Design Optimization Using HyperSizer™

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Abstract

This paper identifies an existing commercial solution that MSC users can benefit from for automated stress analysis and sizing. The HyperSizer™ software is mathematically coupled with MSC/NASTRAN to provide an integrated solution for quick and accurate design optimization. Though specifically developed for the aerospace industry, the approach and methods apply to any industry. A reusable launch vehicle, which contains 7 assemblies, 21 optimization groups, and 203 structural components is used as an example. MSC/NASTRAN is used as the loads model and the entire plane is optimized using HyperSizer's analysis methods that range from closed form, traditional hand calculations repeated every day in industry, to more advanced panel buckling algorithms. Margin-of-safety reporting for every possible failure provides the engineer with a powerful insight into the structural problem. The engineer is able to provide 'real-world' expertise in the optimization process by interacting with HyperSizer for *designs on the fly*.

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Introduction

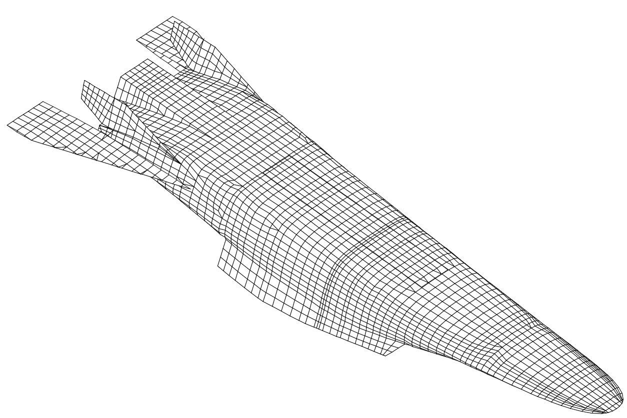
Aerospace vehicle internal load distributions are highly indeterminate and require FEA for solutions. This process is referred to in the aerospace industry as computing ‘running-loads’, publishing ‘internal loads’, or finding ‘load-paths.’ In essence, the integrated effects of flight surface pressures, temperatures, and accelerated inertia get reduced to force and moment components on panels and beams at all locations of the vehicle.

In order to automate the analysis and optimization of structures, the HyperSizer structural sizing software uses the FEA computed panel and beam forces and moments for checking the many different types of failures that may occur within a structure. Some of these potential failures can be effectively predicted with traditional, hand methods. However, other failures require more rigorous methods. In general, physics based solutions are preferred over empirical or special case methods.

HyperSizer is able to do discretely optimize in a manner, which guarantees structural integrity of the selected optimum design, using methods to accurately compute margins-of-safety for all potential failures. Optimization capabilities include finding minimum weight panel or beam concepts, material selections, cross sectional dimensions, thicknesses, and layups from a library of 40 different stiffened and sandwich designs and a database of composite, metallic, honeycomb, and foam materials.

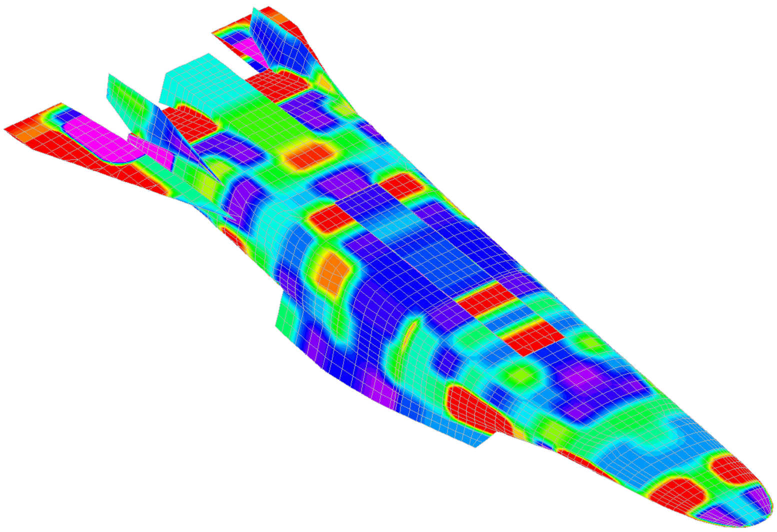
About the Model

The model represents a NASA designed two-stage-to-orbit aerospace plane requiring accurate analysis capabilities to account for a complex thermo-mechanical environment. The integrated airframe/engine design contains a large volume of pressurized cryogenic fuel. Internal bulkheads serve as shape control members to maintain the vehicle's shape. The aeroshell is designed to be graphite/epoxy, hat-shaped stiffened panels.



Though HyperSizer can analyze and optimize FEMs as large as one million DOFs, the choice was made to build a relatively small model of approximately 30,000 degree of freedoms (DOF) for the aerospace vehicle. This allows us to take advantage of HyperSizer's unique panel and beam stiffness formulations that achieve accuracy with coarsely meshed MSC/NASTRAN FEMs. More about this later.

How does HyperSizer Benefit the Aerospace Plane Design?



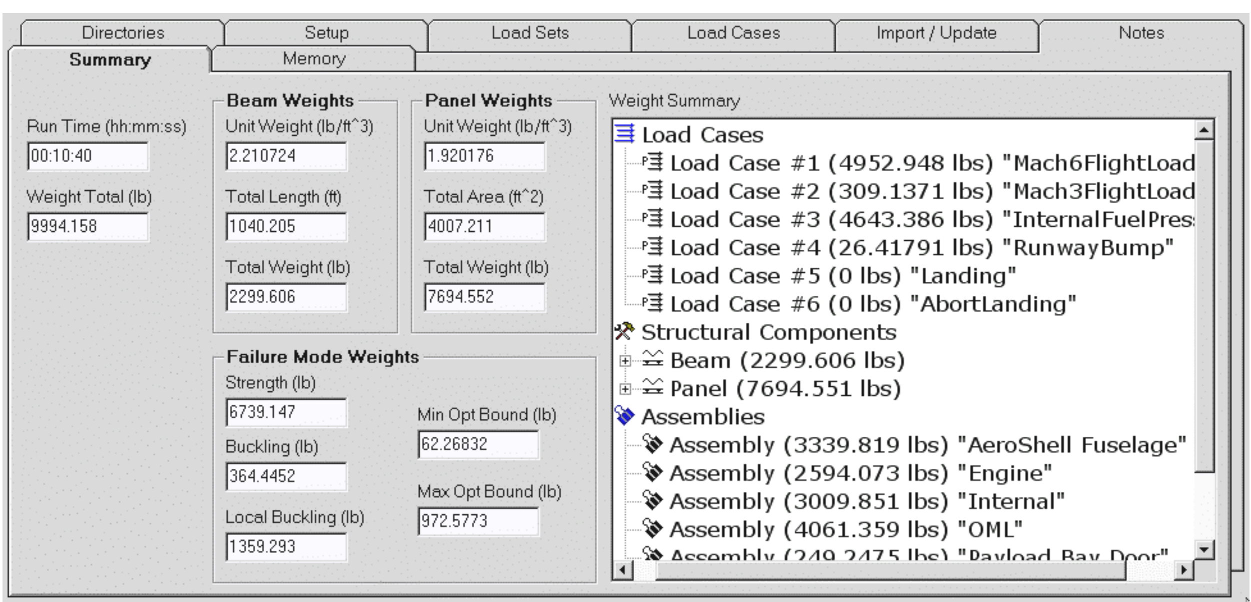
First, HyperSizer provides a complete and detailed analysis of the entire aircraft including concise margin-of-safety (MoS) summaries of all potential structural failure modes for all areas of the vehicle. This contour plot shows critical MoS of the aeroshell panels for all analyses performed. For instance, if local buckling of the facesheet has a lower MoS than panel buckling, then for that surface area, the MoS for local buckling is shown. This plot quickly indicates areas, which do not meet structural integrity requirements, or over-designed areas which can be made lighter.

This entire vehicle, containing 7 assemblies, 21 optimization groups, and 203 structural components, is analyzed on a Pentium Workstation in two minutes.

Second, HyperSizer optimizes all aspects of the aerospace plane structural design including: material selection (Gr/Ep vs. Al); panel and beam concepts (hat stiffened panel vs. honeycomb sandwich panel); and exact cross sectional dimensions (beam flange width of 1.24 vs 1.39).

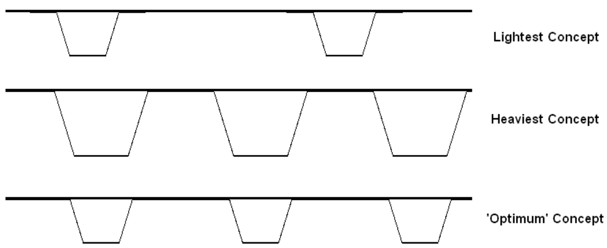
By optimizing all structural variables, HyperSizer will consistently reduce structural weight by 20% or more.

Third, HyperSizer produces accurate structural dry weight predictions as shown in the summary tab here. It is important to accurately quantify dry weight of competing concepts early in the design process. Revolutionary designs such as the Joint Strike Fighter and Reusable Launch Vehicle typically do not have historical weights available.

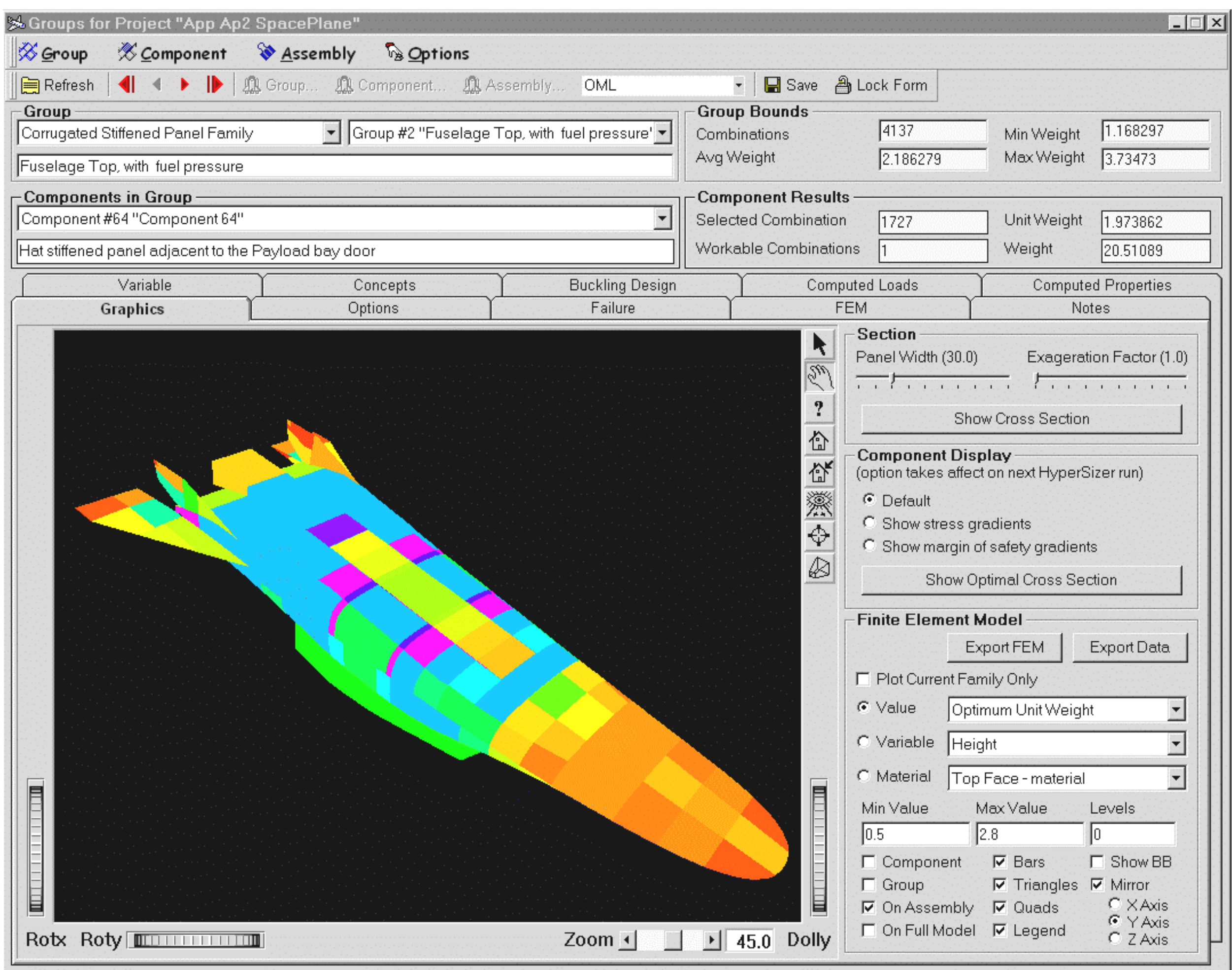


Interaction between the engineer and the software is key to HyperSizer's design process

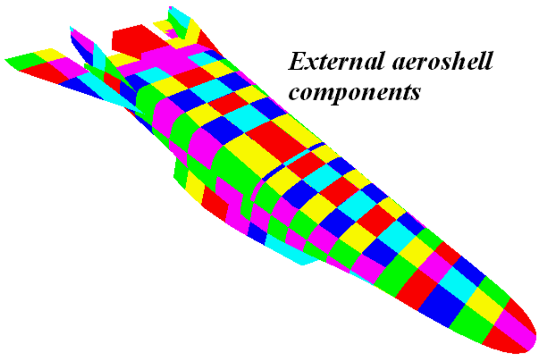
Engineers learn within seconds the strengths and weaknesses of their structural designs from the software's interactive reporting of margins-of-safety. Interactive 3-D graphics provide visual inspection of the structural component layout, assemblies, and drawn to scale optimum panel and beam cross sections. These features are used on the aerospace plane to quickly interpret and understand design flaws. Critical design issues were identified and resolved early in the design process, allowing ample time to perform many design trade studies. This quick and highly interactive process makes the task of saving weight easy and fun.

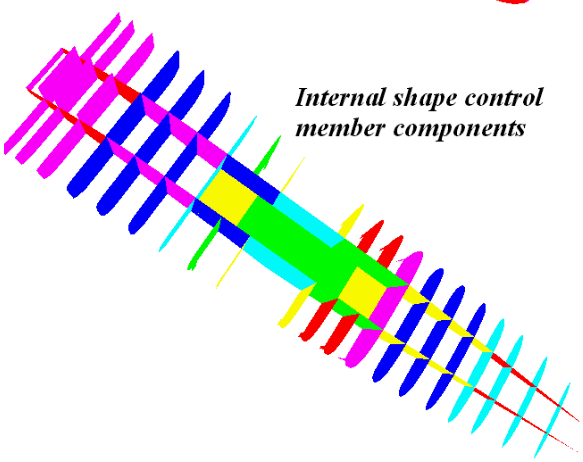


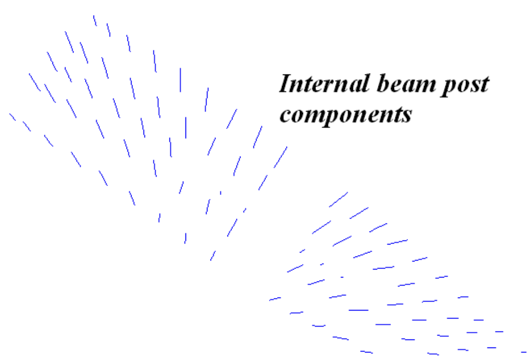
The figure below shows one of the interactive tools provided for display of HyperSizer computed data. Illustrated are the computed optimum panel unit weights on the assembly called 'OML'.



How is HyperSizer used to Analyze and Optimize the Aerospace Plane?





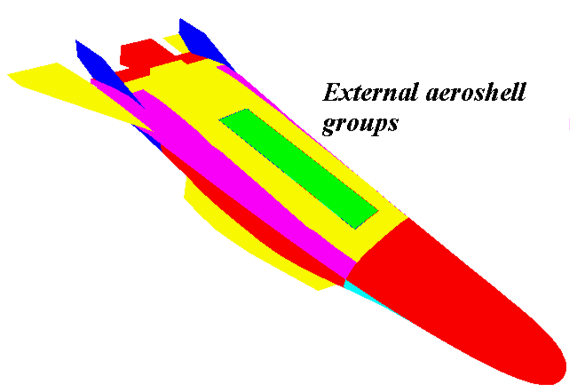


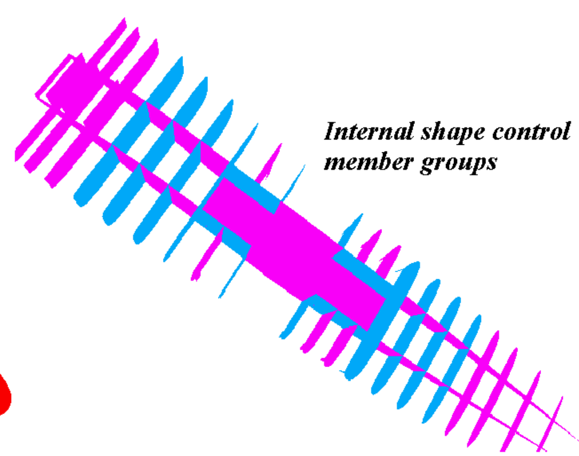
Define Structural Components

While in the FEM building process, modelers assign the same property data to a collection of elements. These collections of elements share the same PSHELL or PBAR record. HyperSizer uses these collections as structural components (***components***) for two primary purposes.

The first purpose is to identify the smallest, practical manufacturable piece of hardware that can be sized independently. The second purpose is to be able to efficiently analyze structure with widely varying load distributions. Statistical methods are used to resolve peak loadings across structural components, and, by so doing, solve the difficult 'pulling-loads' problem that occurs for any automatic analysis procedure. In this way, analyses and optimizations are performed for the structural components, not for the finite elements of the model. The figures to the right illustrate identified structural components of the aerospace vehicle for the external aeroshell, internal panel shape control members, and the internal beam posts.

The figures below represent ***groups*** comprised of any number of the components. Groups are used to assign optimization variables and bounds.



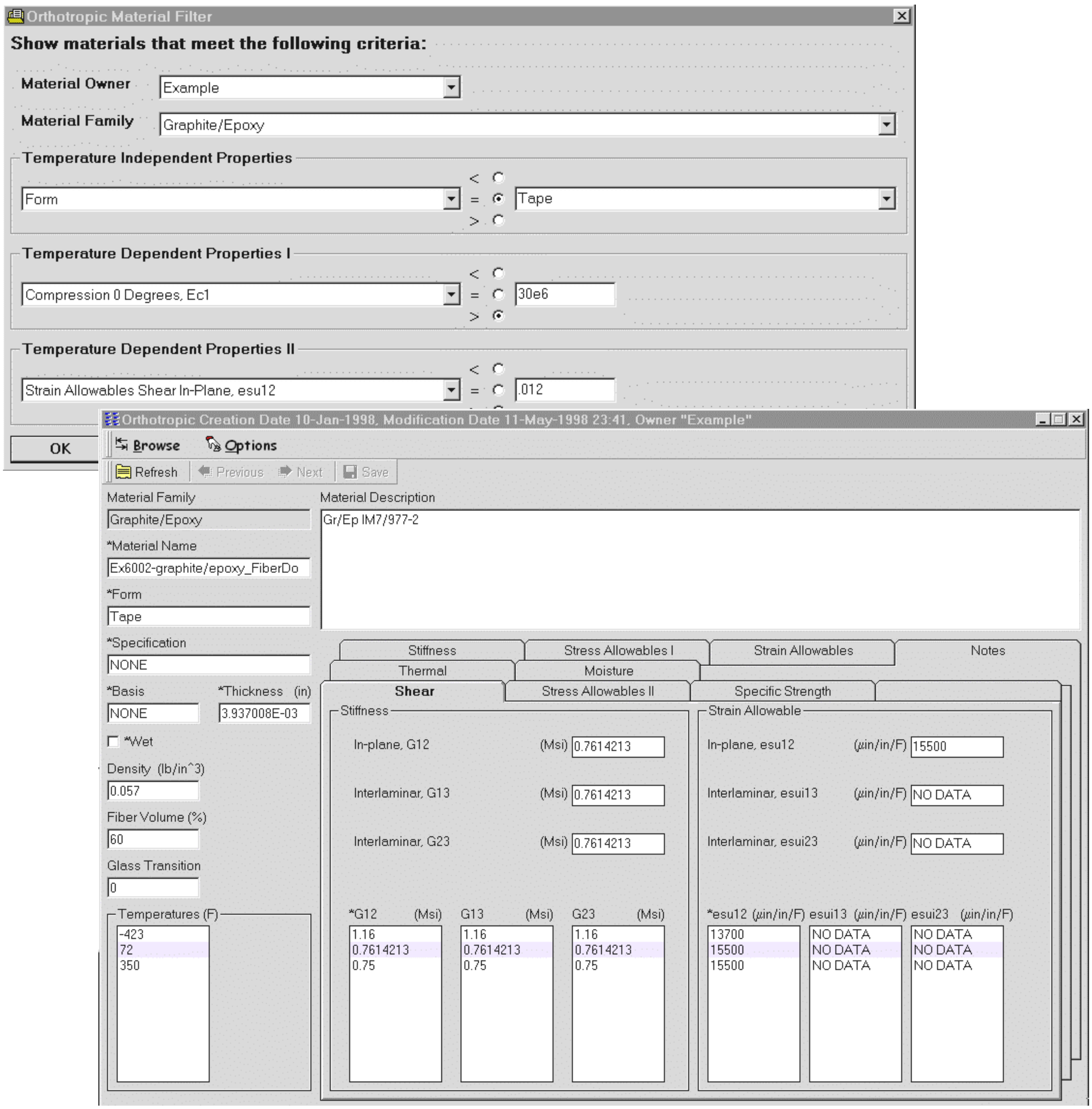


Identify materials, panel and beam concepts, dimension ranges and analysis methods

With an infinite number of possible combinations, HyperSizer was able to make the optimization and analysis manageable by:

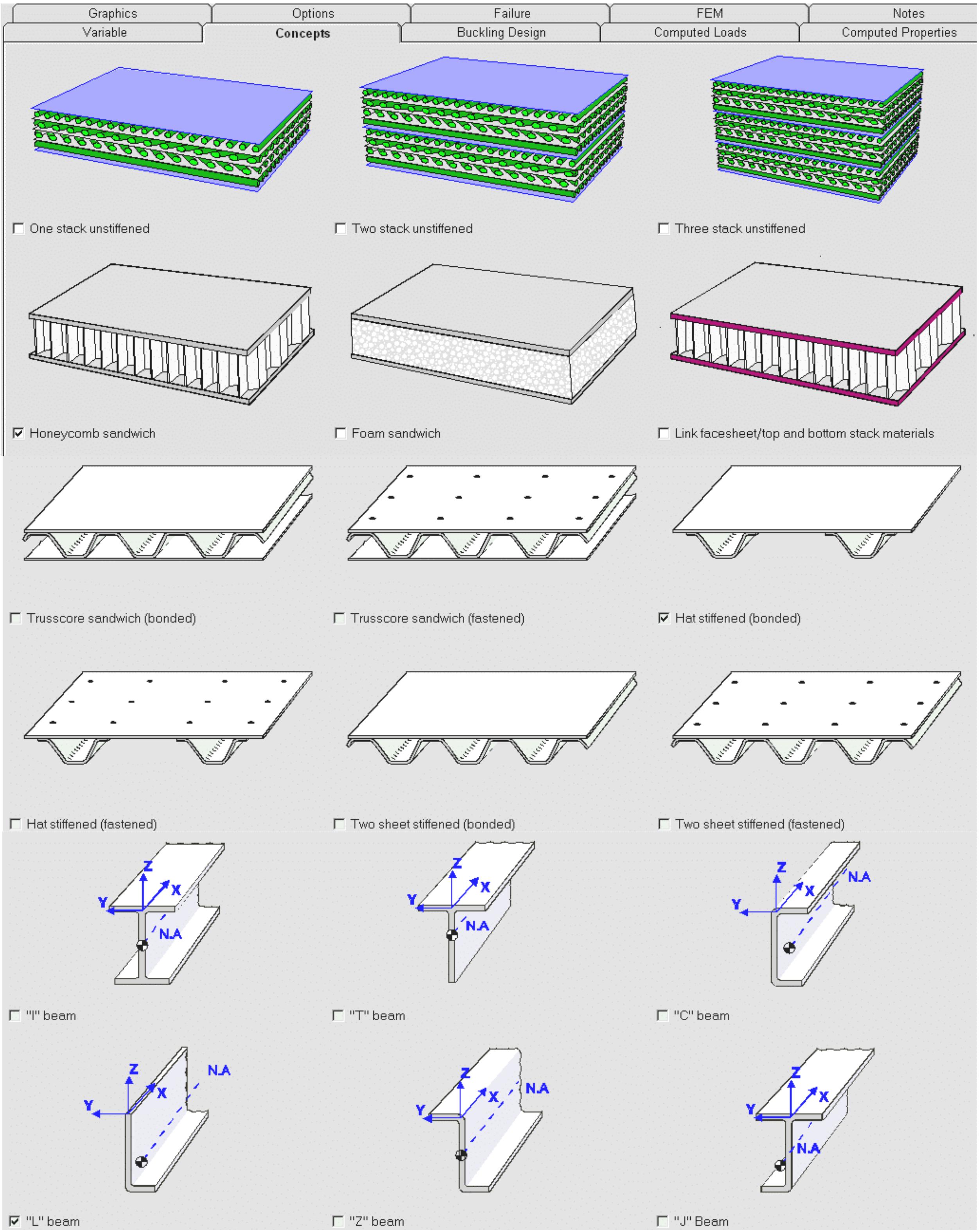
Filtering materials

HyperSizer's integrated database search engine containing metallic, composite, honeycomb and foam materials is used to filter a reduced set of materials.

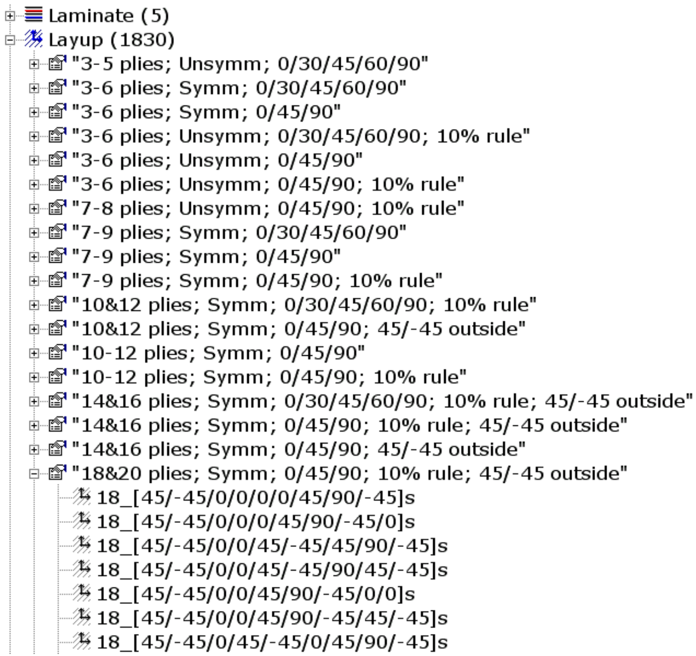


Selecting design concepts

Over 40 unique panel and beam concepts are provided such as hat and Z stiffened panels, honeycomb sandwiches, and I section beams. Fastened, bonded, and integrally machined fabrication details are included. Users simply select one or more concepts for their design.



Optimizing composite layups



A library of over 1800 industry preferred layups makes composite optimization a snap. Layups are arranged into families based on best design practice guidelines and are displayed by a tree browser.

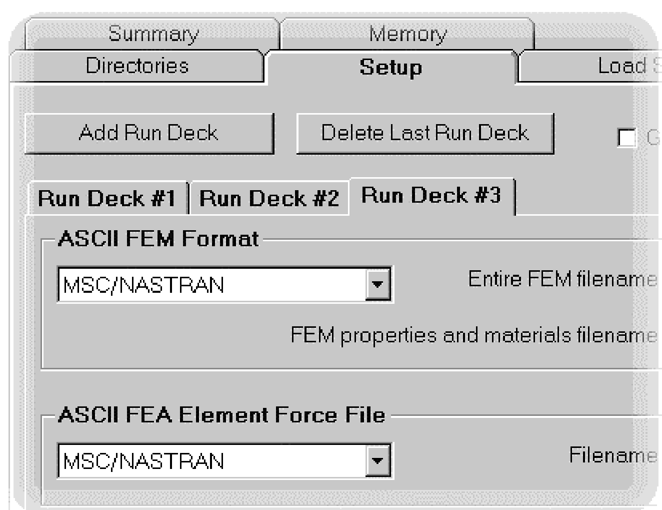
Selecting analysis methods

HyperSizer includes over 100 potential failure modes that are interactively enabled or disabled for ultimate and limit loads.

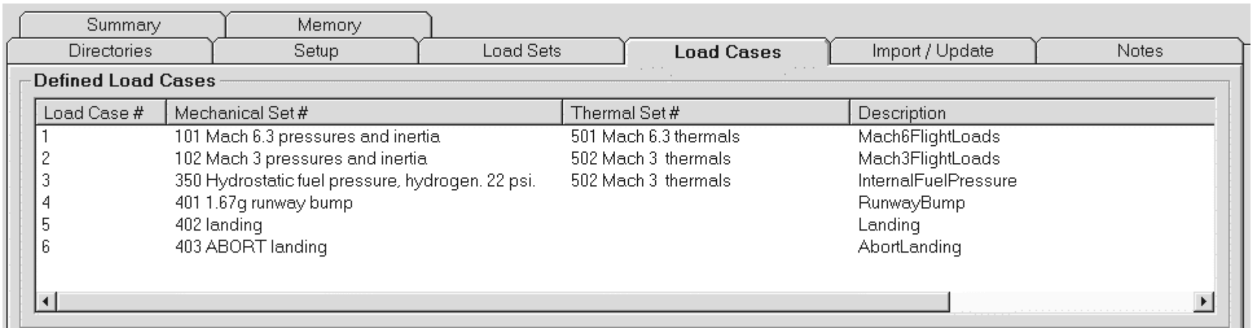
Setup Load Conditions

HyperSizer couples tightly with MSC/NASTRAN to obtain 'design-to' running loads for the aerospace plane.

Very accurate equivalent plate generalized stiffness terms are generated for the composite stiffened panels using exact cross sectional dimensions. Composite layups, temperature dependent properties, thermal gradients and the complex unsymmetric nature of panels leading to membrane-membrane coupling are accurately represented. Tight coupling with MSC/NASTRAN allows finite element properties and materials (PSHELL, PBAR, MAT2, MAT1) to be automatically generated and included in the FEA to obtain correct and consistent running loads.

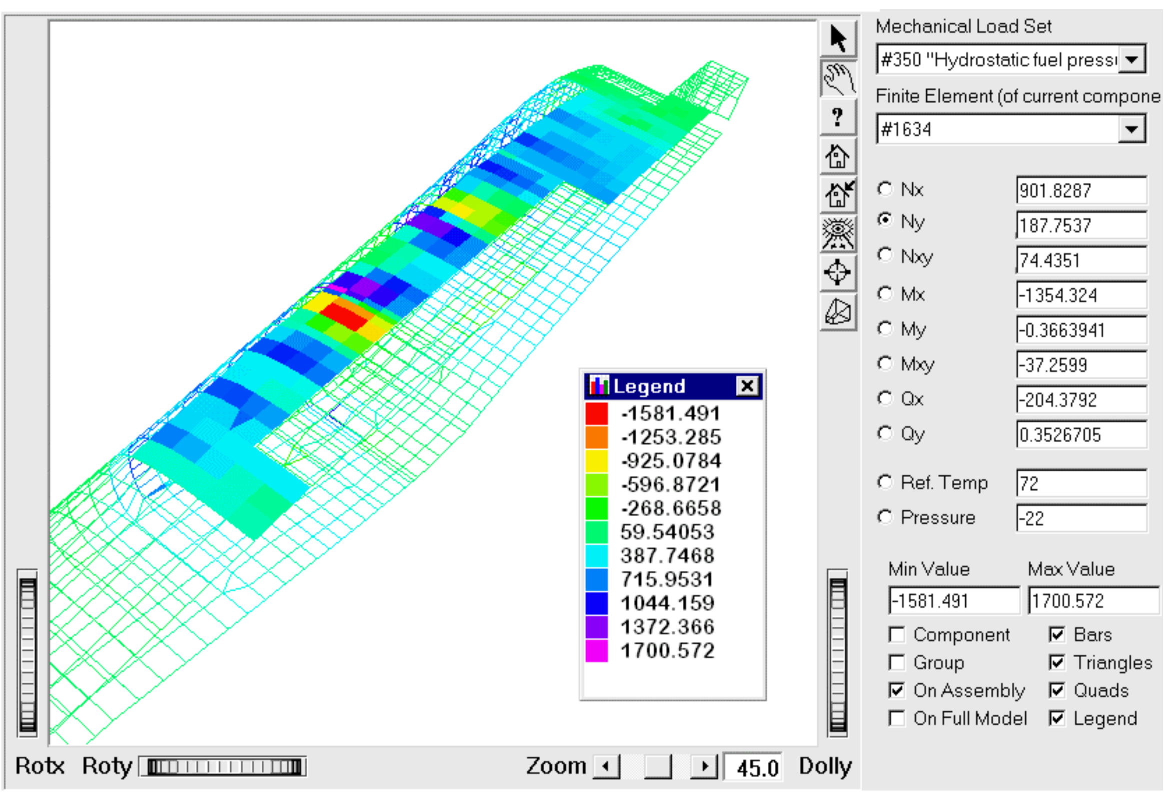


The vehicle was analyzed and optimized to three distinct thermal environments: Mach 6 flight, Mach 3 flight, and takeoff/landing. In addition, six loading conditions were considered including aerodynamic pressure, thermal, landing and runway bump loads.



Load Case #	Mechanical Set #	Thermal Set #	Description
1	101 Mach 6.3 pressures and inertia	501 Mach 6.3 thermals	Mach6FlightLoads
2	102 Mach 3 pressures and inertia	502 Mach 3 thermals	Mach3FlightLoads
3	350 Hydrostatic fuel pressure, hydrogen. 22 psi.	502 Mach 3 thermals	InternalFuelPressure
4	401 1.67g runway bump		RunwayBump
5	402 landing		Landing
6	403 ABORT landing		AbortLanding

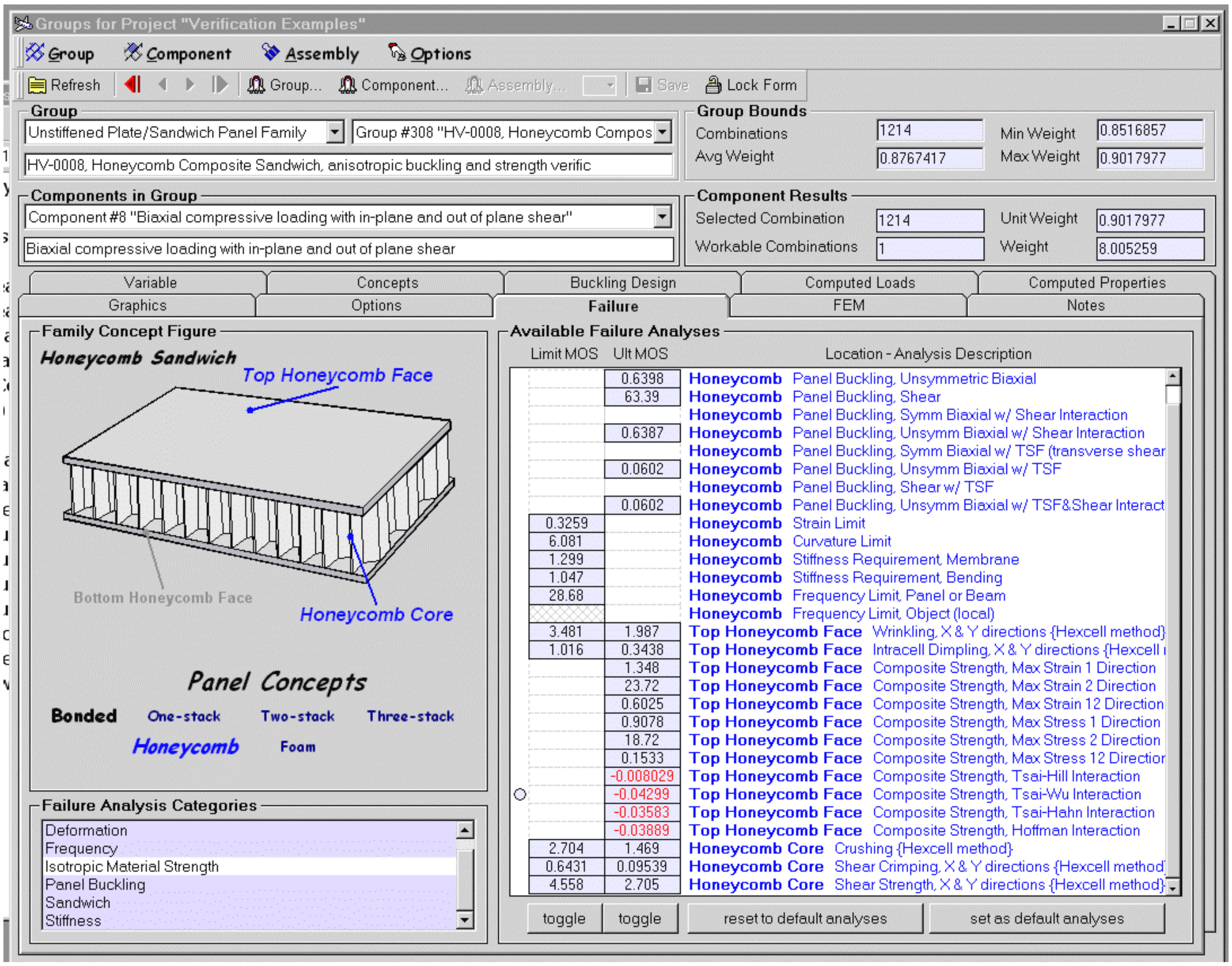
Visual tools provide convenient plotting of finite element loads. Any load, pressure, or temperature can be displayed. The integrated design of the interface automatically limits the view to the active component, group, or assembly. By moving through these different entities, it becomes quite easy to interpret loading magnitudes for specific vehicle areas.



Analyze and Optimize Designs on the Fly

Optimization starts with accurate and comprehensive analysis

The structure is analyzed using literally hundreds of strength and stability methods ranging from closed form, traditional hand calculations repeated every day in industry to more advanced panel buckling algorithms. Some of these methods are modern instability algorithms such as those used for unsymmetric panel buckling. Others are more traditional, simplistic hand calculations. Some of the potential failure modes are shown here for the honeycomb analysis.

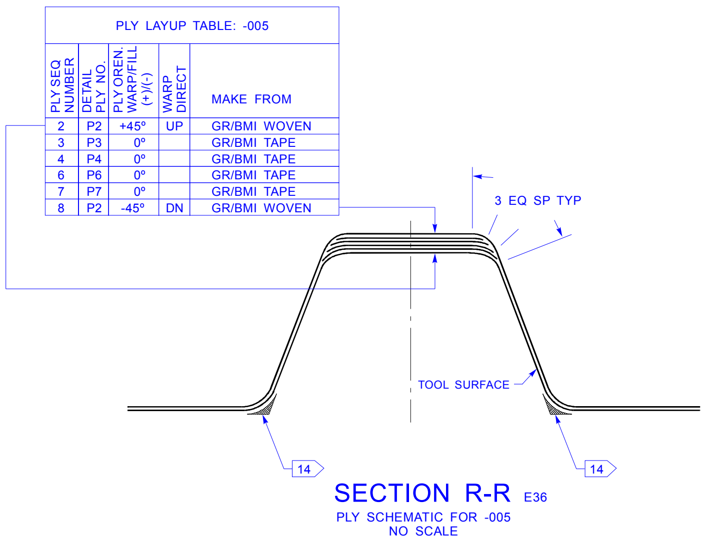


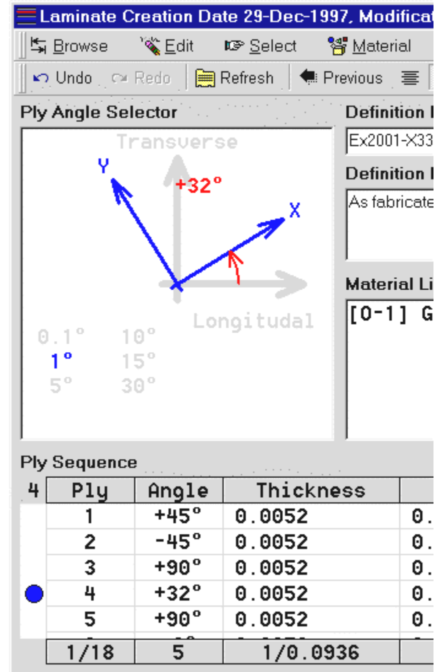
Margin-of-safety reporting for every potential failure provides the engineer with a powerful insight into the structural problem.

All aspects of the structural design are optimized

- Panel and beam concepts
- Material selections
- Design dimensions, thicknesses and layups

- Layups are even customizable to include odd angles and ply dropoffs using an integrated composite layup builder





Design concurrently with multiple engineers

HyperSizer includes a fully relational database management system which allows multiple users to work on the vehicle design concurrently across a local area network. In addition, multiple projects are stored in the same HyperSizer database meaning that archiving of the aerospace plane project and data are automatic. If temporarily pulled off of the aerospace plane project, you can come back weeks later and pick up right where you left off.

Conclusion

The commercially available HyperSizer™ detailed analysis and sizing optimization program, which is integrated with MSC/NASTRAN, is described using an aerospace example. The example model is a reusable launch vehicle referred to as an aerospace plane. It contains 7 assemblies, 21 optimization groups, and 203 structural components. MSC/NASTRAN FEA is used for predicting internal loads. The entire plane is optimized for minimum weight with both composite and metallic materials. Structural integrity is ensured because of over 100 different failure analyses considered by HyperSizer that included strength, buckling, crippling, deformation, and frequency. Run times on a Pentium workstation ranged from two to ten minutes for the entire vehicle.

The graphical display of analysis and design results is shown to provide the engineer with a powerful insight into the structural problem, and in so doing, allows ‘real-world’ expertise in the optimization process. The analytical methods and general approach of this integrated tool apply to MSC users in other industries.

References

1 HyperSizer User's Manual, Book 1: Tutorial and Applications, Collier Research & Development Corp., Hampton, VA, September 1998

2 HyperSizer User's Manual, Book 2: Analytical Method and Verification Examples, Collier Research & Development Corp., Hampton, VA, September 1998

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