STRUCTURAL MODELING AND OpenVSP

Overview Presentation

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INTRODUCTION

- Professional Experience
  - Managing Member, Laughlin Research, LLC (August 2015–Present)
    • Developing tools and methods in the areas of parametric aircraft structural
design and analysis
  - Stress lead at Triumph Aerostructures (October 2012–July 2015)
    • Bombardier Global 7000/8000 weight savings/trailing edge team

- Educational Background
  - Master of Science in Aerospace Engineering (2012)
    • Georgia Tech
  - Bachelor of Science in Aerospace Engineering (2008)
    • Iowa State
  - NASA Graduate Student Researchers Program (LaRC)
    • Structural weight estimation environment for Hybrid Wing Body (HWB)\(^1\)
INTRODUCTION

HWB structural weight estimation environment developed as part of NASA GSRP fellowship while at Georgia Tech. Components were integrated using Phoenix Integration's ModelCenter.

VSP was the starting point

Matlab scripts generated Patran session files to generate structural geometry and FEM.

Automation of HyperSizer using API.
MOTIVATION

Design objective & sizing mission

Aspect ratio selection

Engine SFC data

Design sketch

$S_{wet}/S_{ref}$, $L/D_{max}$, $L/D_{cruise}$

$W_{fuel}/W_{TO}$

$W_{TO}$ guess

$W_{empty}/W_{TO}$ equation

$W_{TO}$ equation

Calculated $W_{TO}$ & $W_{fuel}$
No historical database available for unconventional configurations
## Motivation

<table>
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<tr>
<th>Method</th>
<th>Weight Derivation Drivers</th>
<th>Examples</th>
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<tr>
<td>Statistical</td>
<td>• Parametric variation of statistical weight/physical feature relationships</td>
<td>• OEW vs. $W_{TO}$</td>
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<tr>
<td></td>
<td>• Expressed as a fraction of $W_{TO}$</td>
<td>• Wing weight varied by $t/c$, $AR$, area, etc.</td>
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<td>Quasi-Analytical and Analytical</td>
<td>• Weight generated from theoretical foundation</td>
<td>• Box beam wing analysis</td>
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<td>• Non-optimum weight applied to theoretical weight</td>
<td>• Finite element model for structural systems</td>
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<tr>
<td></td>
<td></td>
<td>(account for 30-80% of the actual weight)</td>
</tr>
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<td>Actual Design</td>
<td>• Part weight calculated and actual weights</td>
<td>• Part volume $\times$ density</td>
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<td></td>
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<td>• Area $\times$ weight per unit area</td>
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Finite element models are not necessarily good weight prediction models.
Structural design and analysis tools vary from company to company. Improvements are needed in these tools, including life prediction tools, weight estimation tools, thermal stress analysis tools, and rapid preliminary sizing tools. These improvements would give the U.S. aerospace industry a distinct competitive advantage.

The design looked promising, but the biggest uncertainty was in estimating wing weight, which had a large impact on the calculated performance. “The weight range of uncertainty in Phase 1 was really big, from better to worse than a conventional wing.”

- Marty Bradley, Sugar principal investigator at Boeing Research & Technology (2014)\textsuperscript{5}

Note: Phase 2 included a detailed finite element model and predicted a favorable wing weight at the lower end of the spectrum.
OBJECTIVES

- Develop a parametric aircraft structural modeling tool to:
  1. Provide improved structural weight estimates during the early stages of design using geometry-driven analyses
     - Results that engineers can use to confidently select the “best” design
  2. Enable efficient, robust, and parametric structural modeling for concept evaluation
     - Results should be available in a short amount of time (days if not hours)
     - Spend less time building models and more time learning more about the problem you’re trying to solve
  3. Generate models that can be transitioned directly into later design stages and matured
     - Ease the transition between design phases
Parameters and methods for structural modeling should be consistent with “The VSP Way”:  
- Intuitive, quick, and easy  
- Familiar to aerospace designers  

So, what are these parameters?

Spars defined parametrically in wing coordinate system
Rib defined relative to spars
How to find all enclosed skin panels?
**Structural Modeling**

- Customized geometry and structural modeling tool developed in Python using a mixture of parametric and “free-form” geometry

![Diagram showing reconstructed NASA VSP model in structural modeling tool and the resulting structural layout including spars, ribs, stringers, and frames.](image-url)
STRUCTURAL MODELING

Vector3D

Line3D

Point3D

Wire3D

```python
p1 = Geom3D.Point3D((0, 0, 0))
p2 = Geom3D.Point3D((5, 5, 0))
p3 = Geom3D.Point3D((10, 0, 0))
p4 = Geom3D.Point3D((15, 5, 0))
p5 = Geom3D.Point3D((20, 10, 0))
p6 = Geom3D.Point3D((25, 5, 0))
p7 = Geom3D.Point3D((0, -5, 0))
p8 = Geom3D.Point3D((25, -5, 0))
p9 = Geom3D.Point3D((0, -10, 0))
p10 = Geom3D.Point3D((25, -10, 0))

line = Geom3D.Line3D(p7, p8)
wire = Geom3D.Wire3D([p1, p2, p3, p4, p5, p6])
vector = Geom3D.Vector3D(p9, p10)
```
Geometry utilities were developed to perform common operations including:

- Intersections
  - line-line
  - line-plane
  - line-wire
  - wire-plane
  - wire-wire

- Projections
  - point-to-line
  - point-to-plane
  - point-to-wire
  - point-to-surface

- Point inversion

```python
spiral = Gecm3D.Utils.arr2Wire3D(pnts, False, True)
vector = Gecm3D.Vector3D(p11, p12)
plane = Gecm3D.Plane3D(p11, vector)
pi = Gecm3D.Utils.intersect_Geom(spiral, plane)
```
**Structural Modeling**

- Reconstruct VSP Hermite data using **first-order** surfaces into new Wing and Fuselage geometry components.

VSP model

Wires created from Hermite data
STRUCTURAL MODELING

Matches VSP Geom Browser

```
OML_wire = VSPGeometry['WING'].extract_OML(0.5, 0.0, 0.5, 1.0, 'upper')
```
**Structural Modeling**

- Built structural components using geometry package and object-oriented approach
  - Wing
    - Spar, rib, stringer
  - Fuselage
    - Frame, longeron, bulkhead, floor, floor post
  - Miscellaneous
    - Beam, rigid body components

- Three methods to define structural geometry
  1. Parametric coordinates \((u, v)\) of parent geometry (wing or fuselage component)
  2. Relative to other structure using parametric coordinates of structural component
  3. Use free-form geometry
**STRUCTURAL MODELING**

Method 1: Using parametric coordinates of parent geometry

Sample script for front and rear spar

```plaintext
# WING FRONT SPAR
FrontSpar = WingSpar()
FrontSpar.WingGeom = WingGeom
FrontSpar.x1 = 0.15
FrontSpar.y1 = 0.05
FrontSpar.x2 = 0.15
FrontSpar.y2 = 1.0
FrontSpar.part_name = 'WING FRONT SPAR'
FrontSpar.symmetry = 'xz'
FrontSpar.color = 'red'
FrontSpar.build()
Structure[FrontSpar.part_name] = FrontSpar

# WING REAR SPAR
RearSpar = WingSpar(WingGeom, 0.65, 0.05, 0.65, 1.0, 'WING REAR SPAR', 'xz')
RearSpar.color = 'blue'
RearSpar.build()
Structure[RearSpar.part_name] = RearSpar
```

Changed only the x-position of spar and the name of the part
**Structural Modeling**

Method 2: Relative to other structure

Sample code for wing box ribs

```python
# RIBS (spaced at 20 inches)
rib_spacing = 20. / 12. # inches to feet
rib_points = FrontSpar.get_spaced_points(.1, .98, rib_spacing)
i = 0
for p1 in rib_points:
    i += 1
    Rib = WingRib(WingGeom, part_name='WING RIB ' + str(i), symmetry='xz')
    Rib.p1 = p1
    p2 = p1.copy(True)
    RearSpar.project_Point2Wire(p2)
    Rib.p2 = p2
    Rib.build()
    Structure[Rib.part_name] = Rib
```

Top view

Normal projection by default
Structural Modeling

Method 3: Free-form geometry

Merge wires of front spar and tip rib to enable seamless projection of points for stringer definition.

Evenly spaced points are created along the upper wire of the root rib. A projection vector is defined parallel to the rear spar.
Completed wing box example generated in less then 10 seconds.
Using the same script that constructs the wing (minus the stringers), the tail structure can be generated by simply providing a different VSP wing component.
STRUCTURAL MODELING

Business jet

Transport
STRUCTURAL MODELING

Hybrid Wing Body

Supersonic Concept
Identifying and constructing enclosed skin panels is a critical step and needs to be very robust

- **Do not** constrain the user’s ability to define the internal structure
- Enclosed bays are easy to see, but how does a blind computer know?

How to find all enclosed skin panels?
STRUCTURAL MODELING

Front and rear spar only

Front, rear, and mid spar only (one line of code)
989 unique skin bays found between spars, ribs, and stringers
Random number generator used to define ribs and test robustness.

Surfaces not shown due to excessive number of edges, but offset red wires show the process was successful.
Future Work

• Intersection methods for structure within different components (wing-to-fuse)

• Export loaded grids for loads transfer and application using Discrete Data Transfer Between Dissimilar Meshes (DDTBDM)$^2$

• Link to HyperSizer
  – Ideal for stiffened panel with axial and shear loads
  – Need to develop additional tools and methods for other types of structure

• Control surfaces and linkage to primary structure

• User interface
Questions?
REFERENCES


