# Integration of LCA as an environment discipline module in MDAO

Thomas Bellier, **Joseph Morlier,** Annafederica Urbano, Cees Bil, and Adrian Pudsey

**AeroBest 2023**

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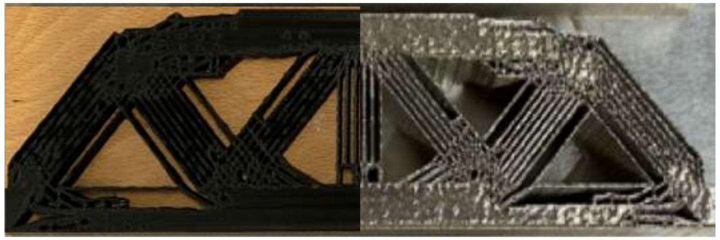
# About Me?

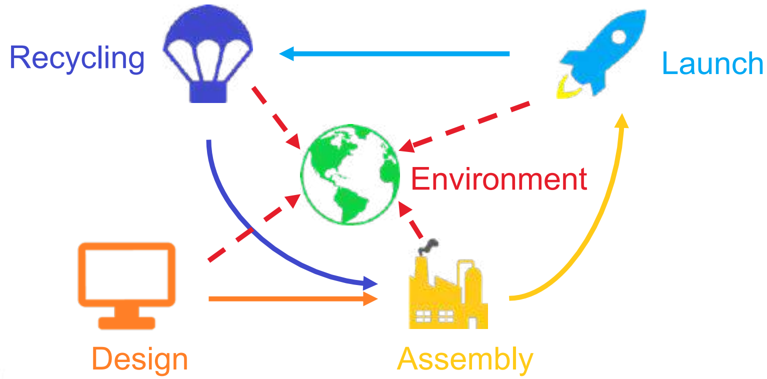
https://ica.cnrs.fr/en/author/jmorlier/

- 6 PhDs, 3 MsCs

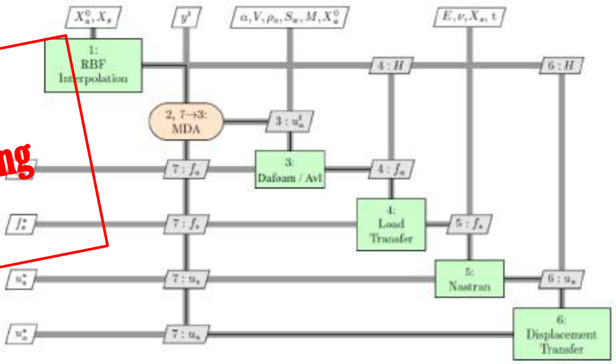
Digital fabrication



EcoOptimization

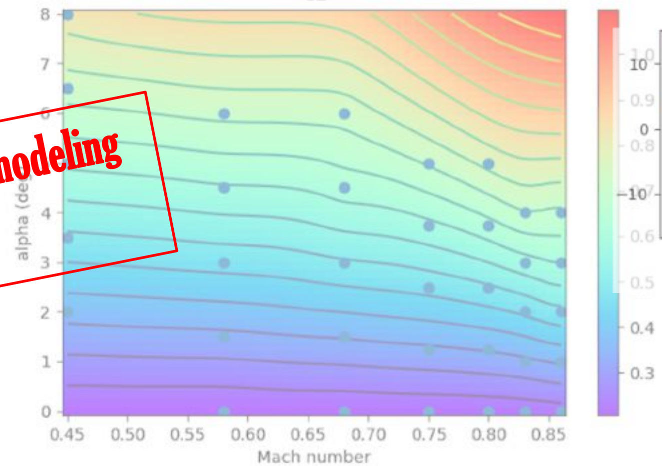


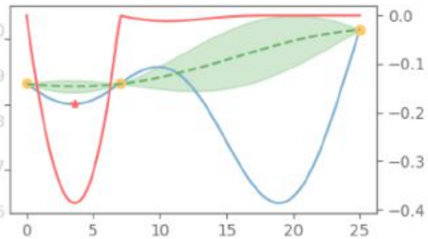

MDO for Aeroelastic Wing design




https://github.com/SMTorg/SMT

Surrogate modeling AI4E



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SA-I

*Sustainable*
*Aerostructures*
*-*
*Interactions*

ELSEVIER

Procedia CIRP
Volume 109, 2022, Pages 454-459

## Ecodesign with topology optimization

Edouard Duriez [a], Joseph Morlier [a], Catherine Azzaro-Pantel [b], Miguel Charlotte [a]

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https://doi.org/10.1016/j.procir.2022.05.278

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ELSEVIER

Cleaner Environmental Systems
Volume 9, June 2023, 100114

## A fast method of material, design and process eco-selection via topology optimization, for additive manufactured structures

Edouard Duriez [a], Catherine Azzaro-Pantel [b], Joseph Morlier [a], Miguel Charlotte [a]

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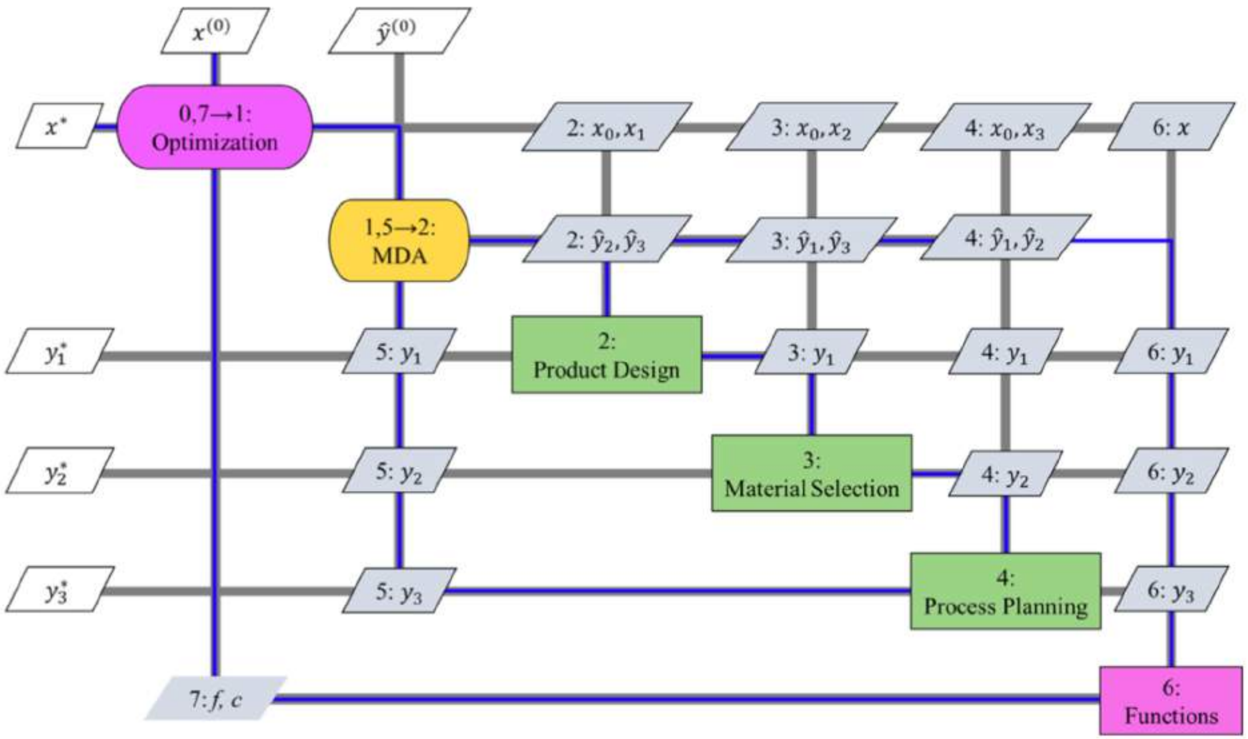
# LCA & Eco Selection as a MDO discipline




https://github.com/mid2SUPAERO/ECODD

LCA & eco selection

- Material
- Process
- from cradle to grave

…

Water withdrawal

Generation of waste

Use recycled:
Fibers
Resin
Metals
Reuse & Repair

Carbon Footprint

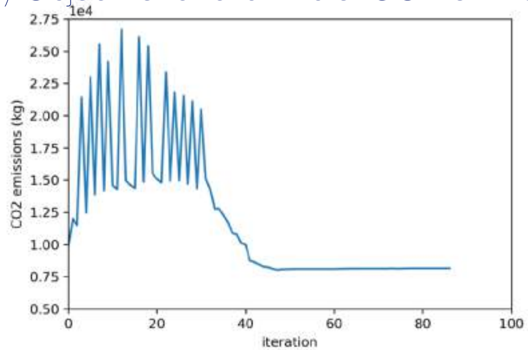
Energy requirement

# First try ;)

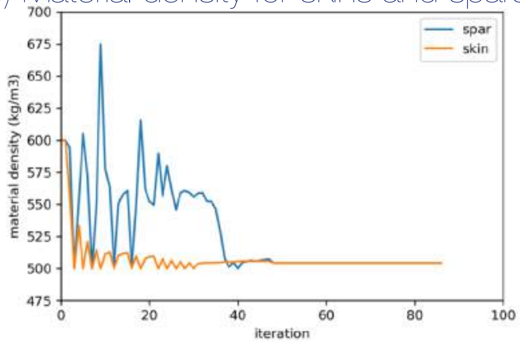
https://arxiv.org/abs/2208.13710

https://github.com/mid2SUPAERO/ecoHALE

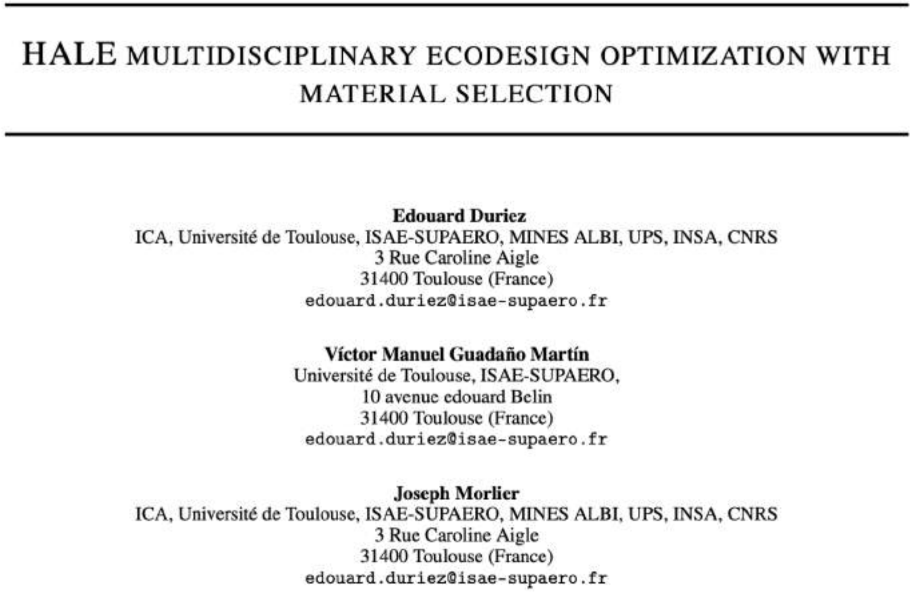
(a) Objective function: total CO2 emitted:




(b) Material density for skins and spars:




Convergence graphs



HALE MULTIDISCIPLINARY ECODESIGN OPTIMIZATION WITH MATERIAL SELECTION

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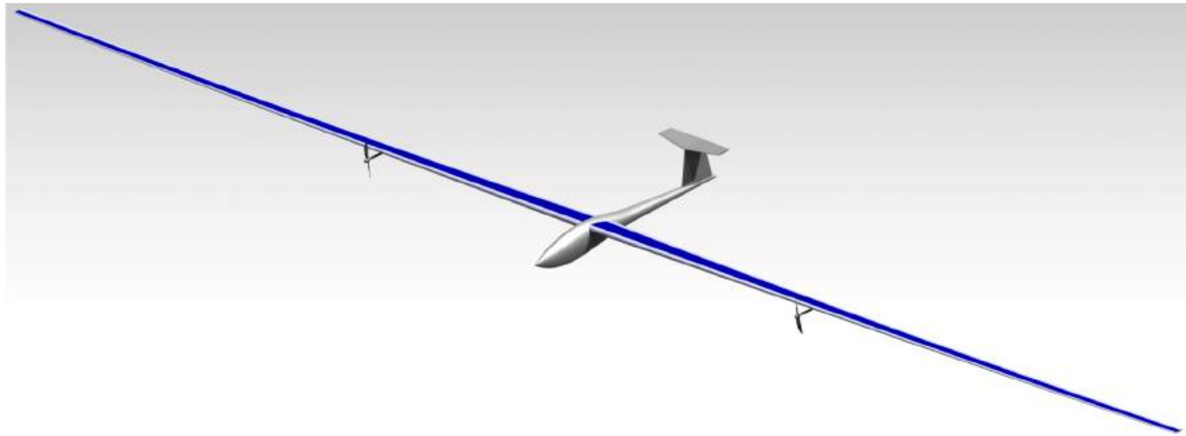
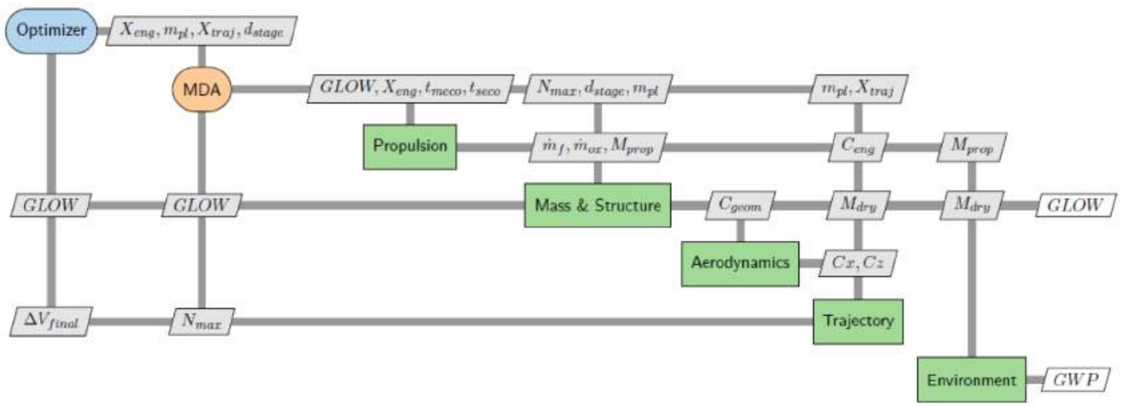


CAD model of the optimal HALE obtained

# Second try ;)

https://hal.science/hal-03888108/

**Objective function** : GLOW
**Design variables** : $X_{eng}, m_{pl}, X_{traj}, d_{stage}$
**Constraints** : $\Delta V_{final} \geq 0$




*73rd International Astronautical Congress (IAC) 2022 – Paris, France*


IAC-22,D2,IPB,26,x71719

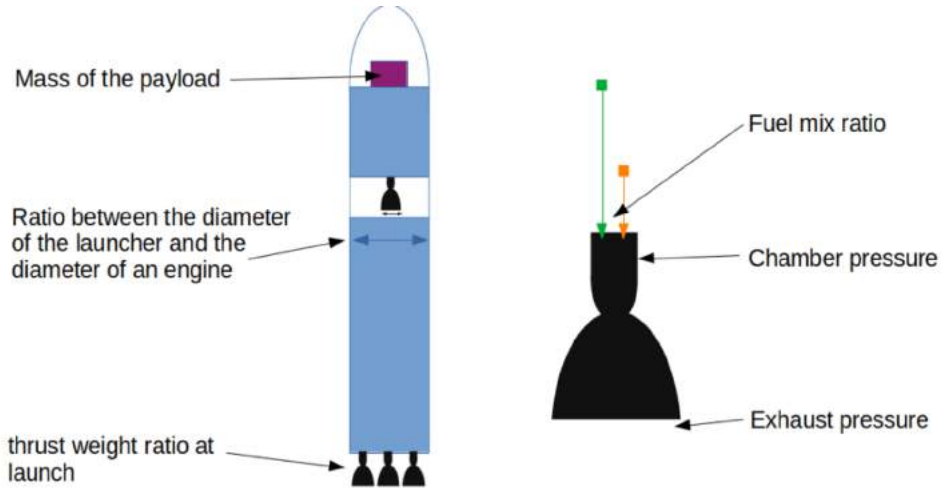
**Impact of Life Cycle Assessment Considerations on Launch Vehicle Design**

Thomas Bellier[1, 2, *], Annafederica Urbano[1], Joseph Morlier[1], Cees Bil[2], and Adrian Pudsey[2]

[1] *Institut Supérieur de l'Aéronautique et de l'Espace SUPAERO, Université de Toulouse, Toulouse, France*

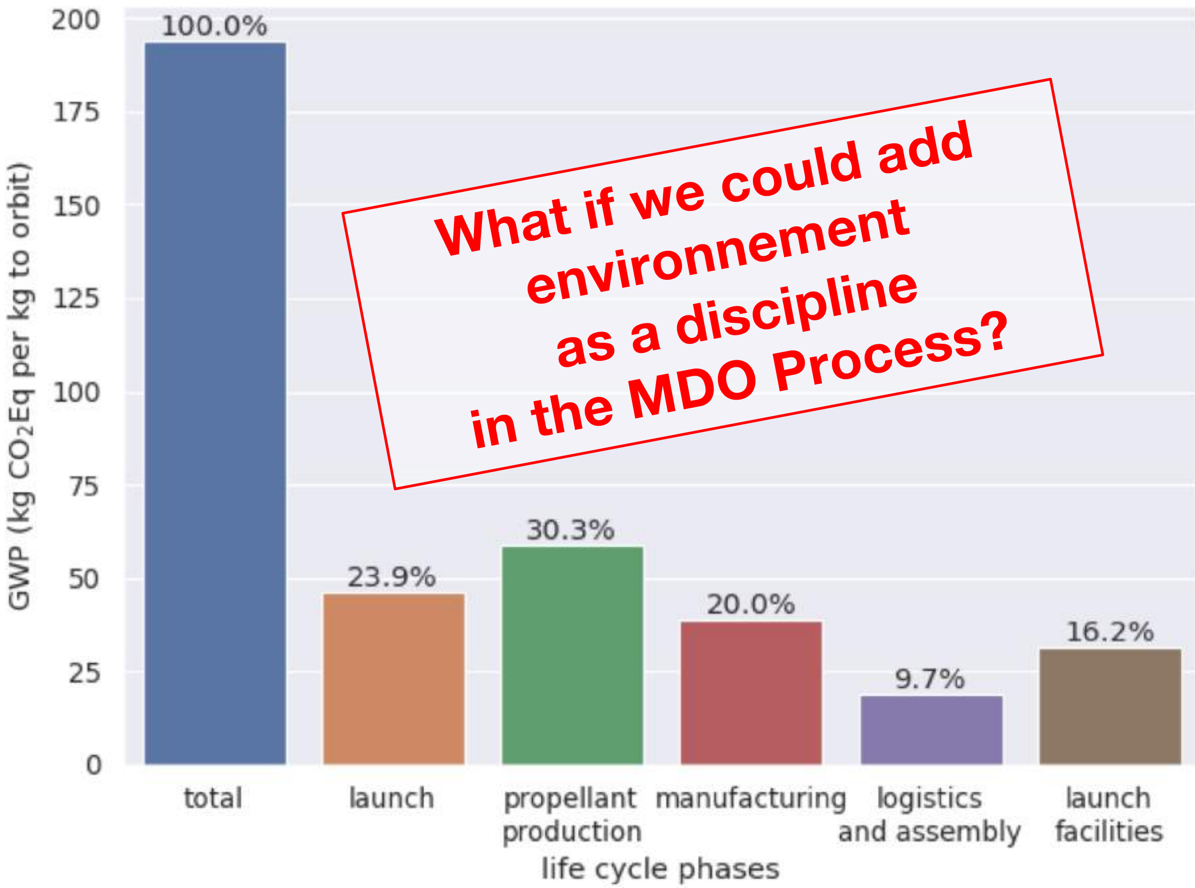
[2] *Royal Melbourne Institute of Technology (RMIT), Melbourne, Australia*

[*] Corresponding author
Email: thomas.bellier@isae-supaero.fr



# X* and LCA (X*)


And avoid Greenwashing !!!




What if we could add environnement as a discipline in the MDO Process?

Early LCA results demonstrate that manufacturing take into account 20% of Global Warming Potential (wrt 1% in Aircraft)

# Summary

1. Eco-design, LCA & MDAO
2. A simple Toy problem: Sellar problem
3. A more advanced problem using OpenConcept for Hybrid Aircraft
4. Opensource code LCA4MDAO

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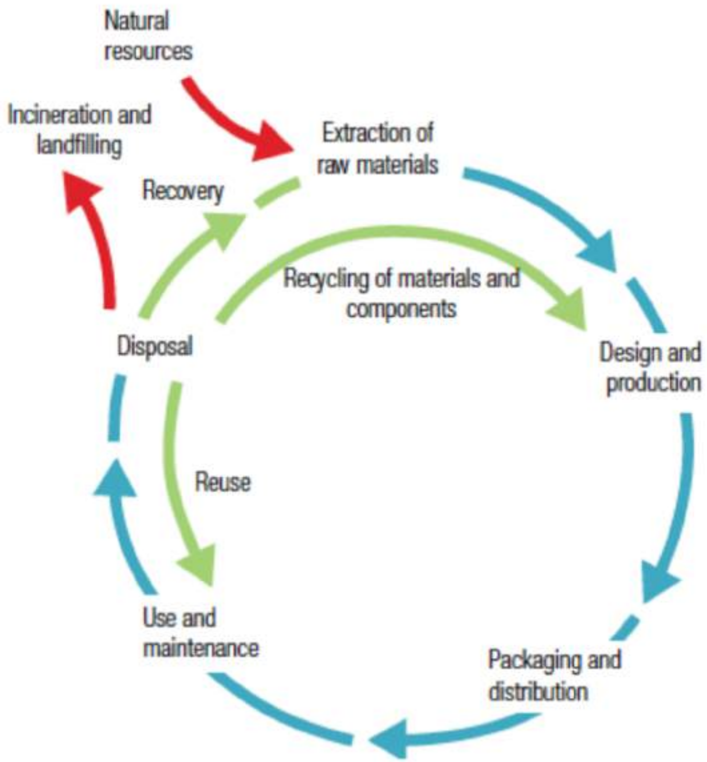
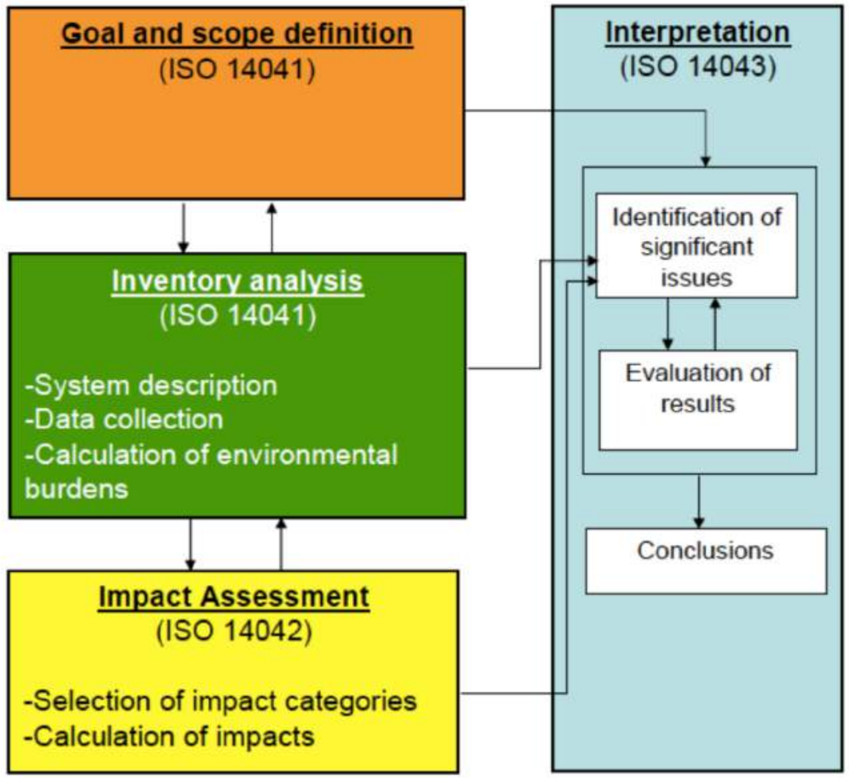
# Life Cycle Assessment



# Eco-design and MDAO

## MDAO

- Custom code or software
- Many simulations on low amounts of variables
- Engineering teams

## Life Cycle Assessment (LCA)

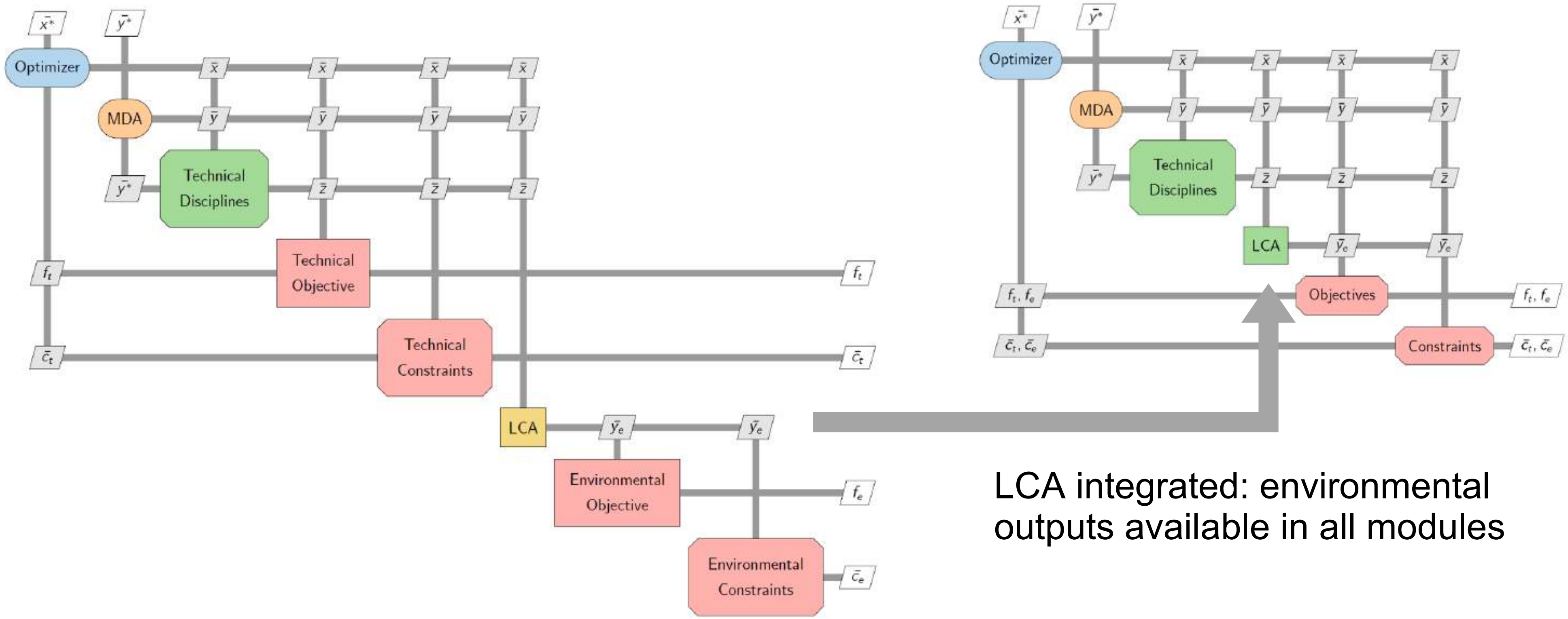
- Independent software (*OpenLCA*, *Simapro*, etc…)
- Single calls on large external databases (*Ecoinvent*, *ILCD*, etc…)
- Dedicated teams or consultancies

# Our python tool

Proposed solution: LCA4MDAO tool

- *OpenMDAO* and *Brightway2*: all in Python
- Direct linkage between *OpenMDAO* variables and *Brightway2* database entries
- LCA computation optimisation to help with repetitive calculation

# With XDSM




LCA integrated: environmental outputs available in all modules

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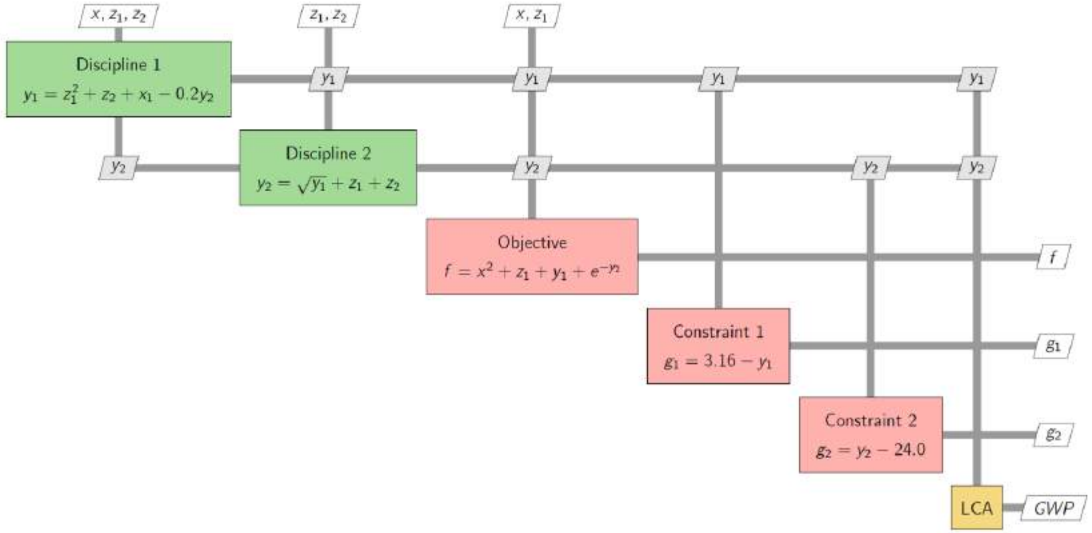
# Sellar Problem

- Simplest OpenMDAO test problem
- No physical representation

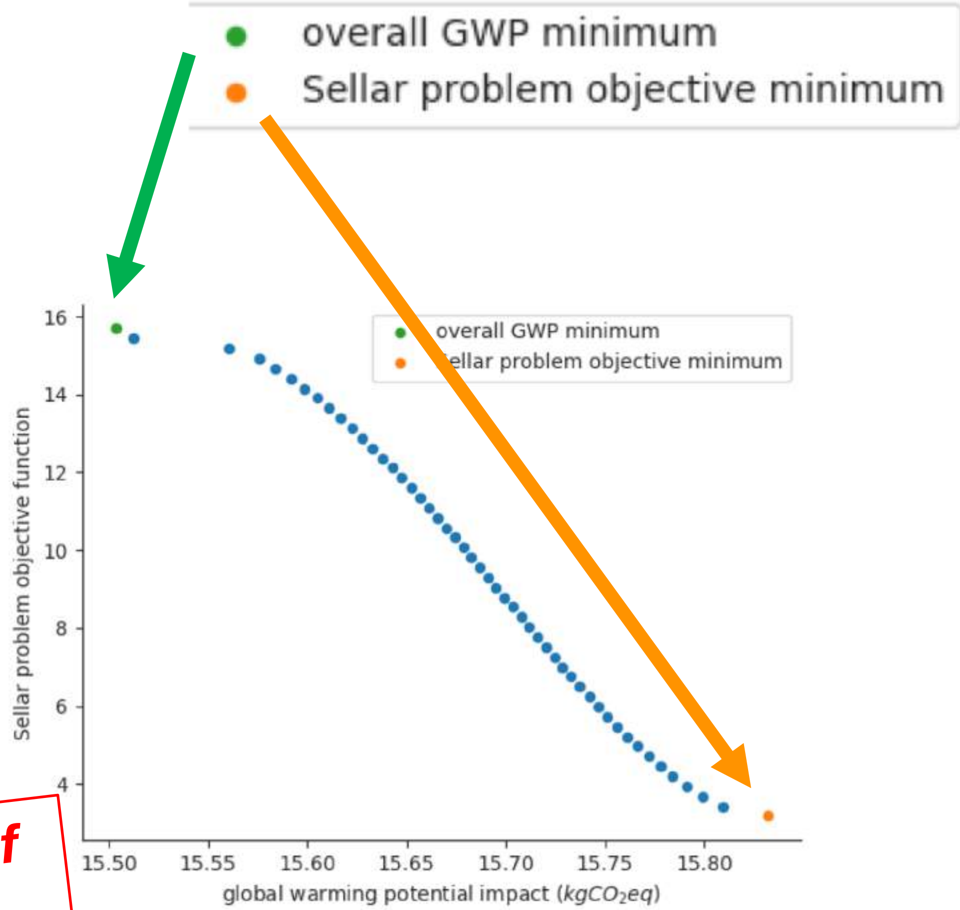



- y1 → steel
- y2 → wood

# SP Results

[https://pymoo.org](https://pymoo.org)

- Multi-objective optimisation using NSGA-2 (pymoo)
- Sellar f versus GWP
- Many more possibilities:
  - Single objective with environmental constraints
  - Injection of environmental parameters into a custom function
  - Multiple environmental objectives
  - ...




***A (non physical) proof of concept***

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# Hybrid Aircraft Problem (MDOlab)

- Hybridised King Air C90GT from OpenConcept, built in *OpenMDAO* format
- Four disciplines:
  - Aero (wing geometry)
  - Propulsion (with hybrid system)
  - Structure
  - Trajectory simulation
- 6 variables converted into LCA database entries

| Model parameter | Ecoinvent entry |
|---|---|
| Battery weight | battery cell production, Li-ion |
| Motor weight | electric motor production, vehicle |
| Engine weight | internal combustion engine production, passenger car |
| Empty weight | aluminium production, primary, ingot |
| Fuel used | market for kerosene |
| Electricity used | market group for electricity, low voltage |

Benjamin J. Brelje and Joaquim R. R. A. Martins, "Development of a Conceptual Design Model for Aircraft Electric Propulsion with Efficient Gradients", 2018 AIAA/IEEE Electric Aircraft Technologies Symposium, AIAA Propulsion and Energy Forum, (AIAA 2018-4979) DOI: 10.2514/6.2018-4979

# Design Variables

**Trajectory optimization overconstrained i.e.; standard mission**

Table 3 presents the design variables values and results after optimisation for this problem, with the range fixed at 400NM and using the GWP as the sole objective, using COBYLA [41]. Figure 6 presents the resulting trajectory and energy consumption for this 400 nautical miles range solution.

Table 3: Example of hybrid aircraft optimisation for a range of $400NM$

| variable | min | init | max | value | units |
|---|---|---|---|---|---|
| MTOW | 4000 | 5000 | 5700 | 5700 | $kg$ |
| wing surface | 15 | 25 | 40 | 34 | $m^2$ |
| engine power | 0 | 1000 | 3000 | 298 | $kW$ |
| motor power | 450 | 1000 | 3000 | 652 | $kW$ |
| battery weight | 20 | 1000 | 3000 | 1607 | $kg$ |
| fuel capacity | 500 | 1000 | 3000 | 500 | $kg$ |
| cruise hybridisation | 0 | 0.5 | 1 | 0.71 | |
| climb hybridisation | 0 | 1 | 1 | 0.785 | |
| descent hybridisation | 0 | 0.5 | 1 | 0.337 | |
| GWP | | | | 0.712 | $kgCO_2eq/km$ |

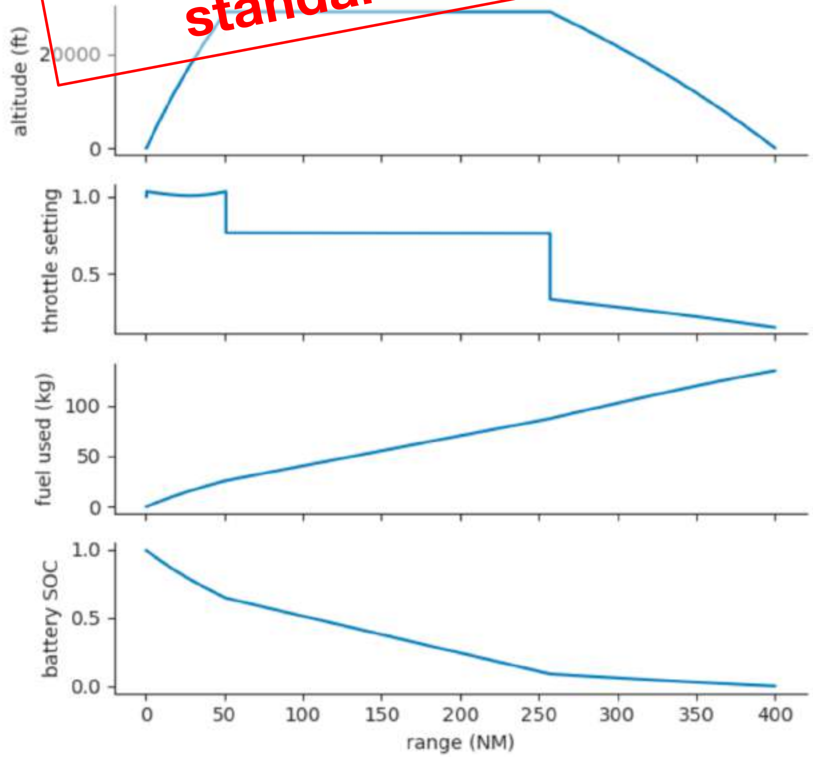
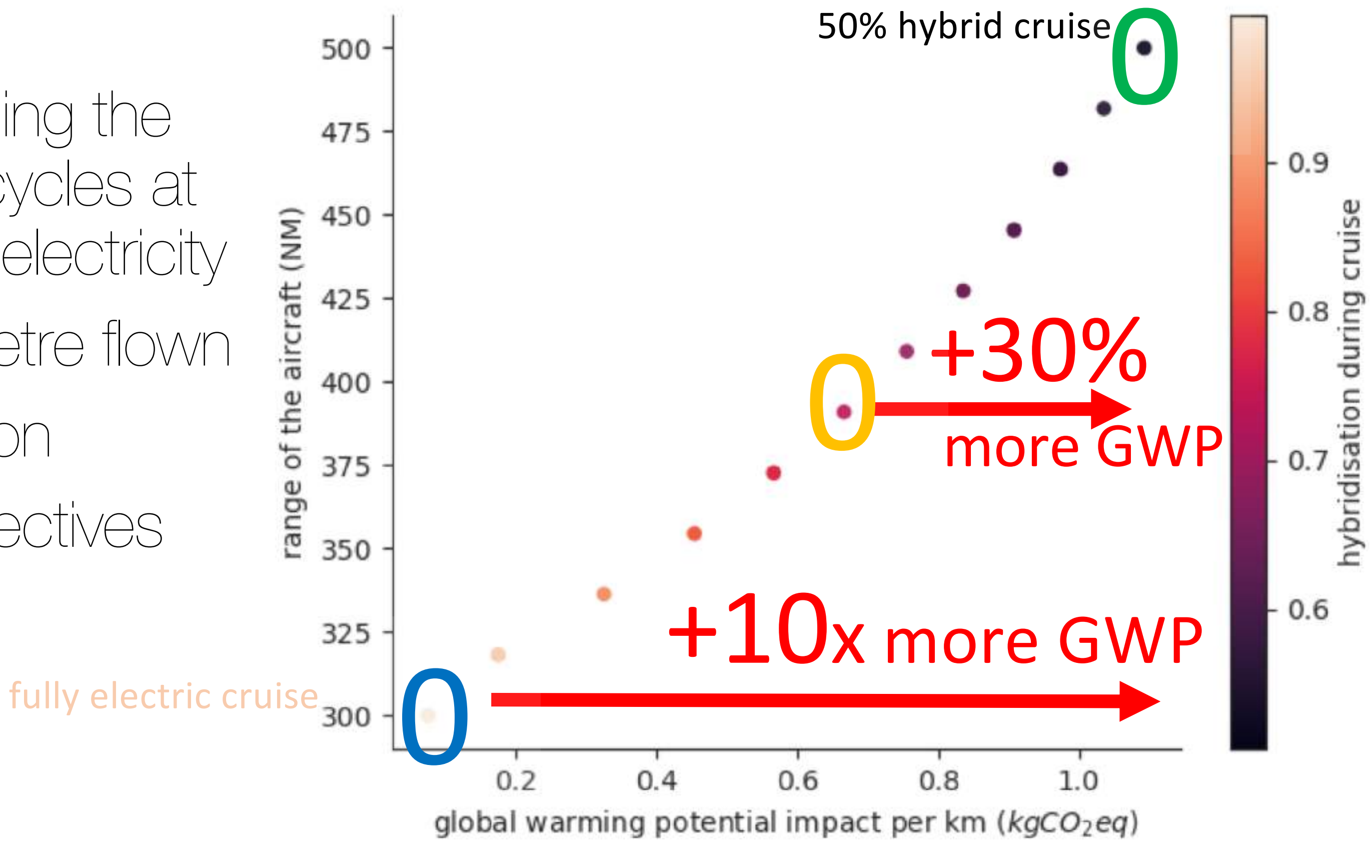



Figure 6: Optimal trajectory and energy utilisation for a hybrid aircraft with 400 nautical miles range

# Results

- LCA scope include building the aircraft and flying 1000 cycles at max range with fuel and electricity
- Functional unit is a kilometre flown
- Multi-objective optimisation
- Range and GWP as objectives



# Results (link to physics of AD)

For the design variables, reducing the range:

- increases the hybridization
- reduces the engine size
- increases the battery weight

| variable | value | units |
|---|---|---|
| MTOW | 5700 | $kg$ |
| wing surface | 34 | $m^2$ |
| engine power | 298 | $kW$ |
| motor power | 652 | $kW$ |
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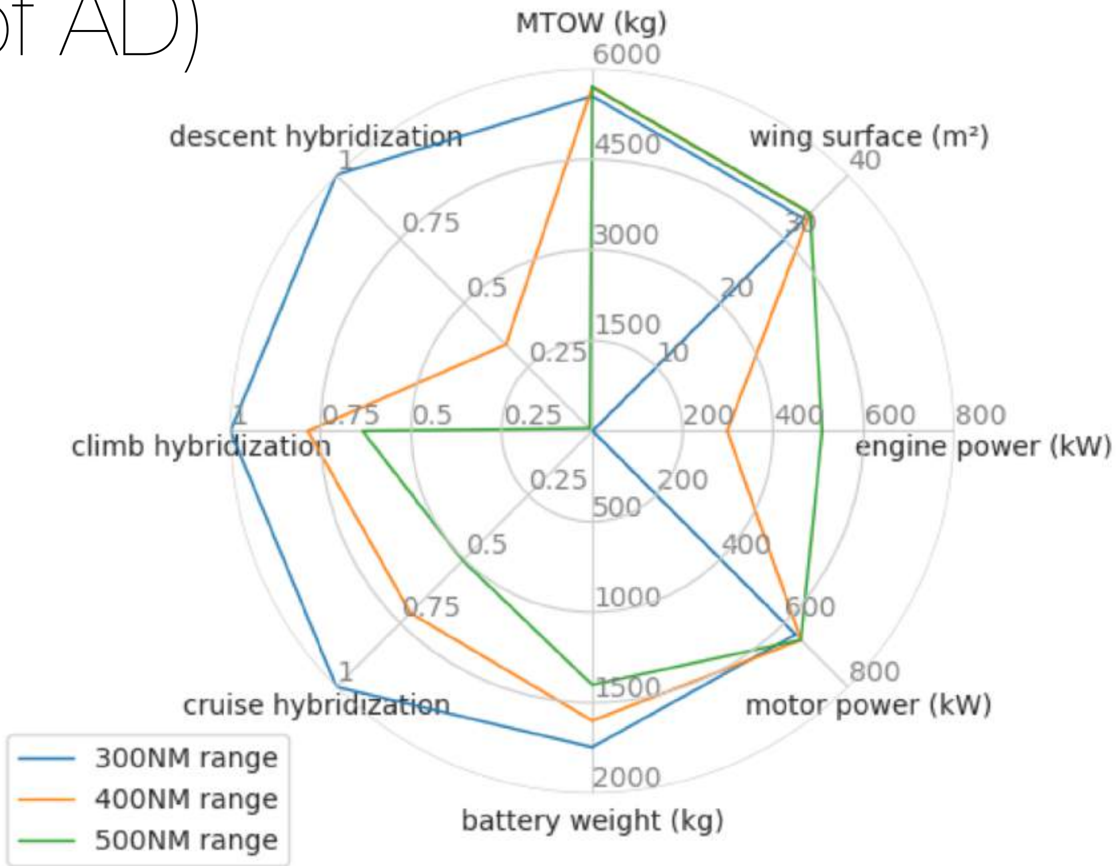

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4. **Opensource code LCA4MDAO**

# LCA4MDAO

- LCA4MDAO

https://github.com/mid2SUPAERO/LCA4MDAO

- Brightway2

- OpenMDAO

# Challenges

- Performance penalties during optimisation due to the large databases used for LCA
- Requires efficient communication or common understanding between the technical parameters and the LCA inventory
- LCA usually carries large uncertainties difficult to account for in MDAO

# Conclusion

- Integrating LCA in MDAO opens possibilities for better eco-optimisation and a better understanding of the environmental performance of a concept
- The availability of Python tools for LCA and MDAO will help to discuss between two fields of science
- There is still a gap between the two disciplines which is difficult to bridge

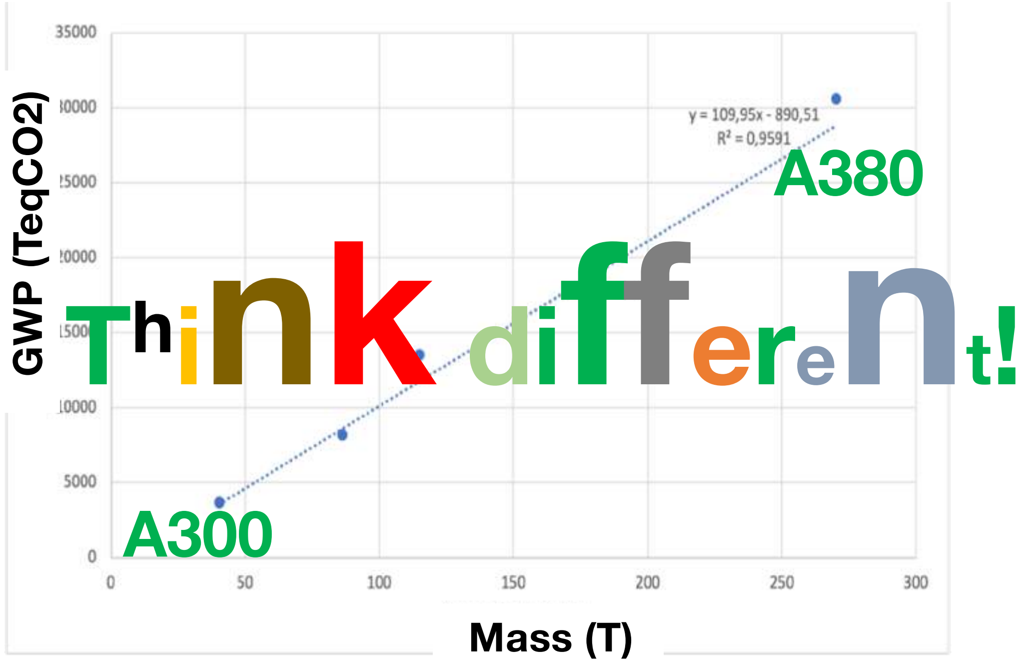
# Future Works

In Aircraft Design:

min {mass} is proportional to min {CO2PP}

Manufacturing <1% of total aircraft emissions

**But what about others flying vehicules?**



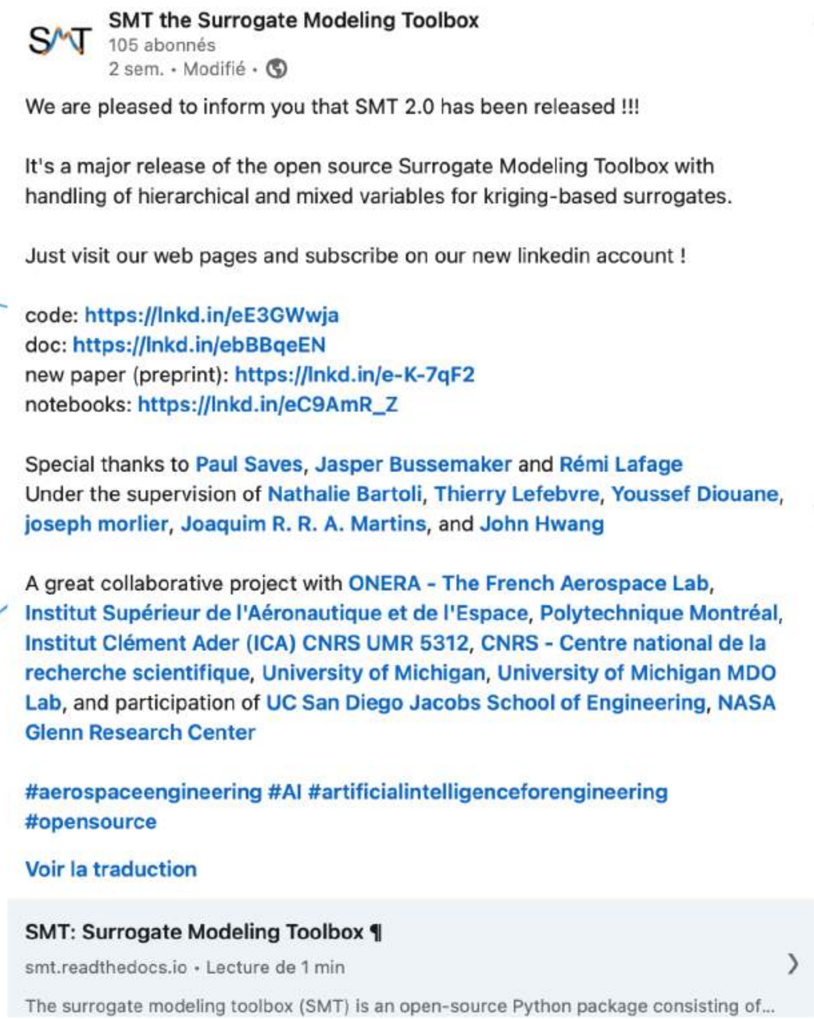

https://smt.readthedocs.io/en/latest/

linkedin.com/company

# Thank you for your attention!

Do you have any question?

↓ you can still check *LCA4MDAO* on github ↓


SMT the Surrogate Modeling Toolbox
105 abonnés
2 sem. • Modifié •

We are pleased to inform you that SMT 2.0 has been released !!!

It's a major release of the open source Surrogate Modeling Toolbox with handling of hierarchical and mixed variables for kriging-based surrogates.

Just visit our web pages and subscribe on our new linkedin account !

code: https://lnkd.in/eE3GWwja
doc: https://lnkd.in/ebBBqeEN
new paper (preprint): https://lnkd.in/e-K-7qF2
notebooks: https://lnkd.in/eC9AmR_Z

Special thanks to Paul Saves, Jasper Bussemaker and Rémi Lafage
Under the supervision of Nathalie Bartoli, Thierry Lefebvre, Youssef Diouane, joseph morlier, Joaquim R. R. A. Martins, and John Hwang

A great collaborative project with ONERA - The French Aerospace Lab, Institut Supérieur de l'Aéronautique et de l'Espace, Polytechnique Montréal, Institut Clément Ader (ICA) CNRS UMR 5312, CNRS - Centre national de la recherche scientifique, University of Michigan, University of Michigan MDO Lab, and participation of UC San Diego Jacobs School of Engineering, NASA Glenn Research Center

#aerospaceengineering #AI #artificialintelligenceforengineering #opensource

Voir la traduction

SMT: Surrogate Modeling Toolbox ¶
smt.readthedocs.io • Lecture de 1 min
The surrogate modeling toolbox (SMT) is an open-source Python package consisting of...