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

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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

INPUT
Lump Mass

I-DEAS FE Model

I-DEAS FE Mesh

INPUT
Gs & Fs

Load Balancing
EXCEL Solver

Loaded I-DEAS
FE Model

Running loads [Nx, Ny, Nxy ......]

HSLoad / HYPERSIZER Model

Panel sizing in
HYPERSIZER

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

New [K] &
Struct. [M]

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

EXCEL Solver

Iteration Loop

POST Flight Profile with
Accelerations &
CBAERO generated
Aero-forces

Zoran N. Martinovic/VAB/NASA LaRC/ June 2004
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

Portable C code with Text Input

# ISAT Reference Mach 3.4 TSTO Vehicle
# Our nose
object dome BST Nose
curvel sc
c1_xscale 15.589
c1_yscale 15.589
length -36
taper para
nodes_circ 21
nodes_axial 20
droop line
zdroop 8
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 …
FEMCI Workshop 2005 Poster Session

Nose Skirt
LOX Tank
Inter tank
FWD LH Tank
Transition Skirts
Bay
AFT LH tank
Thrust
Longerones around circumference

... beams (frames and longerones)
Sub-system masses are mapped and lumped to FEM...

### FEMCI Workshop 2005
Poster Session

**Exploration Concepts Branch**

**Langley Research Center**

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<table>
<thead>
<tr>
<th>WEIGHT (lb)</th>
<th>CENTERS OF GRAVITY (ft/ft)</th>
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<tr>
<td>LEVEL</td>
<td>X/Y/ZREF</td>
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<tr>
<td>III</td>
<td>II</td>
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#### 1.0 Wing
- Exposed wing surface: 42273.0, 0.971 0.000 -0.056
- Carry-through: 30739.0, 0.922 0.000 -0.057
- Wing-body fairing: 3736.0, 0.763 0.000 -0.004

#### 2.0 Tail
- Vertical fins: 4573.0, 1.053 0.000 0.000
- Octagonal section: 81663.0, 0.641 0.000 -0.001

#### 3.0 Body
- Nose section: 7590.0, 0.093 0.000 -0.020
- LH2 tank section: 30995.0, 0.427 0.000 0.002
- TPS: 27768.0, 0.425 0.000 0.000
- Insulation: 2202.0, 0.425 0.000 0.000
- FLD container attach str. - fwd: 470.0, 0.430 0.000 0.000
- Crew vehicle attach str.: 500.0, 0.604 0.000 0.075
- Inter tank section: 2215.0, 0.725 0.000 0.000

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- CONSIZ output file
- Mapping template file
- Mapping file into FEM

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**Component mapping**

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- x
- fofx mapping

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**15**
Individual Unit Loads are applied and model analyzed for each of them …

… 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

Constraints on axial and normal force, and other flight constraints

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