

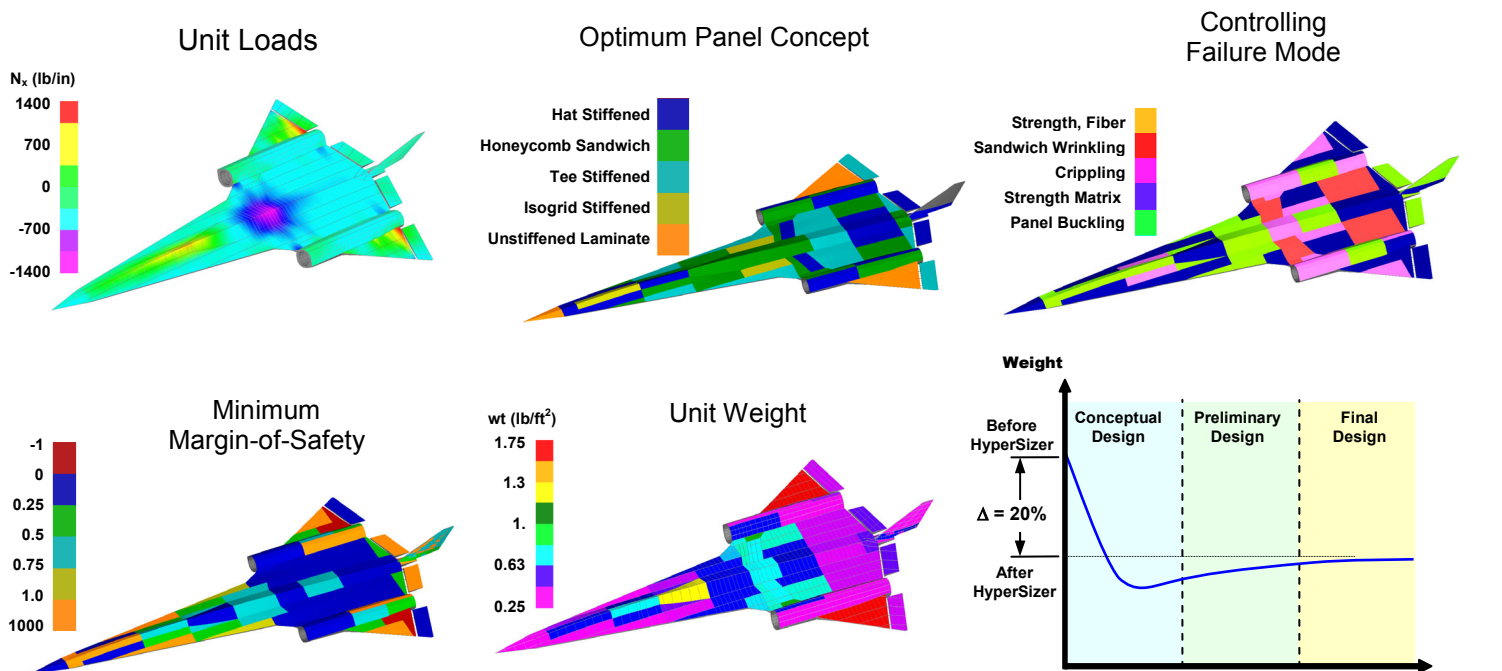
HyperSizer is software for automating the types of airframe structural analyses that are performed by a stress engineer using closed form, empirical based, and state-of-the-art numerical solutions. In this regard, HyperSizer contains specialized aerospace structures knowledge and methods and provides a computational framework for performing these non-FEA based analyses. HyperSizer includes the ability to perform many of the different analyses necessary to certify airframes, especially with composites, and does this very rapidly and accurately.

As a framework, HyperSizer can be customized by the end user. Externally HyperSizer can be controlled by other software such as Excel spreadsheets, Mathcad, Matlab, or Model Center. Customization is provided by a fully operational programming object model. This capability is useful for a larger company design system that integrates many software tools together. Internally HyperSizer can be customized by plugging in company proprietary legacy specialized codes such as those for panel buckling or bolt analysis.

As an optimization tool, HyperSizer can very effectively reduce weight of your design. Customers have realized weight savings of at least 20% for every aerospace application attempted. The process is briefly described with the five vehicle images below. Starting with the FEA computed internal unit loads, HyperSizer determines the optimal combination of panel/beam concepts,

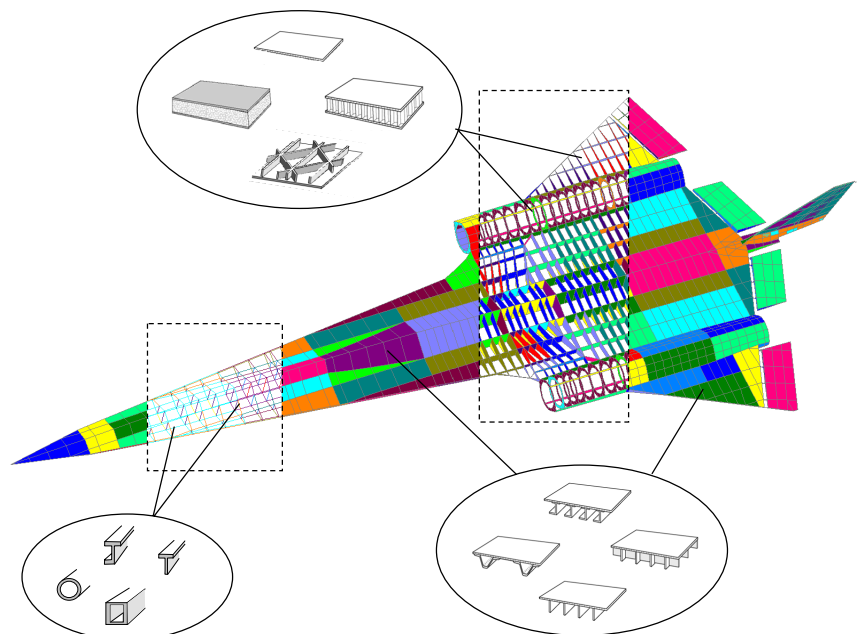
cross sectional dimensions, materials, and layups. In doing so, hundreds of different failure modes are analyzed, achieving positive (near zero) margins-of-safety for all analyses, for all airframe areas, and for all loadcases. Resulting unit weights indicate heavy areas on the airframe. The graph indicates dramatic weight savings in the conceptual optimization design phase and how weight gradually creeps up again but is still within a 20% savings. This entire process, excluding FEM setup, but including all HyperSizer user data entry, project setup, software run time, and results interpretation was accomplished for this early conceptual design in 4 hours.

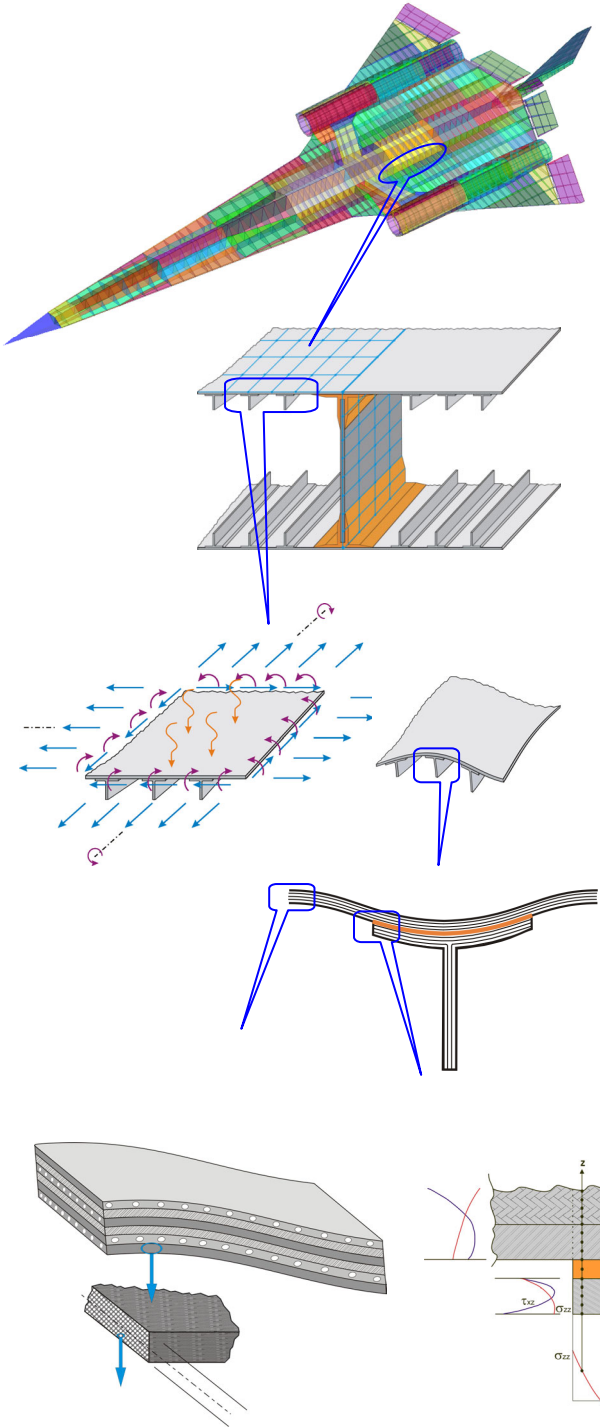
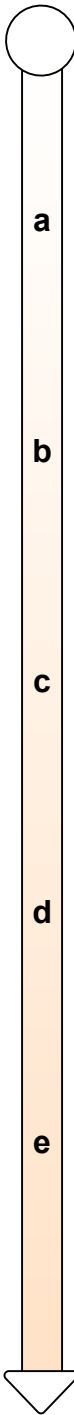
HyperSizer is a software system for management of all data associated with the structural analysis and test data of a major aircraft program. Multiple databases can be setup, with each database able to contain hundreds of variations of an airframe configuration (i.e. different FEMs), material properties, panel and beam concepts, dimensions, and loads. This approach provides apples-to-apples weight prediction comparisons, and a guaranteed store of all margins-of-safety for every configuration. The database also provides an organized and efficient means to capture essential data related to a project with a guaranteed ability to immediately locate and retrieve historical data. Stress reports can be generated at the click of a button at any time documenting current status of a project, indicating critical margins, critical load cases, and critical structural parts.



HyperSizer performs hundreds of different analyses such as panel buckling, crippling, beam-column, bonded and bolted joint, composite strength to damage initiation and damage tolerance criteria, etc. for the entire vehicle from engine nacelles to airframe surface panels and substructure. The figure illustrates how HyperSizer imports a FEM and manages all data associated with a configuration. Wing spars and ribs can consider a range of materials and panel concepts that are different than the subset of user determined design options for the wing skins and fuselage body. HyperSizer also analyses and optimizes internal beams such as spar caps and many other open and closed shapes.

A primary foundational capability of HyperSizer is to accurately analyze any panel concept without the need to discretely mesh with finite elements the shape of the stiffeners or their spacing. This permits tremendous flexibility and rapid turn around of trades with different panel concepts all from the same coarsely meshed FEM.





The figure to the left represents the HyperSizer Global-Local-Detail process that very accurately determines ply-by-ply stresses throughout a panel's cross section. Starting with a vehicle FEM, an arbitrary location on the HyperSizer generated transparent graphic (a), is identified with surface skins as being Tee shaped stiffened panels (b), which are separated by an unstiffened web. Both are modeled in the global loads FEM with a single plane of elements. Note the mesh refinement does not have to align with the stiffener spacing and the user can construct the mesh with as few elements as appropriate to get overall running loads in the skins (b). The image depicts a 6 x 4 element mesh per panel bay, but for this specific model, only one element was needed to span the substructure, full depth webs.

Each panel bay can be modeled with a single finite element because for any general, uniformly applied edge forces or moments including out-of-plane surface pressure, HyperSizer can compute the resulting local panel deformation as portrayed at (c). This includes thermoelastic deformations caused by in-plane and out-of-plane temperature gradients.

HyperSizer automatically couples to FEA codes, and is FEA code independent. However, NASTRAN is the FEA solver most used by our customers and HyperSizer is certified to support MSC, NX, and NEI versions. In essence, the NASTRAN file format is a defacto standard. After HyperSizer has optimized the design of the vehicle, each user identified component will have its generalized temperature dependent stiffness terms updated in the FEM. HyperSizer accomplishes this by regenerating NASTRAN PSHELL and MAT2 data types for shell elements and PBAR and MAT1 for beams. With the new material and design data, another FEA is submitted for the next round on internal loads that capture changed load paths. At this point HyperSizer reads the new computed element forces from the FEA output file. In this manner, the optimizer can evaluate any stiffened panel cross sectional shape without having to remesh the model. Trades between honeycomb sandwich, blade stiffened, and/or hat stiffened panels are lightning fast.

There is no limit to the number of FEM elements, grids, or load cases, permitting HyperSizer to rapidly handle large FEMs. HyperSizer has a linear relationship between run times and model size, not exponential which can become detrimental when going from demonstration to full production FEMs.

HyperSizer can analyze and optimize all structural components of entire airframes to thousands of load cases. Statistical post processing of the FEA computed element forces provide appropriate design-to loads. These loads are used for panel buckling and beam-column type failure analyses and are further resolved into individual panel segment forces (d) for other instability analyses such as local buckling and crippling, and then even further for concentrated stresses/strains.

Specializing in composite analyses and optimization, HyperSizer's progressive Global-Local-Detail process of computing stresses and strains allows hundreds of different failure analyses to be included. Material strength failure predictions for the laminates include the panel span segments (e, left image) and the bonded joint between skin and flange of a stiffened panel (e, right image).

Interlaminar shear and peel stress variation is computed in the adhesive for linear and five different non-linear material methods. The Z axis stress variation is also computed throughout the laminate depth, and also for each individual ply as required for the last ply of a stepped joint, (e, right). The number of integration points and characteristic distance for failure prediction can be selected by user.

In addition to material strength based on damage initiation, damage tolerance residual strength of strain energy release rates (SERR) are computed using a rapid, non-FEA, virtual crack closure technique (VCCT). These values are compared to critical energy release rates  $G_{Ic}$  and  $G_{IIc}$  to predict delamination propagation for a crack between laminate plies and/or a crack between the skin and bonded flange.

The HyperSizer Progressive Design Process consists of three activities. All three activities can interact with each other throughout design maturation. HyperSizer provides unique automation and integration capabilities to each of these design activities.

**Progressive Optimization**

A funneling process performed in stages to target an optimum design. Innovative “back to the drawing board” concepts are proposed, evaluated, and filtered out for the next stage of the design maturation process.

**Progressive Failure Analysis**

An incremental process of including more computationally demanding analysis solutions starting with damage initiation, tracking the progression of failure, and ending with the resulting residual strength at ultimate failure.

**Progressive Detail Design**

An incremental process of including more design detail, such as bonded and bolted joints, ply drop-offs, etc. for both optimization and analysis.

The figure below describes four progressive maturity levels for analysis and design optimization. Each of these correspond to a level of computational effort rather than a level of fidelity, although these often coincide. The intent is to pair the analysis and design levels to achieve the best efficiency of accuracy and optimization throughput. Overall accuracy is based on the analysis accuracy of each isolated failure prediction, as well as the breadth of failure modes included. HyperSizer provides the flexibility to switch between levels (blue dashed line) for obtaining the most revealing and relevant time appropriate results.

## Analyses

*After fully computing stresses/strains for every ply throughout the panel cross section, the following closed form, empirical, or numerical solutions are performed in the following levels:*

- Flat panel buckling, column buckling, local buckling, cross section crippling, Johnson-Euler interaction, buckling knockdown factors
- Honeycomb/foam sandwich facesheet wrinkling and dimpling; core shear, crimping, crushing from concentrated force, flexural bending, joint support
- Metallic strength based on material yield and ultimate allowables von Mises and MIL-HDBK-5 method
- Composite strength based on either
  - 1) equivalent orthotropic approach
  - 2) laminate allowables using AML or A,B,C,D,E polynomial factors
  - 3) ply-by-ply analysis and ply allowables using quadratic theories
  - 4) open hole tension (OHT) and open hole compression (OHC) after impact allowables

- Energy solution for panel buckling with curvature and mixed BC's
- Panel stiffener lateral torsional buckling\*
- Panel stiffener beam-column geometric non-linear strength analysis
- Local and detail panel pressure analysis, initial imperfection
- Physically based composite strength theories: LaRC03 and Hashin
- Bonded joint damage initiation between skin and stiffener flange\*
  - 1) 13 unique bonded joint failure criteria for the adherends, 6 unique failure criteria for the adhesive
  - 2) peak stress damage initiation & ultimate residual strength
- Large notch (discrete source) damage tolerance \*
- Thermal load sets, in-plane and through-thickness temperature gradients, and temperature dependent material properties

- Substructure to surface joints: \*
  - bolted joint, single hole loaded and far field analysis (BJSFM)
  - bonded joint
- For all bonded joint types: stepped tapers, linear and non-linear adhesive analysis with interlaminar (z) stress variation in all plies\*
- Damage tolerance residual strength calculation of strain energy release rates (SERR) for comparison to critical energy release rates  $G_{Ic}$  and  $G_{IIc}$  (a rapid, non-FEA, virtual crack closure technique)\*
  - 1) for crack between laminate plies, delamination propagation
  - 2) for crack between skin and flange of bonded stiffened panel
- Composite strength progressive failure\*
- Local post buckling of stiffened panels\*

**Final stress report**

- Margins-of-safety reported for all failure analyses, for all airframe components, and for all load cases
  - 1) traditional deterministic analysis
  - 2) reliability based probabilistic analysis based on test data

\* not yet commercially released

## Design and Optimization

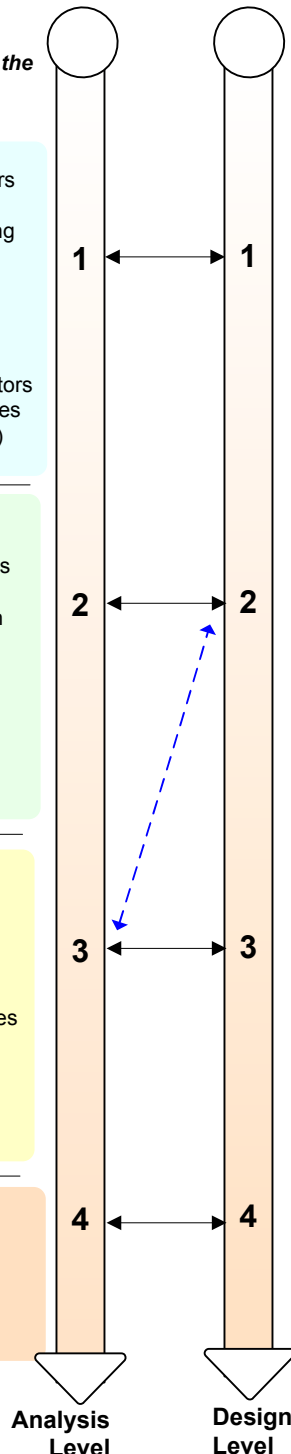
*Many different panel/beam concepts, materials, and combinations of dimensions are evaluated for all airframe structural components at the following levels:*

- Optimization of laminates using equivalent orthotropic material approach
- Statistical optimization
- Multiple optimum solutions
- Linking of cross sectional variables within a component
- Stiffness, frequency, displacement, and strain/curvature limits
- Positive margins-of-safety for all turned-on failure analyses

- A narrower range of optimal cross sectional dimensions identified
- Optimization of composite laminates by either
  - 1) equivalent orthotropic approach
  - 2) explicit ply-by-ply layup sequence
- Specific ply-by-ply layups and user selected cross sectional dimensions linked across adjacent components
- Optimization of stiffened panel bonded joints

- Layup, ply drop off blending between adjacent surface components\*
- Bonded and bolted joints between skin and substructure optimized\*
- Fastener type, material, diameter, and spacing details included\*

All design details included in all analyses





## HyperSizer compared to other commercial composite software packages

HyperSizer has a wealth of valuable and unique composite analysis capability:

- ✓ Completely integrated Global-Local-Detail progressive analysis process, including bonded and bolted joints
- ✓ 50 different stiffened panel shapes analyzed to any combination of mechanical and thermal loadings
- ✓ Interactive layup tool for spontaneous graphical images of failure envelopes and ply-by-ply stresses and strains
- ✓ Ply-by-ply failure prediction using traditional failure criteria such as max-strain and quadratic theories such as Tsai-Wu
- ✓ Physical based theories such as Hashin and the newer LaRC03 that predict failure as unique failure modes such as fiber buckling
- ✓ Laminate failure prediction using methods such as AML or the A,B,C,D,E polynomial equation strain allowable
- ✓ Micromechanics\* failure prediction based on detailed micro-level stresses and strains at the fiber/matrix constituent level
- ✓ Progressive failure\* and ultimate load calculation
- ✓ Thermal residual stresses/strains and warpage from fabrication cool down
- ✓ Verification test cases and validation to over one hundred individual test data points
- ✓ Integrated test database to store and graphically display histograms of test scatter and link to current projects
- ✓ Test data correlation factors (CFs) established for each failure criteria
- ✓ Deterministic and probabilistic reliability analysis based on test data CFs

## HyperSizer compared to commercial FEA optimization packages

HyperSizer's approach for automating the analysis and design process is different than and compliments FEA based mathematical optimization techniques. Two commercial FEA software packages are noted: MSC/ NASTRAN™ Sol 200 and Altair's Optistruct® .

A primary use of MSC/NASTRAN Sol 200 in the aerospace industry is for aeroelastic optimization of wing stiffness. Once an optimal wing's stiffness distribution is identified, each local area's target skin and substructure stiffness can be passed automatically to HyperSizer as constraints. HyperSizer will then satisfy these constraints as it performs additional optimization of panel stiffened cross section dimensions and composite layups to meet more detailed structural integrity criteria.

Optistruct is a FEA based shape and topology optimization software package. Its capability is primarily determining the best overall shape (as an example, think of a complex metal bracket) for minimizing weight. Fundamentally, the capability is based on the fully stressed design (FSD) approach of placing material in the most efficient load path direction, and removing material from other locations. The ability to add or remove material is with the elements of the FEM. However, other approaches are needed for larger skin and substructure components that require a multitude of aerospace specific failure analyses including damage tolerance and specialized composite strength methods which must be met to hundreds of load cases for stress reports and flight certification.

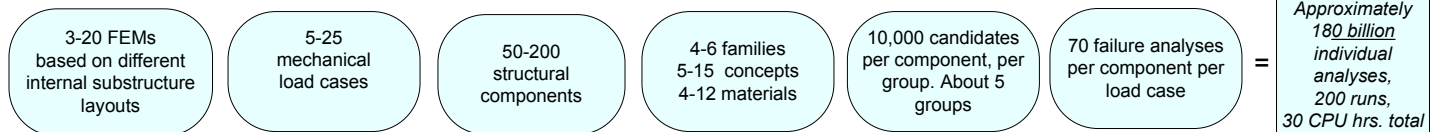
FEA based optimization is considered global optimization in that it satisfies overall vehicle deflection and stiffness. HyperSizer is local optimization that satisfies each area's detailed optimum design and establishes the full listing of failure margins, for the entire airframe, for all load cases and as such satisfies aerospace specific failure analyses requirements. Tighter coupling between commercial FEA optimization and HyperSizer is planned to be provided in the future.

The figure below identifies how HyperSizer's four levels of extensive analyses and progressive optimization fit into the traditional phases of the aerospace engineering design process of conceptual, preliminary, and final design. The numbers represent a full fledged effort to extensively explore the design space. Throughout all levels, the quality of engineering knowledge and experience dramatically improves the results. The proportion of interactive user hours is higher in the earlier design phases where time is spent interpreting results and steering the optimization.

### Conceptual Design

(Level 1)

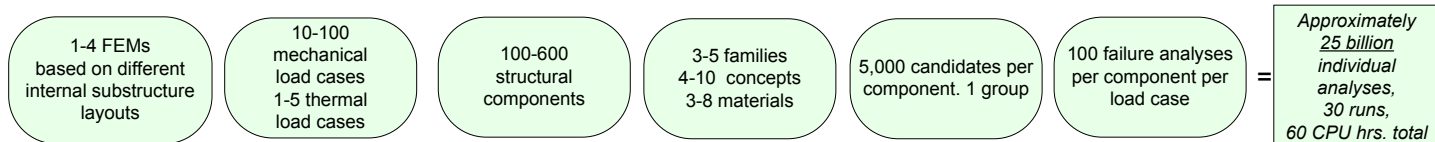
*Design-to loads from either closed form equations implemented in spreadsheets or coarsely meshed FEMs.*



### Preliminary Design

(Levels 2 & 3)

*Design-to loads from the loads group developed FEMs. (Some analyses longer running.)*



### Final Design

(Level 4)

*Design-to loads from the loads group developed FEM and from the stress group local FEMs. (Some analyses much longer running.)*

