https://www.tripadvisor.fr/LocationPhotoDirectLink-g187529-d574612-i349532022-Museum_of_Natural_Science_Museo_de_Ciencias_Naturales-Valencia_Province_o.html

Concevoir une {aéro}structure en LEGO

Prof. Joseph Morlier *et al*

Concevoir une $^{\{aéro\}}$structure en LEGO

Prof. Joseph Morlier *et al*

et al is important

Why ?

Student's Research projects @SUPAERO

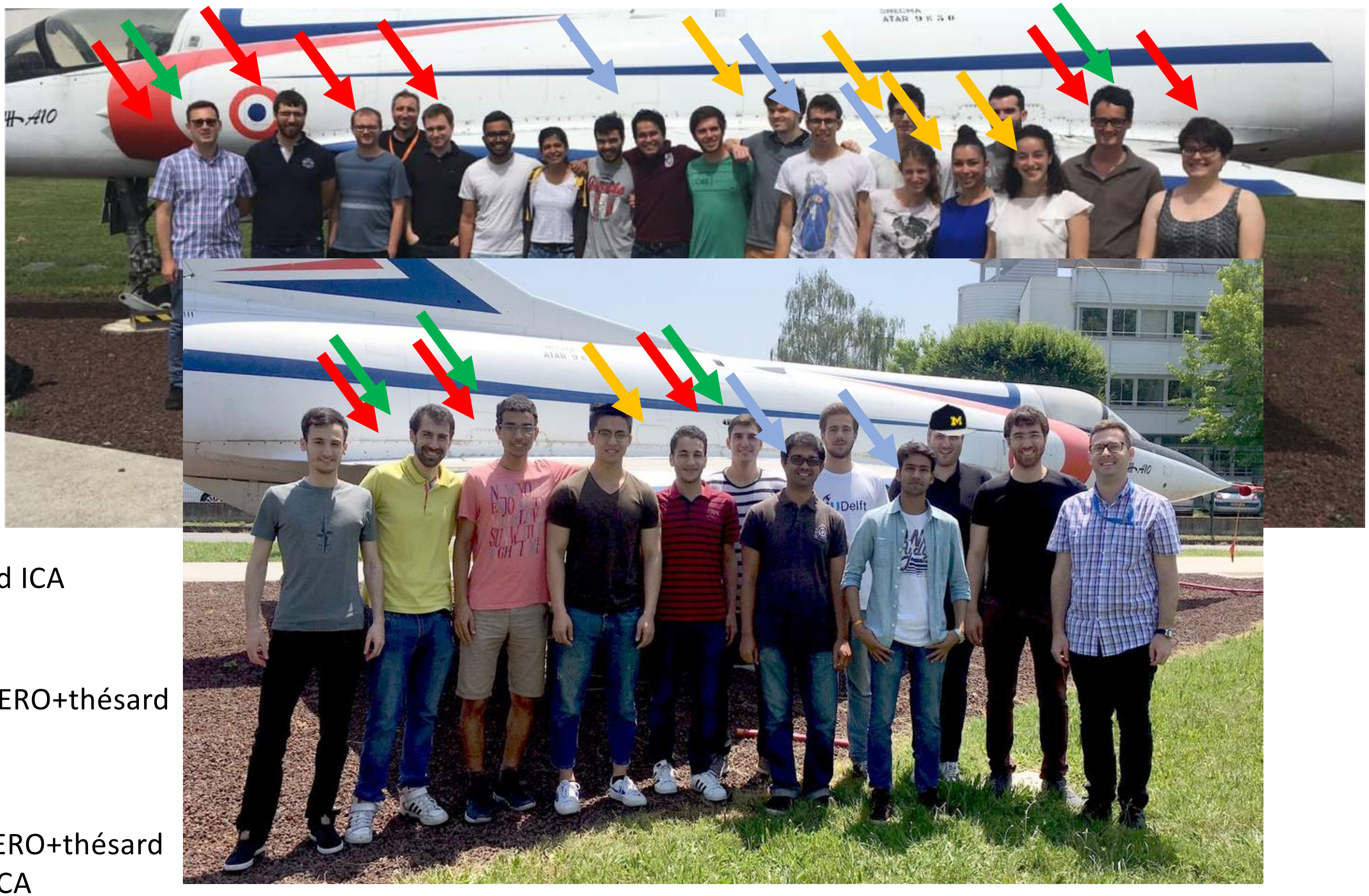
Giving Back with SUPAERO's students

Prof's Impact increases, Students are becoming Phds, or R&T engineers (these new researches feed the courses&RP)

Students produce research papers and obtain new skills !

At master Level: Prof teaches elective courses+ Research Projects with students

Students are PhD Ready in CSM/MDO



resté du
coté
obscure
de la
force

Thésard ICA

SUPAERO+thésard
ICA

SUPAERO+thésard
hors ICA

Popularization

décembre 5, 2017

Construire une aile d'avion en Lego c'est possible

Joseph Morlier, *ISAE-SUPAERO*

Les recherches d'optimisation permettent de créer de nouvelles structures plus légères et plus résistantes. Idéales pour les avions !

https://www.tripadvisor.fr/LocationPhotoDirectLink-g187529-d574612-i349532022-Museum_of_Natural_Science_Museo_de_Ciencias_Naturales-Valencia_Province_o.html

Is it possible to build an aircraft wing in LEGO® ?

Publié le 17 février 2020 Modifier l'article | Voir les stats

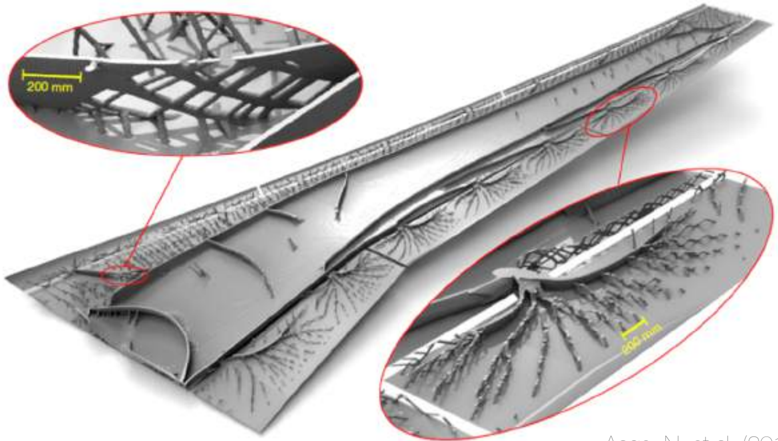
joseph morlier
Professor in Structural and Multidisciplinary Design Optimization, ... any idea?
5 articles

https://www.linkedin.com/pulse/possible-build-aircraft-wing-lego-joseph-morlier/?articleId=6627240732975480832

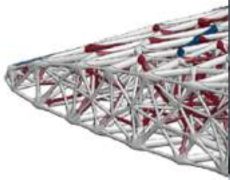
Aerospace app

Continuous (Gradient based) Optimization

Topology optimization



Aage, N. et al. (2017)



Warning

- Restricted in this presentation to 2D domain
- Lot of results limited to Compliance Optimization (classical benchmark)
- SAMO community testcases: L-Shape, MBB, we introduce the Rib. aerostructure

Agenda for today

- Part1 Introduction 4'
- Part2 Topology Optimization & Opensource software 4'
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Agenda for today

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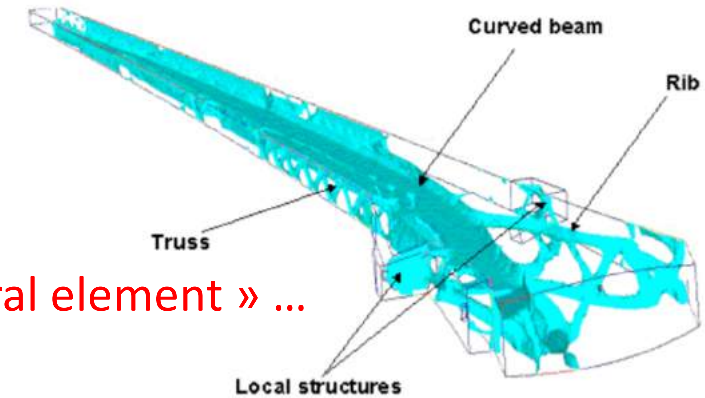
In 2016 I was searching to differentiate my TopOpt research

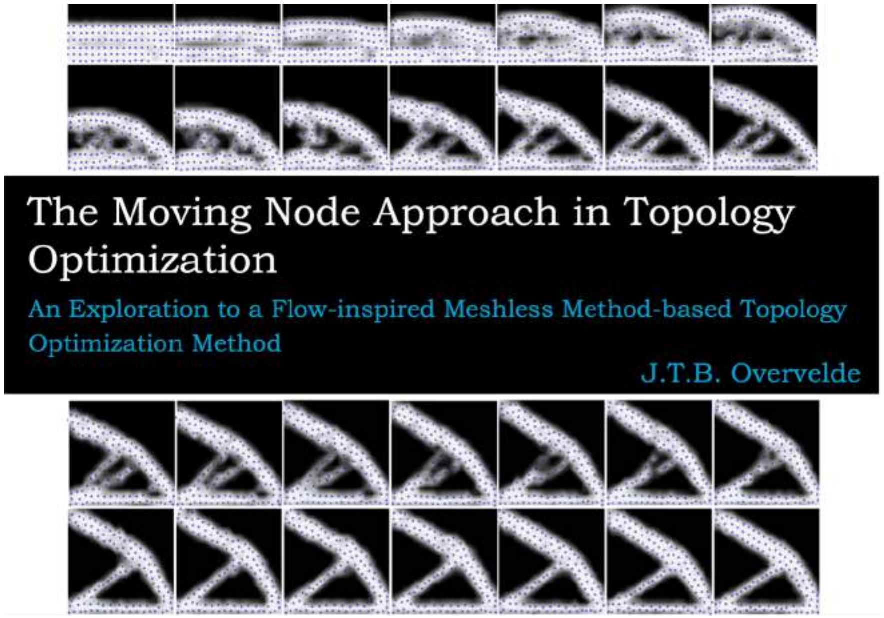
My idea was to use meshless method in TopOpt for « explicit » structural elements, why?

Industrial Results @ AIRBUS
see Grihon's works WSMO 2009, difficult to extract « structural element » …



But this work already existed… in a master thesis

Let's try to follow this paper's conclusions



- Improve the algorithm
  - Convergence
  - Replace meshless methods with FEM

Johannes T. B. Overvelde

SUIVRE

Associate Professor, AMOLF & Eindhoven University of Technology

Adresse e-mail validée de amolf.nl - Page d'accueil

Soft Matter Mechanical Metamaterials Soft Robotics Computational Engineering Optimization

So we started with a SUPAERO's student project

CSMA 2017
13ème Colloque National en Calcul des Structures
15-19 Mai 2017, Presqu'île de Giens (Var)

OPTIMISATION TOPOLOGIQUE SANS MAILLAGE
Vers la reconnaissance d'éléments structuraux

G. Raze[1], M. Charlotte [2], J. Morlier[2]

[1] *Université de Toulouse, ISAE SUPAERO, 10 avenue Edouard Belin, 31405 Toulouse, France*
[2] *Institut Clément Ader (ICA), Université de Toulouse, ISAE SUPAERO-CNRS-INSA-Mines Albi-UPS, Toulouse, France*

Résumé — Cet article présente des résultats d'une étude d'optimisation topologique utilisant une nouvelle approche par ajout de variables de localisation des nœuds. Dans cette approche, la discrétisation spatiale est découplée de la distribution matérielle. Les effets de la méthode de discrétisation, de l'optimiseur et de la fraction de volume sont étudiés. Les résultats de l'approche par ajout de variables de localisation des nœuds sont prometteurs et suggèrent que cette approche pourrait constituer une alternative aux méthodes actuellement utilisées en optimisation topologique.

Mots clés — Mécanique des structures ; Optimisation topologique ; Compliance minimale ; Méthodes sans maillage ; Approche par ajout de variables de localisation des nœuds ; Méthode des éléments finis

Ghislain Raze
PhD Student, University of Liège
Adresse e-mail validée de uliege.be

SUIVRE

TITRE	CITÉE PAR	ANNÉE
A digital nonlinear piezoelectric tuned vibration absorber G Raze, A Jadoul, S Guichaux, V Broun, G Kerschen Smart Materials and Structures 29 (1), 015007	14	2019
Active tuned inerter-damper for smart structures and its $\mathcal{H}_\infty$ optimisation G Zhao, G Raze, A Paknejad, A Deraemaeker, G Kerschen, C Collette Mechanical Systems and Signal Processing 129, 470-478	12	2019

According to Bendsøe (1989), Topology optimization:
"… should consist of a determination for every point in space whether there is material in that point or not."

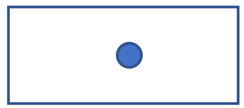
Moving Node Approach (MNA)

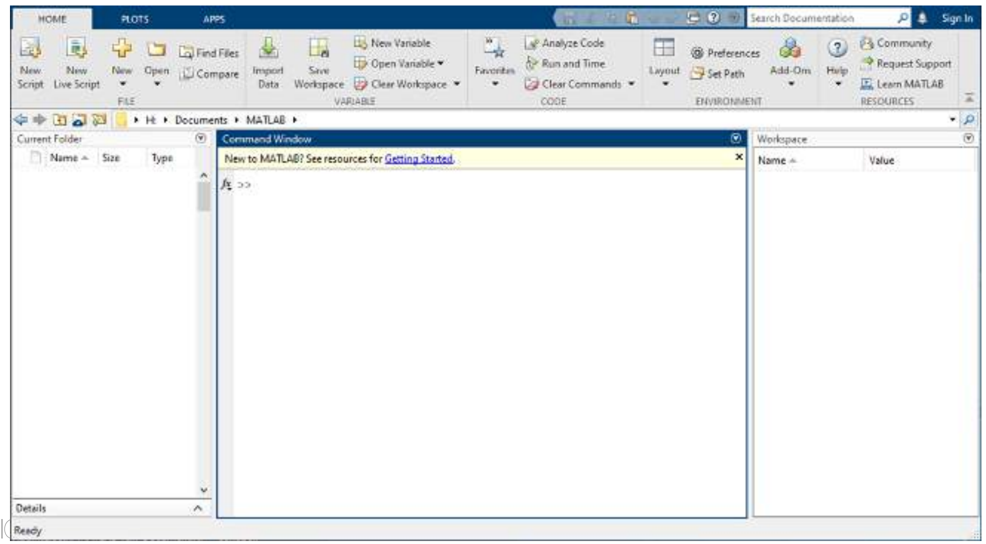
5 variables per node

Structural Members: Beam is the primitive chosen here

Optimization variables :

- Positions (x,y)
- Orientation (θ)
- Dimensions (Lx,Ly)

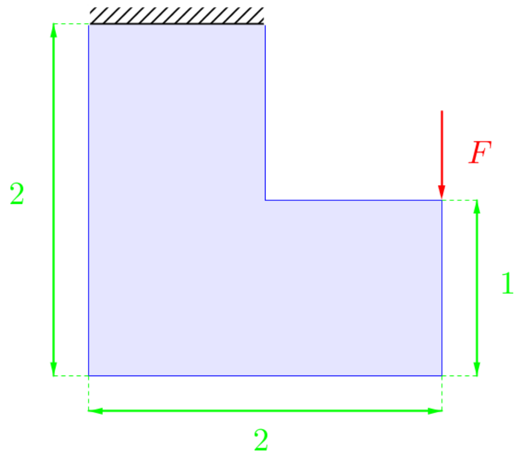


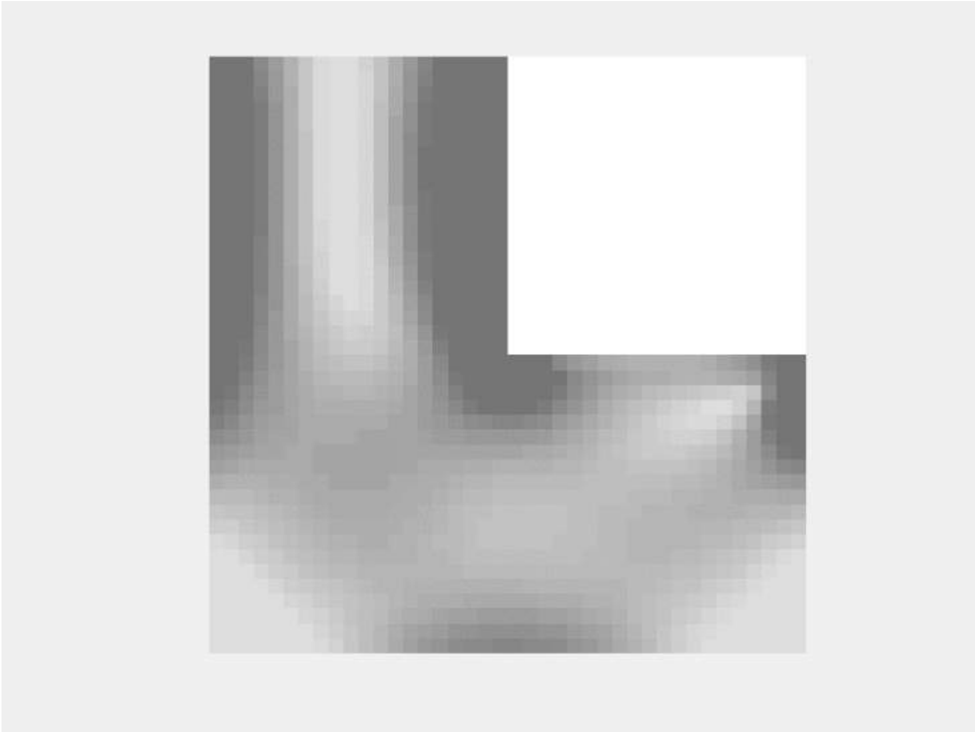



```
disp('SIMP')
top88(nelx,nely,volfrac,3,2,1)

disp('MNA')
topmna(x0,nelx,nely,volfrac,3,[ratio;aspect],tolchange);
```

Results SIMP nelx=nely=40→ 1600 design variables minC wrt Volfrac=0.25 , Ku=f



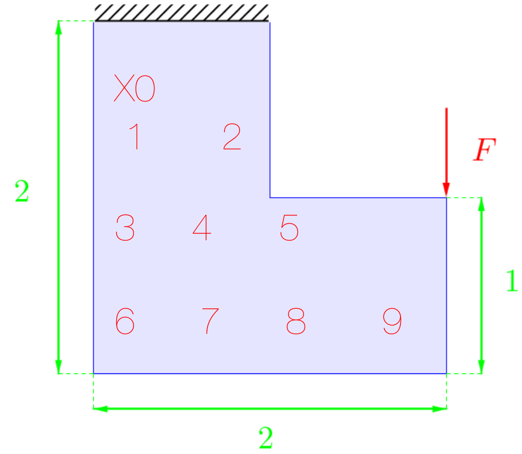


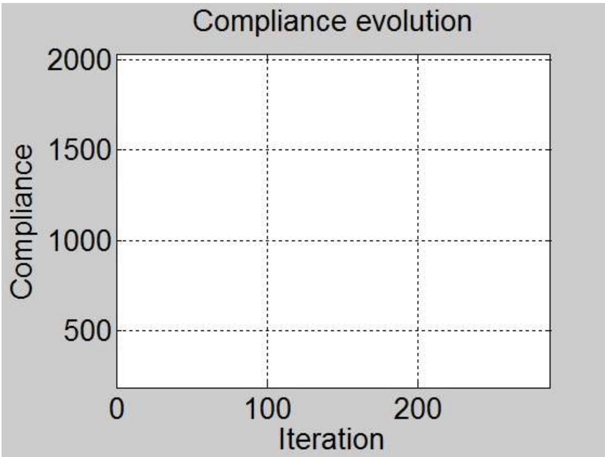
Andreassen, E., Clausen, A., Schevenels, M., Lazarov, B. S., & Sigmund, O. (2011). Efficient topology optimization in MATLAB using 88 lines of code. Structural and Multidisciplinary Optimization, 43(1), 1-16.

http://www.topopt.mek.dtu.dk

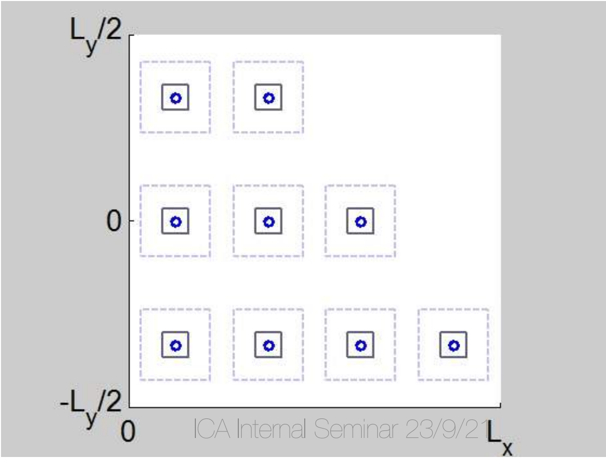
Results MNA, 9*5=45 design variables minC wrt Volfrac=0.25 , Ku=f

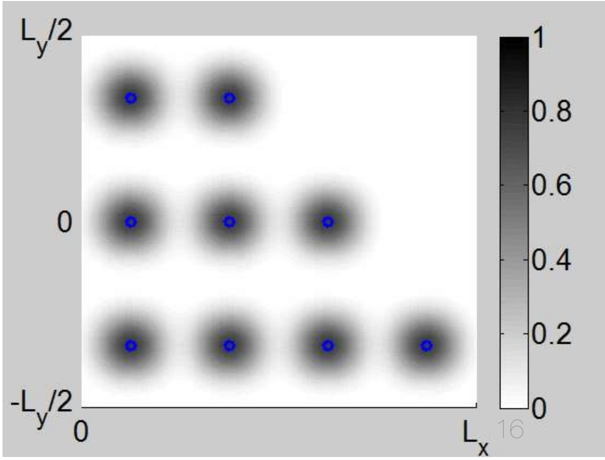
At the end, explicit assembly of beams i.e. Structural Layout
But sensitivity to X_0/mesh





Raze, G., & Morlier, J. (2021). Explicit topology optimization through moving node approach: beam elements recognition. arXiv preprint arXiv:2103.08347..





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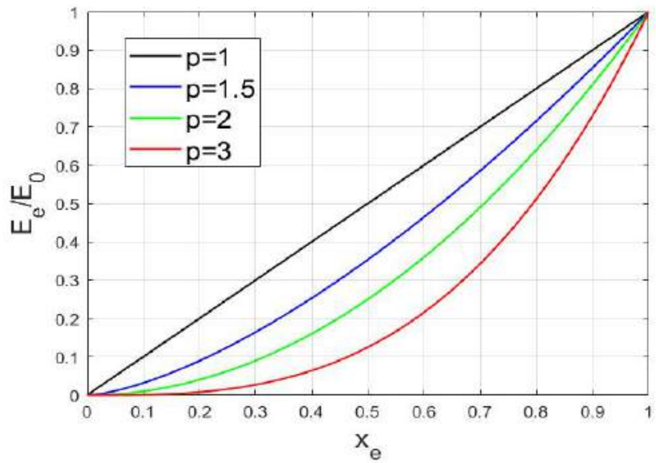
Topology Optimization

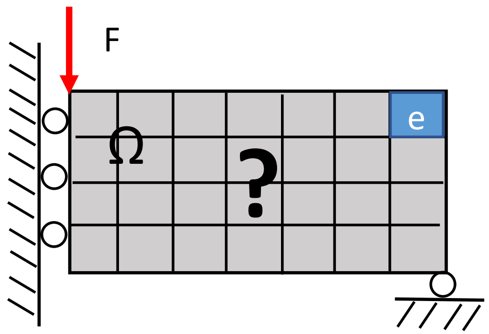
Solid Isotropic Material with Penalization
SIMP method (*Sigmund et al.)*

$$E_e(x_e) = E_{\min} + x_e^p (E_0 - E_{\min})$$

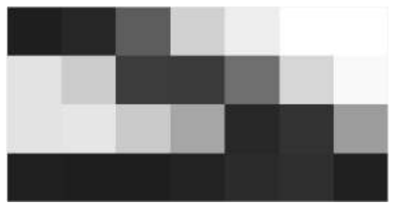


Optimization Problem (*Andreassenet al.*)

$$\begin{aligned}
\min_{\mathbf{x}} : \quad & c(\mathbf{x}) = \mathbf{U}^{\mathrm{T}}\mathbf{K}\mathbf{U} = \sum_{e=1}^{N} E_e(x_e)\mathbf{u}_e^{\mathrm{T}}\mathbf{k}_0\mathbf{u}_e \\
\text{subject to :} \quad & V(\mathbf{x})/V_0 = f \\
& \mathbf{K}\mathbf{U} = \mathbf{F} \\
& \mathbf{0} \leq \mathbf{x} \leq \mathbf{1}
\end{aligned}$$



top88 result



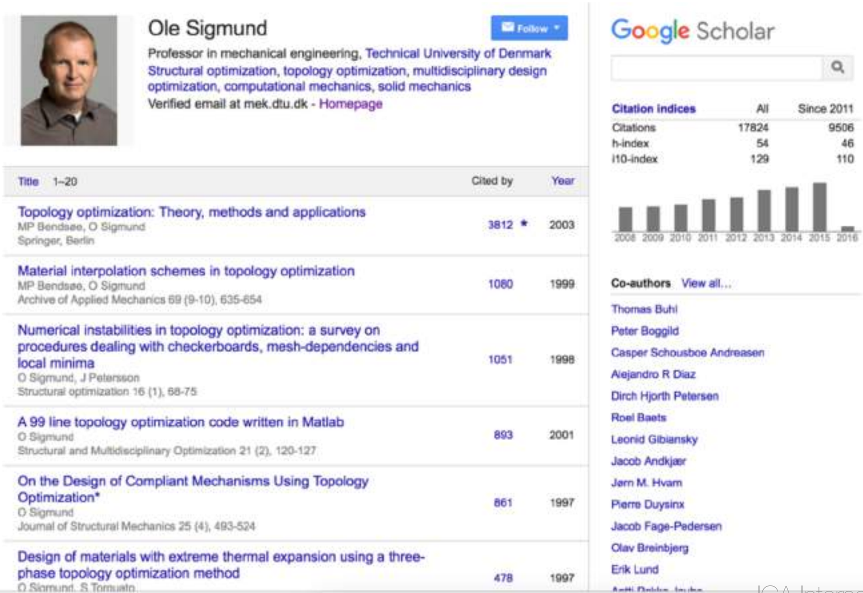
- Ole Sigmund. Morphology-based black and white filters for topology optimization. *Structuraland MultidisciplinaryOptimization*, 33(4):401–424, Apr2007.
- Erik Andreassen, Anders Clausen, Mattias Schevenels, BoyanS. Lazarov, and Ole Sigmund. Efficient topology optimization in matlab using 88 lines of code. *Structuraland MultidisciplinaryOptimization*, 43(1):1–16, Jan2011.

BUT …IN PRACTICE?

Educational article:

O. Sigmund , A 99 line topology optimization code written in Matlab Struct Multidisc Optim 21, 120–127 Springer-Verlag 2001

Heuristic formulation (intuitiive method of optimisation, but with no convergency proofs) to update xe by bi-section algorithm



1. Transform discrete variables continuously (TO USE gradient-based algorithms)
2. Find an objective function with "cheap" derivatives

Cheap derivative (1)

Compliance Sensitivity

Compliance

$$C = \mathbf{F}^T \mathbf{U}$$

$$\frac{\partial C}{\partial x_i^l} = \frac{\partial \mathbf{F}}{\partial x_i^l}^T \mathbf{U} + \mathbf{F}^T \frac{\partial \mathbf{U}}{\partial x_i^l}$$

No body forces, no accelerations:

$$\frac{\partial \mathbf{F}}{\partial x_i^l} = 0$$

Cheap derivative (2)

Compliance Sensitivity

Discrete equilibrium equation

$$\mathbf{K}\mathbf{U} = \mathbf{F}$$

$$\frac{\partial \mathbf{K}}{\partial x_i^l}\mathbf{U} + \mathbf{K}\frac{\partial \mathbf{U}}{\partial x_i^l} = \frac{\partial \mathbf{F}}{\partial x_i^l} = 0$$

Hence

$$\frac{\partial \mathbf{U}}{\partial x_i^l} = -\mathbf{K}^{-1}\frac{\partial \mathbf{K}}{\partial x_i^l}\mathbf{U}$$

$$\boxed{\frac{\partial C}{\partial x_i^l} = \mathbf{F}^T\frac{\partial \mathbf{U}}{\partial x_i^l} = -\mathbf{U}^T\mathbf{K}^T\mathbf{K}^{-1}\frac{\partial \mathbf{K}}{\partial x_i^l}\mathbf{U} = -\mathbf{U}^T\frac{\partial \mathbf{K}}{\partial x_i^l}\mathbf{U}}$$

Knowing displacements
you also know gradients

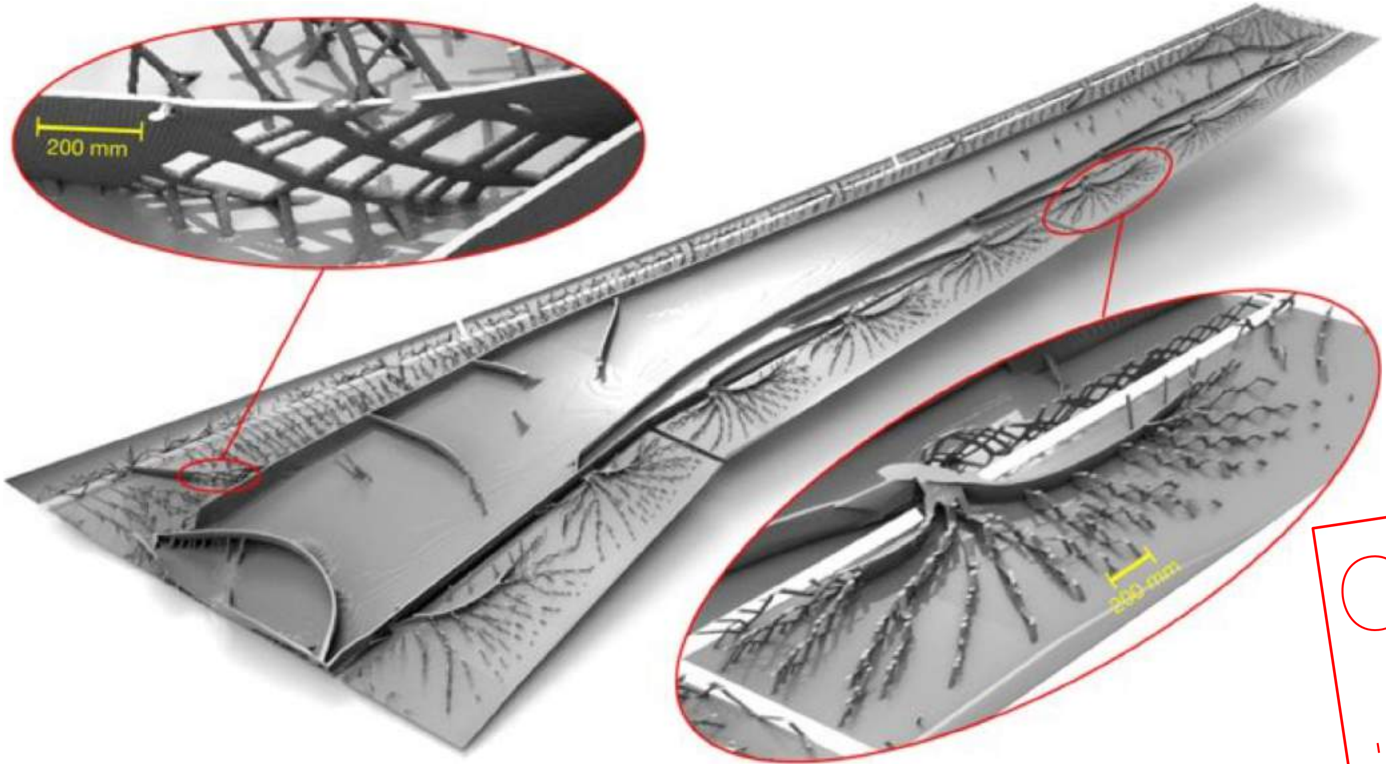
Pixels?

When the size of the FE model is increasing, the SIMP optimization problem is … increasing

Chris Columbus et al, Pixels, movie 2015

Use HPC and lot of time

Niels Aage, Erik Andreassen, Boyan S Lazarov, and Ole Sigmund. Giga-voxel computational morphogenesis for structural design. Nature, 550(7674):84, 2017.



Or

...

Agenda for today

- Part1 Introduction 3'
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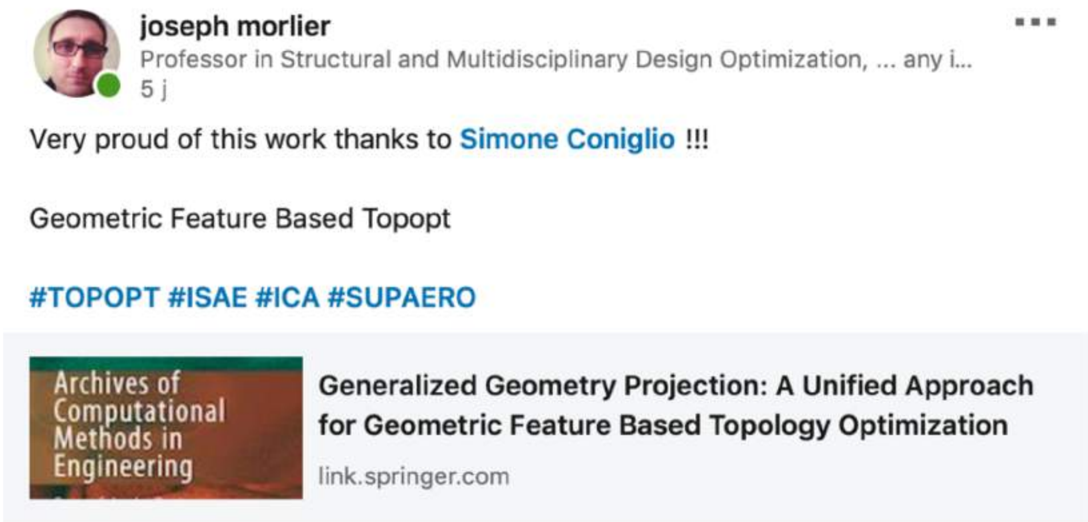
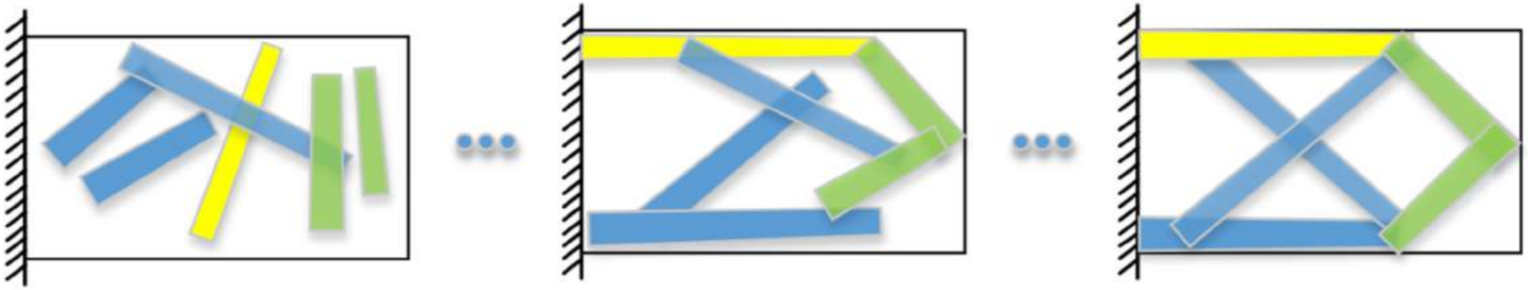
- **Part3 GGP for aerostructures 5'**
- Part4 Ecoptimization & Computational Fabrication 5'

Explicit TopOpt



https://github.com/topggp/blog



Eulerian VS Lagrangian

Design variables update

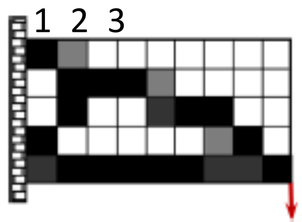
Interpretation

Model update
Density, Young modulus

Density based

variables : material density

$$x_1 = 1$$
$$x_2 = 0.5$$
$$x_3 = 0$$
$$\ldots$$

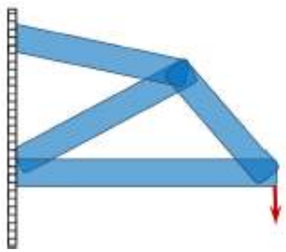


Innovative approach to help engineering solution identification : Components are placed in design space according to variables and material density are derived accordingly.

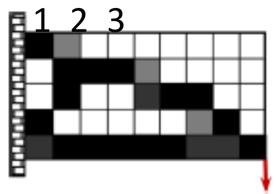
Lagrangian approaches

Variables : geometrical data

$$x_1 = Position$$
$$x_2 = Length,$$
$$Height \ldots$$



Projection



[12] Zhang, Weisheng, Jian Zhang, and Xu Guo. "Lagrangian description based topology optimization—a revival of shape optimization." *Journal of Applied Mechanics* 83.4 (2016): 041010.

Design is made of engineering bricks like: beam, plate, brick….

The Team

Thanks also to Miguel and christian @ICA

Simone Coniglio
Topology Optimization Engineer at Airbus

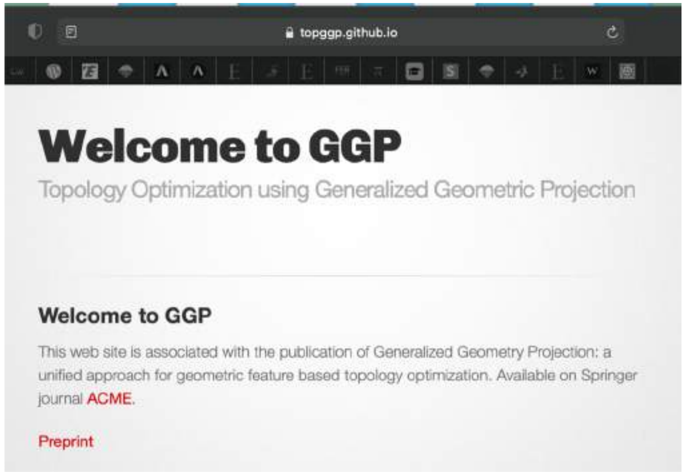
João Matos
Data Science Intern at GSK

K Vilasraj BHAT
Looking for Opportunities in Aerospace Structure domain | Research Assistant at ISAE-SUPAERO & Institut Clément Ader

Robin Grapin
Étudiant(e) à ISAE-SUPAERO

Gabriele Capasso
PhD Candidate Airbus/UPS. MSc ISAE-SUPAERO/Politecnico di Torino

Different Programing language &app



Matlab (historic top88)
code by S. CONIGLIO: Matlab's topggp
Python
code by J. CRUZ-FERREIRA-MATOS: Python's topggp
Julia (differential programing)
code by R. GRAPIN & J. MORLIER: Julia's topggp
Applications for Aerospace
Tutorials available by V. BHAT and J. MORLIER
Aerospace's topggp
Applications for ALM
Tutorials available by G. CAPASSO, V. BHAT S. CONIGLIO, C. GOGU and J. MORLIER
ALM's topggp

Generalized **G**eometry **P**rojection (GGP)

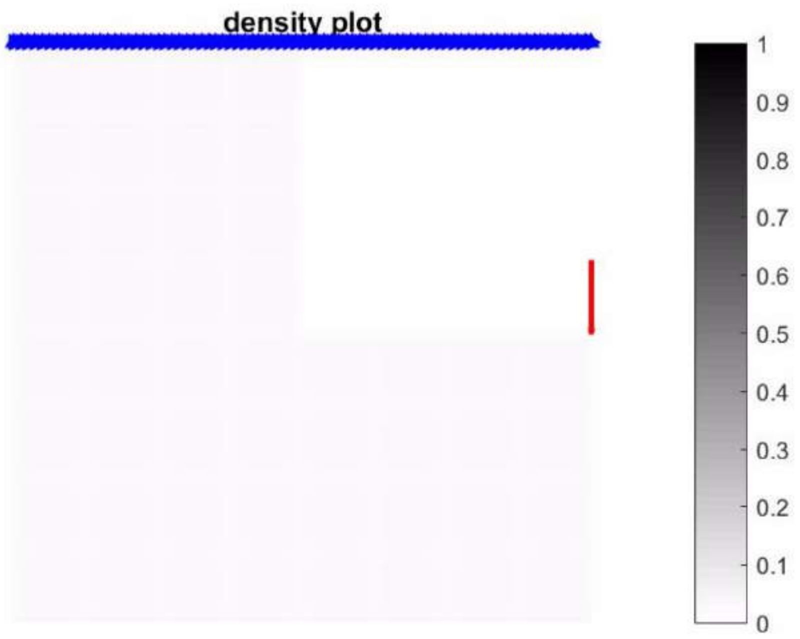
Table 1: Choice to be made to recover all other approaches using Generalized Geometric Projection

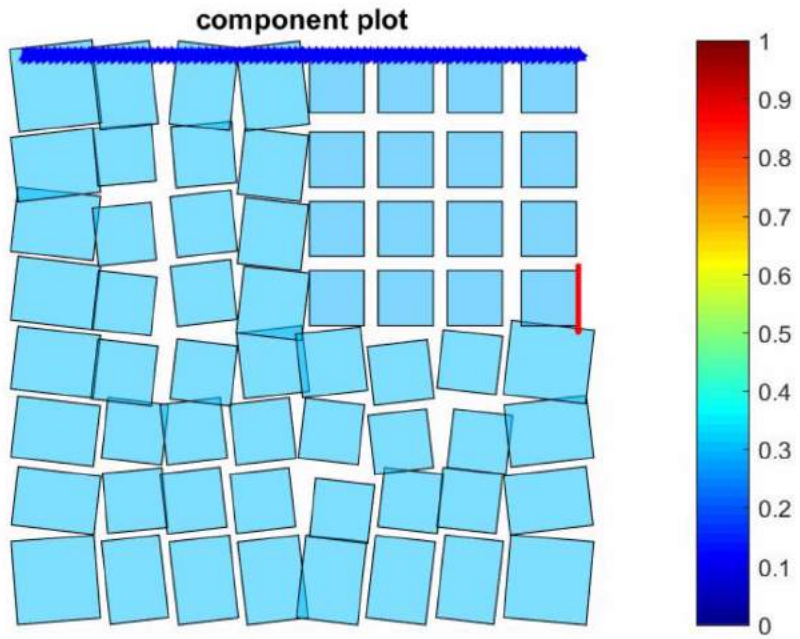
Method	MMC	GP	MNA
W^c	$H_\epsilon(\chi^{el})^q$	$\tilde{\delta}_i^{el} m_i^{\gamma_c}$	$m_i^{\gamma_c} w_i^{el}$
W^v	$H_\epsilon(\chi^{el})$	$\tilde{\delta}_i^{el} m_i^{\gamma_v}$	$m_i^{\gamma_v} w_i^{el}$
p	∞	∞	∞
R	$\frac{\sqrt{3}}{2} dx$	$\frac{1}{2} dx$	$\frac{1}{2} dx$
N_{GP}	4	1	1
$\mathbb{V}$	$\frac{\sum_{j=1}^{4} H_\epsilon(\chi_j^{el})}{4}$	$\Pi(\left\{\hat{\delta}^{el}\right\}_v, \kappa)$	$\Pi(\{\delta^{el}\}_v, \kappa)$
$\mathbb{M}$	$\frac{\sum_{j=1}^{4} (H_\epsilon(\chi_j^{el}))^q}{4}$	$\Pi(\left\{\hat{\delta}^{el}\right\}_c, \kappa) E$	$E_{min} + (E - E_{min}) \Pi(\{\delta^{el}\}_c, \kappa)^{p_b}$

- All reviewed approach can be represented as a special case of Generalized Geometry Projection
- One can moreover change sampling window size (R),shape (p), Gauss Points number (N_{GP})
- Changing the number of Gauss point one can avoid optimization saddle points induced by the projection

Results MNA, 8*8*6=384 design variables minC st Volfrac=0,4

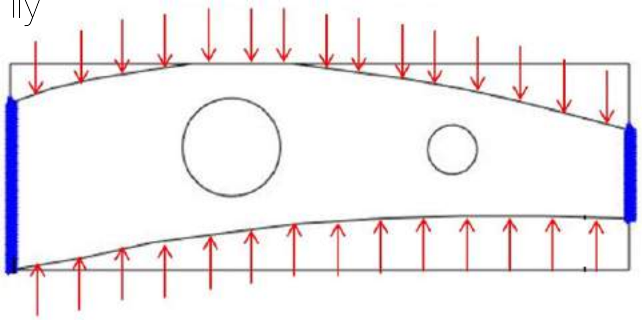
LEGO style!



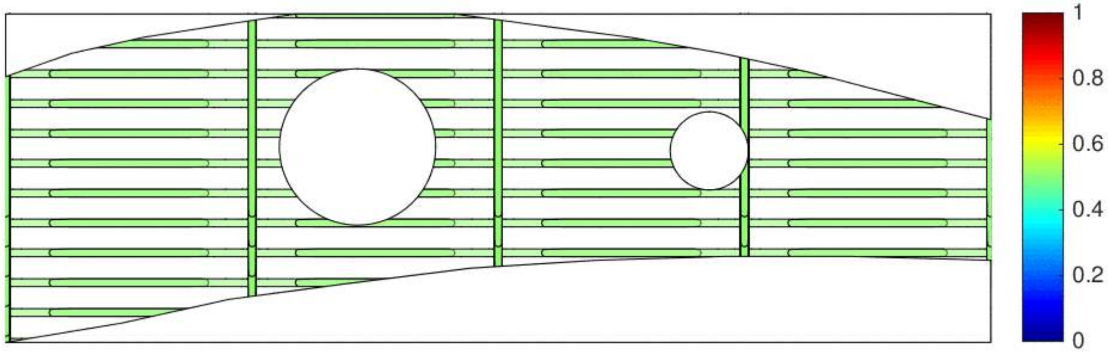


A typical Aerostructures

- Rib with pressure loads only



Fast convergence…



Play with

https://github.com/topggp/blog

TOPGGP is Opensource

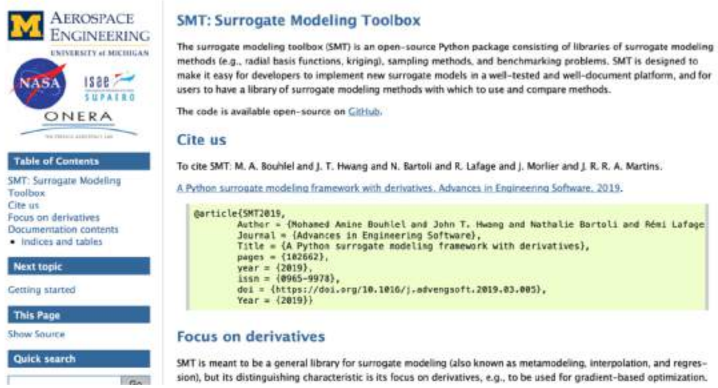
- https://www.youtube.com/watch?v=pPm3LrmBew4

Researcher view (Reproducible Research)

- https://www.topopt.mek.dtu.dk
- https://www.top3d.app

- https://github.com/topggp/blog
- https://github.com/mid2SUPAERO/EMTO

- https://smt.readthedocs.io/en/latest/



Aerospace Engineering
University of Michigan
NASA
isae SUPAERO
ONERA

Table of Contents

SMT: Surrogate Modeling Toolbox
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Focus on derivatives
Documentation contents
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Getting started

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Quick search

SMT: Surrogate Modeling Toolbox

The surrogate modeling toolbox (SMT) is an open-source Python package consisting of libraries of surrogate modeling methods (e.g., radial basis functions, kriging), sampling methods, and benchmarking problems. SMT is designed to make it easy for developers to implement new surrogate models in a well-tested and well-document platform, and for users to have a library of surrogate modeling methods with which to use and compare methods.

The code is available open-source on GitHub.

Cite us

To cite SMT: M. A. Bouhlel and J. T. Hwang and N. Bartoli and R. Lafage and J. Morlier and J. R. R. A. Martins.

A Python surrogate modeling framework with derivatives. Advances in Engineering Software, 2019.

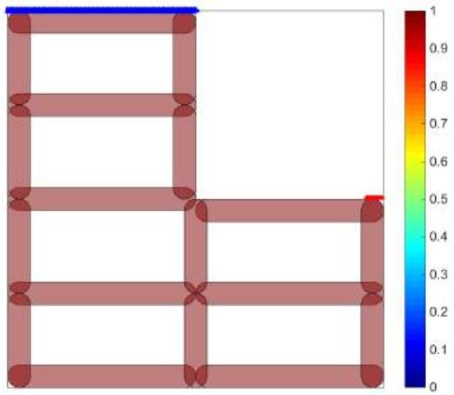
```
@article{SMT2019,
        Author = {Mohamed Amine Bouhlel and John T. Hwang and Nathalie Bartoli and Rémi Lafage
        Journal = {Advances in Engineering Software},
        Title = {A Python surrogate modeling framework with derivatives},
        pages = {102662},
        year = {2019},
        issn = {0965-9978},
        doi = {https://doi.org/10.1016/j.advengsoft.2019.03.005},
        Year = {2019}}
```

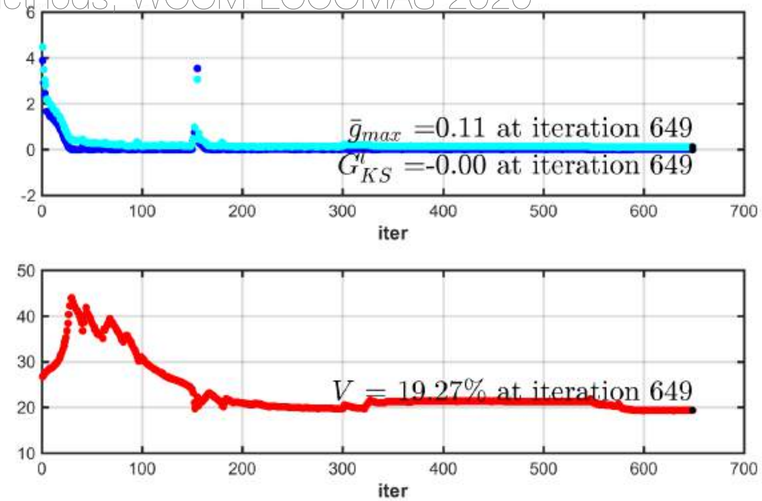
Focus on derivatives

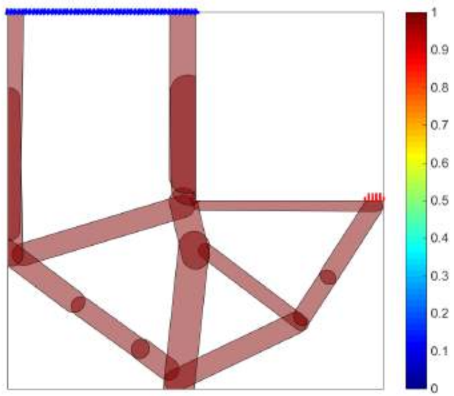
SMT is meant to be a general library for surrogate modeling (also known as metamodeling, interpolation, and regression), but its distinguishing characteristic is its focus on derivatives, e.g., to be used for gradient-based optimization.

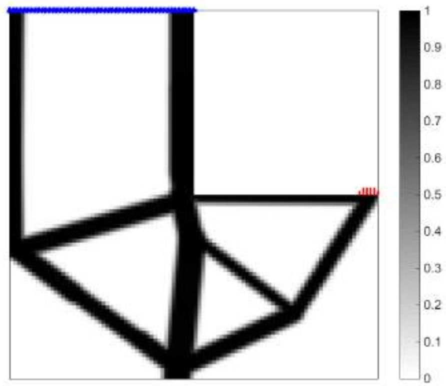
Remind my warning…

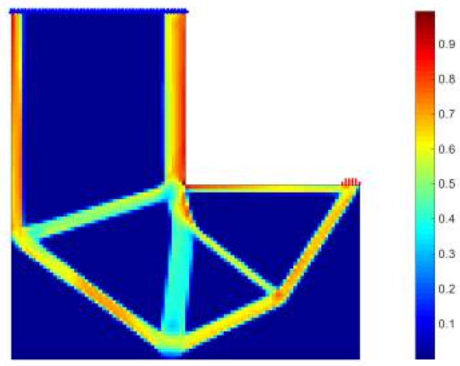
S. Coniglio, J. Morlier, C. Gogu, An introduction to Generalized Geometry Projection, a unified framework for feature-based topology optimization methods, WCCM-ECCOMAS 2020







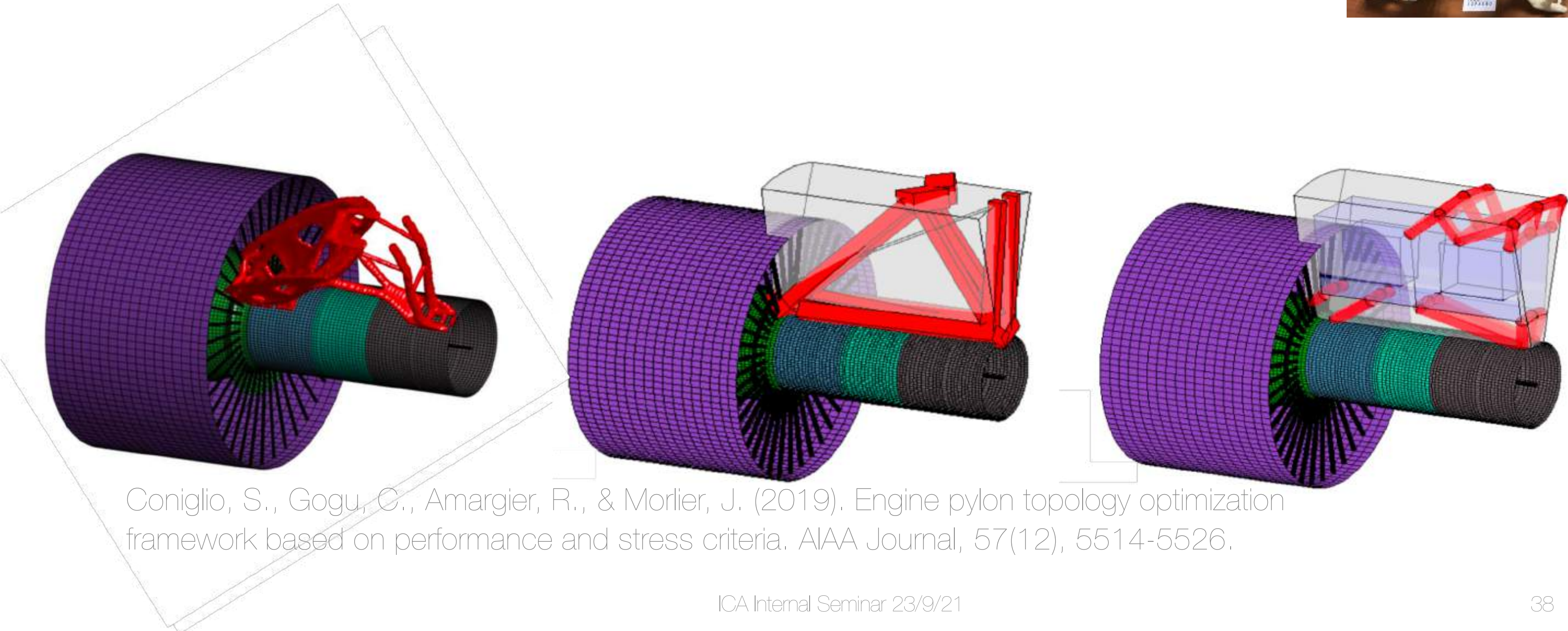




Bionic Design? AIRBUS

RESULTS OF SIMONE CONIGLIO's PHD at AIRBUS

under the supervision of Christian Gogu and I



Coniglio, S., Gogu, C., Amargier, R., & Morlier, J. (2019). Engine pylon topology optimization framework based on performance and stress criteria. AIAA Journal, 57(12), 5514-5526.

Agenda for today

- Part1 Introduction 3’
- Part2 Topology Optimization & Opensource software 3’
- Part3 GGP for aerostructures 5’
- **Part4 Ecoptimization & Computational Fabrication 5’**

How to **ECO**design tomorrow's structures?

Prof. Joseph Morlier, Vilas Bhat*, Edouard Duriez, Enrico Stragiotti

#Multiscale aerostructures
#Reasoned HPC
#AI4E
#MDO including Ecodesign of Materials & Process, 3Dprinting, SHM …

*

ONERA
THE FRENCH AEROSPACE LAB

ICA
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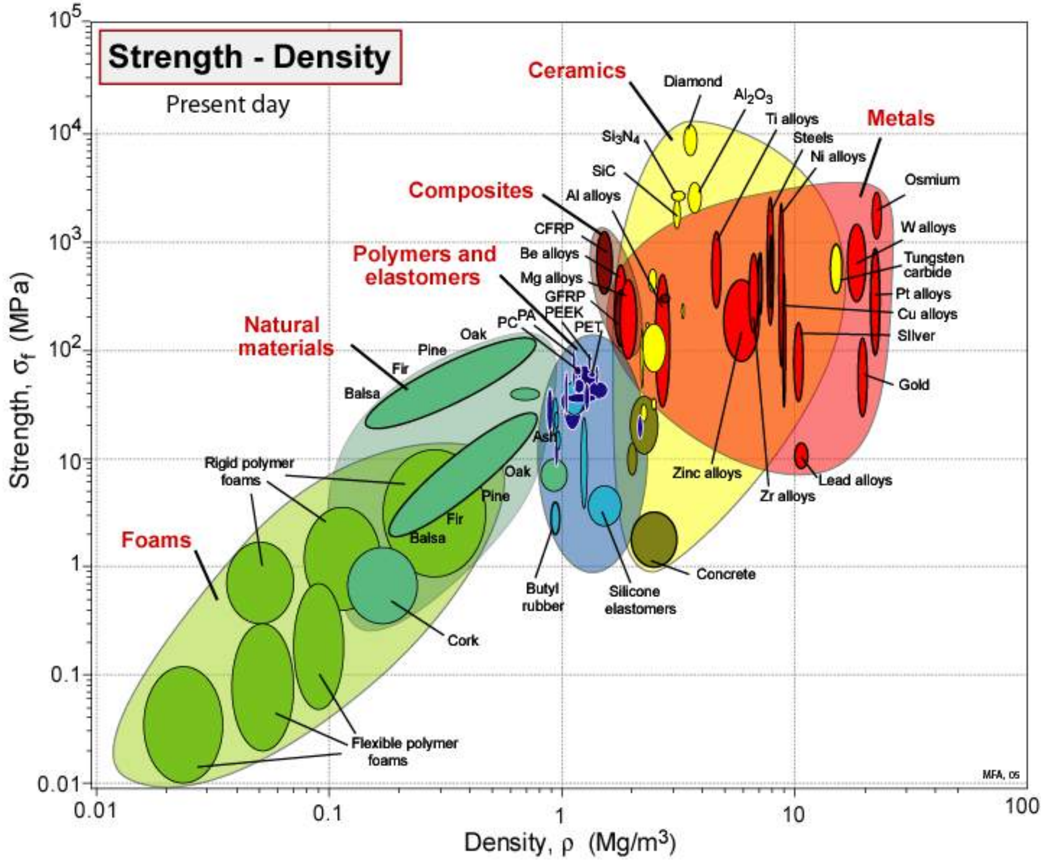
AGENCE NATIONALE DE LA RECHERCHE
ANR

l'X
ÉCOLE POLYTECHNIQUE
IP PARIS

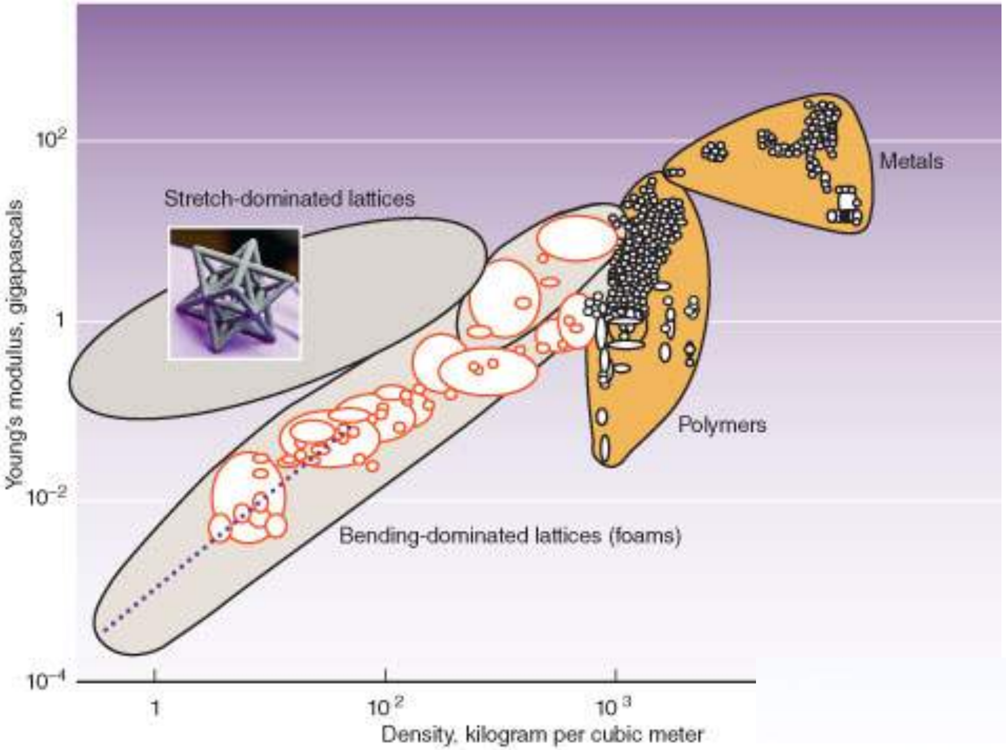
isae
Institut Supérieur de l'Aéronautique et de l'Espace
SUPAERO

PRESENT DAY



21st Century

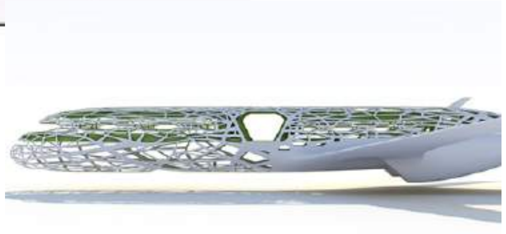
AND TOMORROW?

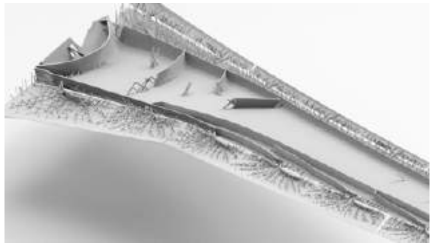


(a)

(b)

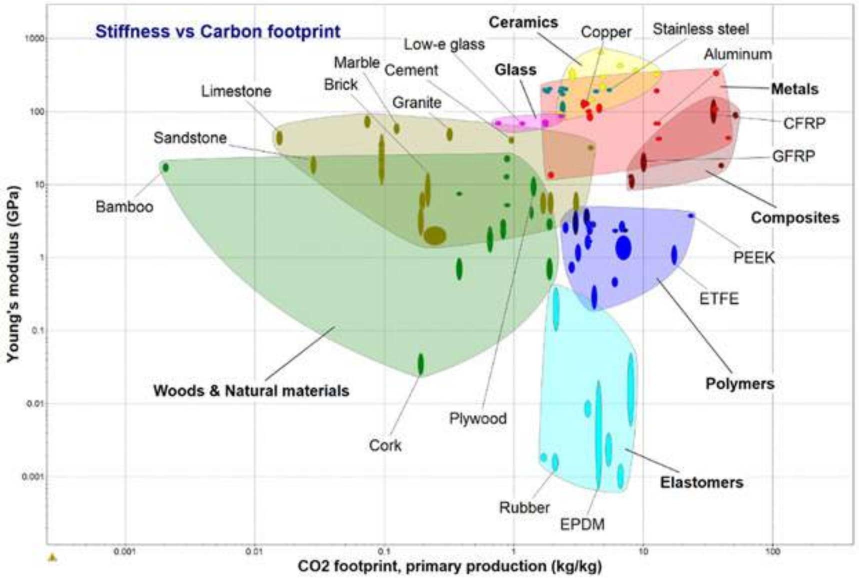
Chris Spadaccini (llnl,USA) "By controlling the architecture of a microstructure, we can create materials with previously unobtainable properties in the bulk form."

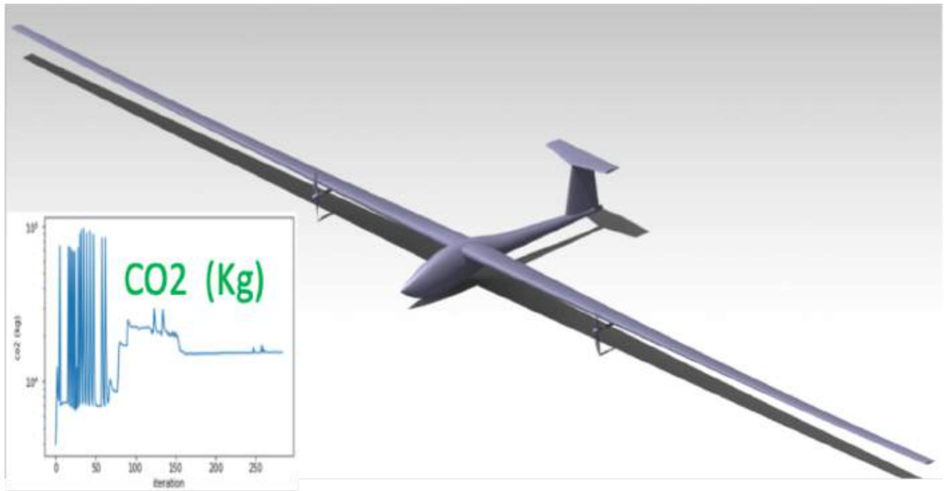




Min Mass or Min CO2

- Trade-off between use phase (young's modulus and density) and production phase (CO2 footprint)





Ashby, M.F., Miller, A., Rutter, F., Seymour, C., Wegst, U.G.K., n.d. The CES Eco Selector – Background Reading 24.

HALE

- HALE ➤ High-Altitude Long Endurance
- Atmospheric satellites or atmosats
- Services conventionally provided by space satellites
- Environment-friendly ➤ Powered by solar energy
- CO2 emissions ➤ Manufacturing and materials

Fig. 1: Airbus-built HALE Zephyr

From OAS to EcoHale

- Commercial aircraft
- Breguet range equation
- Fuel consumption
- 2.5G manoeuvre
- High Reynolds number
- Fixed structural material

➤ HALE drones

➤ Power equilibrium

➤ Power from batteries and solar panels

➤ Shear gust wall

➤ Low Reynolds number

➤ Material choice optimization

Objective function

- CO2 emitted by the HALE drone during its life cycle

- No fuel ➤ CO2 from materials and processing

  - Structure ➤ $CO2_{struct} = M_{spar} \cdot CO2_{mat1} + M_{skin} \cdot CO2_{mat2}$

  - Solar panels ➤ $CO2_{PV} = P_{needed} \cdot CO2_{/W}$

  - Batteries ➤ $CO2_{bat} = P_{needed} \cdot t_{night} \cdot CO2_{/Wh}$

- $CO2_{total} = CO2_{struct} + CO2_{PV} + CO2_{bat}$

DV

- 8 geometric design variables:
  - Twist + Angle of attack control points
  - Skin thickness control points
  - Spar thickness control points
  - Thickness-to-chord ratio control points
  - Span
  - Root chord
  - Taper ratio
  - Motor spanwise location

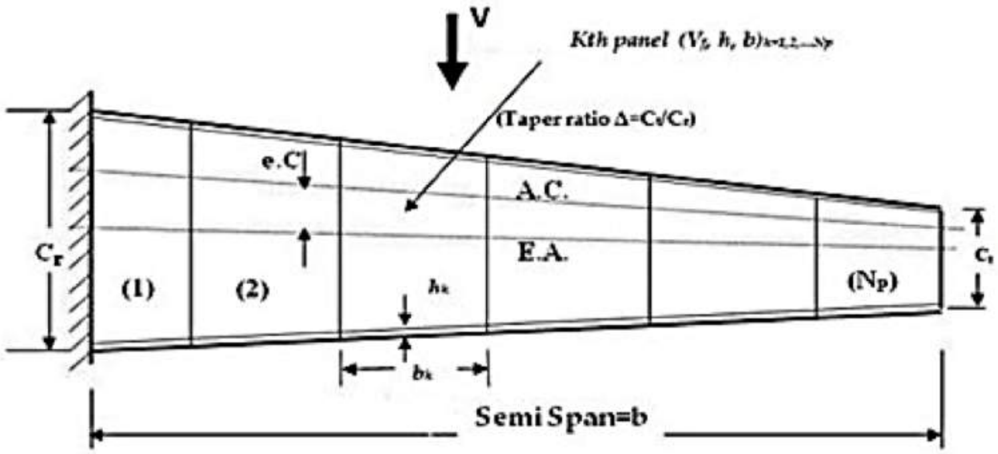


Fig. 4: Trapezoidal wing planform

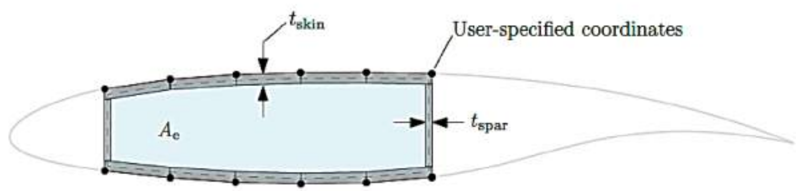


Fig. 5: Wingbox cross-section model [1]

[2] S. S. Chauhan and J. R. Martins, "Low-fidelity aerostructural optimization of aircraft wings with a simplified wingbox model using OpenAeroStruct," in International Conference on Engineering Optimization, pp. 418-431, Springer, 2018.

Discrete Material Choice inspired from SIMP

- 1 material design variable with 2 components:
  - Density of the material used for the spars
  - Density of the material used for the skins
- Material properties as a function of the density:
  - Young's modulus
  - Shear modulus
- Continuous variable by interpolating each material property in the space between real materials from a discrete catalogue

$E(\rho) = A \cdot \rho^p + B$ with $A = \frac{E_{i+1} - E_i}{\rho_{i+1}^p - \rho_i^p}$ and $B = E_i - A \cdot \rho_i^p$

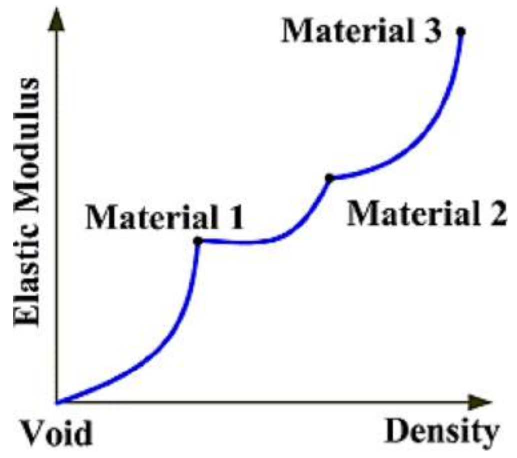


Fig. 6: Young's modulus example of penalized interpolation of materials [1]

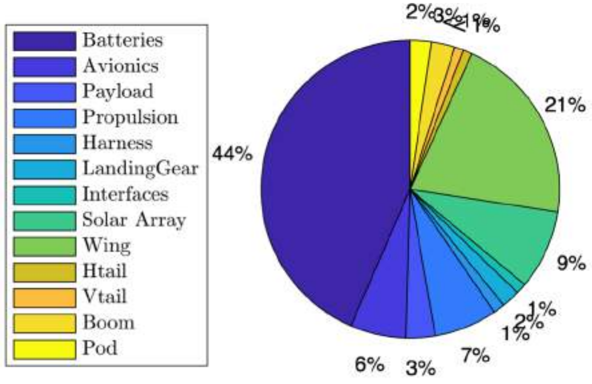
[3] Zuo, Wenjie, and Kazuhiro Saitou. "Multi-material topology optimization using ordered SIMP interpolation." Structural and Multidisciplinary Optimization 55.2 (2017): 477-491.

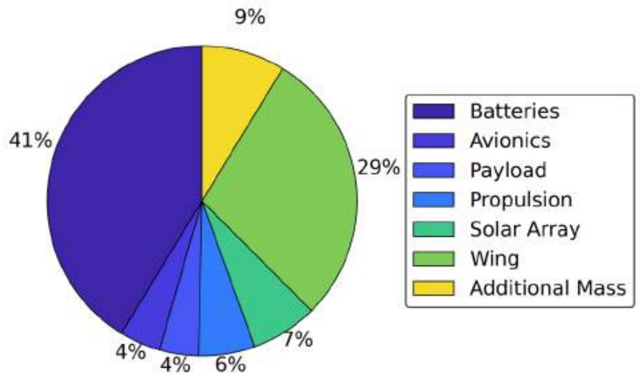
Mass minimisation

Tab. 1: Final design variable values for validation case

Design variable	Unit	FB HALE [1]	Our case
Span	m	45.6	53.5
Root chord	m	-	1.4
Taper ratio	-	-	0.3
Total mass	kg	320	245
Wing surface	m^2	71.8	50.3
Aspect ratio	-	29	57
C_L^{cruise}	-	1.33	1.39
$(C_L^{3/2}/C_D)^{cruise}$	-	40.1	50.2
$y_{engine}/(b/2)$	-	0.46	0.33

(a) FBHALE [1] ➤





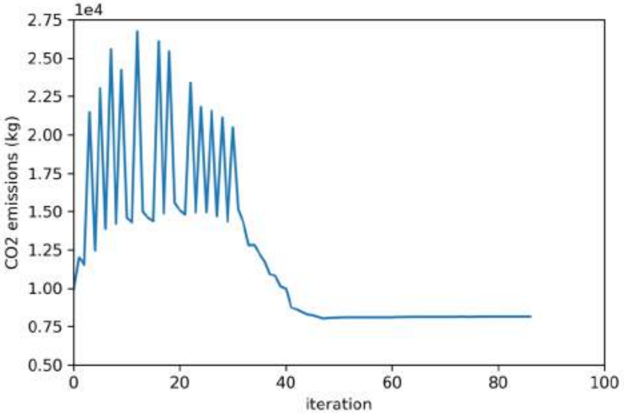
➤ (b) Our case

Fig. 7: Comparison of the mass breakdowns

[4] D. Colas, N. H. Roberts, and V. S. Suryakumar, “HALE multidisciplinary design optimization Part I: Solar-powered single and multiple-boom aircraft,” in 2018 AviationTechnology, Integration, and Operations Conference, p. 3028, 2018.

CO2 footprint minimization

(a) Objective function: total CO2 emitted:



(b) Material density for skins and spars:

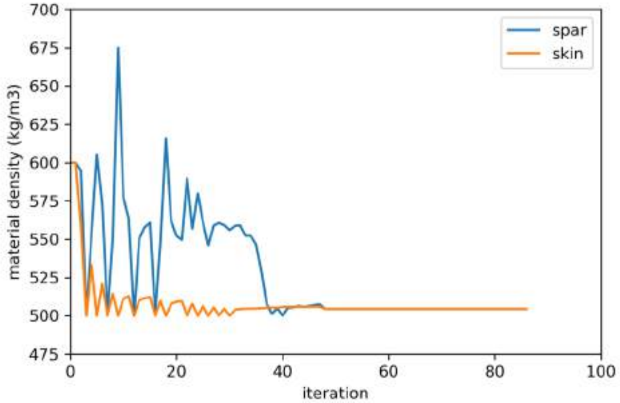


Fig. 8: Convergence graphs

- Optimization algorithm ➤ SLSQP
- Stopping criteria:
  - ➤ Convergence accuracy: 10^{-3}
  - ➤ Maximum number of iterations: 250

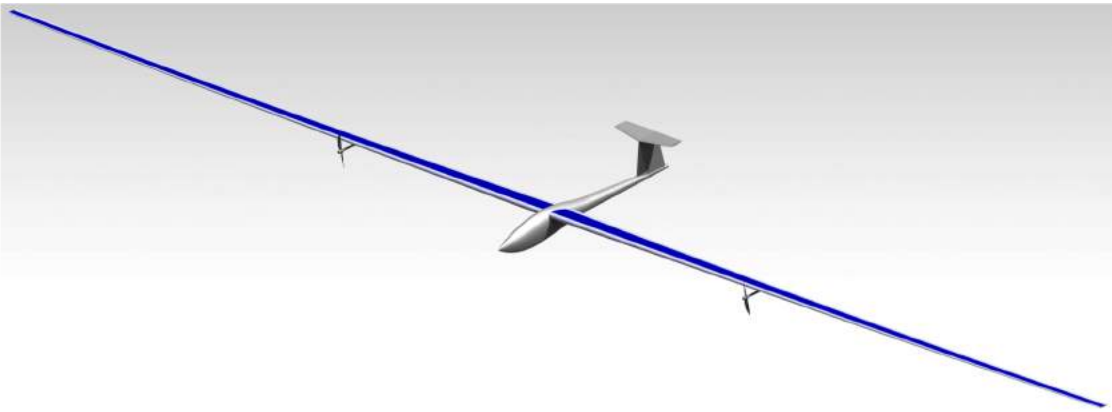
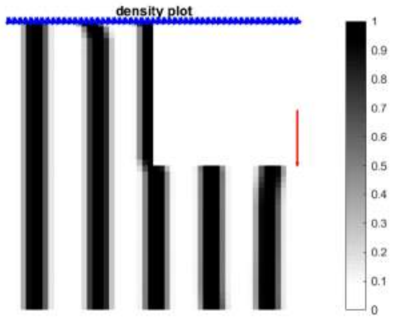
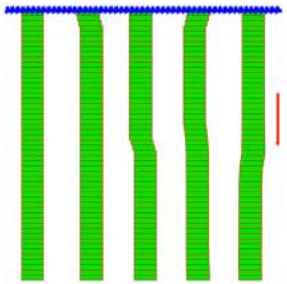


Fig. 9: CAD model of the optimal HALE obtained

Again… we started with a SUPAERO's student project





$N_x = N_y = 52$
$v_f = 0.4$
$5\ printing\ components$
$18\ printing\ intervals$
$5{\times}18{\times}2\ design\ variables$

CSMA 2019
14ème Colloque National en Calcul des Structures
13-17 Mai 2019, Presqu'île de Giens (Var)

Une approche par projection pour l'optimisation topologique de structures imprimées par fabrication additive

K. Vilasraj Bhat[1], S. Coniglio[2], J. Morlier[3], M. Charlotte[4]

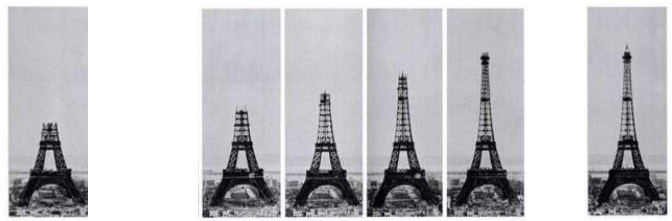
[1] *International Masters, ISAE-SUPAERO, k-vilasraj.bhat@student.isae-supaero.fr*
[2] *Airbus Operations SAS, 316 Route de Bayonne - 31300 Toulouse France*
[3] *Univ Toulouse, ISAE SUPAERO-INSA-Mines Albi-UPS, joseph.morlier@isae-supaero.fr*
[4] *Univ Toulouse, ISAE SUPAERO-INSA-Mines Albi-UPS, miguel.charlotte@isae-supaero.fr*

CNRS UMR5312, Institut Clément Ader

F31055 Toulouse Cedex 04, France,

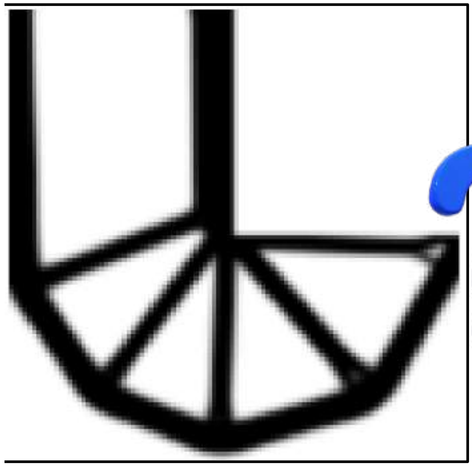
Résumé — Ce papier présente une exploration et l'application de méthodes visant à intégrer la fabrication additive (FA) à l'optimisation topologique. Les contraintes classiques dites d'overhang sont appliquées sans traitement supplémentaire (post processing). Les techniques courantes de post-traitement incluent souvent l'interprétation de la solution (lissage) et des éléments structuraux (poutre, plaque etc...) via le logiciel de post traitement. La méthodologie proposée fournit une expression explicite de la solution, contenant notamment pour les procédés de FA par déposition des informations sur les largeurs d'impression, les positions et le nombre de couches de matériaux déposés.

Mots clés — Optimisation topologique, fabrication additive, méthode par dépôt en fusion

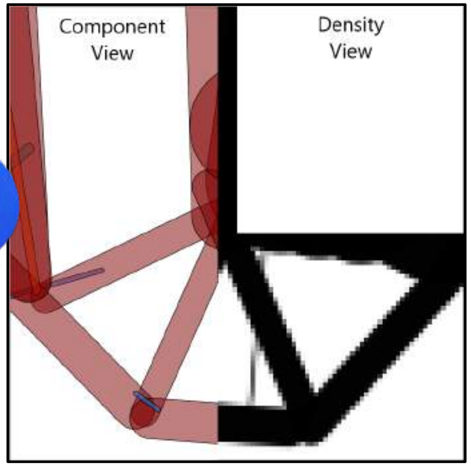


GGP For ALM?

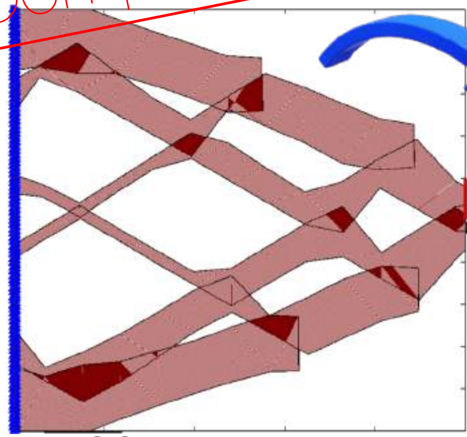
New paper in Elsevier's Computer & Graphics



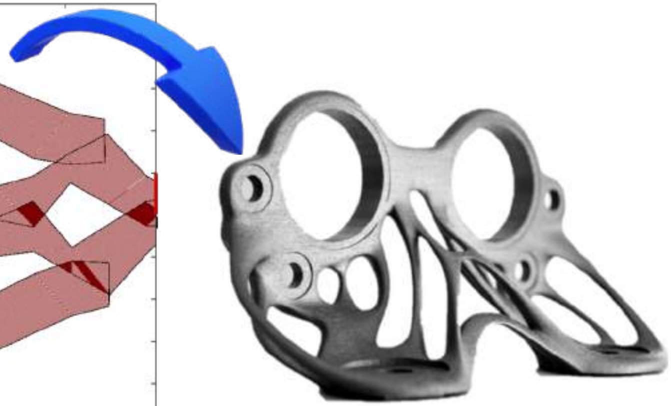
SIMP



GGP

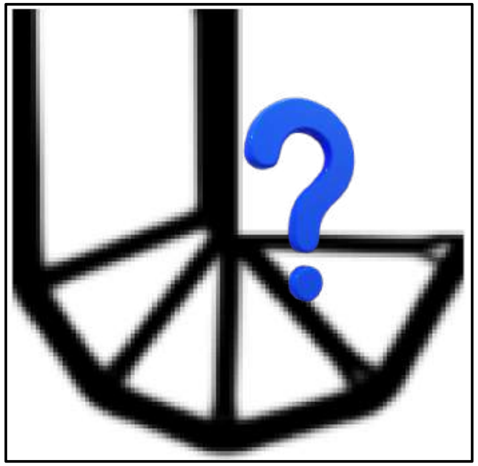


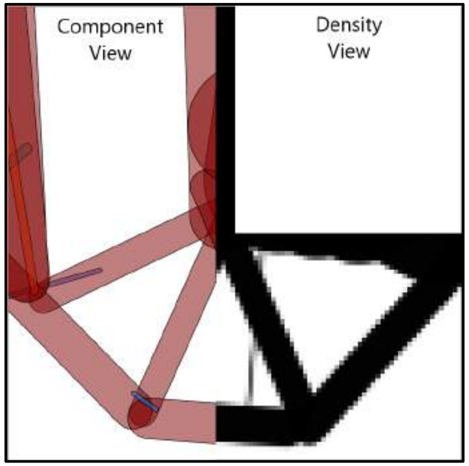
GGP for 3D printing

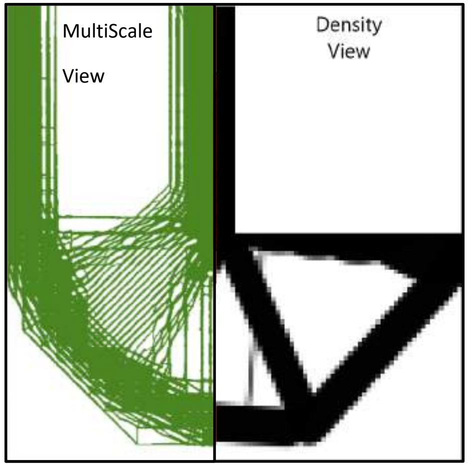


3D Printed part

G. Capasso, V. Bhat, S. Coniglio, J. Morlier, C. Gogu, Topology Optimization of Additive Layer Manufacturing products using Generalized Geometric Projection, WCCM-ECCOMAS 2020

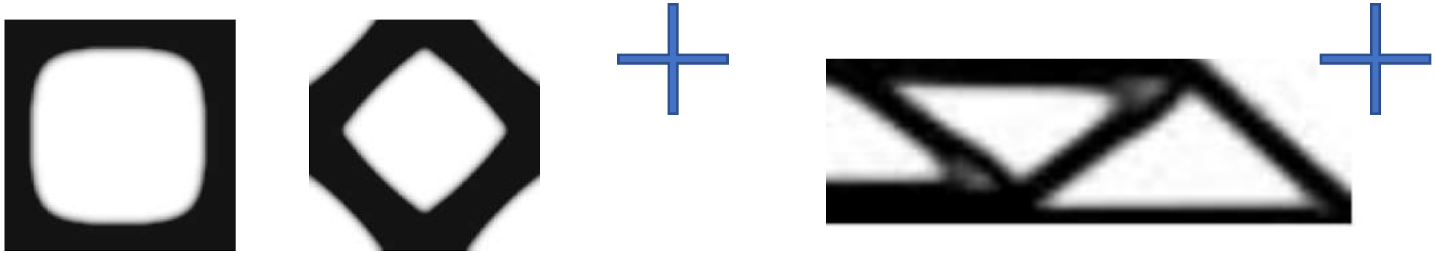



Component View
Density View

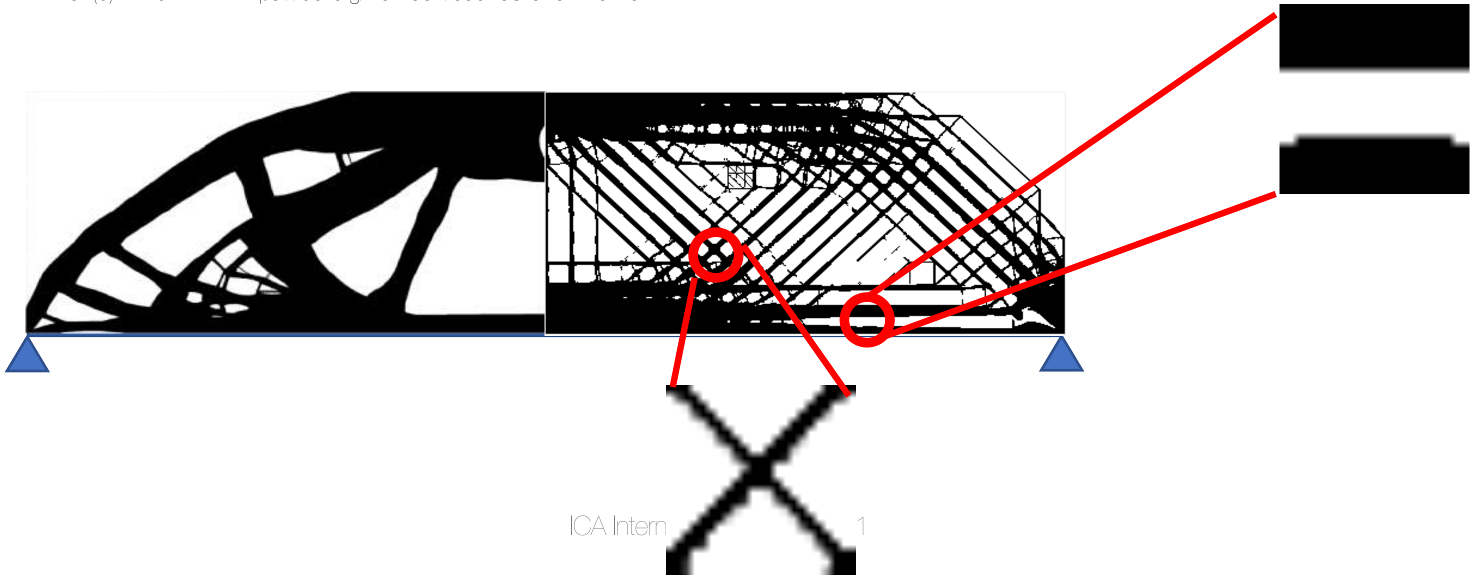

MultiScale View
Density View

Multi-scale TO

i.e. Write a two level optimization that combines Unit cell design & Topology Optimization

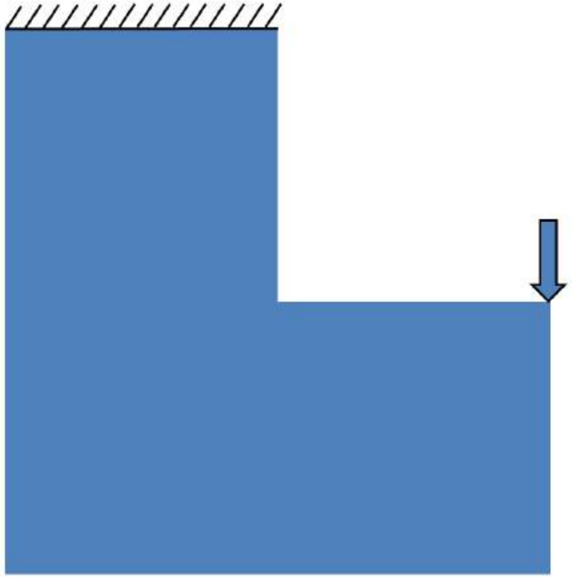


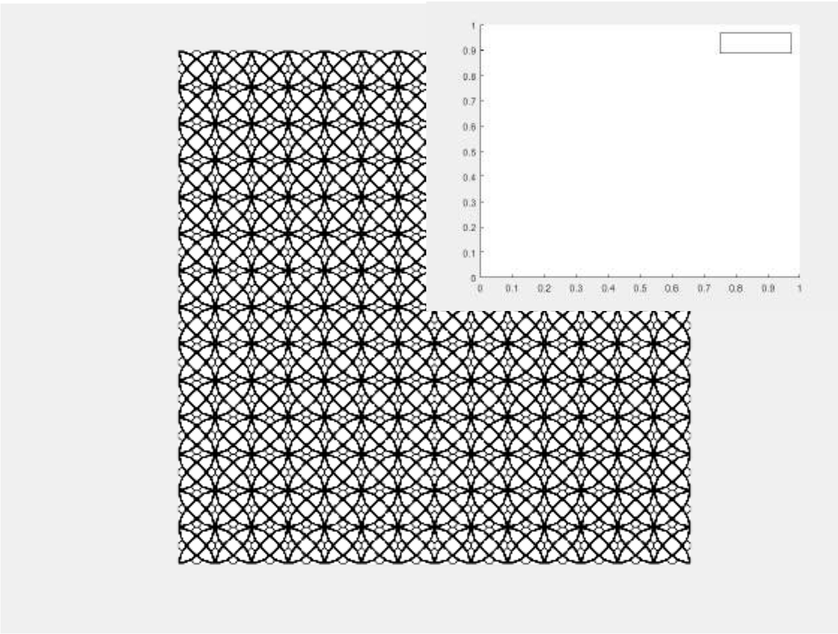
Xia L, Breitkopf P (2015) Design of materials using topology optimization and energy-based homogenization approach in Matlab. Struct Multidisc Optim 52(6):1229–1241. https://doi.org/10.1007/s00158-015-1294-0



EMTO on L-shape (cellular /architectured materials)

Duriez, E., Morlier, J., Charlotte, M., & Azzaro-Pantel, C. (2021). A well connected, locally-oriented and efficient multi-scale topology optimization (EMTO) strategy. Structural and Multidisciplinary Optimization, 1-24.





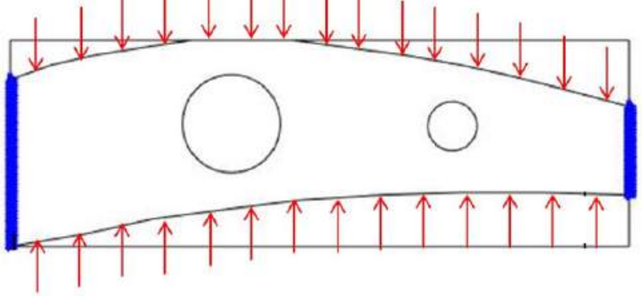
https://github.com/mid2SUPAERO/EMTO

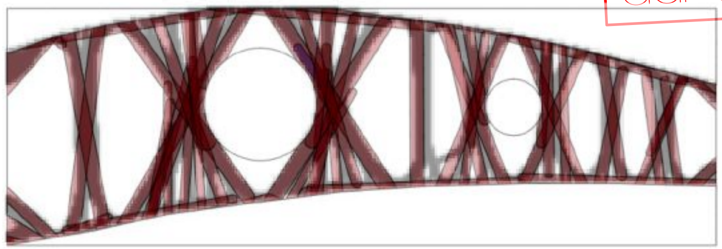
Aircraft rib design

GGP := EASY EXPLORATION of POTENTIAL DESIGN OF STRUCTURES

GGP-AGP: C=0.165

- Again Only pressure loads

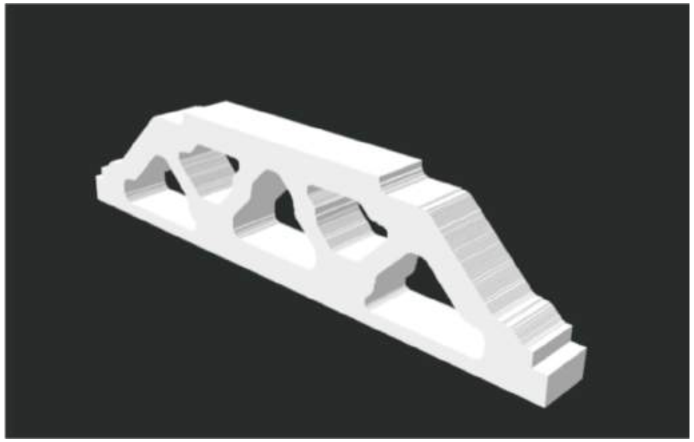




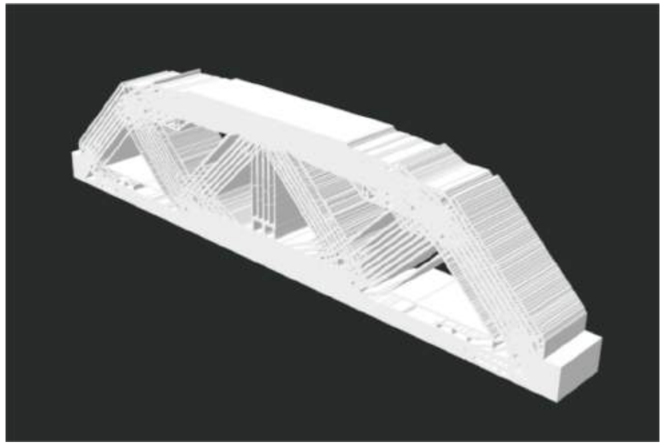
SIMP : c=0.198

EMTO : c=0.172(homogenized) c=0.178-0.206(estimate)

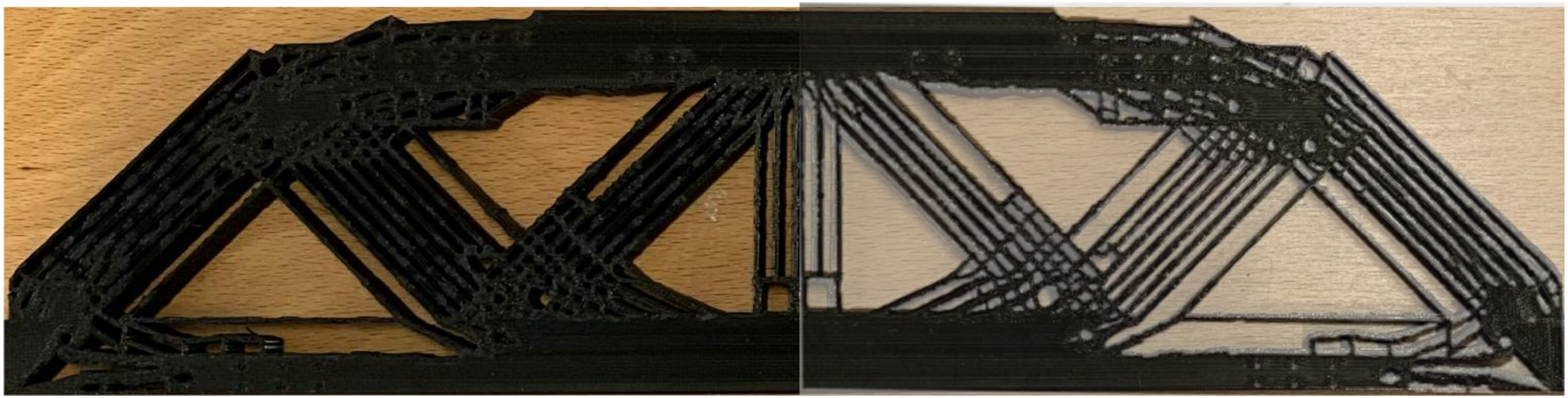
3points bending

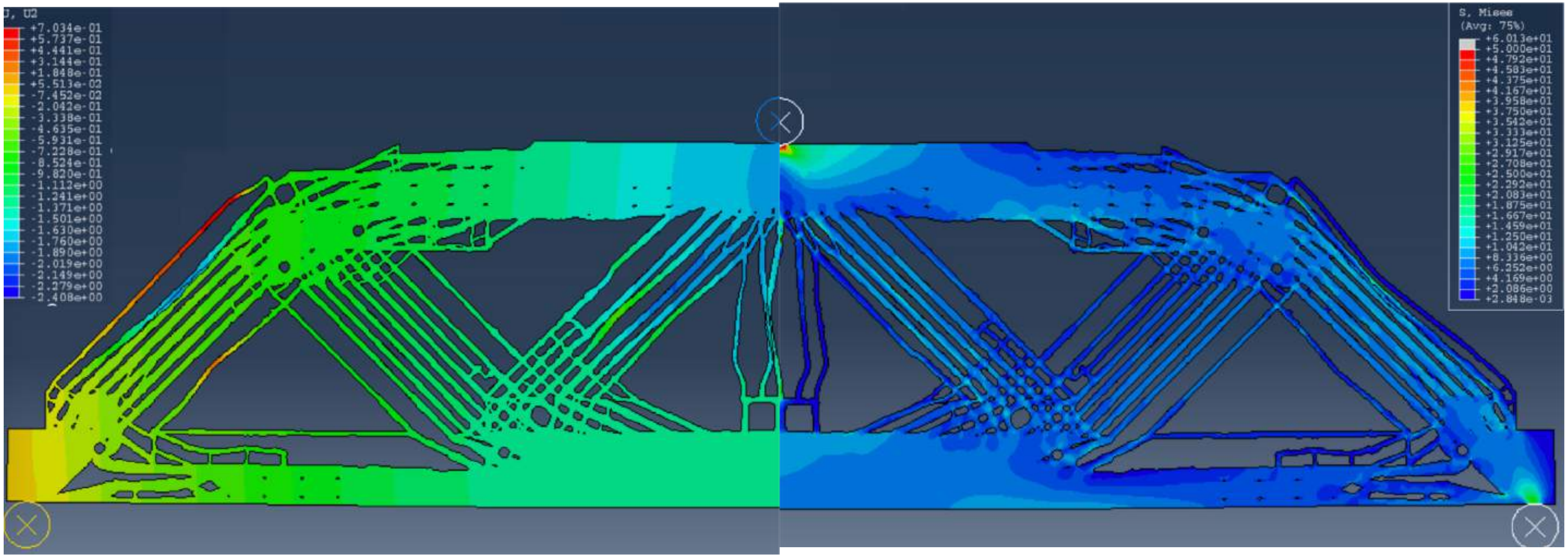


Versus



PLA 3D printing

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-3.338e-01
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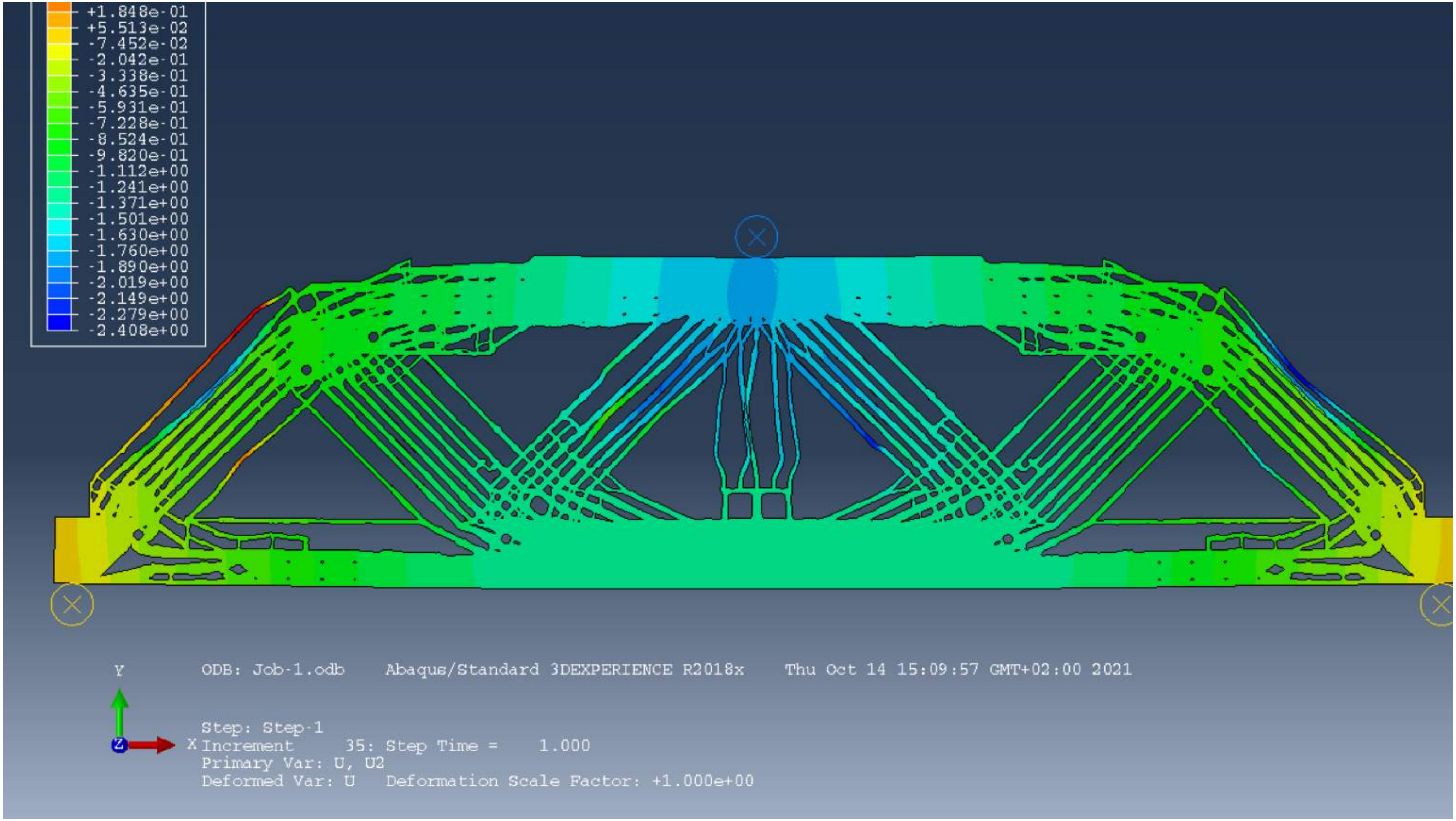
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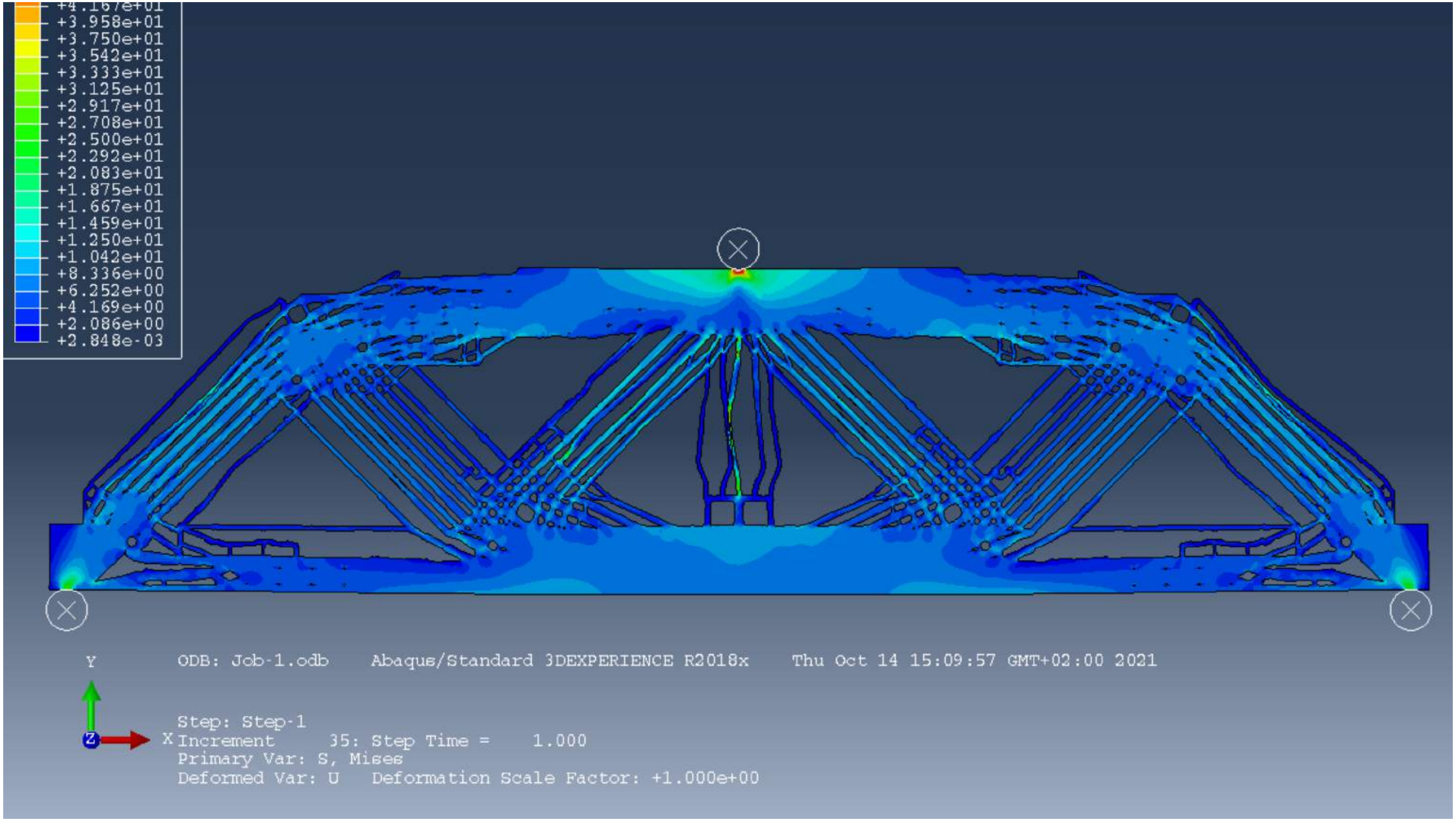
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+2.708e+01
+2.500e+01
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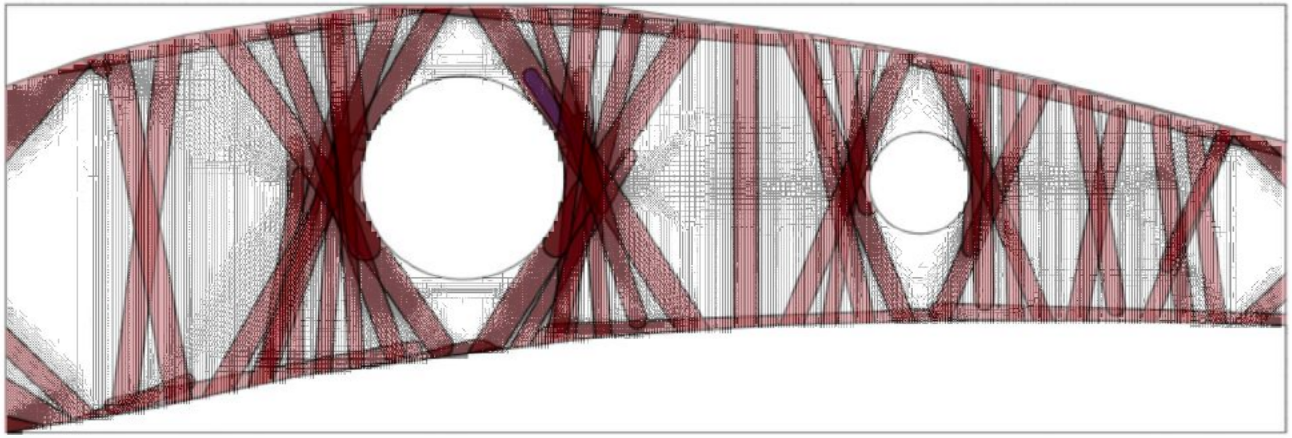
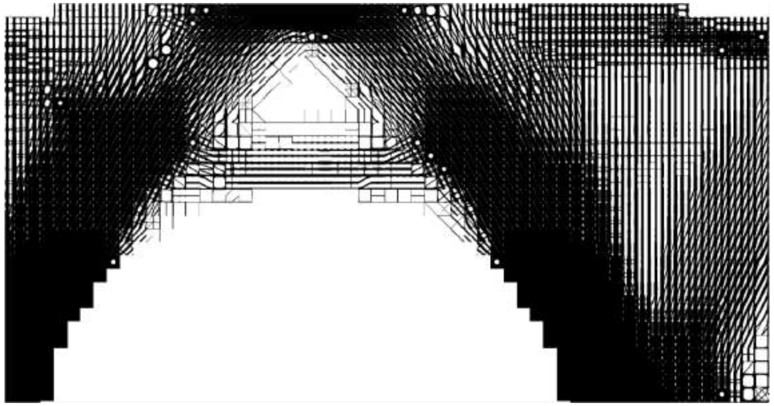
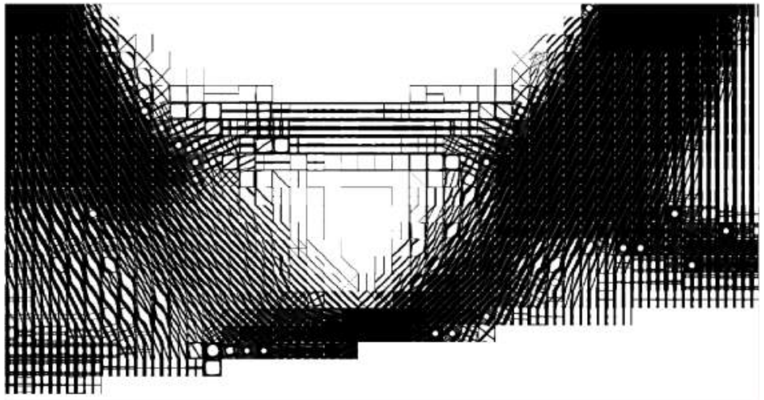
EMTO vs GGP



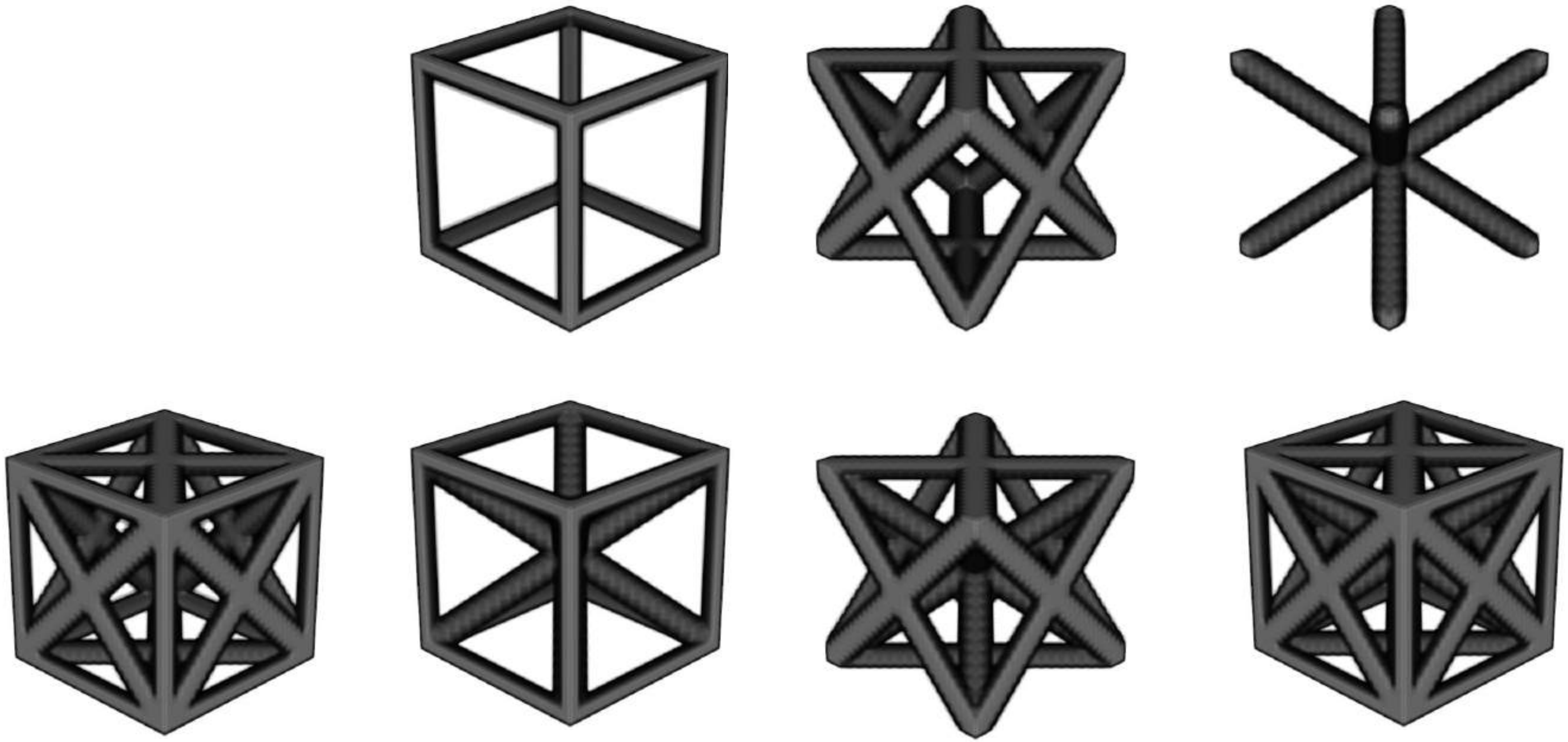
Multiscale approach is a complete REDESIGN: Creation of multiple paths for internal forces





It should be manufactured by machine

« Explicit » 3D unit cell

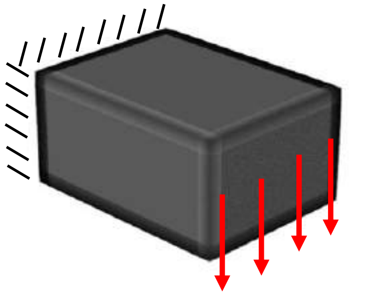


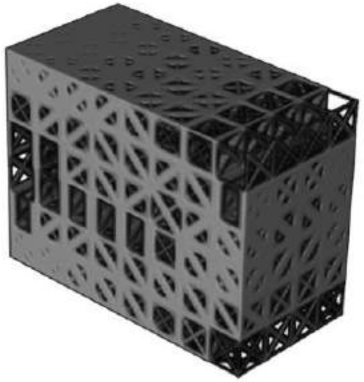
Toward 3D

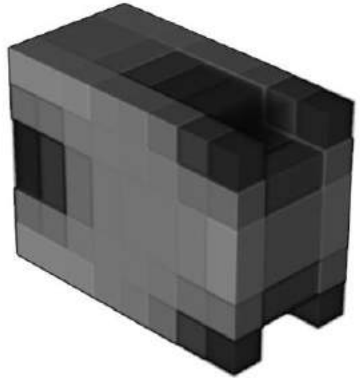
EMTO13P

top3d

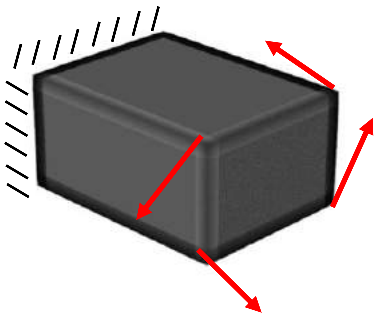
Cantilever 8x6x4

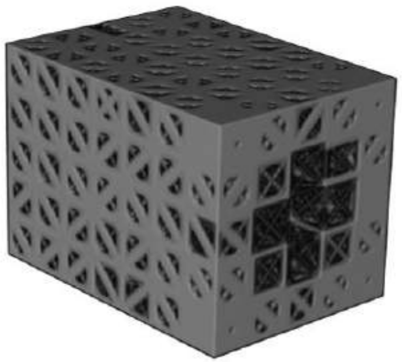


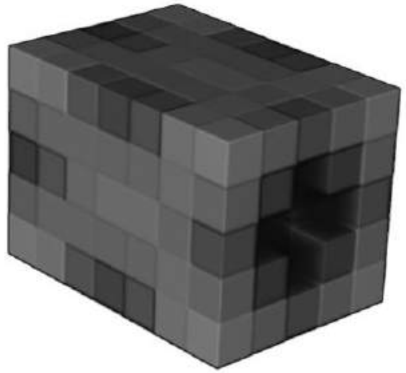




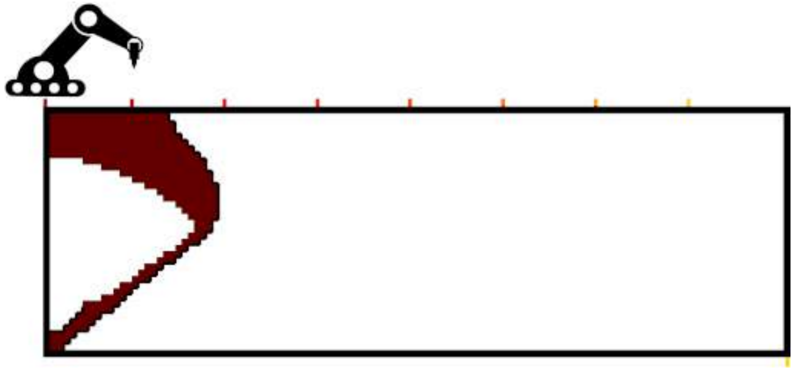
Torsion 7x5x5







Conclusions

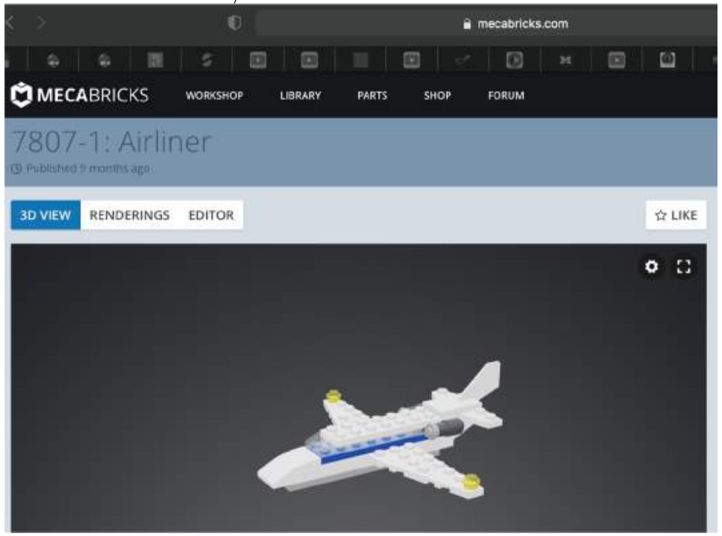


- In Phase with Computational fabrication
(see Jun Wu's TUDelft research)

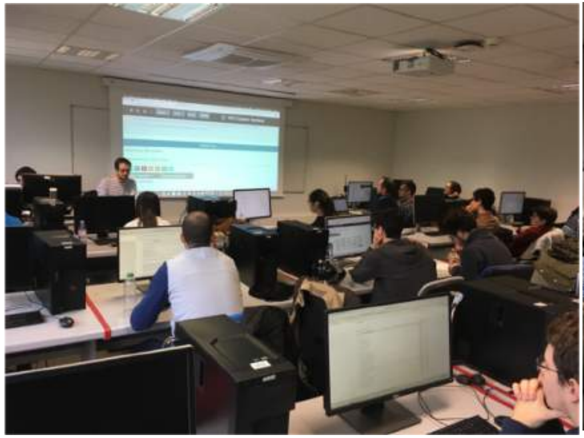
- NextGen Aerostructures : Structural mass optimization → CO2 optimization & optimal Manufacturable solution using ALM & AFP (Edouard'& Enrico's thesis)

- Et oui on peut construire une aerostructure en LEGO ;)

https://www.mecabricks.com/en/models/0DvYp8rdj9e



If you want to start in design optimization




- Sensitivity Of Finite Element Code
- Structural/Topology Optimization
- Continuous Constrained Optimization
- Surrogate/DOE using **SMT**
- UQ
- Artificial Intelligence For Engineers
- Reduced Order Modeling
- MDO using **Openmdao**

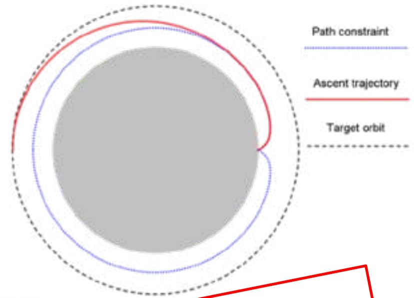
https://github.com/jomorlier/mdocourse

https://github.com/jomorlier/mdo_ml_21

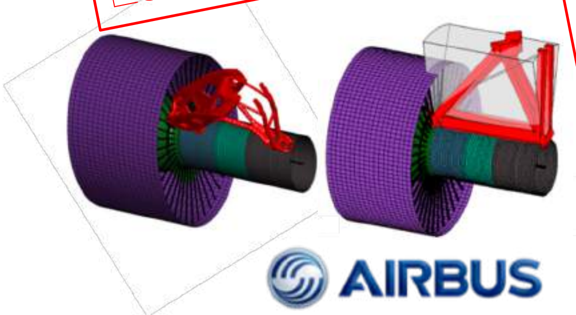
https://github.com/jomorlier/OptimizationCourse

INSTITUT CLÉMENT ADER

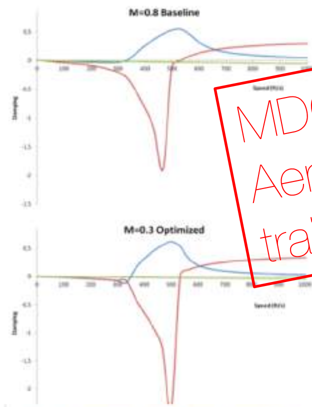
https://ica.cnrs.fr/author/jmorlier/



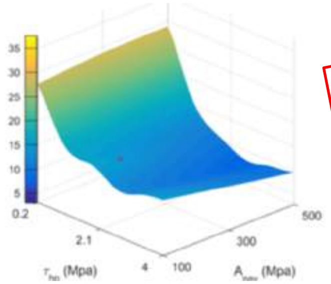
Structural Optimization & Ecodesign



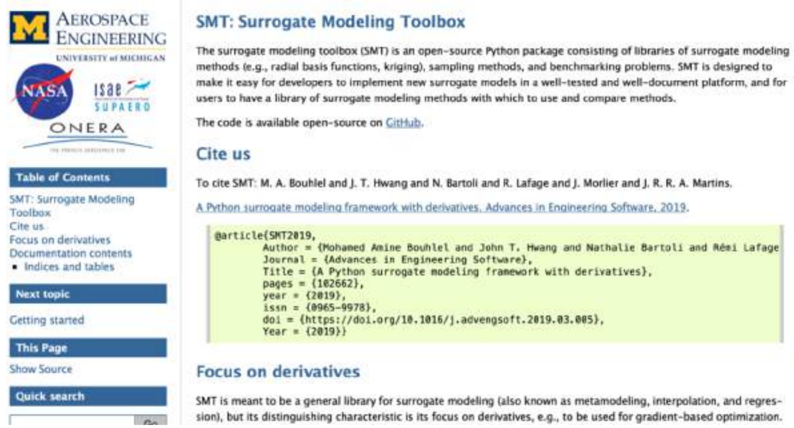
THANK for Your ATTENTION



MDO with Aeroelasticity, trajectory or control



#AI4E
Artificial Intelligence For Engineers



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SMT: Surrogate Modeling Toolbox

The surrogate modeling toolbox (SMT) is an open-source Python package consisting of libraries of surrogate modeling methods (e.g., radial basis functions, kriging), sampling methods, and benchmarking problems. SMT is designed to make it easy for developers to implement new surrogate models in a well-tested and well-document platform, and for users to have a library of surrogate modeling methods with which to use and compare methods.

The code is available open-source on GitHub.

Cite us

To cite SMT: M. A. Bouhlel and J. T. Hwang and N. Bartoli and R. Lafage and J. Morlier and J. R. R. A. Martins.

A Python surrogate modeling framework with derivatives. Advances in Engineering Software, 2019.

```
@article{SMT2019,
        Author = {Mohamed Amine Bouhlel and John T. Hwang and Nathalie Bartoli and Rémi Lafage
        Journal = {Advances in Engineering Software},
        Title = {A Python surrogate modeling framework with derivatives},
        pages = {102662},
        year = {2019},
        issn = {0965-9978},
        doi = {https://doi.org/10.1016/j.advengsoft.2019.03.005},
        Year = {2019}}
```

Focus on derivatives

SMT is meant to be a general library for surrogate modeling (also known as metamodeling, interpolation, and regression), but its distinguishing characteristic is its focus on derivatives, e.g., to be used for gradient-based optimization.

https://github.com/SMTorg/smt