LaRC/Exploration Concepts Branch 3D Finite Element Based Structures Tools

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Goddard Space Flight Center

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Objective:

- To quickly create coarse vehicle 3D models which are subject to typical structural design loads
- To estimate Level 2 primary structure weights during conceptual design phase
  - Level 0 weight estimates are based on historical data
  - Level 1 weight estimates are line model subject to shear, moment and axial force estimates
  - Level 2 coarse FEM structural weight estimates
  - Level 3 detailed FEM structural weight estimates
- To do structural trade studies

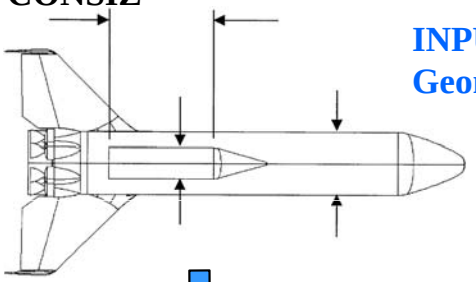
Tool Outline

Semi-automated iterative procedure for structural weight estimation and trade studies of new vehicle design concepts

- JAVA - Object Oriented process control language (original process was wrapped in Phoenix Integration/Model Center)
- UGS / I-DEAS - CAD/CAE
- Collier Research / HyperSizer - Structural component sizing
- LOFT - Swales code to quickly create FEMs with property assignment regions defined
- EXCEL Solver - utility used for balancing of flight loads
- HSLOAD - Swales code to automate the HyperSizer design process
- Multidisciplinary input from CONSIZ (Subsystem weights), POST (Trajectory), CBAERO (Aero)

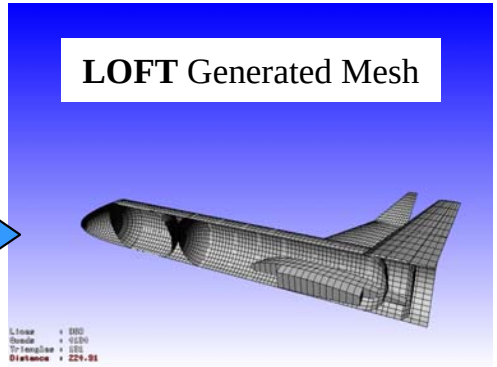
Process Outline

Vehicle Geometry and Weights
CONSIZ

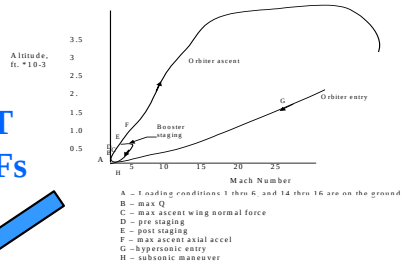


INPUT Geometry

LOFT Generated Mesh



POST Flight Profile with Accelerations &
CBAERO generated Aero-forces

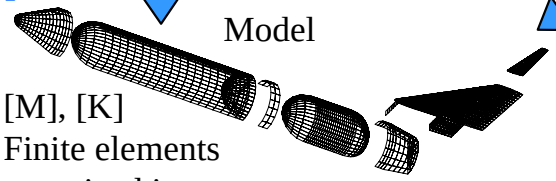


INPUT Gs & Fs

INPUT Lump Mass

I-DEAS FE Model

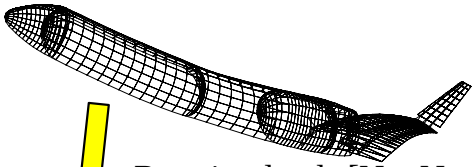
INPUT FE Mesh



[M], [K]
Finite elements organized in groups/Panels

Load Balancing
EXCEL Solver

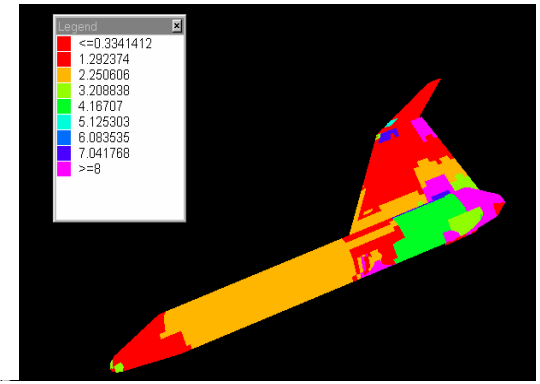
Loaded **I-DEAS** FE Model



ITERATION LOOP

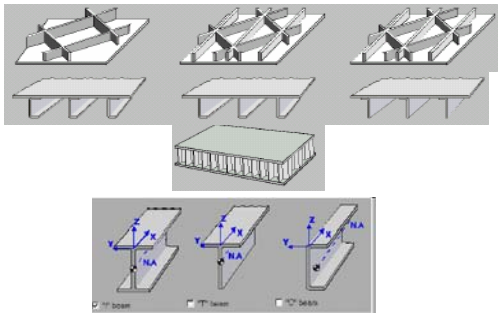
Running loads [Nx, Ny, Nxy ……]

HSLoad / HYPERSIZER Model



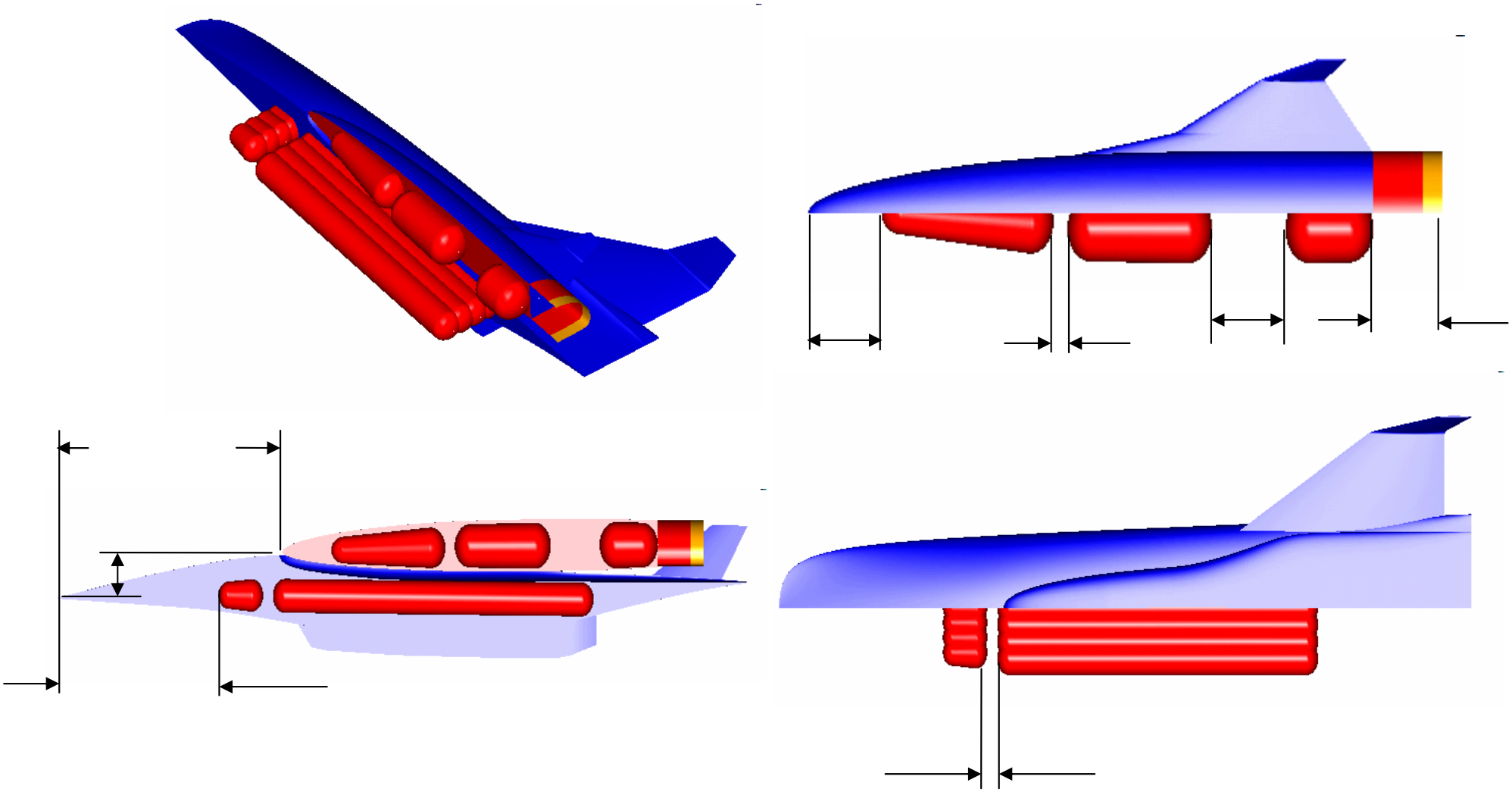
New [K] & Struct. [M]

Panel sizing in **HYPERSIZER**



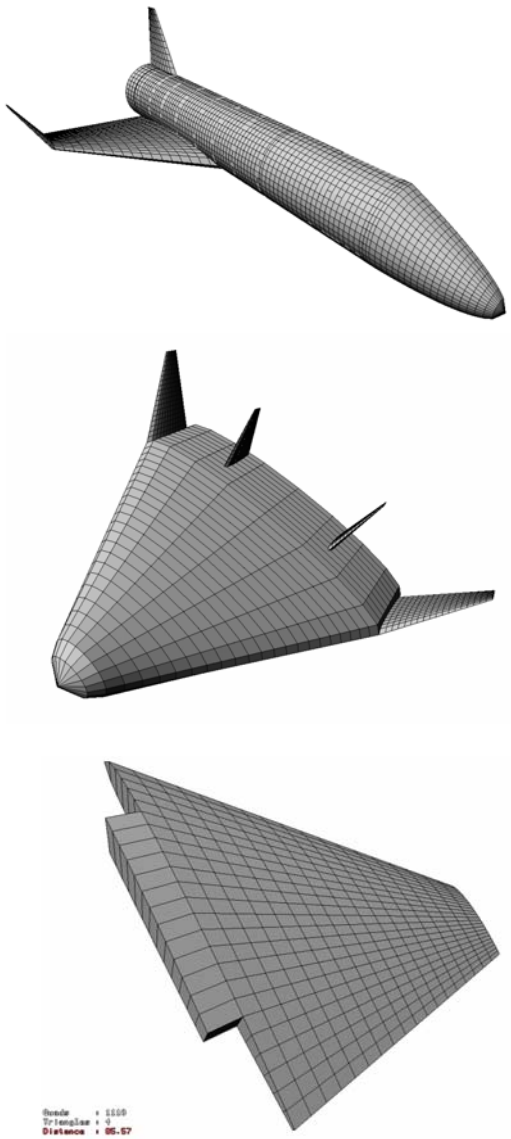
Assign:
- Panel/beam Concept
- Material
- Limits on design variables
- Failure Criteria

Geometry, packaging and sub-system weights received …..



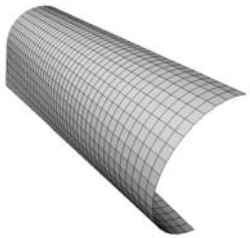
LOFT

Automatic Finite Element Mesh Generation For Aerospace Vehicles

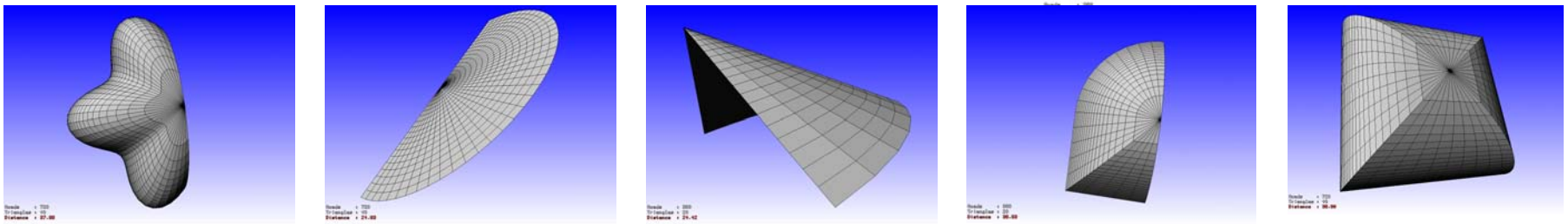


- Use supplied Geometric Dimensions
- Generate Panels, Frames, Beams/Bars for a full or partial vehicle
- Mark each element with User Specified component names and coordinates
- Attach to commercial codes for FEA and sizing
- Post process sizing results

LOFT

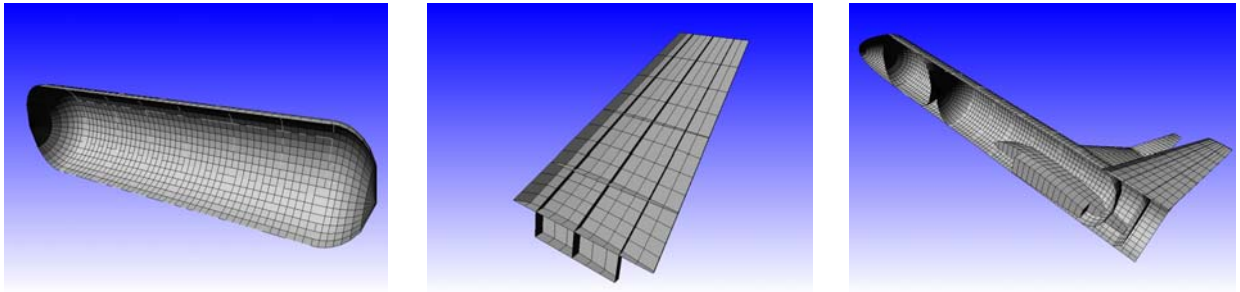


Extrudes between arbitrary cross sections



Builds objects using panels, beams and bars

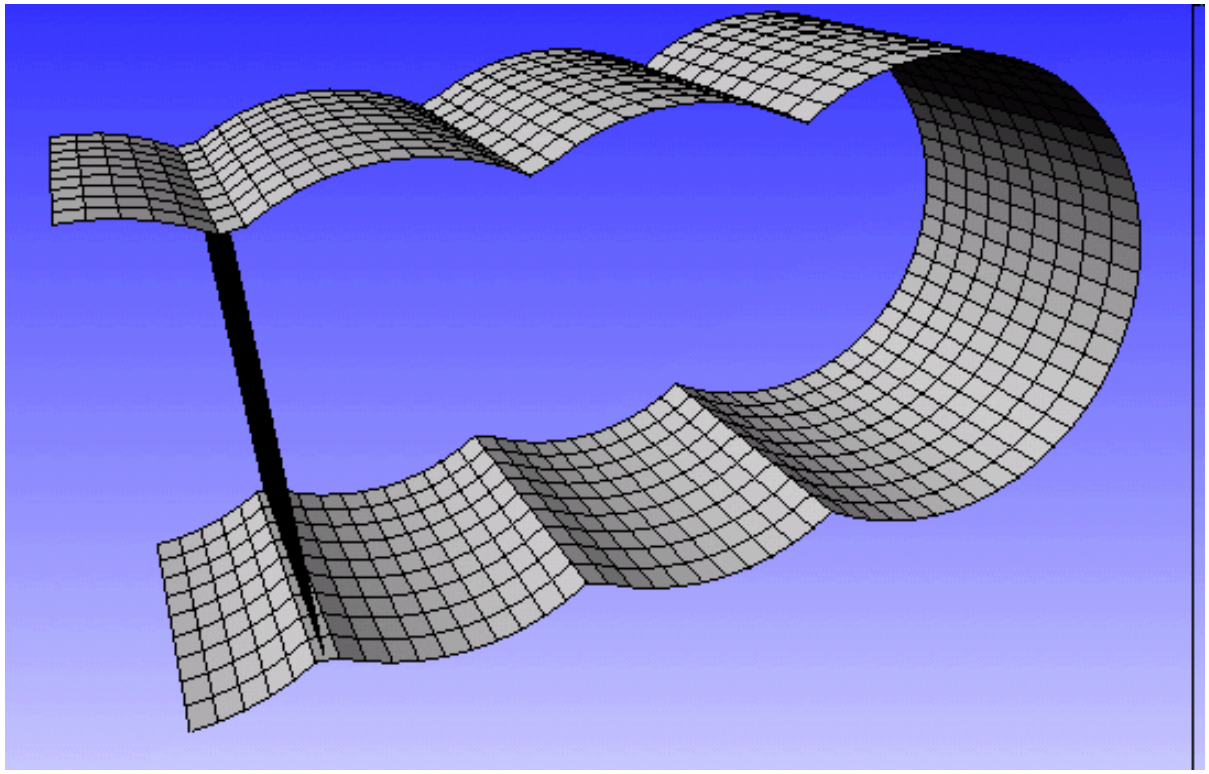
Merges objects to form a single FE model



```
# ISAT Reference Mach 3.4 TSTO Vehicle
# Our nose
object dome BST Nose
curve1 sc
c1_xscale 15.589
c1_yscale 15.589
length -36
taper para
nodes_circ 21
nodes_axial 20
droop line
zdroop 8
```

Portable C code with Text Input

Desired forms are programmed …



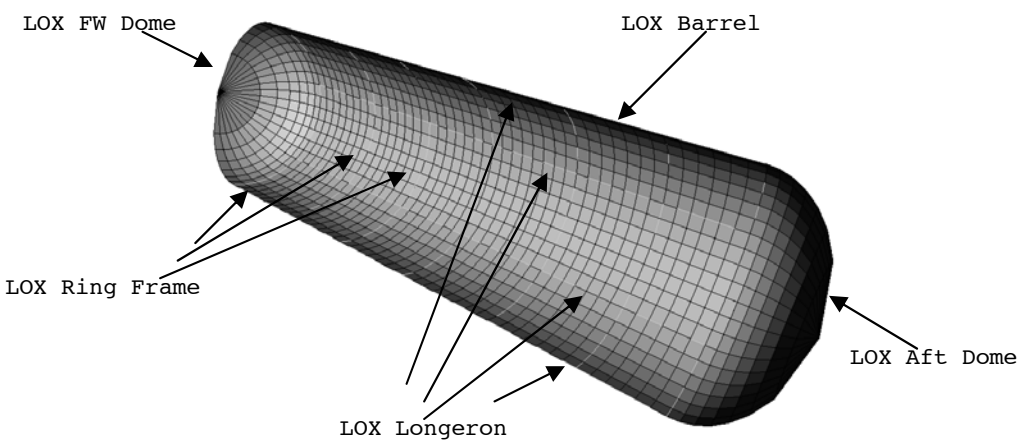
Example of LOFT input file

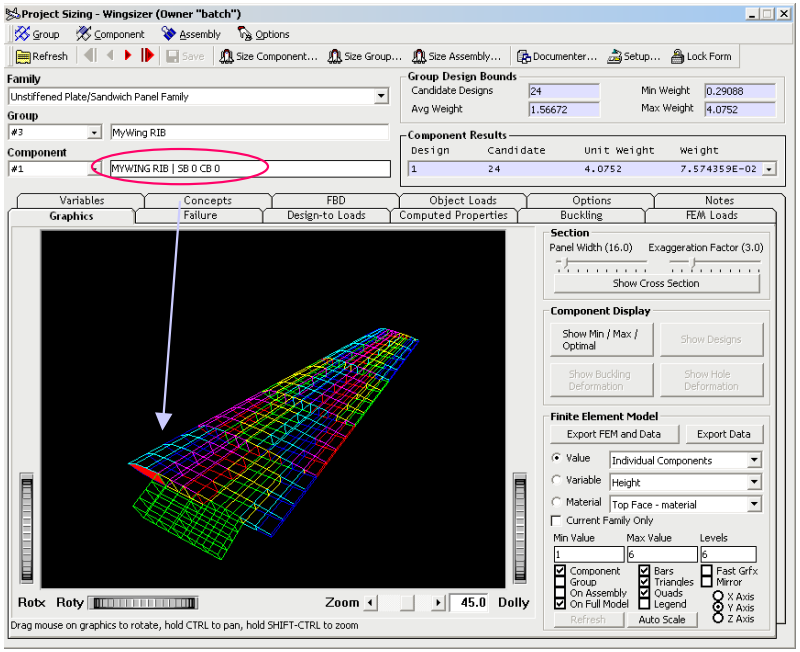
```
# ************************
#
#      ** NOSE Assembly **
#
#      * Nose Tip *
#
object dome NoseTip
curve1 sc
c1_xscale 58.05
c1_yscale 58.05
length -35.82
taper para
droop line
zdroop 0
nodes_circ 11
nodes_axial 5
components_circ 5
components_axial 2
#
#      * Nose Cone *
#
object section NoseCone
curve2 sc
c2_xscale 207
c2_yscale 207
length 319.18
nodes_axial 13
components_axial 4
#
```

Property Assignments

Create Physical and Material Property Names to mark Engineering components

Allows easy application of sizing parameters to different Vehicle sections and easy post processing





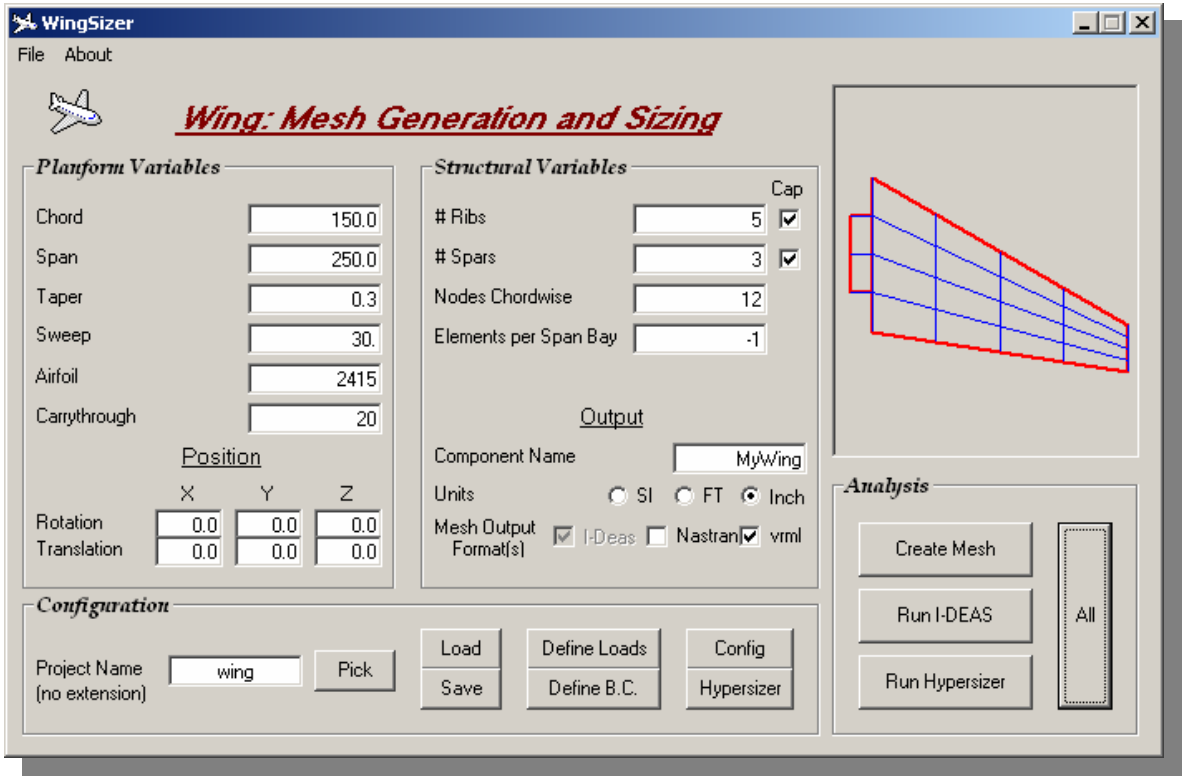
Meaningful names allow different construction approaches across the vehicle

High fidelity tool to estimate wing structural weights

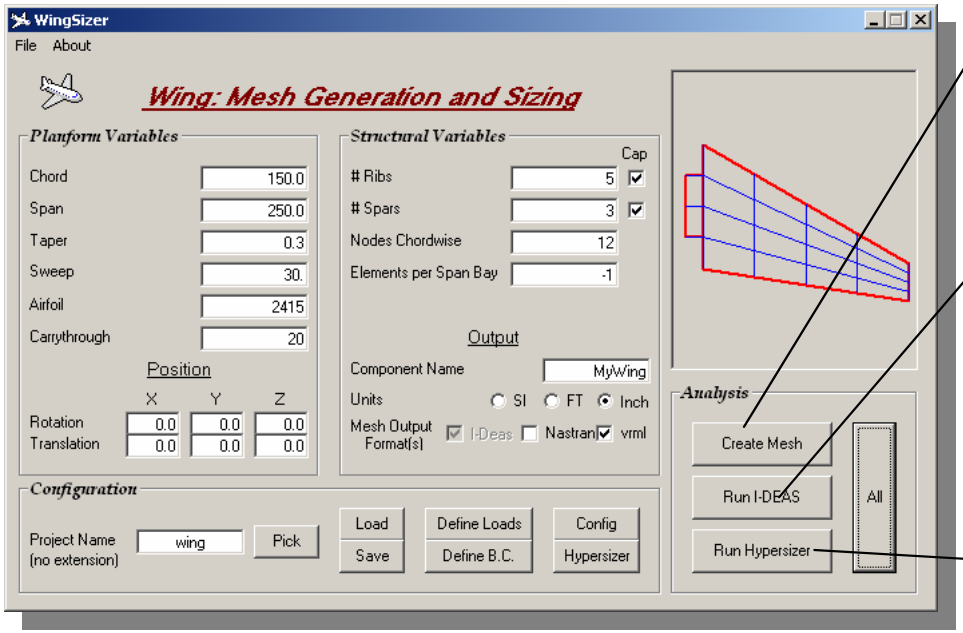
- Generates detailed FE mesh
- Calls FEA solver
- Calls and controls sizing program
- Postprocesses results

Proof of Concept: *WingSizer*

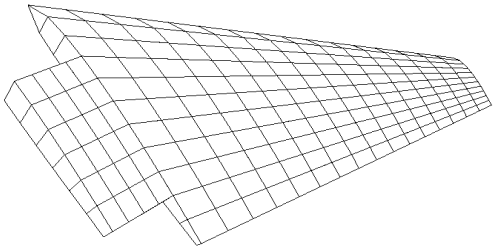
If only wing needs to be studied, user may use a standalone program: *Wingsizer* ….



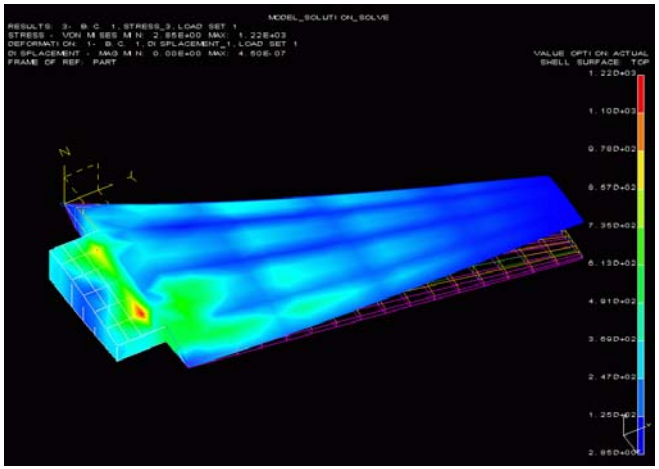
WingSizer Analysis



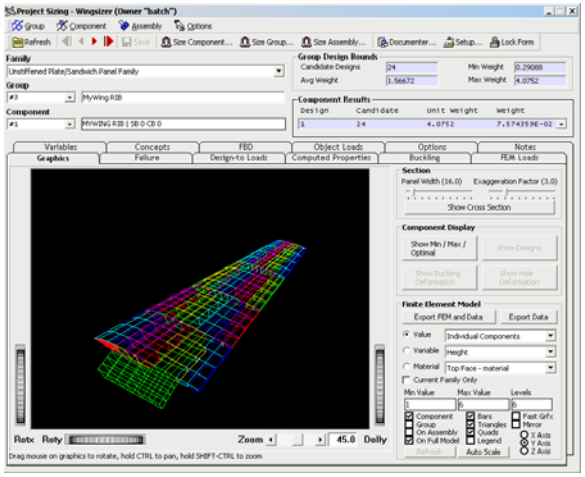
Mesh



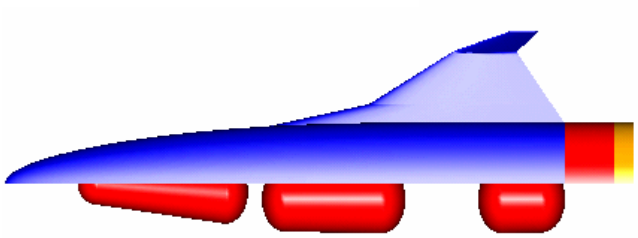
FEA

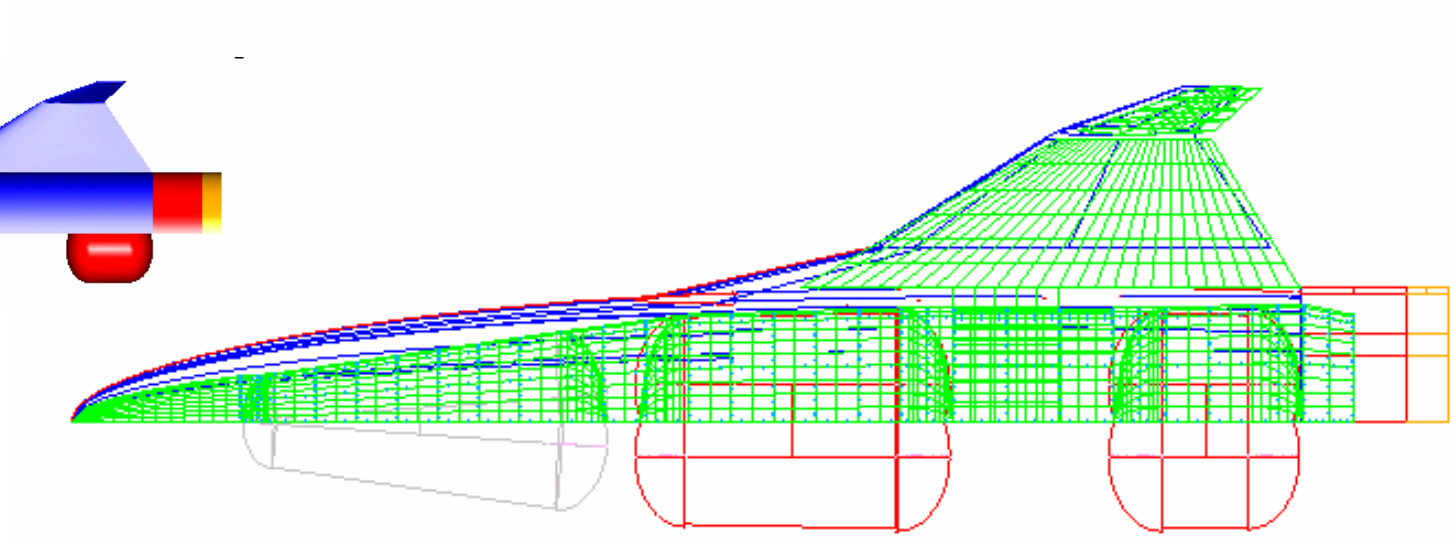


Size

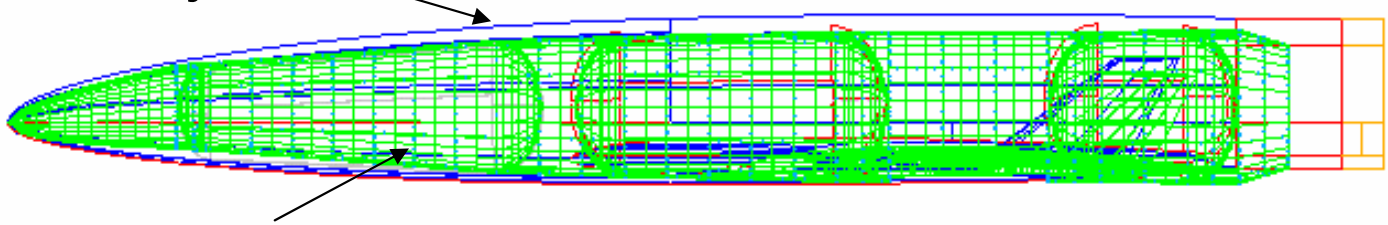


Process Highlights



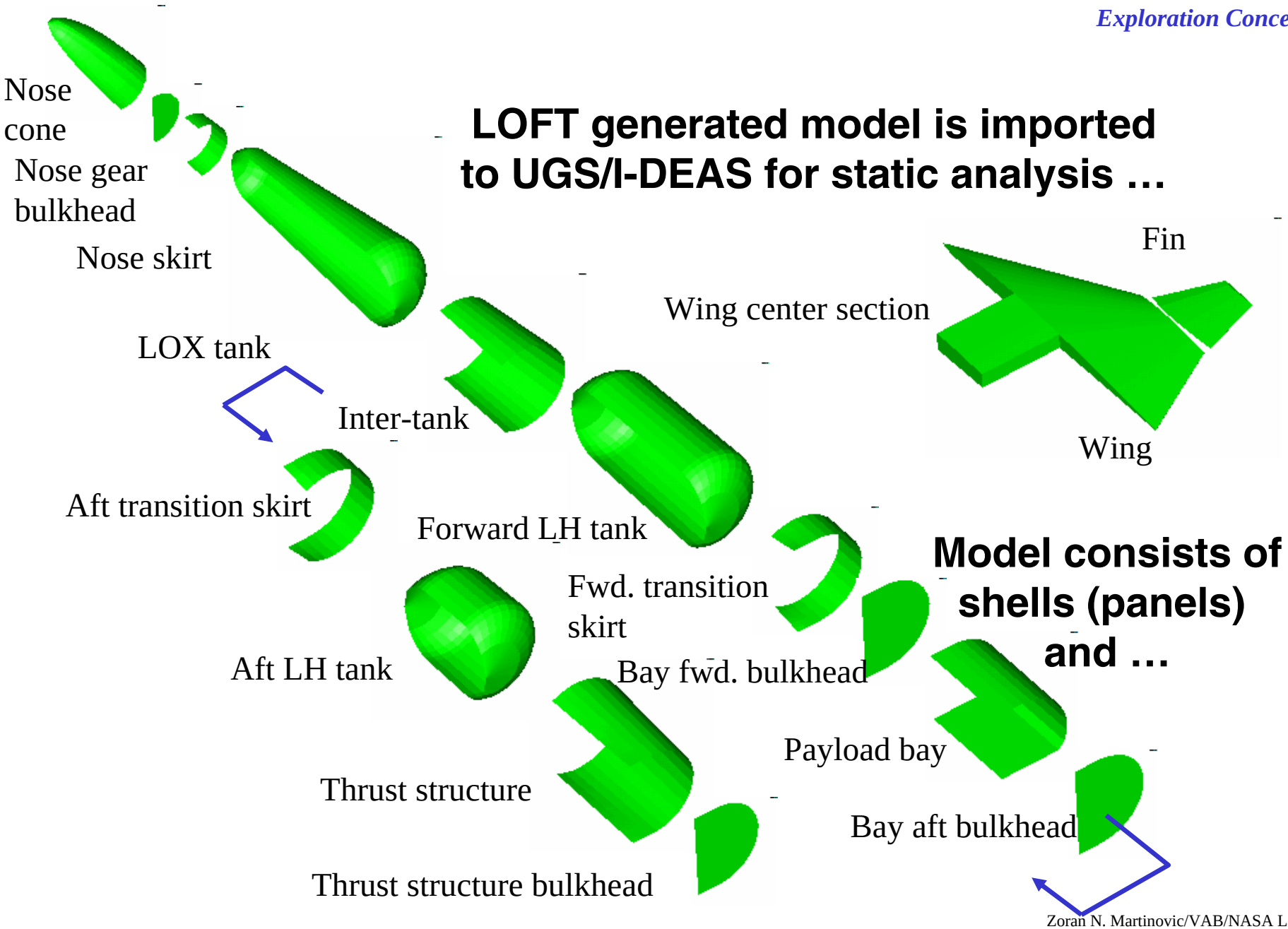


Geometry Model

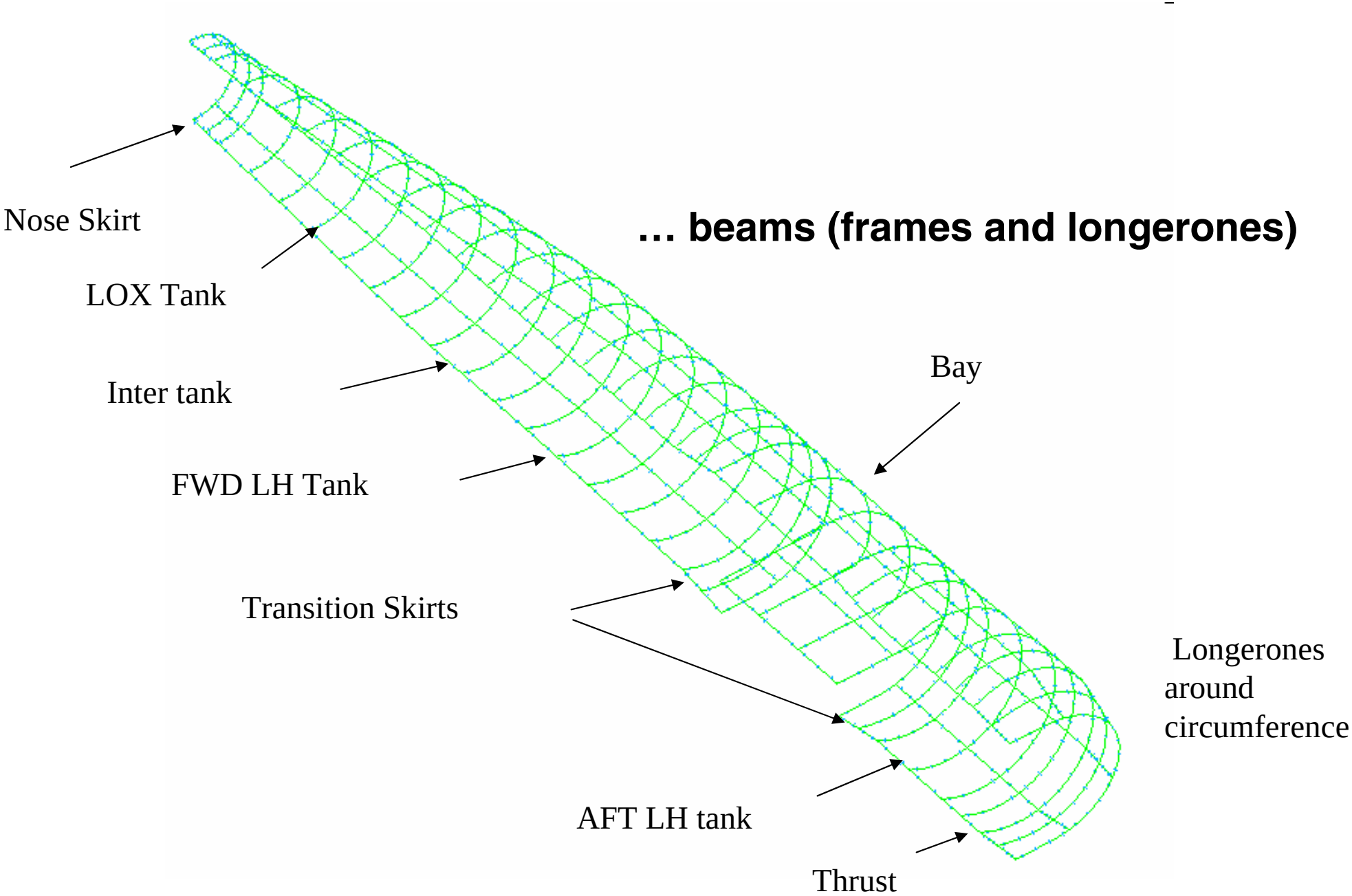


LOFT FEM Mesh

LOFT generated model is imported to UGS/I-DEAS for static analysis …



Model consists of shells (panels) and …



… beams (frames and longerones)

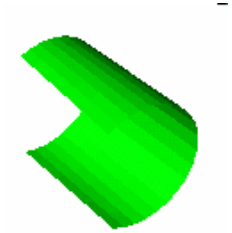
Sub-system masses are mapped and lumped to FEM …

	WEIGHT (lb) LEVEL III	II	I	CENTERS OF GRAVITY (ft./ft.) X/XREF	Y/YREF	Z/ZREF
1.0 Wing			42273.	0.971	0.000	-0.056
Exposed wing surface		30739.		0.993	0.000	-0.057
Carry-through		7798.		0.972	0.000	-0.057
Wing-body fairing		3736.		0.783	0.000	-0.044
2.0 Tail			4573.	1.083	0.000	0.000
Vertical fins		4573.		1.083	0.000	0.000
3.0 Body			81663.	0.641	0.000	-0.001
Nose section		7590.		0.093	0.000	-0.020
LH2 tank section		30939.		0.427	0.000	0.002
Tank structure	27768.			0.425	0.000	0.000
Insulation	2202.			0.425	0.000	0.000
TPS carrier panels *	0.			0.434	0.000	0.000
P/L container attach str. - fwd	470.			0.604	0.000	0.076
Crew vehicle attachment str.	500.			0.382	0.000	0.076
Intertank section		2215.		0.725	0.000	0.000

CONSIZ output file

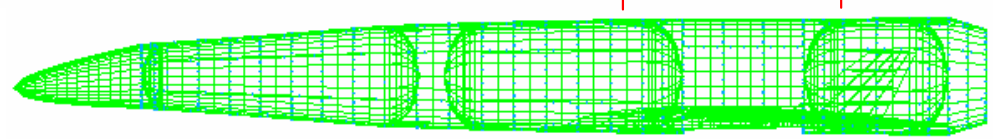
Mapping template file

Mapping file into FEM



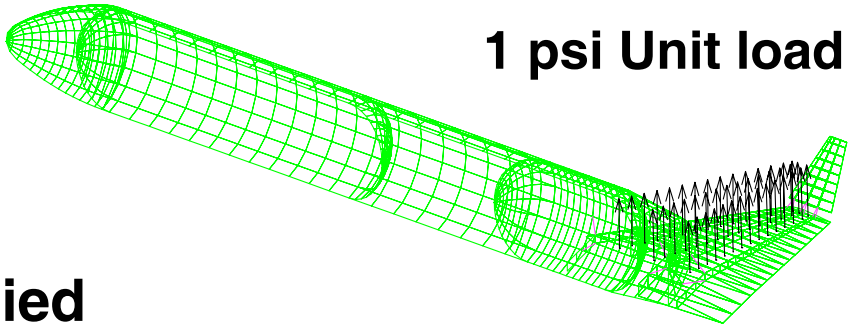
Component mapping

```
.....
CONSIZ_Component   FEA_GROUP          Weight    Mapping     XB  XE
begin_components
wing_exposed       wing_exposed       30739     component   0   0
wing_carrythru     wing_carrythru     7798      component   0   0
wing_fairing       fuselage_side      3736      fofx        1521 2688
vert_fin           vertical_tail      4573      component   0   0
nose               nose               7590      component   0   0
..........
..........
end_components
.......
```



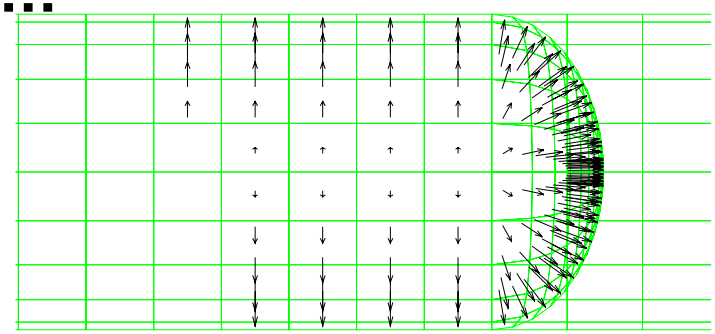
fofx mapping

Individual Unit Loads are applied and model analyzed for each of them …



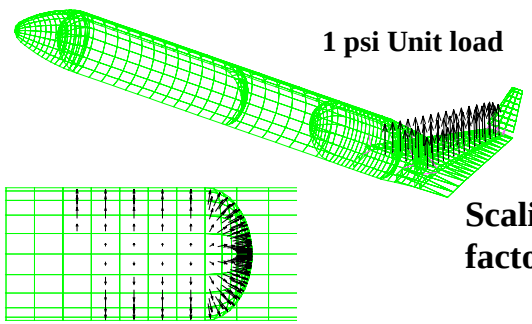
1 psi Unit load

… propellant loads are applied for each flight point and model analyzed for each of them …



Scaling of unit Loads And Loads and Balancing

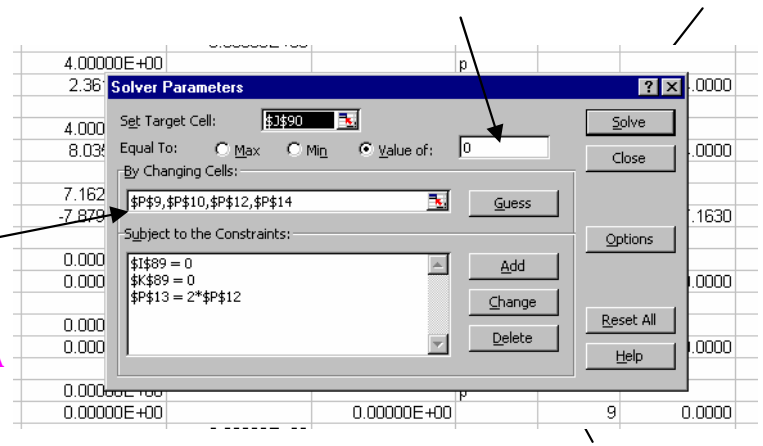
Objective function: Pitch moment = 0



1 psi Unit load

Scaling factors

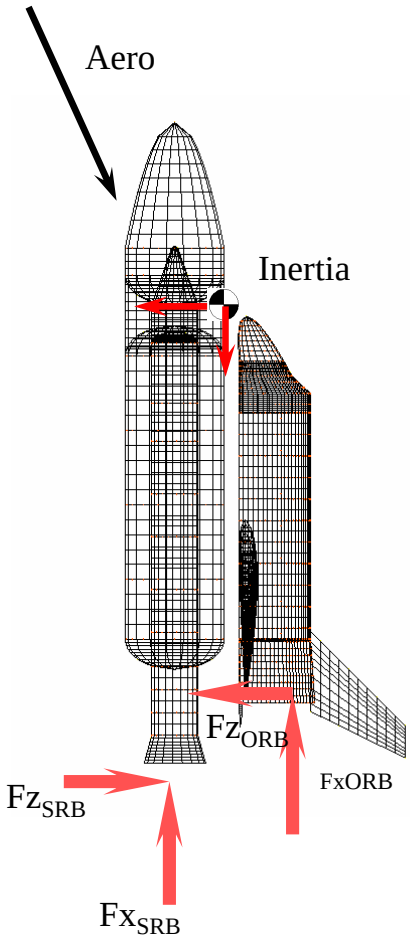
I-DEAS/EXCEL/Text/JAVA



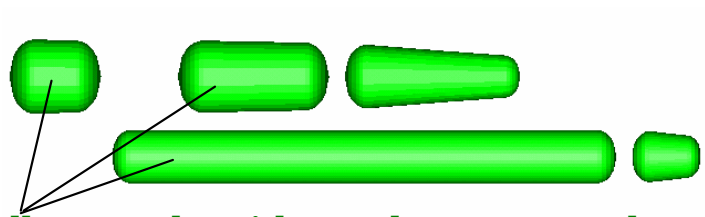
Constraints on axial and normal force, and other flight constraints

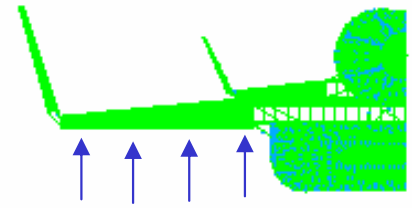
Summation	Fx	-2.32831E-10	Fz	0.00000E+00
		My	0.00000E+00	

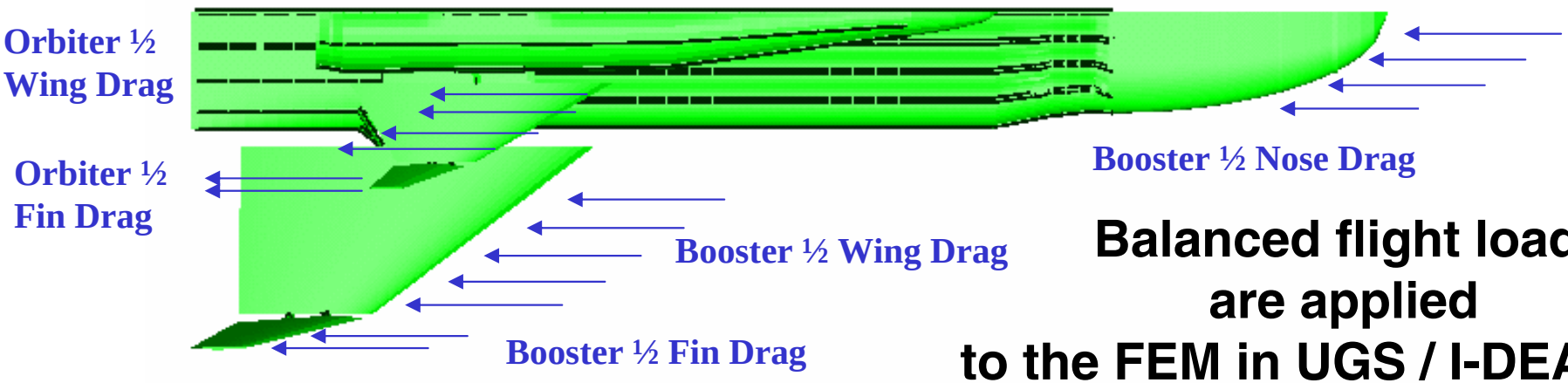
Sum of balanced forces and moment



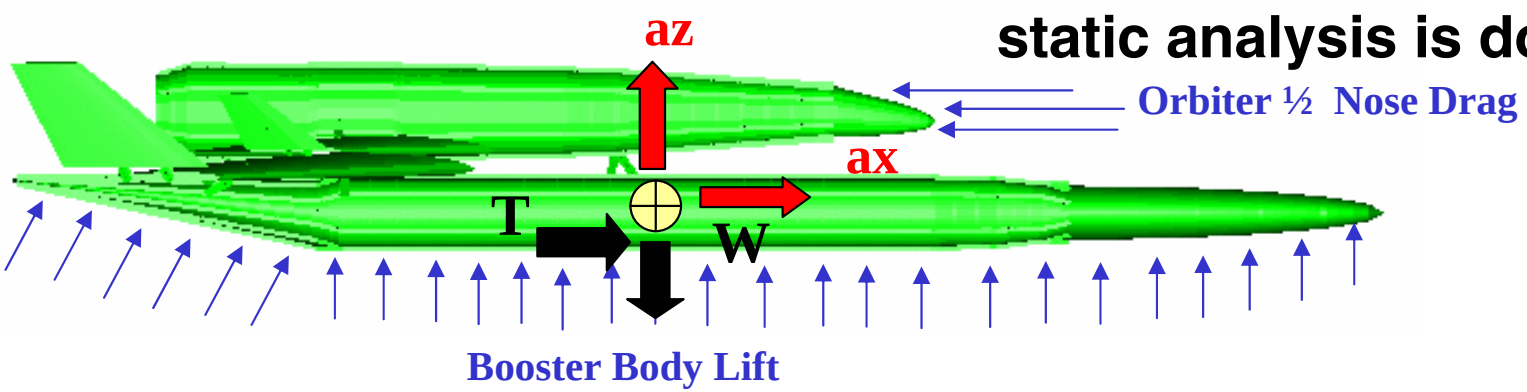
- **Unit load sets are scaled, combined and balanced to create actual design loads.**
- **Inputs are vehicle accelerations from design conditions (POST) and aero loads mapped from CBAERO (or user input fields in FEA)**

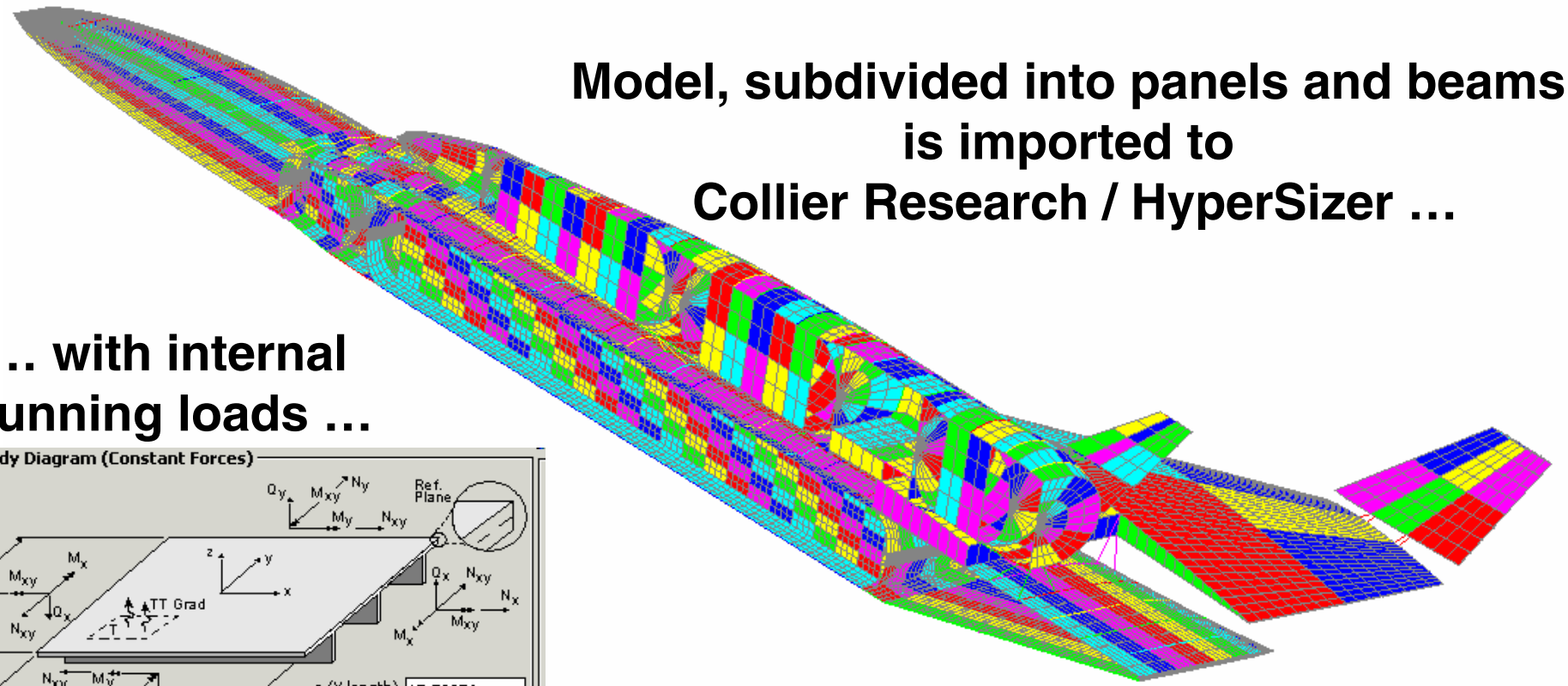






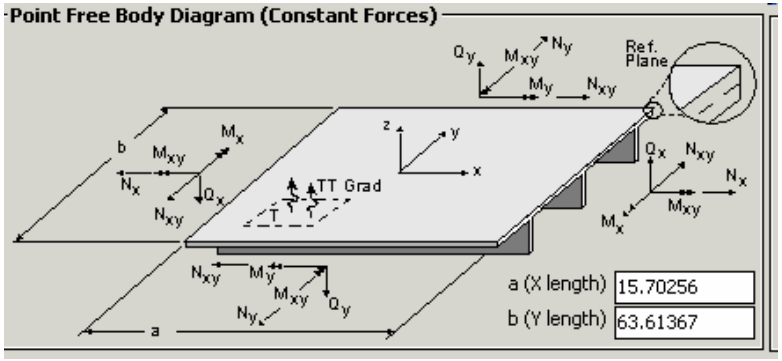
Balanced flight loads are applied to the FEM in UGS / I-DEAS and static analysis is done …



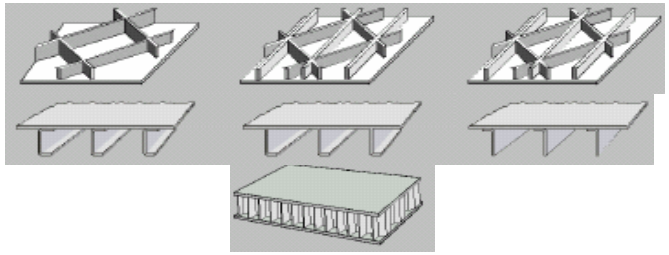


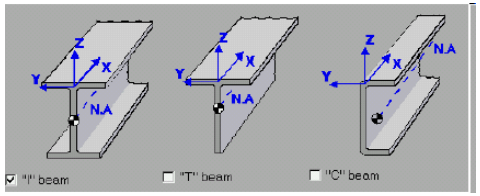
Model, subdivided into panels and beams, is imported to Collier Research / HyperSizer …

… with internal running loads …



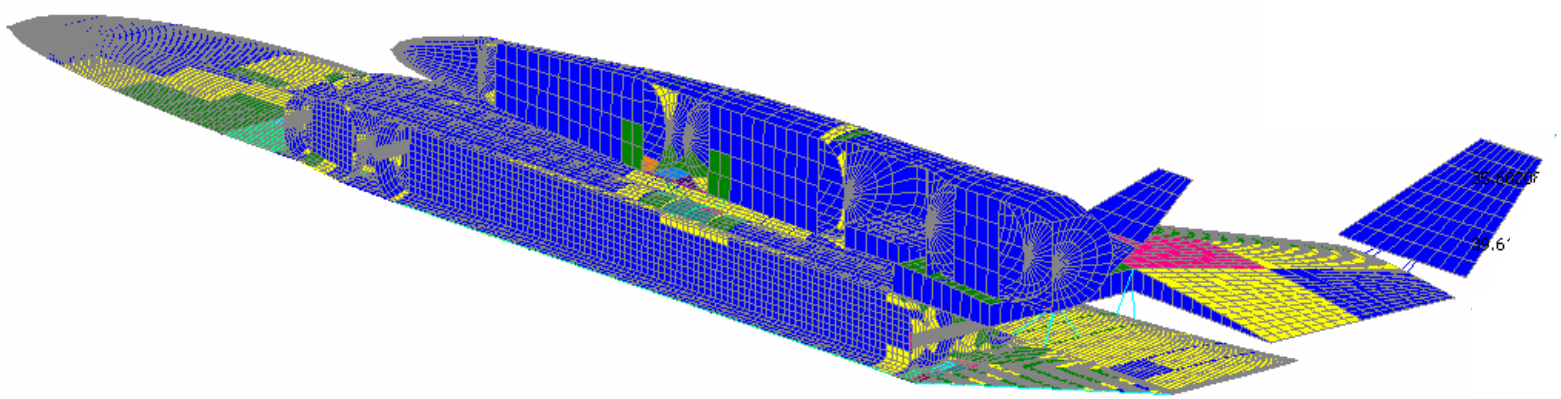
… and sized for minimum weight with different structural concepts and materials





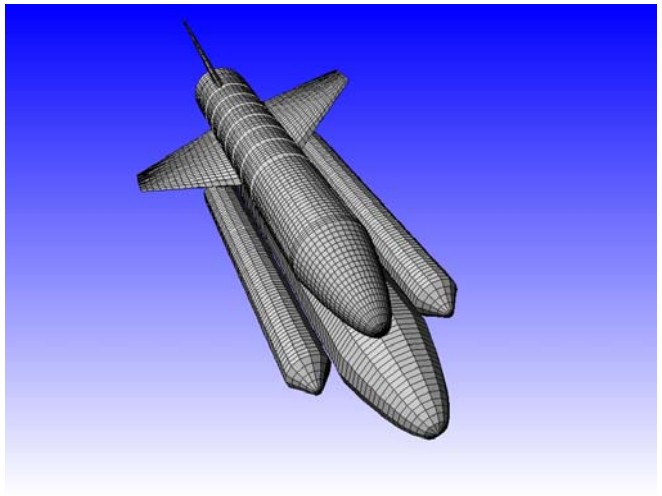
Finite Element Model
Sizing Result - Optimum Unit Weight (By Data Bins)

Model with new structural mass and stiffness is imported to UGS /I-DEAS and process iterates until converges.

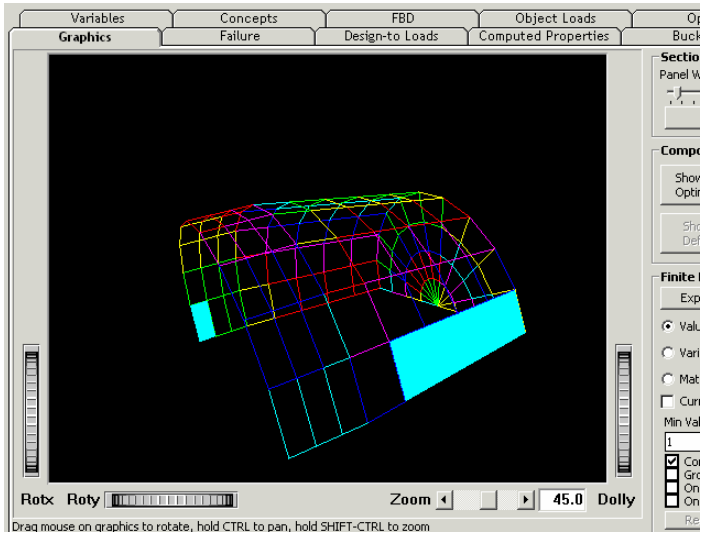


CTRL to Pan, ALT to Pivot, SHIFT to Area Zoom, CTRL-SHIFT to Free Zoom, Right-Click for Pop-up Menus

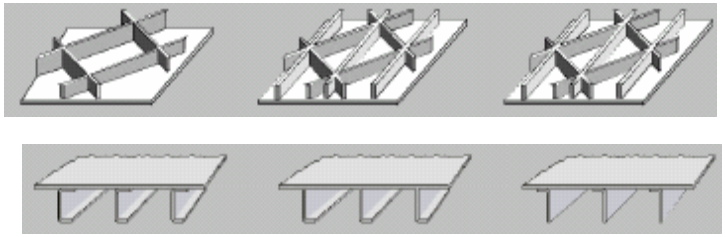
Summary

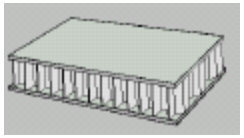


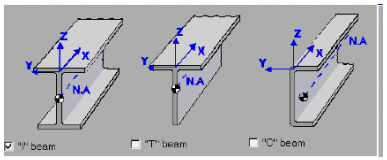
Complex vehicle designs
- **multiple body**
- **ground/ascent/entry loads**

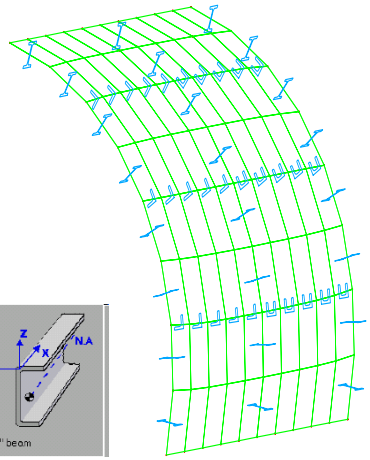


Integral panels





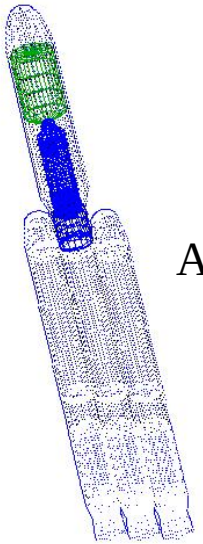




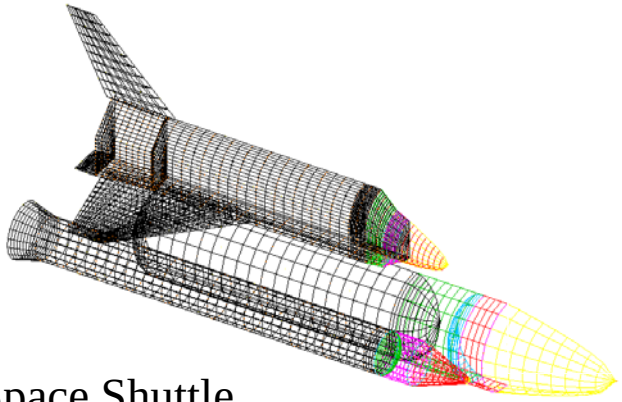
Variety of panel and beam designs
- **metallic**
- **composite**

Frame Stiffened
Semi-monocoque shell

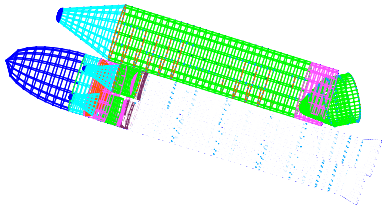
Reference configurations in development



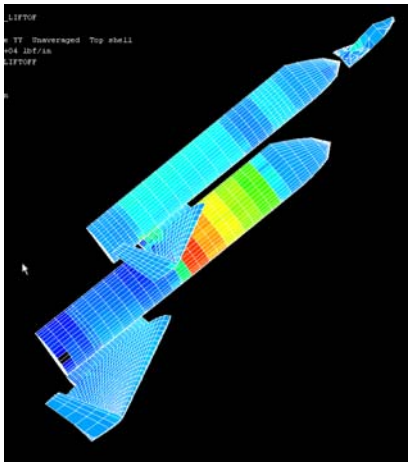
Atlas 5 Heavy



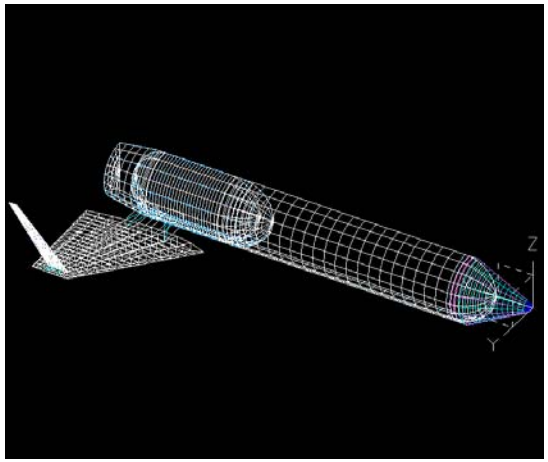
Space Shuttle



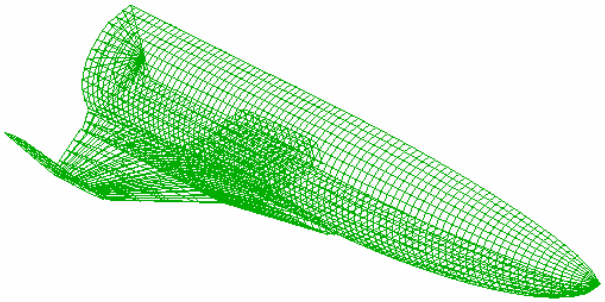
Shuttle Derived



RLV – TSTO and OSP

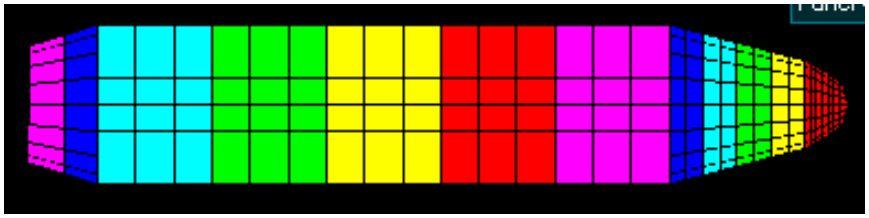


RLV - SSTO

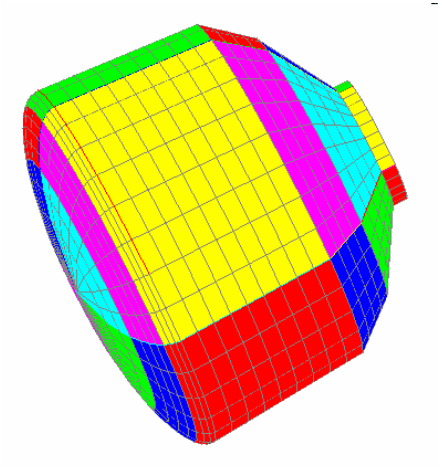


Lifting Body

Other applications under considerations



Launch vehicle payload fairings



Capsules