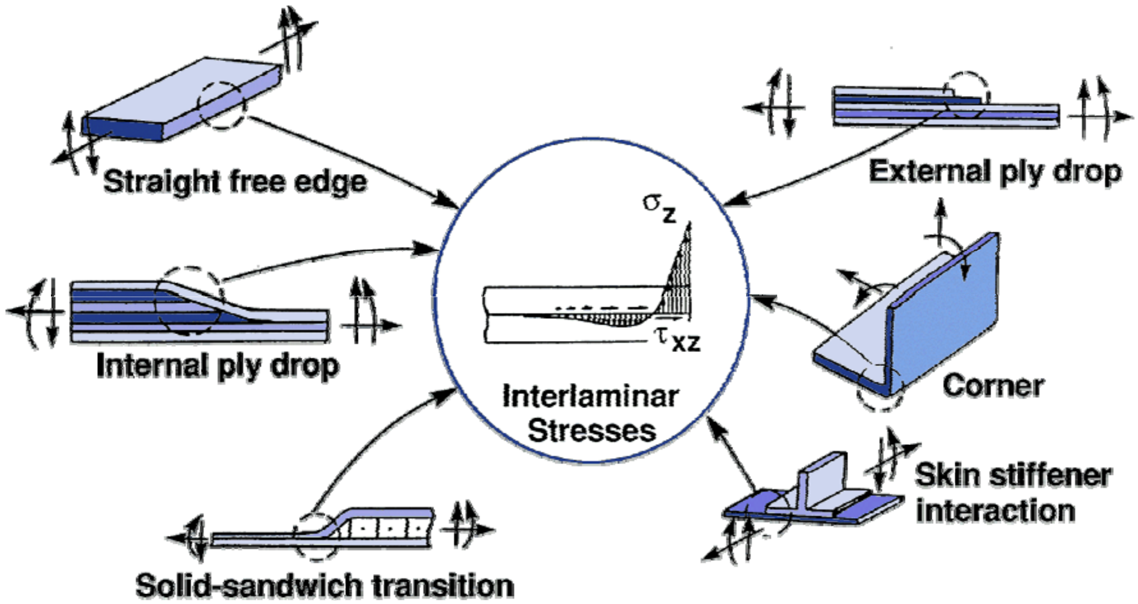

Figure 2: Delamination Sources at Geometric and Material Discontinuities

One of the most promising approaches to quantify delamination is through the use of fracture mechanics. Because delaminations are constrained to grow at the interface between composite plies, they typically are mixed-mode cracks involving some combination of crack opening (mode I), sliding shear (mode II) and scissoring shear (mode III). The strain energy release rate, G, associated with each mode must be determined analytically and summed to obtain the total G (figure 3).

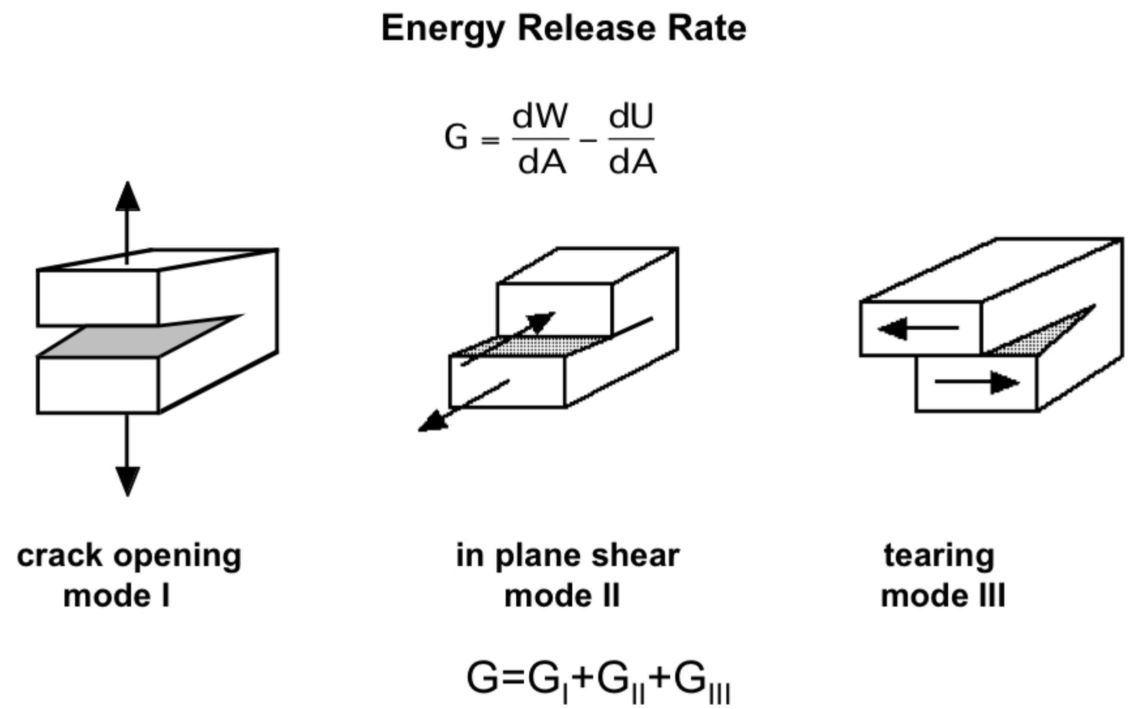

Figure 3: Fracture Mechanics Approach for Delamination

Delamination characterization is achieved by measuring the critical value of G in each mode and combinations thereof (figure 4). This characterization is performed for both monotonically increasing (static) loads as well as cyclic (fatigue) loads. The fatigue characterization is performed for both delamination onset and growth. A detailed description of the testing required to achieve this characterization is outlined in Volume I of Composite Materials Handbook 17 [1].

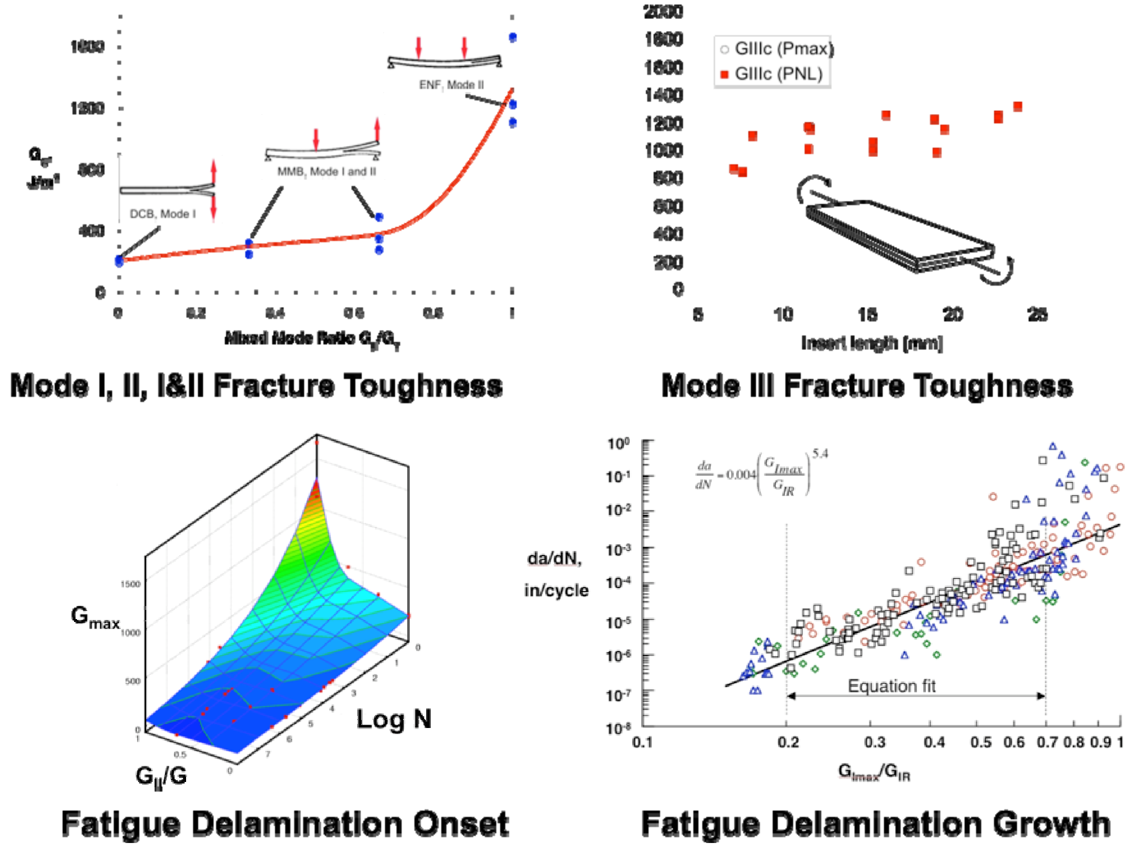

Figure 4: Delamination Characterization

3.0 Project implementation

For this project, a detailed test matrix was identified to characterize delamination onset and growth in IM7/8552 carbon-epoxy composites. The matrix includes 385 specimens made from two different CRI sources for all three fracture modes, mixed-mode I&II, static and cyclic onset and growth, and ambient as well as hot/wet environments.

Two analytical methods were chosen to calculate energy release rates: (1) the virtual crack closure technique (VCCT) [2-4] and (2) decohesion elements [5-7]. Both of these techniques have been, and are currently being, incorporated in several commercial finite element codes including ABAQUS, ANSYS and NASTRAN.

Benchmark problems have been, and are being, identified to help establish realistic input parameters required in these codes for numerical stability [8-9].

Several subcomponent validation articles are being designed, built, inspected, and tested to validate the delamination onset and growth predictions that will be made using these two approaches. The first sub-components will be tubes with various ply drops, creating gaps and overlaps, to simulate discontinuities in dynamic rotor components such as main rotor blade spars. These tubes will be subjected to cyclic torsion loads.

The second sub-components will be single and multiple stringer reinforced panels (figure 5) with either embedded flaws or barely visible low velocity impact to simulate delamination growth under cyclic loading from impact damage in structure such as a tilt-rotor wing. These stiffened panels will be subjected to cyclic compression loads.

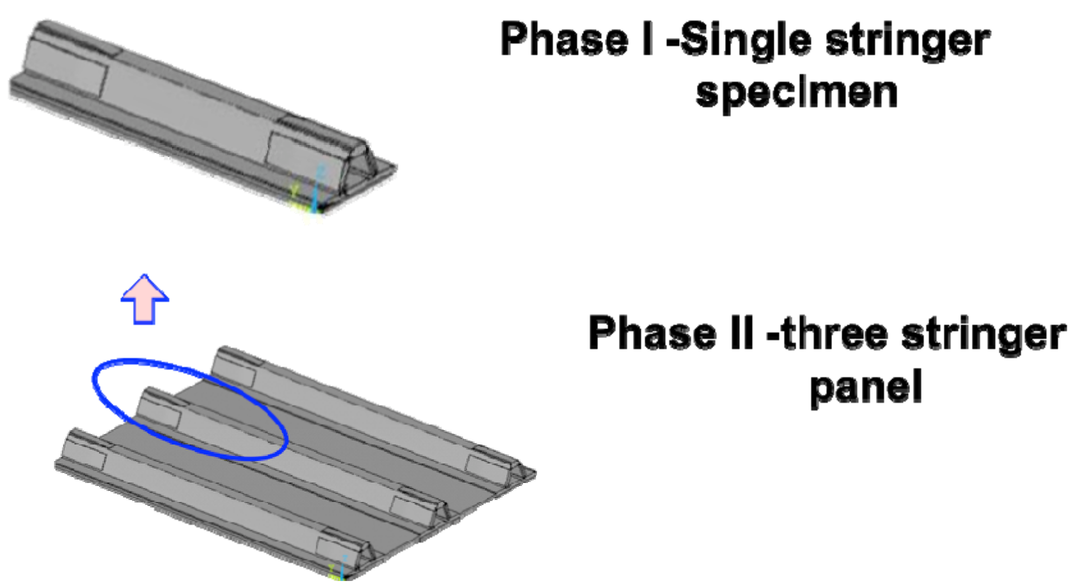

Figure 5: Stringer Reinforced Test Specimens

All subcomponents will be inspected in-situ using various non-destructive methods, such as thermography and ultrasonics, to document the onset and growth of delamination. Where necessary, test specimens may be removed for external inspection using ultrasonics and X-ray techniques.

4.0 Summary

NASA Langley Research Center is developing delamination fatigue life prediction methodology using fracture mechanics. The overall goal of these research activities is to improve confidence in analytical tools available for predicting delamination onset and growth. Several subcomponent validation articles are being designed, manufactured, inspected, and tested to validate these tools. Final results will be documented in NASA Technical Publications, and eventually, in peer-reviewed journal articles.

5.0 References

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