Topology Optimization of an Aircraft Component as a Fluid-Structure System with Unstructured Mesh

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1 - Introduction

TOPOLOGY OPTIMIZATION
FLUID-STRUCTURE SYSTEM
WITH UNSTRUCTURED MESH
TOPOLOGY OPTIMIZATION
TOPOLOGY OPTIMIZATION

Solid structure, with too much unnecessary material

Less loaded material removed: structure optimized
TOPOLOGY OPTIMIZATION

Material volume  Stiffness

0 1 2 3
TOPOLOGY OPTIMIZATION

• Part of the design of a structure
  • Generation of an optimized concept
  • Then it needs to be converted to CAD

• Depends on the problem definition
  • Domain that can be occupied by the structure
  • Loads and boundary conditions

• Seeks the best possible characteristics of a structure that uses less material
  • Reduces weight and potentially costs
  • Final characteristics may be worse than the ones found in the original structure
TOPOLOGY OPTIMIZATION
FLUID-STRUCTURE SYSTEM
TOPOLOGY OPTIMIZATION
FLUID-STRUCTURE SYSTEM

The fluid applies forces on the structure due to its pressure.
TOPOLOGY OPTIMIZATION
FLUID-STRUCTURE SYSTEM

Movable boundaries

Fixed boundaries
TOPOLOGY OPTIMIZATION
FLUID-STRUCTURE SYSTEM

• Optimization method described in the literature: BEFSO

• Bi-directional Evolutionary Fluid-Structure Optimization
TOPOLOGY OPTIMIZATION
FLUID-STRUCTURE SYSTEM
WITH UNSTRUCTURED MESH
(also irregular)
TOPOLOGY OPTIMIZATION

FLUID-STRUCTURE SYSTEM

WITH UNSTRUCTURED MESH

(also irregular)
TOPOLOGY OPTIMIZATION
FLUID-STRUCTURE SYSTEM
WITH UNSTRUCTURED MESH
(also irregular)
2 - Objectives

• Modify the BEFSO topology optimization method to obtain this functionality
3 - Justification

• Build upon the topology optimization method, so it can be used in cases with more complex geometry using less elements
4 - Methodology

- Start
- Problem formulation
- Current structure configuration
- FEM analysis
- Initial sensibility calculation
- Filtering of the sensibility
- Structure modification
- Current desired volume of the structure
- Reduction of the structure volume, due to the evolution rate
- Current volume equals the desired volume?
  - Yes: Stop criteria satisfied, Final structure configuration
  - No: Current volume equals the desired volume?
4 - Methodology

Definition of the domain and boundary conditions
4 - Methodology

Mesh generation
4 - Methodology

FEM analysis
4 - Methodology

Calculation of the sensibility (contribution) of each element
4 - Methodology

Filtering of the sensibility values
4 - Methodology

New structure with less material, without the elements with the lowest contributing elements.
4 - Methodology

Several iterations until the final structure
5 - Results

Half piston

Regular mesh
Movable F-S interface

a) Result found by Vicente (2013)*

b) Result achieved with 8375 elements

* Vicente, W.M. 2013 Otimização Topológica Evolucionária Aplicada a Sistemas Elasto-Acústicos. Doctoral Thesis in Mechanical Engineering, Campinas State University, Campinas, SP, Brazil.
5 - Results

NACA 4412 profile with an angle of attack of 13°57’

Optimization of internal cross structure of an airplane wing. In this case, there is a fixed interface between the fluid and the structure, because the external profile of the wing is determined by its aerodynamic behavior that is not simulated here.

The distribution of external pressure caused by air during its operation is given by Allen (1939)*, function of the dynamic pressure.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flow Velocity</td>
<td>$U = 200 \text{ km/h (55.57 m/s)}$</td>
</tr>
<tr>
<td>Air density</td>
<td>$\rho_{\text{air}} = 1.007 \text{ kg/m}^3$</td>
</tr>
<tr>
<td>Dynamic pressure</td>
<td>$q = 1554.0 \text{ Pa}$</td>
</tr>
<tr>
<td>Altitude</td>
<td>$H = 2000 \text{ m}$</td>
</tr>
<tr>
<td>Wing profile</td>
<td>NACA 4412</td>
</tr>
<tr>
<td>Angle of attack</td>
<td>$\alpha = 13^\circ57'$</td>
</tr>
<tr>
<td>Chord</td>
<td>$c = 2 \text{ m}$</td>
</tr>
<tr>
<td>Thickness of the fixed interface layer</td>
<td>$T = 10 \text{ mm}$</td>
</tr>
<tr>
<td>Number of elements</td>
<td>$n = 15790$</td>
</tr>
</tbody>
</table>

Results for optimization of the internal structural cross section in a wing profile NACA 4412. The colored regions represent the fluid with the fringe indicating the pressure levels. The gray circular region represents a beam perpendicular to image, where the fixed conditions are applied.
6 - Conclusions

✓ The developed software was capable to optimize cases with unstructured and irregular meshes, and with or without movable interface.

✓ It was possible to implement the topology optimization code BEFSO without any dependence on external commercial programs. As example, one aircraft wing was optimized using an unstructured and irregular mesh.