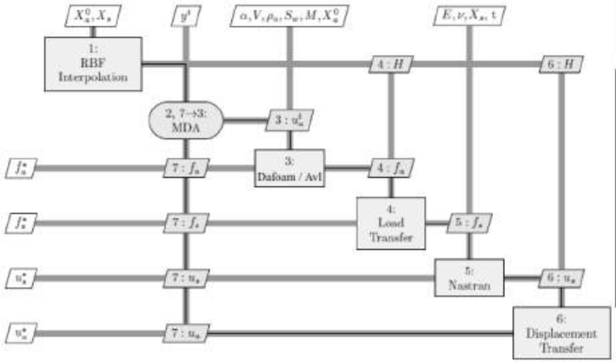
Integration of LCA as an environment discipline module in MDAO

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

AeroBest 2023

Prof. J. Morlier

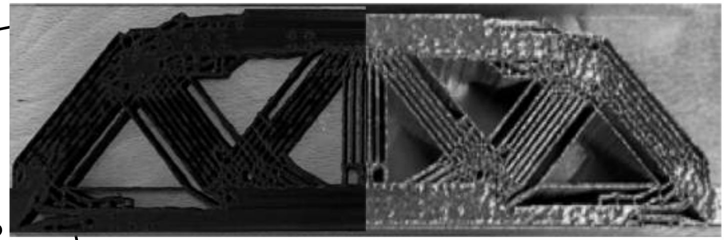


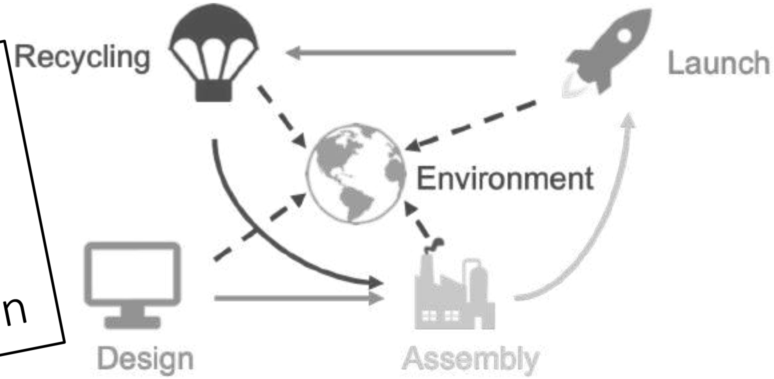
LCA & eco selection

- Material
- Process
- from cradle to grave

...

Digital fabrication including eco material/process selection





AI4E
Design Acceleration using SMT

Water withdrawal

Generation of waste

Carbon Footprint

Energy requirement

Use recycled:
Fibers
Resin
Metals
Reuse & Repair

MDO for Aerospace
Including LCA
EcoOptimization

SA-I

Sustainable
Aerostructures
Initiative

HTTPS://MICROLEARNING.GROUPE-ISAE.FR

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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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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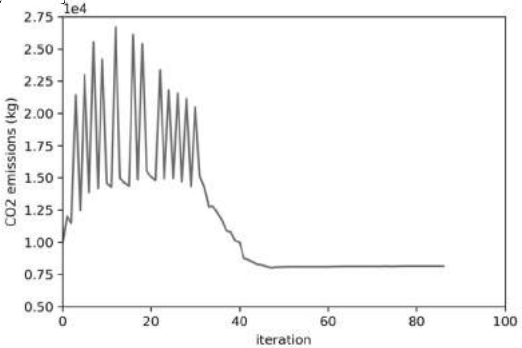
First try ;)

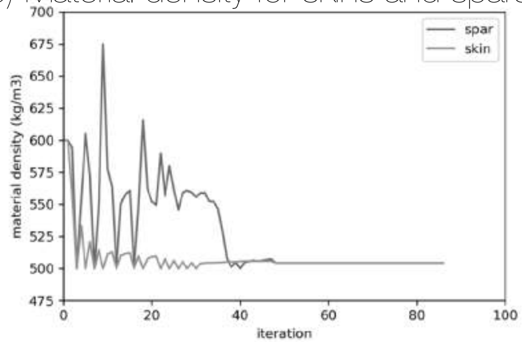
https://arxiv.org/abs/2208.13710

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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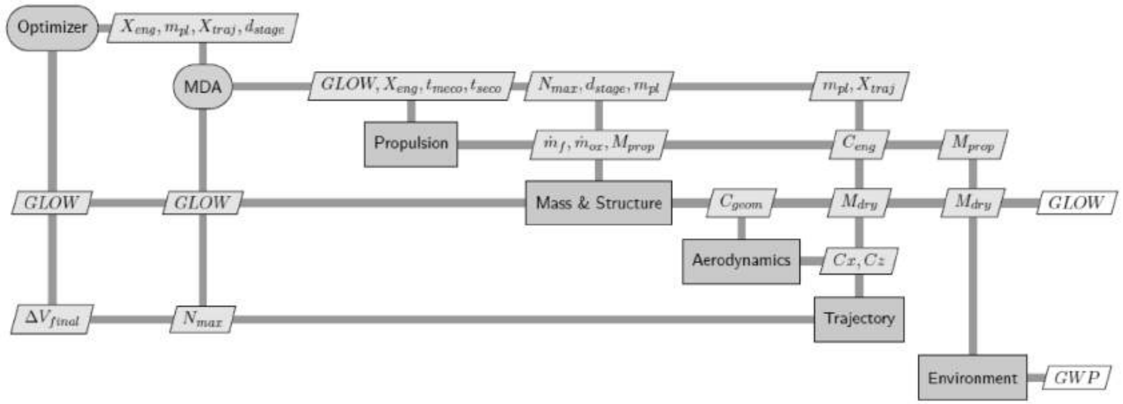
CAD model of the optimal HALE obtained

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]

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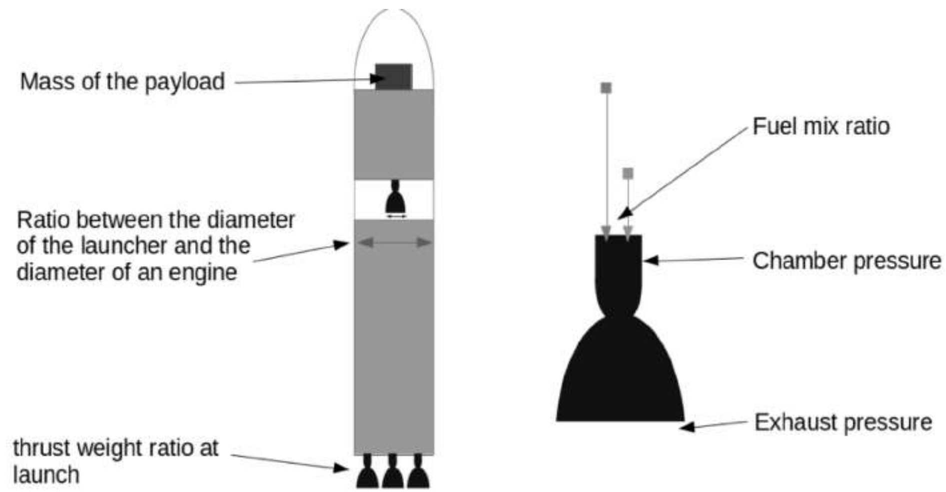
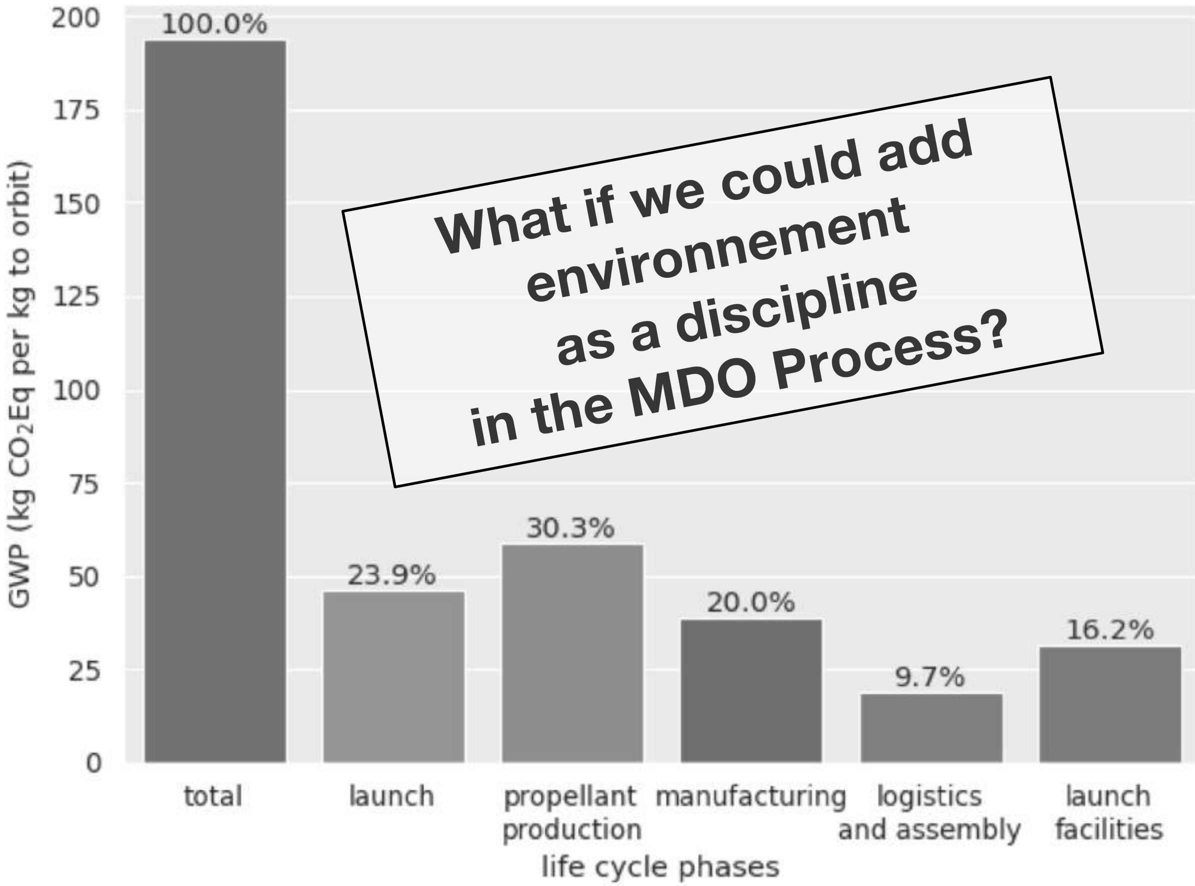


X* and LCA (X*)

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)

Aerobest 2023

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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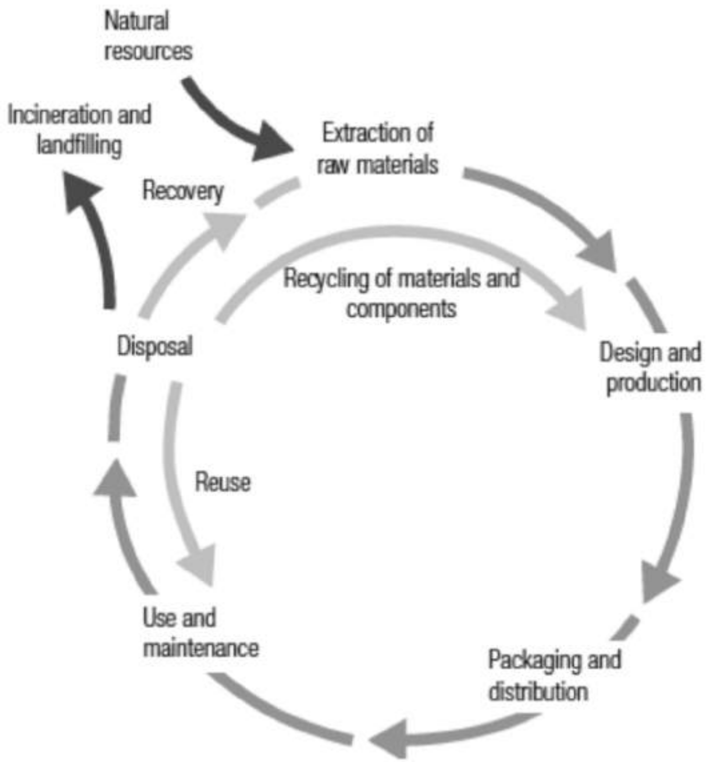
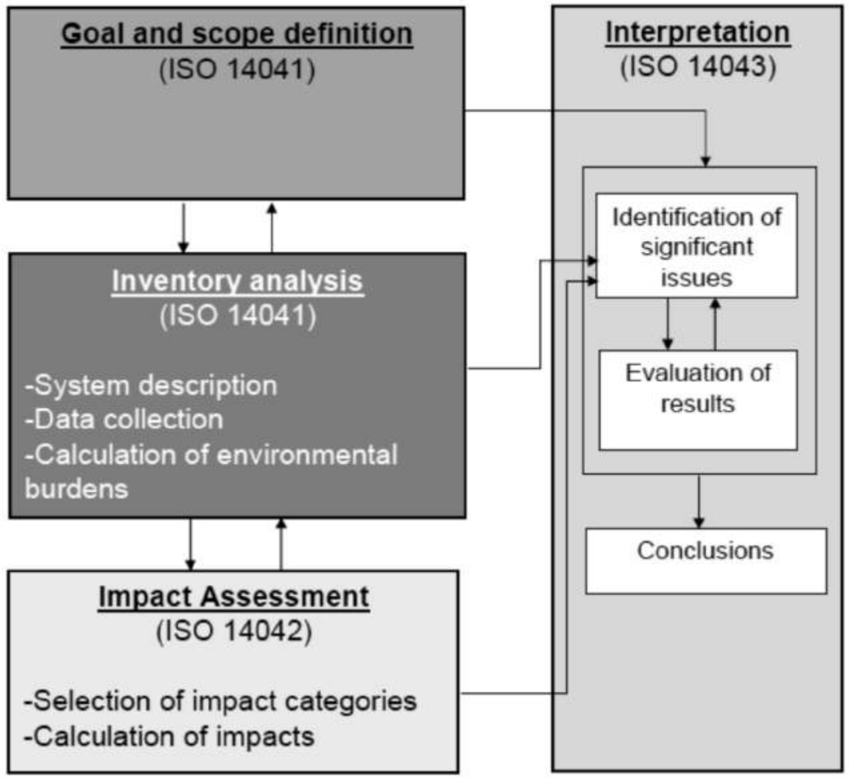
Life Cycle Assessment

ISO norm:

- Proper goal and scope definition, including functional unit
- Inventory analysis and the database problem
- Selection of impacts, and difference between raw flux, midpoint, and endpoint impacts





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

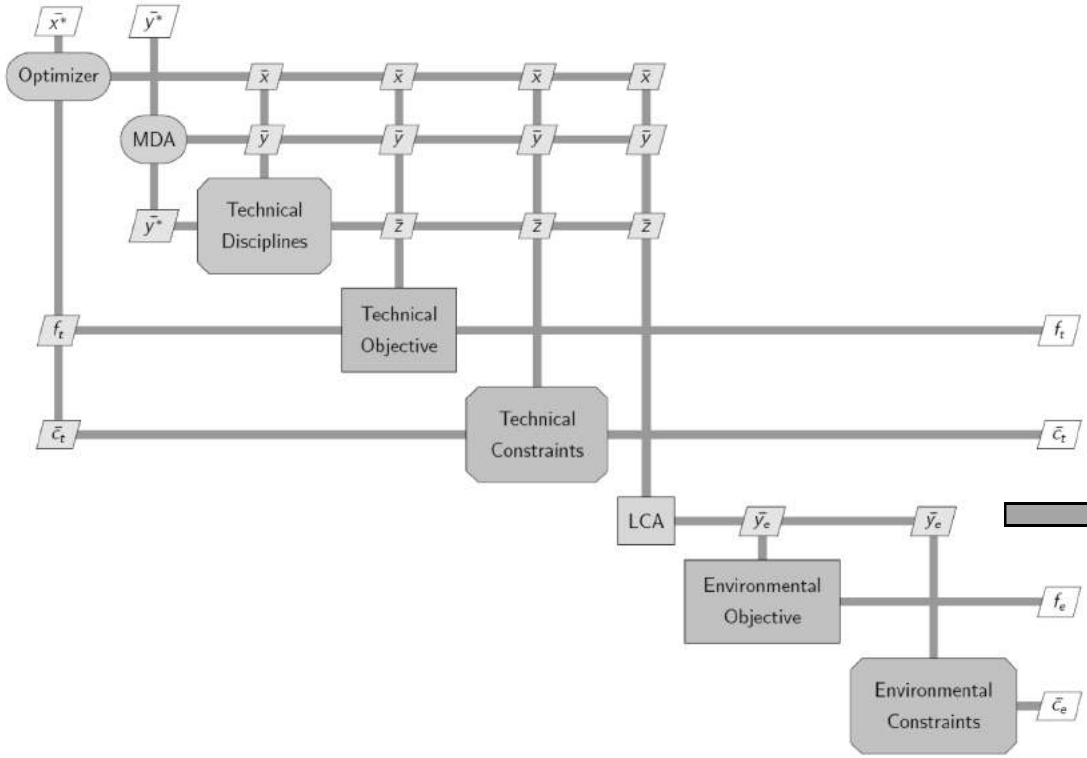
Proposed solution: LCA4MDAO tool

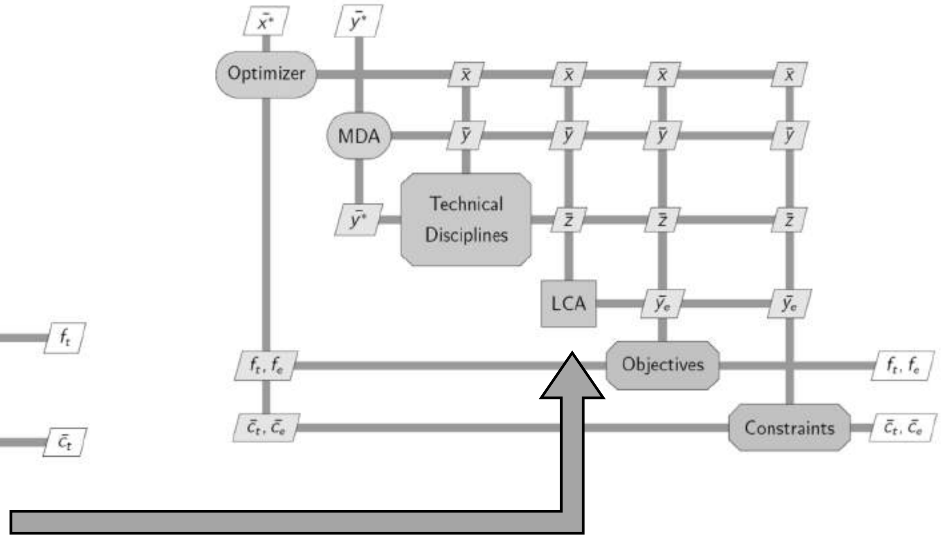
- *OpenMDAO* and *Brightway2*: all in Python
- Direct linkage between *OpenMDAO* variables and *Brightway2* database entries
- LCA computation is tuned so that we avoid repetitive (and useless) tasks

Mutel, C. (2017). Brightway: an open source framework for life cycle assessment. *Journal of Open Source Software*, *2*(12), 236.

Gray, J. S., Hwang, J. T., Martins, J. R., Moore, K. T., & Naylor, B. A. (2019). OpenMDAO: An open-source framework for multidisciplinary design, analysis, and optimization. *Structural and Multidisciplinary Optimization*, *59*, 1075-1104.

With XDSM





LCA integrated: environmental outputs available in all modules

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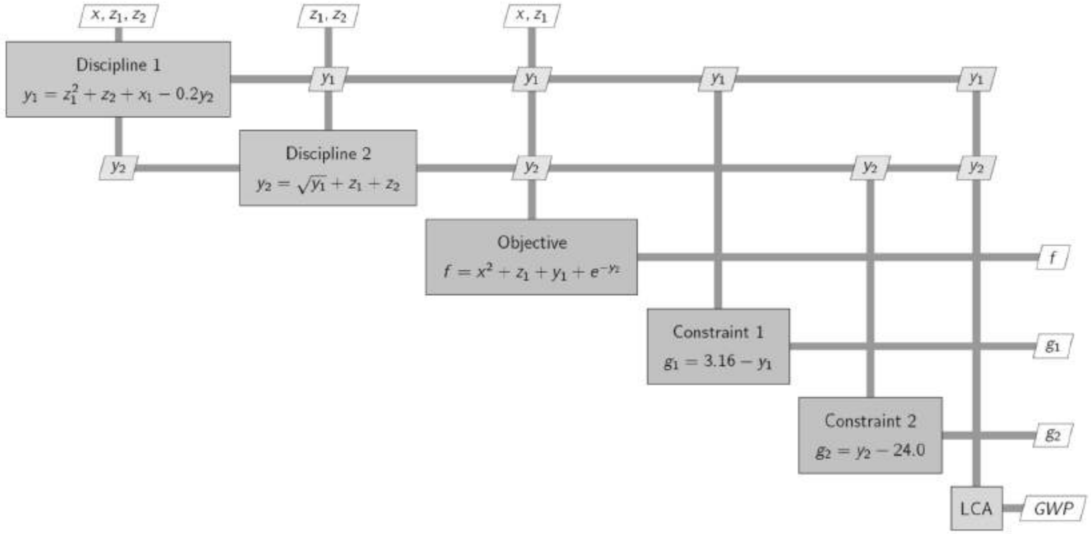
Sellar Problem {SP}

Sellar, R., Batill, S., & Renaud, J. (1996, August). Response surface based, concurrent subspace optimization for multidisciplinary system design. In *34th aerospace sciences meeting and exhibit* (p. 714).

- Simplest OpenMDAO test problem
- No physical representation



- y1 → steel
- y2 → wood

MOO

f1=Minimize (f_sellar) and f2=minimise (GWP)

%f1=Minimize (-range) and f2=minimise (GWP) % second problem

$$f = \alpha * f1 + (1 - \alpha) * f2$$

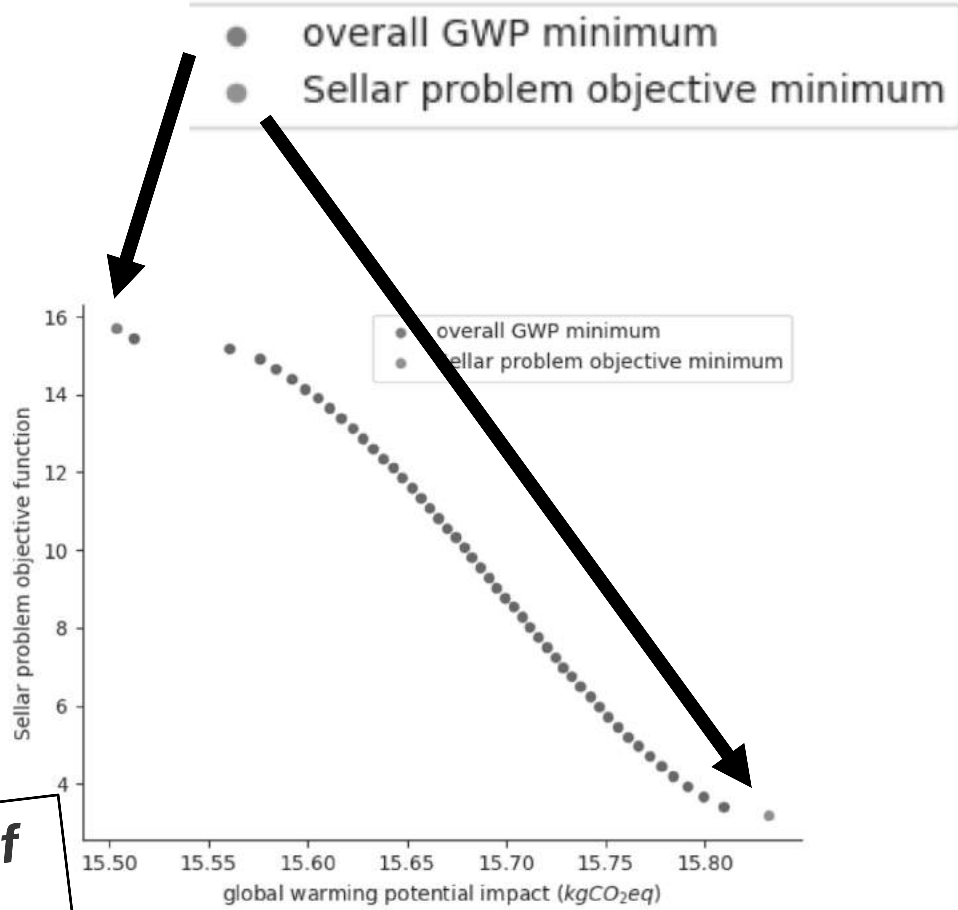
SP Results

Multi-objective Optimization in Python

pymoo

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

Eytan J. Adler and Joaquim R. R. A. Martins, "Efficient Aerostructural Wing Optimization Considering Mission Analysis", Journal of Aircraft, 2022. DOI: 10.2514/1.c037096

Design Variables

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 400*NM*

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	$kgCO_2eq/km$

minimise (GWP)
wrt range=400NM

Trajectory optimization overconstrained i.e.; standard mission

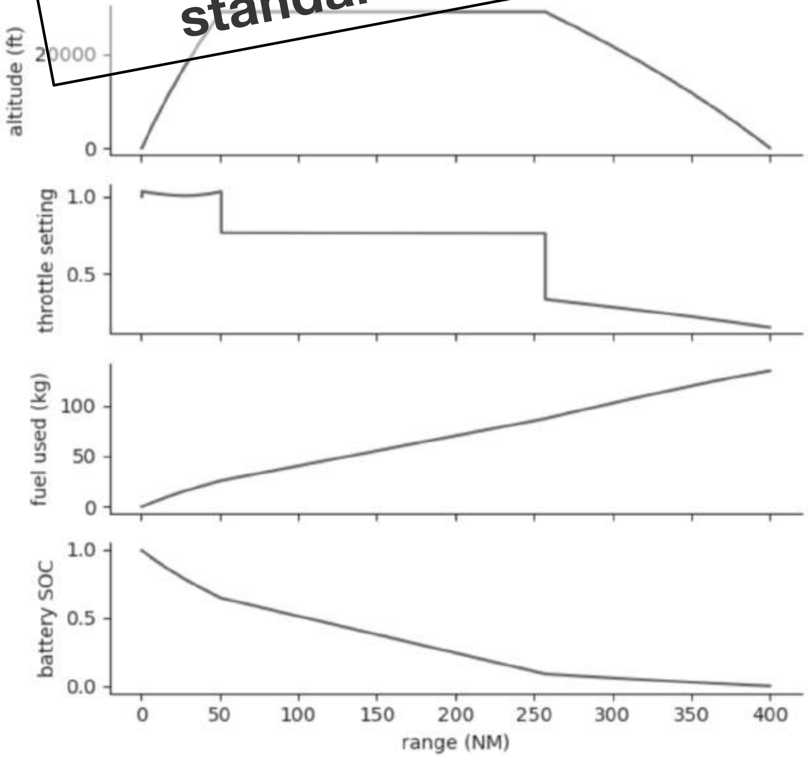
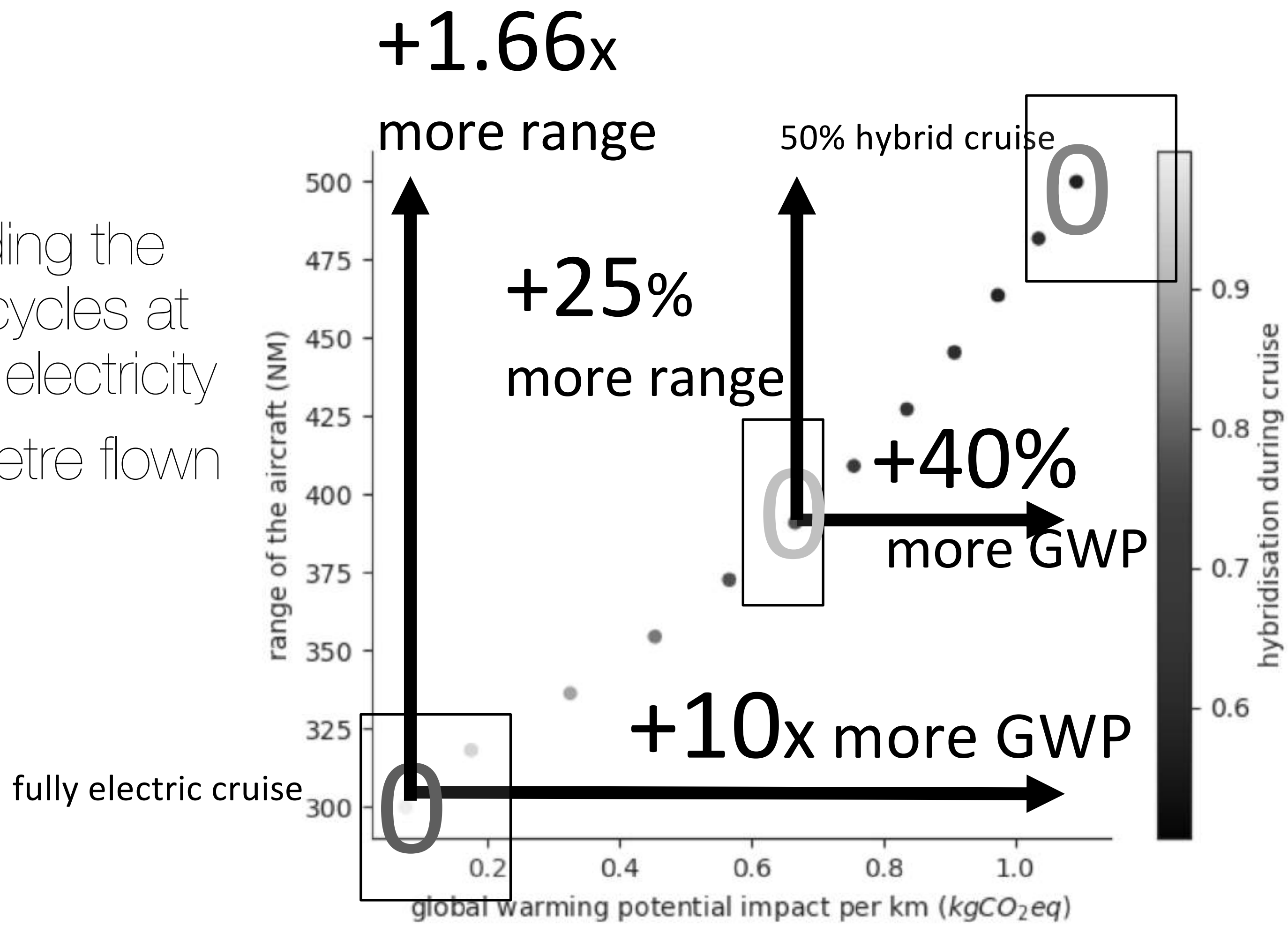


Figure 6: Optimal trajectory and energy utilisation for a hybrid aircraft with 400 nautical miles range

Results MOO

- LCA scope include building the aircraft and flying 1000 cycles at max range with fuel and electricity
- Functional unit is a kilometre flown



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
battery weight	1607	kg
fuel capacity	500	kg
cruise hybridisation	0.71	
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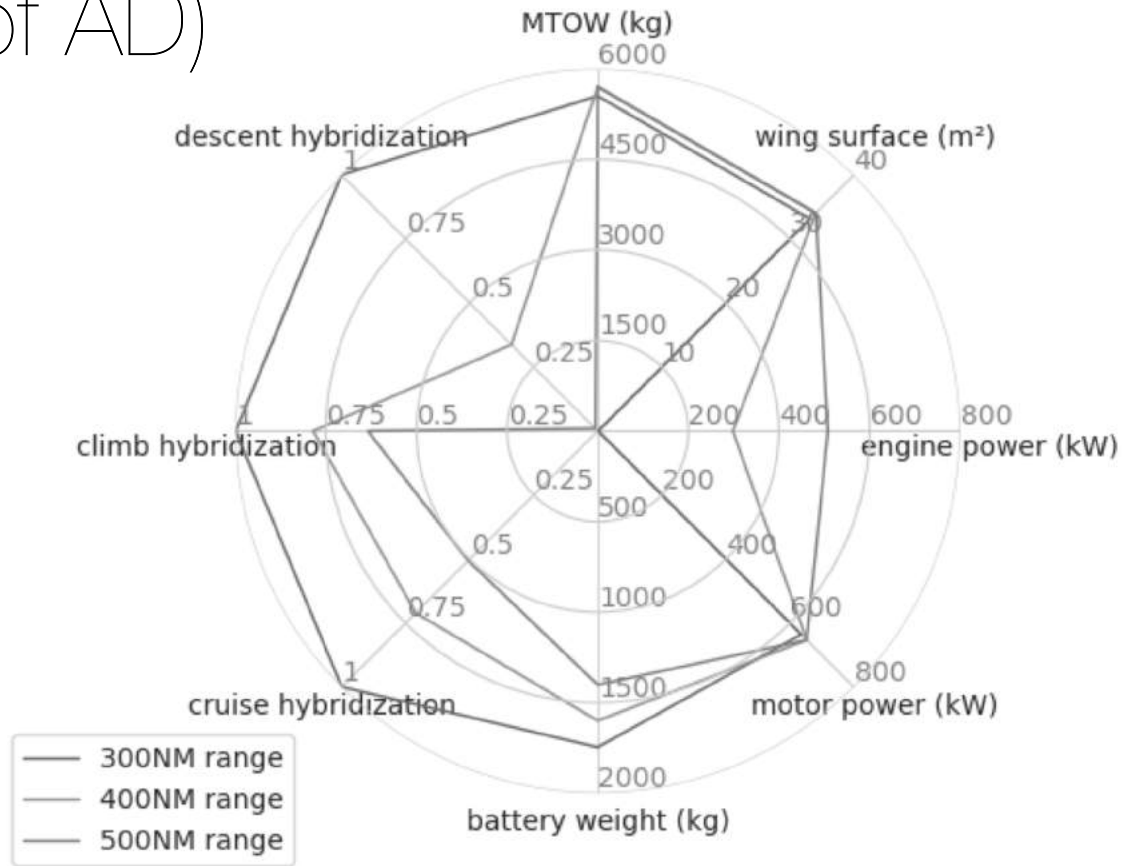
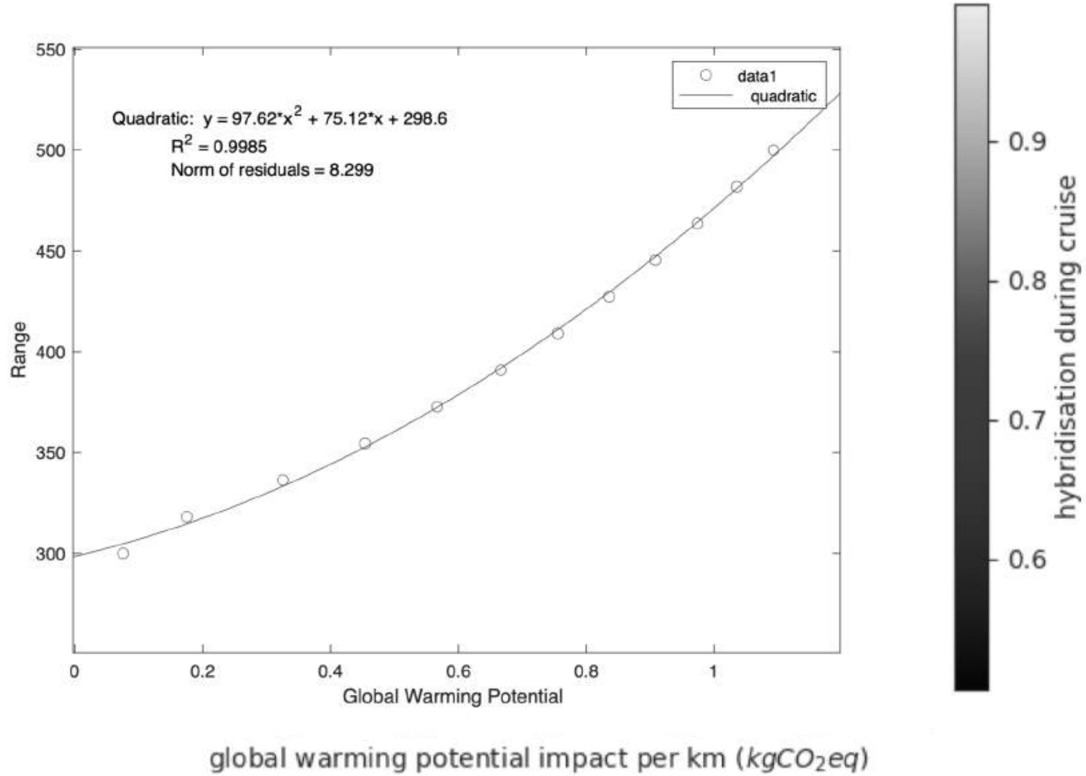


Polynomial Regression

?



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LCA4MDAO

- LCA4MDAO (**needed LCA database ecoinvent)**

https://github.com/mid2SUPAERO/LCA4MDAO

- Brightway2
- OpenMDAO

Challenges

- Performance penalties during optimisation due to the large databases used for LCA (SQL, memory access due to large trees of properties
- Requires efficient communication or common understanding between the technical parameters and the LCA inventory
- LCA usually carries large uncertainties (→**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
- Ecodesign will be a hard constraint in the near future for every academic/industrial projects

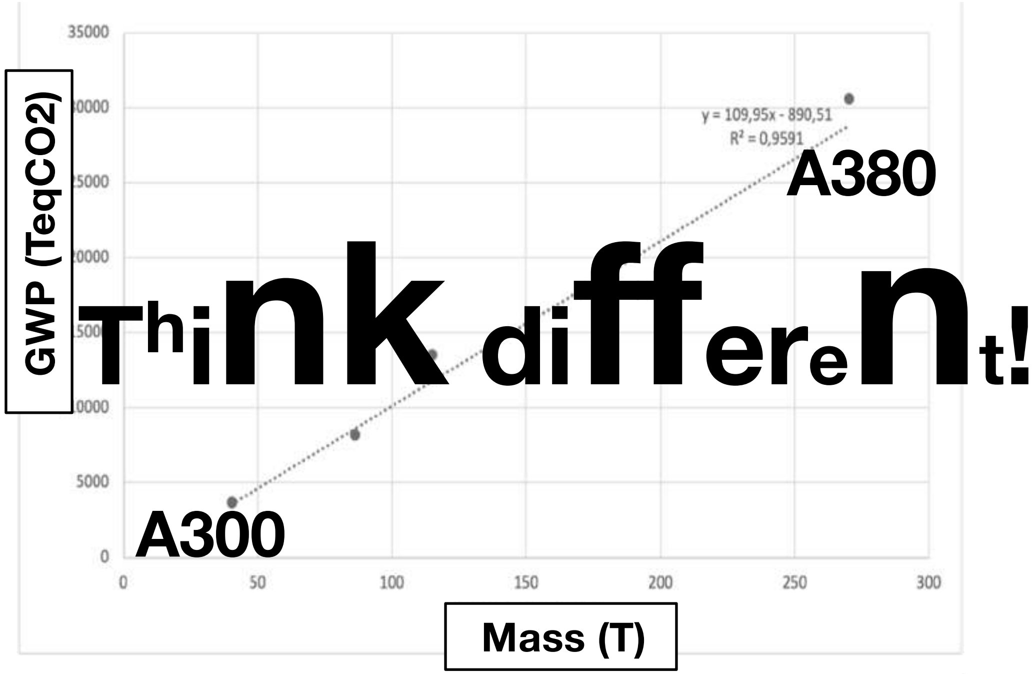
Future Works

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/
www.linkedin.com/company/smt-the-surrogate-modeling-toolbox

Thank you for your attention!

any question?

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...