Optimizing Airframe Design Requires Sophisticated Analysis

As aerospace fuel-efficiency demands become increasingly stringent, weight reduction is of paramount importance. Designers not only must optimize all aspects of the entire structure, they also need to manage extensive engineering data and resolve various manufacturability issues—especially where composites and hybrid laminates are concerned. Even with the most sophisticated CAD and FEA software, barriers to innovation still exist throughout the aerospace industry.

Engineers tasked with designing ever more efficient airframe wing boxes are confronted with a host of challenges, some of which can be solved with the right software.

This is due to significant limitations built into many of today's standard industry processes. For example, engineers have only a partial view of options and are forced to overdesign to be "safe" within the fast-paced design-cycle schedule, which adds unnecessary weight. Optimization tools are not as integrated as they should be, so engineers must perform this task manually. Finally, the iterative nature of the design process itself requires swapping critical data back and forth, often from multiple engineering groups.

Given the growing adoption of complex composites in wing box and other airframe structures—as in the Boeing 787, Airbus 350, and Bombardier Learjet 85 and CSeries—analysis is now a highly complex exercise involving layups in some areas that are nearly 100 plies thick. Some specialized CAD-based composite software packages offer partial solutions to these issues, featuring tools that can be used with FEA on the analysis side to provide a degree of efficiency and process integrity. They can simulate and graphically represent details—such as ply drape and rosette angle changes across a part's curved surface—and can pass cutting-pattern data directly to fabrication equipment on the factory floor. However, while useful on the manufacturing side, these tools do not explore composite structures with an integrated design and analysis method that provides the extensive trade-off studies and weight reduction calculations necessary to generate the best engineering concepts. Thorough, global optimization procedures that enable a faster design cycle are needed.

Fig. 1 – *Finite element model highlights load-carrying wing box structure (the section of the fuselage between wing roots) for a commercial aircraft. HyperSizer structural sizing and composite analysis software complements FEA in optimizing wing box and other airframe structure designs by reducing weight while maintaining structural strength and improving manufacturability.*

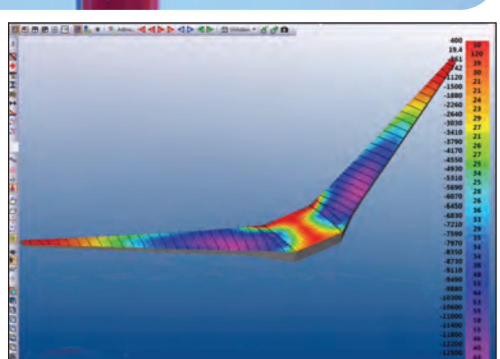

Fig. 2 – *A HyperSizer screen shot shows a FEA-computed axial running load for airframe stiffened panel skins, where purple indicates peak compressive force. HyperSizer iterates in an automated loop with FEA software to calculate the most lightweight and robust design options.*

Advanced software increases design exploration and options

One approach to addressing limitations in airframe design is a software program called HyperSizer, developed at NASA and Collier Research Corp., which offers design, analysis, and optimization tools for both composites and metals. Used on NASA's current Space Launch System heavy launch vehicle, and in higher volume by a variety of Tier 1 and 2 aircraft manufacturers, the software can be deployed from one end of the design process to the other. In this role, it serves as an independent and neutral hub for industry-accepted CAD, FEA, and composite software, automating data exchanges without loss of information or extra engineering effort.

Collier's HyperFEA tool allows HyperSizer to automatically iterate in a continuous loop with FEA solvers, searching for lightweight and structurally sound options and visualizing structural details to the ply level. HyperSizer also complements the various composite codes while performing actions such as defining laminate zones, determining sequencing and interleaving, and minimizing ply drops and adds—all of which improve manufacturability.

Standard industry practice relies on two types of finite element models in the design of metallic and composite wing boxes and their associated stringer/stiffener, spar, rib, and skin components, as seen in Fig. 1. The process generally begins with a smeared model in the preliminary design phase, during which all sizing variables are optimized concurrently. Having decided on stiffener location—and "frozen" tooling specifications—analysts can transition their 2D smeared models to 3D discrete stiffener models (DSMs). In this stage, engineering teams typically perform detailed structural analyses for all key panel-segment components. As design progresses, other cross-sectional dimensions are locked down as well. Laminate specifications are finalized, and margins of safety calculated, with failure analyses documented for all parts required for flight certification. These accepted practices could be further enhanced.

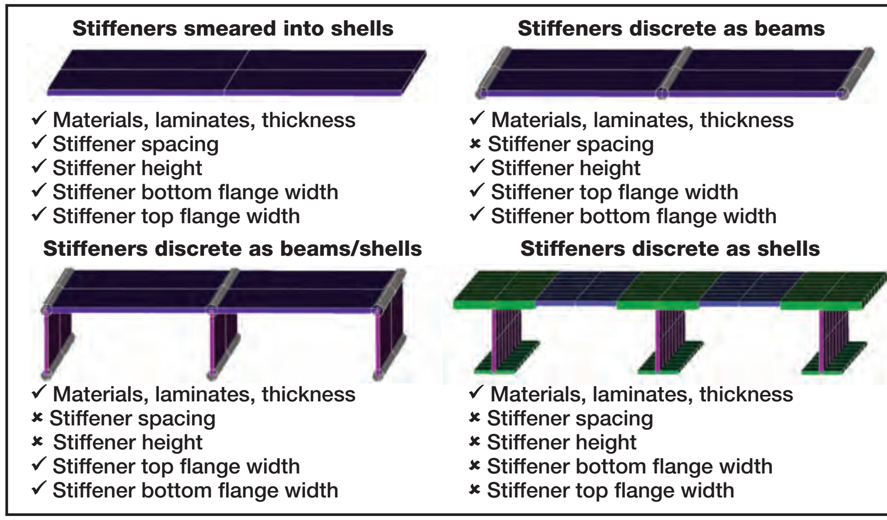

Fig. 3 – *During preliminary design, HyperSizer software can be used with a smeared model (top left) to conduct trade studies and optimize concurrently for all variables listed. Variables appear in order of significance and are checked if they can be optimized. HyperSizer can be used later in design with the three discrete stiffener models shown (top right and two bottom examples), although certain variables are "frozen" in each model (marked with an "x"), which reduces optimization flexibility. Using HyperSizer with both smeared and discrete model types is ideal, optimizing for different variables while moving from preliminary to final design.*

Exploring tradeoffs through optimization

By using the software during preliminary design, teams can explore more extensive conceptual space and perform tradeoff studies involving thousands of alternatives. This enables calculation of robust and minimal weights for each option, an approach that leads to the greatest overall weight savings and, more importantly, to multiple alternatives for considerations such as cost. The software also determines initial sizing based on fiber orientation and thickness and can handle tasks such as modeling a stiffened panel or accurately representing any panel shape or size, while extracting individual panel loads for each (Fig. 2). With the smeared model, the structure's stiffeners are represented using a single plane of shell elements, which helps to optimize stiffener spacing (Fig. 3, top left). By optimizing placement early in the design, engineers can eliminate the need to come back later and remake the model.

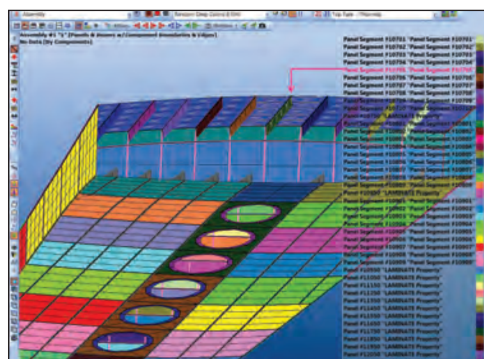

Fig. 4 – *A discrete model of a stiffened airframe panel design. Individual panel segments (varying colors) are automatically identified by HyperSizer and used for analysis.*

During structural analysis, the software provides additional workflow automation. All material, loading, and sizing data can be automatically transferred intact from the smeared to the discrete stiffener model. Once in the DSM, stringers are represented individually by beam or shell elements, or a combination of the two (Fig. 3, remaining models). Engineers can identify each stiffener as a separate panel segment, select failure analyses, and determine unique safety margins for each. With this added flexibility, panel bays with stringers of varying dimensions and materials can be created, and strength and weight benefits of non-uniform spacing and termination can be captured. Other advantages include interpreting how stringers and skins fit together to form a stiffened panel, calculating stiffener spacing and heights automatically, and mapping loads for crippling and buckling analyses (Fig. 4).

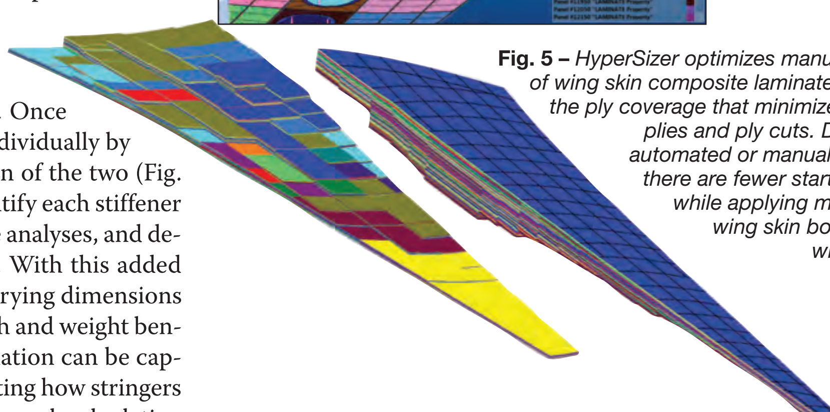

Fig. 5 – *HyperSizer optimizes manufacturability of wing skin composite laminates by finding the ply coverage that minimizes individual plies and ply cuts. During either automated or manual fabrication, there are fewer starts and stops while applying material. Left, wing skin bottom. Right, wing skin top.*

A six-step process included in the software generates effective laminates, defines laminate FEM zones, and performs ply-count compatibility. It also helps produce discrete laminates, create the most effective sequencing, and finalize layup specifications (Fig. 5). These steps ultimately lead to a reduction in ply drops and fabrication steps, such as fewer layer applications on the tool and fewer ply cuts. Airframe designers have decreased the weight of their structures by as much as 20% using the software.

As the commercial aircraft and aerospace industries continue to embrace composites and other advanced materials in search of lightweight structures, new challenges are on the horizon. Solutions will emerge from optimization modeling that can address every variable, identify substantial weight savings, and generate several alternative designs. Doing all of this seamlessly and without disrupting existing processes will help engineering teams achieve the best results possible. In an ideal airframe design process, wide-open design space exploration will lead to lightweight, structurally sound designs that are easily manufactured and certified to fly. ❒

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