Helius:MCT™ Case Study: Achieving Composite Progressive Failure With Multiscale Analysis

The Challenge: Achieving Structure-Level Failure Analysis

Composite materials have proven to be an attractive option for structural designers. The advantages of constituent properties provide opportunities for weight reduction and design optimization. In the aerospace industry, such optimization can result in increased payload performance or reduced manufacturing and launch costs. This designer nature however also makes composite materials challenging to analyze. The inability to accurately and efficiently simulate load response and progressive failure at the structural level has driven design engineers to compensate for uncertainty, preventing optimization of design with composite materials.

To address this challenge, a joint program between the US Air force Research Laboratory, CSA Engineering and Firehole Technologies, Inc. set out to investigate and improve the ability of the aerospace industry to accurately model and simulate large composite structures. The program would provide definitive results by measuring failure analysis against rare structural-level failure testing.

The Solution: Multiscale Analysis of Large Composite Structure

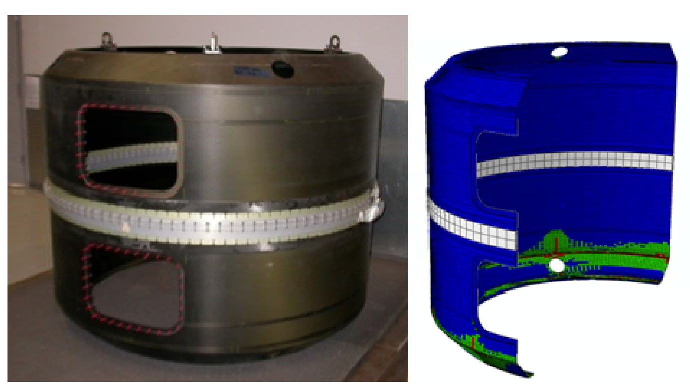
Composite material failure is a progression of non-continuous, discrete failure events occurring separately in the matrix and fiber constituents resulting in nonlinear behavior. Homogenous, linear-elastic methods employed by most traditional failure criterion mask this unique phenomenon. This approach results not only in inaccurate predictions, but often fails to converge on any solution at all.

Helius:MCT™
Enhanced Composites Simulation

To demonstrate the capabilities of Helius:MCT, Firehole Technologies performed the analysis on this program to compare with the experimental results. Helius:MCT is based on multicontinuum technology (MCT) which allows composite material simulations to accurately and efficiently include material behavior at the fiber and matrix level. **The inclusion of this multi-scale information enables Helius:MCT to correctly identify failure of individual material constituents and degrade the composite material accordingly.** Using Helius:MCT to enhance structural analysis software, it is possible to predict the evolution of localized matrix cracking and more accurately determine the point of failure.

Program Success: Progressive Failure Analysis Represents Real World

The program started with test and analysis of the Composite Adapter for Shared Payloads (CASPAR), a structure designed to carry multiple payloads aboard the Minotaur IV launch vehicle. Consisting of two symmetric, 74' diameter solid composite thick laminate cylinders, CASPAR is constructed from an industry standard carbon/epoxy pre-preg. A detailed model was created using 3D layered solid elements. Using Helius:MCT, a 122,000 element progressive failure model was run on a desktop computer.

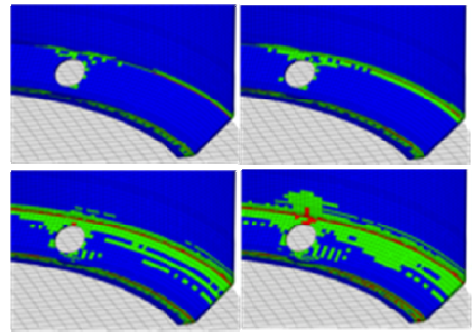


The Composite Adapter for Shared Payloads (CASPAR) and its simulation with Helius:MCT in Abaqus.

The CASPAR structure was successfully tested to failure, exhibiting highly nonlinear behavior. A significant level of localized matrix and fiber failures occurred prior to the ultimate failure of the structure.

Helius:MCT analytical and experimental results demonstrated excellent correlation; initial matrix cracking was predicted within 11%, gradual global softening of the structure was predicted with the increase of matrix failures, failure of the lower radius was predicted within 1%, and the ultimate failure of the structure was predicted with 15%.

% FLL	Experimental Failure Event	% FLL	Analytical Failure Event
234	Initial matrix cracking noise	260	Initial matrix failure
319-469	Occasional matrix cracking noise	261-480	Matrix failure progression
470 +	Continuous matrix cracking noise	500 +	Rapid matrix failure progression
658	Fiber failure noise	740	First fiber failure
792	Lower radius failure	800	Fiber failure in lower radius
847	Ultimate failure	980	Ultimate Failure



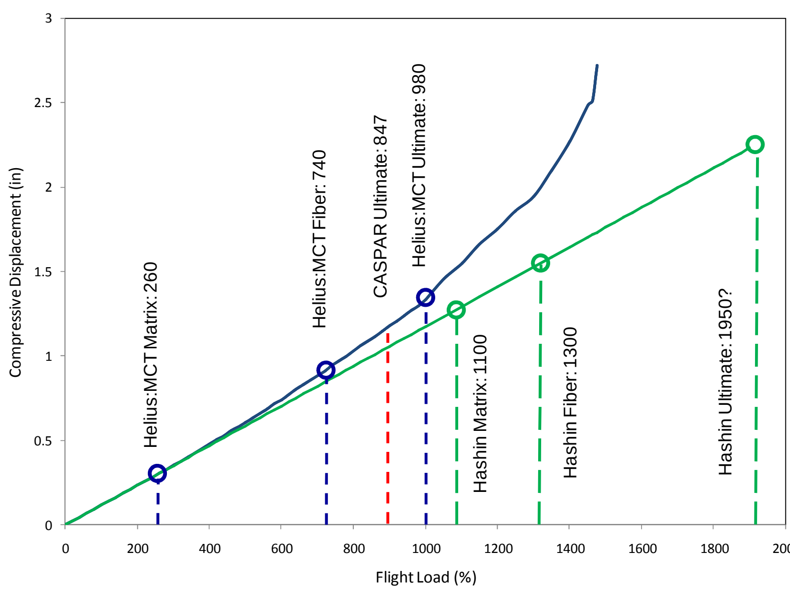
CASPAR failure progression….

Superior Results with Helius:MCT

As part of the effort to assess the existing capability of the industry, the Helius:MCT analysis was compared to the state of the art method available through commercial FEA packages. The Hashin method is distinguished from other traditional failure criterion in that it differentiates between fiber and matrix failure and between tensile and compressive modes. However, it was shown that its inability to capture the non-linear failure progression resulted in overestimation of matrix and fiber failures by 4x and 2x respectively. A linear response is predicted until the analysis failed to converge.

"The comparison to the Hashin and Tsai-Wu criterion and with experiments shows the Mayes and Hansen [MCT] criterion capable of the better estimates."

Ugo Icardi, 2007 in ASME's Applied Mechanics Reviews



Conclusion: Accurate Results are Achievable

The CASPAR structure survived a loading of more than 8 times the worst case load requirement. The cost of design uncertainty was excess conservatism and mass inefficiency. Through the CASPAR program, it was shown that accurate failure predictions can be realistically achieved for these large structures. Using only industry-standard data, Helius:MCT is able to efficiently provide valuable insight into the progressive failure of composite designs – eliminating a significant hurdle to optimization with composite materials.