Open Parametric Aircraft Model 1 (OPAM1)

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Background

- NASA’s *CFD Vision 2030 Study* identified “mesh generation” as a pacing in the adoption of CFD.
- “Mesh generation and adaptivity continue to be significant bottlenecks in the CFD workflow…”
- “A much higher degree of automation in all steps of the analysis process is needed including geometry creation, mesh generation and adaptation,…”
- “Flexibility to tackle … parameter studies and design optimization…”
Challenges

1. Geometry: develop a watertight model of a transport-type aircraft from a given mathematical description

2. Mesh generation: create “medium” meshes on a series of aircraft configurations (from above or from supplied STEP files)

- Both require several variations
  - some change shape but not topology
  - some change both shape and topology

- For both challenges, emphasis is on usability in a design optimization environment
Baseline Configuration (case 3a): Top
Baseline Configuration (case 3a): Side
Baseline Configuration (case 3a): Front
Configuration Construction

- Configuration is adjustable via 53 design parameters
- Entire vehicle is comprised of spheres, cylinders, cones, and “ruled” surfaces
- Cross-sections (for ruled surfaces) are either NACA 4-series airfoils or super-ellipses
- All dimensions are in feet
- An implementation of the build recipe can be found in the baseline.csm file
- The pictures here were generated by the Engineering Sketch Pad, which can be downloaded from acdl.mit.edu/ESP
Wing Schematic

ESP has been initialized and is attached to 'serveCM'
"../data/GMGW2/09AMT/baseline.com" has been loaded
"../data/GMGW2/09AMT/baseline.com" file has been changed.
Partial build (through Brch_000032) complete, which generated 1 Body(s)
Wing Construction Notes

- Constructed as a “ruled” surface between 3 NACA 4-series airfoils that are parallel to the aircraft centerline
  - “root” is in centerline plane
  - “break” is at $y = \text{wing:break} \times \text{semispan}$
  - “tip” is at $y = \text{semispan}$

- Standard NACA 4-series definition is used (which results in a blunt trailing edge), with $p = 0.40$ (see next slide)

- Airfoils are rotated about the leading edge by the indicated setting angle (measured from the horizontal)

- Wing is moved to place the root leading edge at the specified $(x_{\text{root}}, 0, z_{\text{root}})$
The NACA 4-digit thickness is given by

\[ y_t = \frac{t}{0.20} \left( 0.2969\sqrt{x} - 0.1260x - 0.3516x^2 + 0.2843x^3 - 0.1015x^4 \right) \]

and the camber is given by

\[ y_c = \begin{cases} 
\frac{m}{p^2} (2px - x^2) & \text{for } x \leq p \\
\frac{m}{(1-p)^2} [(1 - 2p) + 2px - x^2] & \text{for } x \geq p
\end{cases} \]

To get an actual point on the airfoil, add the thickness to the camber, using:

\[ x_U = x - y_t \sin \theta \quad y_U = y_c + y_t \cos \theta \]
\[ x_L = x + y_t \sin \theta \quad y_L = y_c - y_t \cos \theta \]

where \( \theta = \tan^{-1} \left( \frac{dy_c}{dx} \right) \).
**Design Parameters with Baseline Values: Wing**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>wing:area</td>
<td>4240</td>
<td>area</td>
</tr>
<tr>
<td>wing:aspect</td>
<td>9.00</td>
<td>aspect ratio</td>
</tr>
<tr>
<td>wing:taperi</td>
<td>0.48</td>
<td>inboard taper ratio</td>
</tr>
<tr>
<td>wing:tapero</td>
<td>0.23</td>
<td>outboard taper ratio</td>
</tr>
<tr>
<td>wing:sweep</td>
<td>35.0</td>
<td>leading edge sweep</td>
</tr>
<tr>
<td>wing:dihedral</td>
<td>7.0</td>
<td>dihedral</td>
</tr>
<tr>
<td>wing:break</td>
<td>0.37</td>
<td>inboard/outboard</td>
</tr>
<tr>
<td>wing:alphar</td>
<td>-3.0</td>
<td>setting angle at root</td>
</tr>
<tr>
<td>wing:thickr</td>
<td>0.15</td>
<td>thickness ratio at root</td>
</tr>
<tr>
<td>wing:camberr</td>
<td>0.04</td>
<td>camber ratio at root</td>
</tr>
<tr>
<td>wing:alphab</td>
<td>-3.0</td>
<td>setting angle at break</td>
</tr>
<tr>
<td>wing:thickb</td>
<td>0.15</td>
<td>thickness ratio at break</td>
</tr>
<tr>
<td>wing:camberb</td>
<td>0.04</td>
<td>camber ratio at break</td>
</tr>
<tr>
<td>wing:alphat</td>
<td>-8.0</td>
<td>setting angle at tip</td>
</tr>
<tr>
<td>wing:thickt</td>
<td>0.08</td>
<td>thickness ratio at tip</td>
</tr>
<tr>
<td>wing:cambert</td>
<td>0.04</td>
<td>camber ratio at tip</td>
</tr>
<tr>
<td>wing:xroot</td>
<td>54.0</td>
<td>xloc at root LE</td>
</tr>
<tr>
<td>wing:zroot</td>
<td>-5.0</td>
<td>zloc at root LE</td>
</tr>
</tbody>
</table>
Fuselage Construction Notes

- Constructed by the fusion of a sphere at the nose and a ruled surface between 5 super-ellipses
  - section 1 is a circle that is tangent to the nose sphere
  - section 2 is a circle whose center is midway between sections 1 and 3 and which is inclined to be perpendicular to the line connecting the centers of section 1 and 3
  - section 3 is a super-ellipse at the forward end of the mid-fuselage, centered at \((\text{fwdLength}, 0, 0)\)
  - section 4 is a super-ellipse at the rearward end of the mid-fuselage, centered at \((\text{fwdLength}+\text{midLength}, 0, 0)\)
  - section 5 is a super-ellipse at the tail, centered at \((\text{fwdLength}+\text{midLength}+\text{aftLength}, 0, \text{aftCenter})\)
- The nose sphere is centered at \((\text{noseRad}, 0, \text{noseHeight})\)
The super-ellipse is defined by

\[ y = \pm \text{width} \times \cos^{2/n}(\theta) \]
\[ z = \pm \text{height} \times \sin^{2/n}(\theta) \]

for \(0 \leq \theta \leq 2\pi\).

Note that if \(n = 2\), the normal circular ellipse results.
### Design Parameters with Baseline Values: Fuselage

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>fuse:noseRad</td>
<td>2.5</td>
<td>nose radius</td>
</tr>
<tr>
<td>fuse:fwdLength</td>
<td>28</td>
<td>length of forward fuselage</td>
</tr>
<tr>
<td>fuse:noseHeight</td>
<td>-2</td>
<td>zloc of center of nose</td>
</tr>
<tr>
<td>fuse:midLength</td>
<td>115</td>
<td>length of mid fuselage</td>
</tr>
<tr>
<td>fuse:midWidth</td>
<td>20</td>
<td>width of mid fuselage</td>
</tr>
<tr>
<td>fuse:midHeight</td>
<td>20</td>
<td>height of mid fuselage</td>
</tr>
<tr>
<td>fuse:power</td>
<td>3</td>
<td>super-ellipse power of mid and aft fuselage</td>
</tr>
<tr>
<td>fuse:aftLength</td>
<td>44</td>
<td>length of aft fuselage</td>
</tr>
<tr>
<td>fuse:aftWidth</td>
<td>1</td>
<td>width of aft fuselage</td>
</tr>
<tr>
<td>fuse:aftHeight</td>
<td>3</td>
<td>height of aft fuselage</td>
</tr>
<tr>
<td>fuse:aftCenter</td>
<td>8.5</td>
<td>zloc of aft fuselage</td>
</tr>
</tbody>
</table>
Pod is the fusion of a hemisphere, cylinder, and cone

Cone length is 4 times the pod’s radius

Nose of pod is positioned relative to the wing leading edge $(dx_{pod}, 0, dz_{pod})$ at the specified spanwise position
Design Parameters with Baseline Values: Pod

- **pod:ymb**: 0.50 # semispan location of pod
- **pod:dxnose**: -15.0 # x offset of nose from wing leading edge
- **pod:dznose**: -5.0 # z offset of nose from wing leading edge
- **pod:length**: 25.00 # length of pod
- **pod:thick**: 0.25 # thickness ratio
Pylon Schematic
Pylon Construction Notes

- Pylon is composed of a swept uncambered NACA 4-series airfoil
  - sweep is computed by connecting a point at a given offset from the nose of the pod (dxpod) to a point at a given offset from the leading edge of the wing (dxwing) at the given spanwise location
Design Parameters with Baseline Values:

**Pylon**

- `pylon:dxwing` 1.00  # x offset from leading edge of wing
- `pylon:dxpod` 1.00  # x offset from leading edge of pod
- `pylon:length` 9.50  # length of pylon
- `pylon:thick` 0.10  # thickness ratio of pylon
Both horizontal and vertical tail are generated in exactly the same way as the wing (but without a “break”)
Design Parameters with Baseline Values: Vertical Tail

vtail:area 610 # vtail area
vtail:aspect 1.80 # vtail aspect ratio
vtail:taper 0.28 # vtail taper ratio
vtail:sweep 45 # vtail sweep
vtail:thick 0.08 # vtail thickness
vtail:xroot 150 # xloc of root LE
vtail:zroot 9 # zloc of root LE
## Design Parameters with Baseline Values: Horizontal Tail

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>htail:area</td>
<td>810</td>
<td>htail area</td>
</tr>
<tr>
<td>htail:aspect</td>
<td>4.15</td>
<td>htail aspect ratio</td>
</tr>
<tr>
<td>htail:taper</td>
<td>0.33</td>
<td>htail taper ratio</td>
</tr>
<tr>
<td>htail:sweep</td>
<td>40</td>
<td>htail sweep</td>
</tr>
<tr>
<td>htail:dihedral</td>
<td>12</td>
<td>htail dihedral</td>
</tr>
<tr>
<td>htail:thick</td>
<td>0.08</td>
<td>htail thickness</td>
</tr>
<tr>
<td>htail:xroot</td>
<td>145</td>
<td>xloc of root LE</td>
</tr>
<tr>
<td>htail:zroot</td>
<td>5</td>
<td>zloc of root LE</td>
</tr>
</tbody>
</table>
Shape Variation 1 (case 3b)

Widen Fuselage

fuse:midWidth = 30.0
Shape Variation 2 (case 3c)

Increase Wing Sweep

wing:sweep = 40.0
Topology Variation 1 (case 3d)
Move Pylon to Wing Break 1

$pod: yb = 0.372$
Topology Variation 6 (case 3e)
Narrow Pod and Shorten Pylon

\[
\begin{align*}
\text{pod:dxnose} &= 0.0 \\
\text{pod:dznose} &= -0.8 \\
\text{pod:thick} &= 0.01 \\
\text{pylon:length} &= 2.0 \\
\text{pylon:dxwing} &= 4.0 \\
\text{pylon:dxpod} &= 4.0 \\
\end{align*}
\]