COMPOSITE PANEL OPTIMIZATION USING LAMINATION PARAMETERS AND INVERSE DISTANCE WEIGHTING INTERPOLATION

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AGENDA

• Introduction
• Objective
• Methodology
• Model
• Results
• Conclusion
• Future Work
INTRODUCTION
INTRODUCTION

• Aircraft industry is becoming more complex and competitive

• The necessity for efficiency and low operation costs is critical

• The application of composites in civilian and military aircraft is following
INTRODUCTION

INDUSTRY DEMANDS

- Deadline
- Lightweight structure
- Cost
- Certification

CHALLENGE

Design a light and reliable structure with an efficient and robust process
OBJECTIVE

- Make use of lamination parameters methodology for defining laminate stiffness matrix
- Perform a two step optimization process in order to optimize a composite wing
- Implement an interpolation strategy as a manner to reduce the number of design variables
METODOLOGY
• $A_{ij}$ is the extensional stiffness matrix

• $B_{ij}$ is the bending-extension coupling stiffness matrix

• $D_{ij}$ is the bending stiffness matrix
Lamination parameters

\[ V_1(A, B, D) = \int_{-\frac{1}{2}}^{\frac{1}{2}} \cos(2\theta)[1, \bar{z}, \bar{z}^2]d\bar{z} \]
\[ V_2(A, B, D) = \int_{-\frac{1}{2}}^{\frac{1}{2}} \sin(2\theta)[1, \bar{z}, \bar{z}^2]d\bar{z} \]
\[ V_3(A, B, D) = \int_{-\frac{1}{2}}^{\frac{1}{2}} \cos(4\theta)[1, \bar{z}, \bar{z}^2]d\bar{z} \]
\[ V_4(A, B, D) = \int_{-\frac{1}{2}}^{\frac{1}{2}} \sin(4\theta)[1, \bar{z}, \bar{z}^2]d\bar{z} \]

ABD matrices can be written as a function of:

- total thickness \( t \)
- lamination parameters \( V_i^A, V_i^B, V_i^D \)
- material invariant properties \( \Gamma_i \)
METODOLOGY

Spatial Interpolation

• We want to reduce the number of design variables and computational cost

• Use points with calculated values to estimate values at all other unknown points
METODOLOGY

Inverse Distance Weighting method

\[ u(x) = \frac{\sum_{i=1}^{n} w_i(x) u_i}{\sum_{i=1}^{n} w_i(x)} \]

- Known value
- Weight function
- Unknown value
- Power coefficient
MODEL
The conceptual aircraft used by Castro (2009) is called PRIME 900 and was a preliminary project of the 10th EMBRAER's specialization program.
MODEL

• Contour condition
MODEL

Loading cases

- 3G positive (667 kN) and a 1G negative (222 kN)

- Both applied as pressure load in panel elements
MODEL

Simplifications

• Symmetric laminate constituted of the same material
  - Bending-extension coupling (B matrix) is reduced to 0

• Balanced laminate
  - No shear-extension coupling (terms $A_{16}$ and $A_{26}$)

• Bend-twist coupling also neglected: $D_{16}$ and $D_{26}$
  - Only 4 lamination parameters are left

\[(V_1^A; V_3^A; V_1^D; V_3^D)\]
Grenestedt and Gudmundson (1993) derived explicit expressions between in-plane and out-of-plane lamination parameters and additionally proved that the feasible region was necessarily convex.

\[
\frac{1}{4}(V_i^A + 1)^3 - 1 \leq V_i^D \leq \frac{1}{4}(V_i^A - 1)^3 + 1
\]

where \(i = 1, 3\)
MODEL

Optimization steps

Step 1

Max \quad \lambda

s.a.:

1 - V_1^D + \frac{1}{4}(V_1^A + 1)^3 \geq 0

V_1^D - \frac{1}{4}(V_1^A + 1)^3 + 1 \geq 0

1 - V_3^D + \frac{1}{4}(V_3^A + 1)^3 \geq 0

V_3^D - \frac{1}{4}(V_3^A + 1)^3 + 1 \geq 0

var. : \quad -1 \leq V_1 A \leq +1

-1 \leq V_3 A \leq +1

-1 \leq V_1 D \leq +1

-1 \leq V_3 D \leq +1

Step 2

Min \quad \text{Weight}

s.a.:

\frac{1}{\lambda} < 1 \quad \text{or} \quad \lambda \geq 1

var. : \quad 3mm \leq t \leq 20mm
MODEL

Step 1

Configuration 1

Configuration 2
Step 1

Configuration 1
- 9 design variables for each skin
- 1 design variable per rib
- 3 design variables for spar 1
- 3 design variables for spar 2
- 0 design variables for spar 3
Total of 49 design variables

Configuration 2
- 20 design variables for each skin
- 1 design variable per rib
- 3 design variables for spar 1
- 3 design variables for spar 2
- 0 design variables for spar 3
Total of 71 design variables
MODEL

Step 2

- No interpolation implemented
- All wing properties had their thicknesses optimized
- Identical setup for all models
RESULTS
## RESULTS

### Step 1

<table>
<thead>
<tr>
<th></th>
<th>Configuration 1</th>
<th></th>
<th></th>
<th>Configuration 2</th>
<th></th>
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</thead>
<tbody>
<tr>
<td></td>
<td>49 variables</td>
<td></td>
<td></td>
<td>71 variables</td>
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<td></td>
</tr>
<tr>
<td><strong>Power function</strong></td>
<td>1</td>
<td>2</td>
<td></td>
<td>1</td>
<td>2</td>
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<tr>
<td><strong>Design Cycles</strong></td>
<td>36</td>
<td>42</td>
<td></td>
<td>26</td>
<td>38</td>
<td></td>
</tr>
<tr>
<td>(\lambda_{\text{initial}})</td>
<td>2.16</td>
<td>2.16</td>
<td></td>
<td>2.16</td>
<td>2.16</td>
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</tr>
<tr>
<td>(\lambda_{\text{final}})</td>
<td>3.44</td>
<td>3.40</td>
<td></td>
<td>3.38</td>
<td>3.41</td>
<td></td>
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<tr>
<td>Elapsed optimization time</td>
<td>25min 24s</td>
<td>24min 22s</td>
<td></td>
<td>17min 26s</td>
<td>24min 16s</td>
<td></td>
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</table>
CONFIGURATION 1
RESULTS
RESULTS

Configuration 1 - Step 1 - \( p = 1 \)
RESULTS

Configuration 1 - Step 1 - p = 1
RESULTS

Configuration 1 - Step 1 - $p = 1$

Lamination parameter value

Design cycle
RESULTS

Configuration 1  -  Step 2  -  \( p = 1 \)

Thickness results

Upper skin

Lower skin
CONFIGURATION 2

RESULTS
RESULTS

Configuration 2 - Step 1 - $p = 2$
RESULTS

Configuration 2 - Step 1 - $p = 2$
RESULTS

Configuration 1 - Step 2 - $p = 1$

Current results

<table>
<thead>
<tr>
<th>Component</th>
<th>Weight [kg]</th>
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<tbody>
<tr>
<td>Upper skin</td>
<td>319.73</td>
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<tr>
<td>Lower skin</td>
<td>203.17</td>
</tr>
<tr>
<td>Ribs</td>
<td>133.94</td>
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<tr>
<td>Spar 1</td>
<td>23.97</td>
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<tr>
<td>Spar 2</td>
<td>17.11</td>
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<tr>
<td>Spar 3</td>
<td>4.46</td>
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<tr>
<td>Total</td>
<td>702.38</td>
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Tanaka’s Results

<table>
<thead>
<tr>
<th>Component</th>
<th>Weight [kg]</th>
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<tbody>
<tr>
<td>Upper skin</td>
<td>327.4</td>
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<tr>
<td>Lower skin</td>
<td>224.1</td>
</tr>
<tr>
<td>Ribs</td>
<td>105.5</td>
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<tr>
<td>Spar 1</td>
<td>25.6</td>
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<tr>
<td>Spar 2</td>
<td>40.1</td>
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<tr>
<td>Spar 3</td>
<td>4.5</td>
</tr>
<tr>
<td>Total</td>
<td>727</td>
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CONCLUSIONS
CONCLUSIONS

- More design variables added more complexity to the optimization model and resulted in a higher final weight.

- With higher values of $p$, the interpolated points get to be more influenced by local values and suffer less influence from further points.

- The influence of the change in $p$ depends on the model interpolation parametrization.
QUESTIONS?