BWB Wingbox Design with Aeroelasticity Constraints

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S2 Research Project Final Presentation

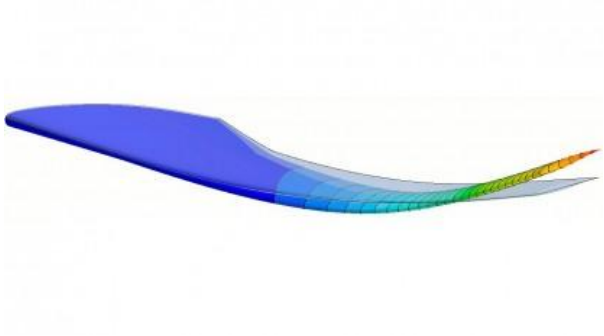
aviationweek.com

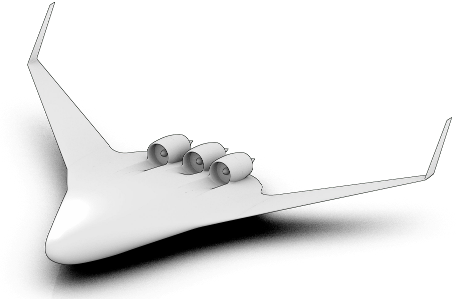
Table of Contents

Important Aspects

1. Aerostructural Coupling

2. Blended Wing Body Design





Plan for the Long Term Project

1. Topology Optimization

2. Wingbox Design

3. MDO

4. BWB

Work I did (1)

Work to be continued by future students (2, 3, 4)

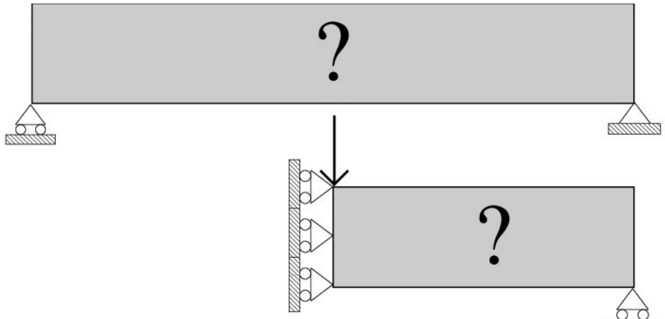
Semesters 2 and 3 Goals

1. State of the Art.
2. Learn more about Topology Optimization.
3. Create a Topology Optimization implementation in Python.
4. Add all the different methods to the code.
5. Add the Wing Rib boundary condition to the code.

Theoretical Background

Topology Optimization with SIMP

$$
\begin{cases}
min_{\{x\}}\ c = U\ F = \displaystyle\sum_{e=1}^{N} (x_e)^p\ u_e^T\ k_e\ u_e \\
\dfrac{V(x)}{V_0} \leq\ Volume\ Fraction \\
0 \leq\ x_{min} \leq x \leq 1 \\
F\ = K\ U
\end{cases}
$$




Methods Implemented

- Generalized Geometry Projection (GGP) - Coniglio, S. et al (2019)
- Moving Morphable Components (MMC) - Guo et al. (2014)
- Moving Node Approach (MNA) - Overveld (2012)
- Geometry Projection (GP) - Norato (2015)

Already Existent Topology Optimization Implementations

- A 99 line topology optimization code written in MATLAB - Sigmund, O. (2001)
- Efficient topology optimization in MATLAB using 88 lines of code - Andreassen, E. et al. (2011)
- Generalized Geometry Projection - Coniglio, S. et al (2019)
- Topology optimization codes written in Python

Python Topology Optimization

Numerical Implementation

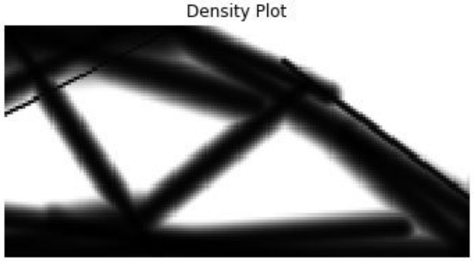
Implementation

- Python
- SIMP
- Method of Moving Asymptotes - Svanberg, K. (1987)

$$\begin{cases} min_{\{x\}}\ c = U^T K U = \sum_{e=1}^{N} (x_e)^p\, u_e^T\, k_e\, u_e \\ \dfrac{V(x)}{V_0} \leq Volume\ Fraction \\ 0 \leq\ x_{min} \leq x \leq 1 \end{cases}$$

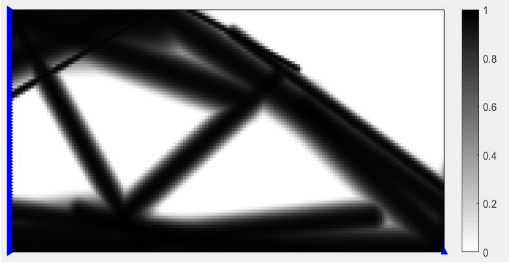
Implementations Comparison

```
it.: 1 , obj.: 113843.451 Vol.: 0.090, kktnorm.: 10.001  ch.: 1.000
it.: 2 , obj.: 8116.545 Vol.: 0.181, kktnorm.: 140.791  ch.: 0.071
it.: 3 , obj.: 2519.770 Vol.: 0.252, kktnorm.: 106.133  ch.: 0.068
it.: 4 , obj.: 1020.707 Vol.: 0.297, kktnorm.: 129.679  ch.: 0.062
it.: 5 , obj.: 573.373 Vol.: 0.331, kktnorm.: 104.725  ch.: 0.059
it.: 6 , obj.: 324.040 Vol.: 0.370, kktnorm.: 173.326  ch.: 0.040
it.: 7 , obj.: 189.456 Vol.: 0.430, kktnorm.: 36.548  ch.: 0.044
it.: 8 , obj.: 159.171 Vol.: 0.452, kktnorm.: 19.003  ch.: 0.043
it.: 9 , obj.: 141.515 Vol.: 0.473, kktnorm.: 11.453  ch.: 0.045
it.: 10 , obj.: 128.585 Vol.: 0.492, kktnorm.: 7.597  ch.: 0.030
```



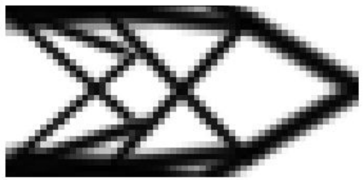
New Python Implementation

```
It.:    1 Obj.:1.138e+05 Vol.:  0.090 kktnorm.: 10.001 ch.:  1.000
It.:    2 Obj.:8.117e+03 Vol.:  0.181 kktnorm.:140.791 ch.:  0.071
It.:    3 Obj.:2.520e+03 Vol.:  0.252 kktnorm.:106.133 ch.:  0.068
It.:    4 Obj.:1.021e+03 Vol.:  0.297 kktnorm.:129.679 ch.:  0.062
It.:    5 Obj.:5.734e+02 Vol.:  0.331 kktnorm.:104.725 ch.:  0.059
It.:    6 Obj.:3.240e+02 Vol.:  0.370 kktnorm.:173.326 ch.:  0.040
It.:    7 Obj.:1.895e+02 Vol.:  0.430 kktnorm.: 36.548 ch.:  0.044
It.:    8 Obj.:1.592e+02 Vol.:  0.452 kktnorm.: 19.003 ch.:  0.043
It.:    9 Obj.:1.415e+02 Vol.:  0.473 kktnorm.: 11.453 ch.:  0.045
It.:   10 Obj.:1.286e+02 Vol.:  0.492 kktnorm.:  7.597 ch.:  0.030
```

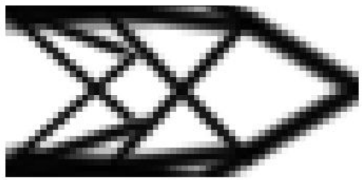


Old MATLAB Implementation

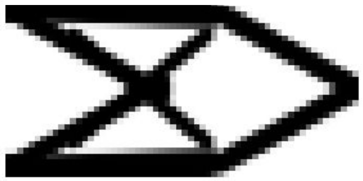
Methods



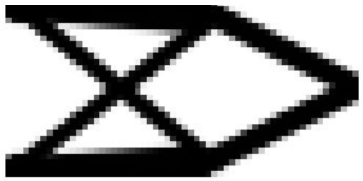
Generalized Geometry Projection (GGP)



Moving Morphable Components (MMC)



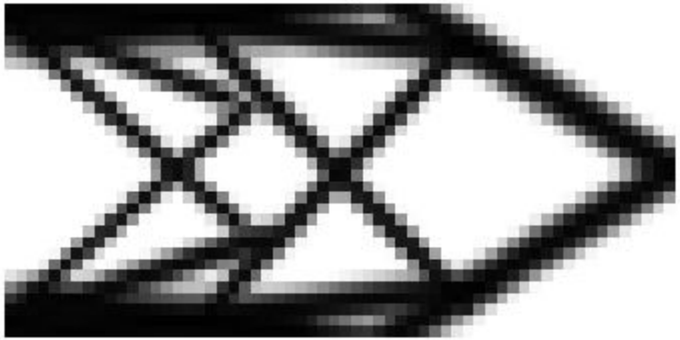
Geometry Projection (GP)



Moving Nodes Approach (MNA)

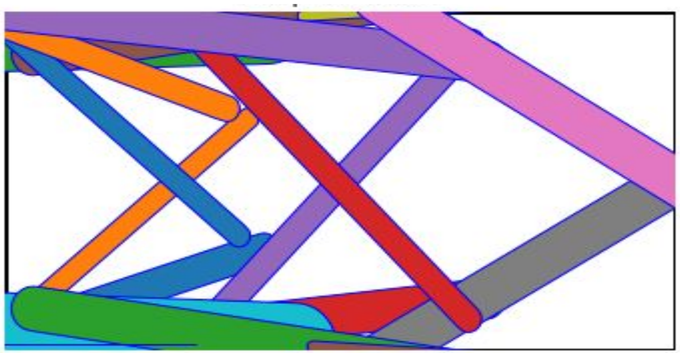
Density and Components Plots

Black → xe = 1 (Fully Material)
White → xe = 0 (Void)



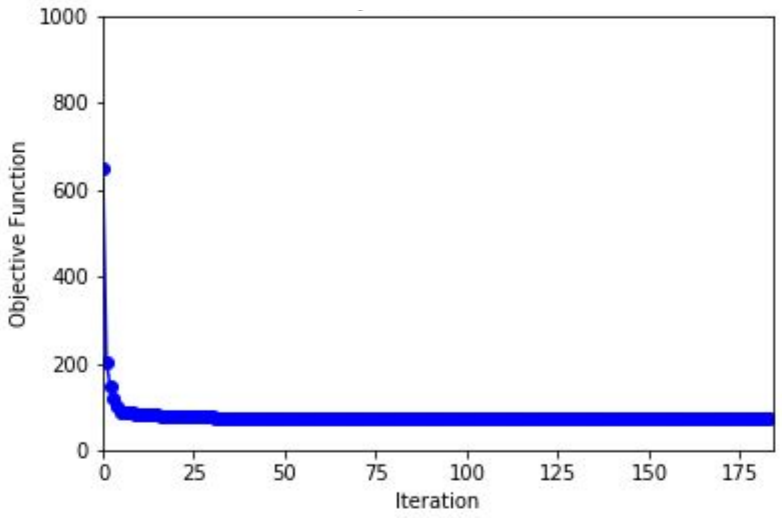
Density Plot

Each component is defined by:
x, y, L, h, Θ



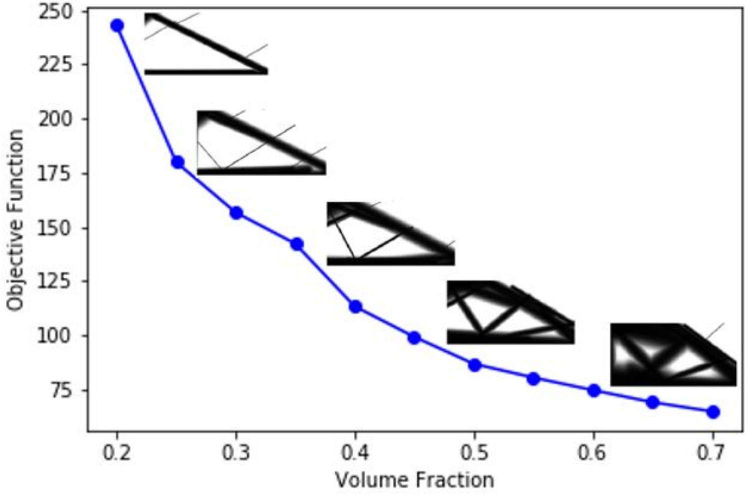
Components Plot

Objective Function

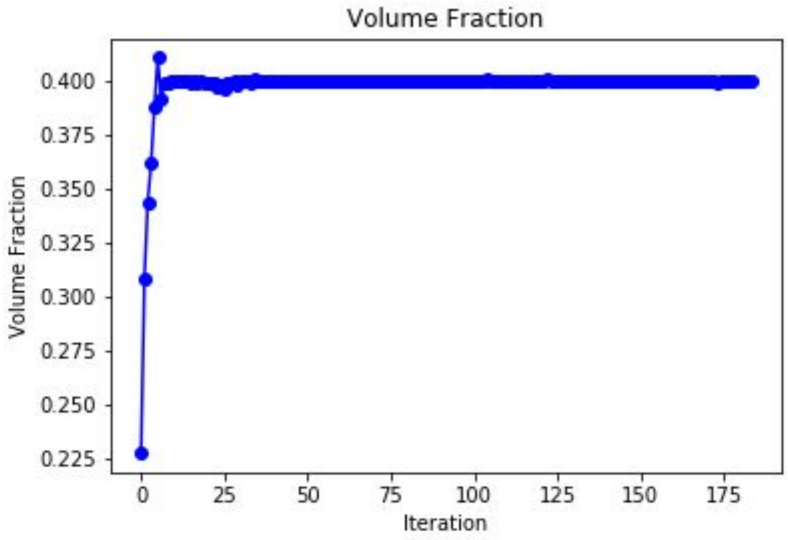


$$min_{\{x\}}\ c = \sum_{e=1}^{N} (x_e)^p\ u_e^T\ k_e\ u_e$$

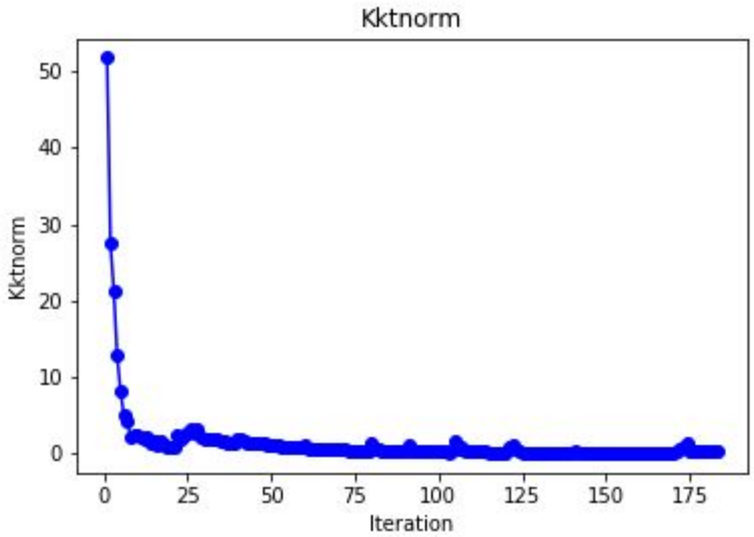
Objective Function and Volume Fraction



Volume Fraction



KKtnorm

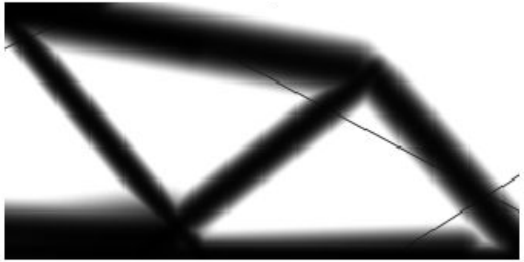

Kktnorm
Kktnorm
Iteration
0
10
20
30
40
50
0
25
50
75
100
125
150
175

Mesh Sizes


40 x 20 elements


80 x 40 elements

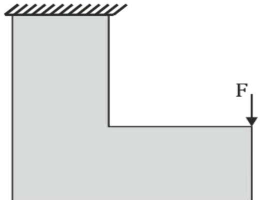

120 x 60 elements


320 x 160 elements

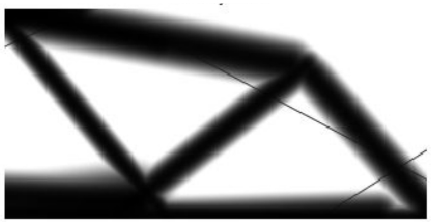
Test Cases

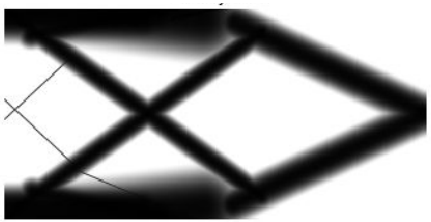
MBB

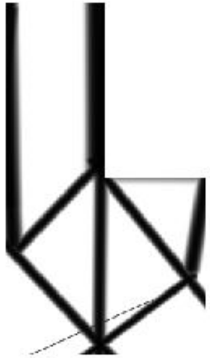
Short Cantilever



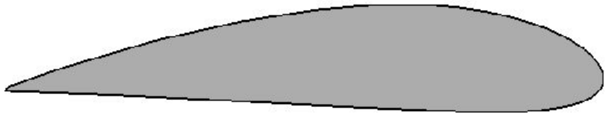
L Shape

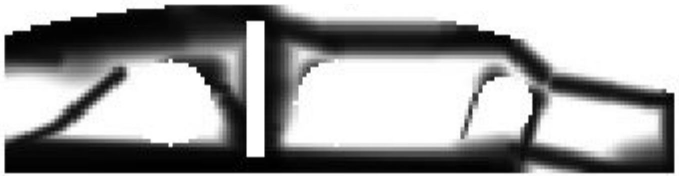






Wing Rib





Conclusions

Conclusions

1. Developed a Wing Rib Topology Optimization implementation in Python.

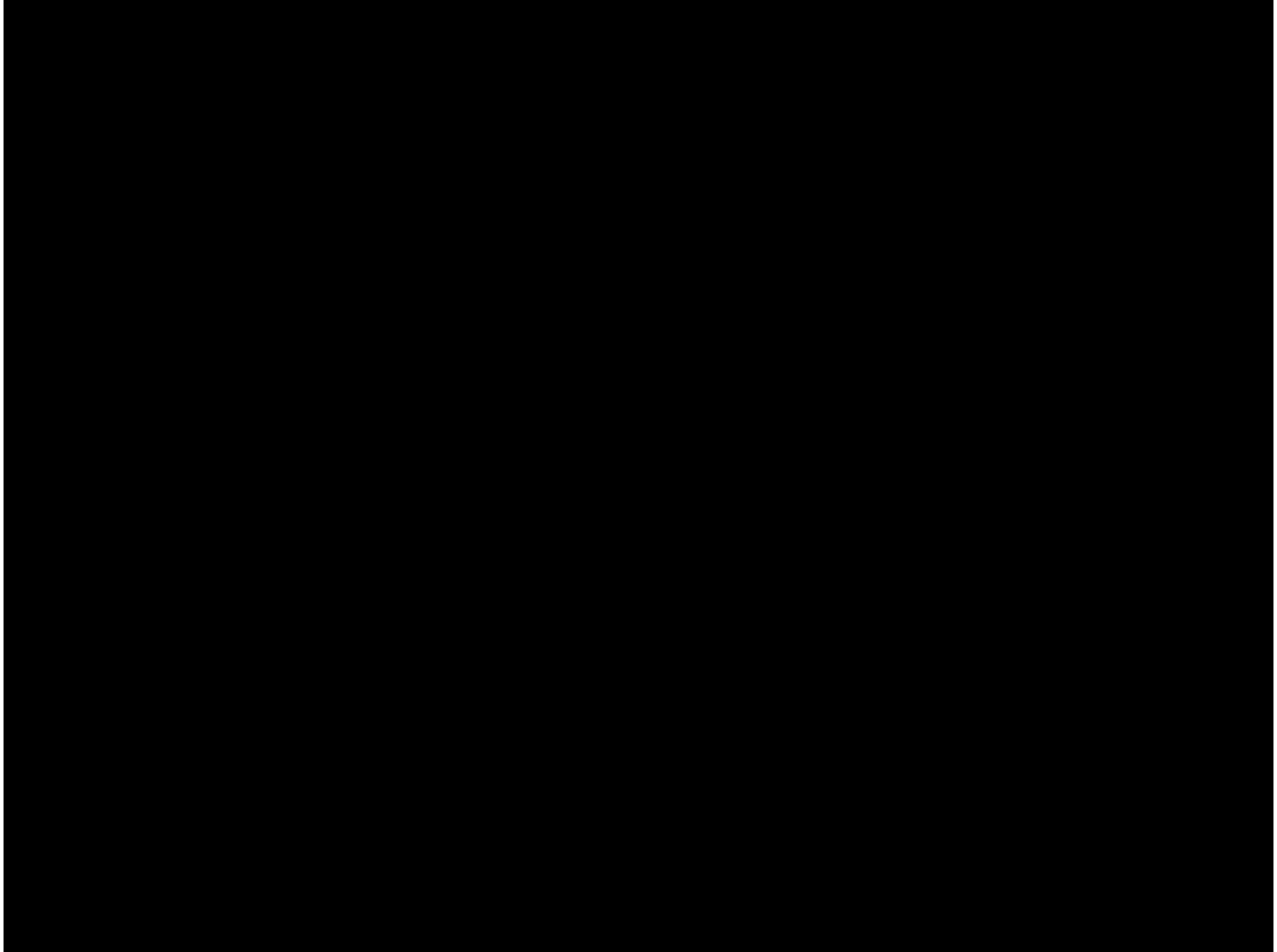
2. Developed a faster and separate MNA Wing Rib Python implementation

3. Developed a Method of Moving Asymptotes (MMA) solver in Python

Possible Future Work

Possible Future Work

- Create a Wingbox MDO formulation using OpenMDAO with the Pyton MNA Top Rib code.
- Add aeroelasticity constraints to the OpenMDAO formulation
- Apply to the Wingbox of a BWB.



Any Questions?

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