Blended Wing Body Wingbox Design with Aeroelasticity Constraints

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1 Introduction

This is a summary of the progress of a research project on a blended wing body wingbox design with aeroelasticity constraints. The project consists in designing a wingbox through topology optimization and with multidisciplinary optimization add to the designing process the aerodynamic forces applied on the wing. This wingbox design will be applied to the an innovative aircraft design, a blended wing body design.

1.1 Project Objectives

The project is separated in five different steps all completely dependent on each other, so the work in each step can only start once the previous step has already been completed.

1. Develop a topology optimization implementation in Python.
2. Add wingbox boundary conditions to the implementation.
3. Build a MDO formulation to design a wingbox with the topology optimization code.
4. Add aeroelasticity constraints.
5. Apply it to a blended wing body design (BWB).

To achieve the project goal of designing an optimized wingbox structure for a BWB, an OpenMDAO formulation with multiple disciplines is needed. For the aerodynamics discipline it already exists an aeroelasticity toolbox created by J. Mas Colomer but for the structures discipline there is the needed to create a topology optimization code that optimizes a wingbox.

1.2 Semester 2 Objectives

The goals of the project for the semester were well defined. First a solid state of the art was needed, to find out what has been done in topology optimization and how to start the project. With the state of the art done there were still entry barriers to get into the topology optimization topic, so a lot of work to learn more about it was done. Knowing more about the topic it was easier to understand the different implementation codes already developed on topology optimization.
The main goal for the semester was to develop a new topology optimization code in Python, this was possible from joining and translating some of the already developed codes. To this the new developed code in Python, some more boundary conditions and some different methods were added.

2 State of the Art

2.1 Topology Optimization

The semester's work focused mostly in topology optimization. Topology optimization is normally used in preliminary phases of the designs to predict the optimal material distribution within a given initial design space. According to Hayoung Chung (2019) topology optimization is a numerical method that computes an optimal structural layout for a set of objectives and constraints with the goal of getting a lighter structure using less material, that will only have material in the most critical areas.
The typical topology optimization beam is shown in Figure 2.1, where the force and the boundary conditions can be seen.

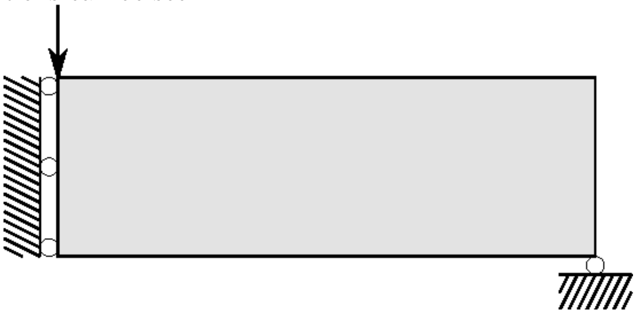

Figure 2.1: MBB Beam

There are different formulations in topology optimization, in this project it will be used the Solid Isotropic Materials with Penalization (SIMP) method.
The SIMP topology formulation that will be used in the implementation is presented on Equation 2.1. The objective of this problem is to minimize the compliance.

$$\begin{cases} min_{\{x\}} c = U^T F = \sum_{e=1}^{N} (x_e)^p u_e^T k_0 u_e \\ \frac{V(x)}{V_0} \leq f \\ 0 \leq x_{min} \leq x \leq 1 \end{cases} \tag{2.1}$$

Where c is the compliance, U is the global displacement vector, K is the global stiffness matrix, N is the number of elements, u_e is the element displacement vector, k_e is the element stiffness matrix, $V(x)$ is the material volume, V_0 is the design domain volume, f(volfrac) is

the constrained volume fraction, x is the vector of design variables (the density of each element) and x_{min} is a minimum density to avoid singularity.
This optimization problem can be solved using different methods like the Optimally Criteria and the Method of Moving Asymptotes (Svanberg, 1987). In this project it will only be used the Method of Moving Asymptotes (MMA).

3 Numerical Implementation

The topology optimization implementation developed in Python uses the as mentioned before the SIMP approach. Two SIMP approach methods were implemented on the code: the Moving Morphable Components (MMC) (Guo et al., 2014) and the Generalized Geometry Projection (GGP) by Simone Coniglio. These methods differ mostly on their approaches to the penalizations on the intermediate densities around the defined components.
The optimizer used to solve on the project to solve this optimization problem was the Method of Moving Asymptotes (Svanberg, 1987).

4 Results

On the implementation the program plots the graphs with a rate of $plot\_rate = 100$ iterations. It plots the density plot (Figure 4.1), the components plot, the compliance and the volume fraction.
The density plot in Figure 4.1 shows in black the elements with full material ($x_e = 1$), in white the void ($x_e = 0$) and in different shades of grey the intermediate densities that correspond to the boundaries of the components. These intermediate densities were penalized by the SIMP method.

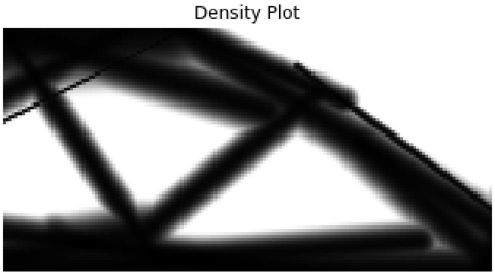

Figure 4.1: Density Plot

The less material in a structure, the less stiff the structure is. In Figure 4.2 is plotted the graph of the compliance as a function of the volume fraction and it shows the density plots for 20%, 30%, 40%, 55% and 70% of volume fraction. The figure proves that the higher the volume fraction of material in the structure, the smaller the compliance in the structure is, which means that the structure has bigger stiffness.
The volume fraction is one of the inputs in topology optimization and engineers try to find the perfect equilibrium between lighter and stiffer structures.

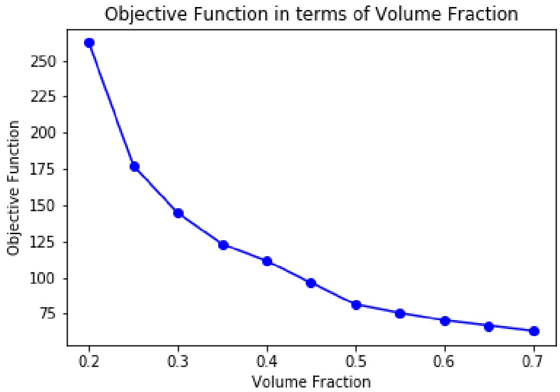

Figure 4.2: Compliance in terms volume fraction

5 Conclusion and Perspectives

The main achievement for this semester was to develop a topology optimization code in Python with the SIMP approach to be able to use OpenMDAO next semester. Next semester it will be added to the code the top rib boundary conditions to optimize a wingbox. As well as two more method approaches: the Moving Node Approach (MNA) by Overveld (2012) and the Geometry Projection (GP) by Norato (2015). These methods are almost implemented but they still need some improvement.
OpenMDAO will be used for the aerostructural coupling, a really important part of the project, to optimize the wingbox having in attention both the structure and aerodynamic forces. For the next semester the main focus will be on OpenMDAO. This platform will be used to create a wingbox and to add the aeroelasticity constraints using J. Mas Colomer work. Finally all of the wingbox design will be applied to an innovative aircraft, a blended wing body.

References

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