KICK-OFF. INITIAL STATE OF THE ART REVIEW.

Almudena Cobo

WHICH IS THE GOAL OF ECODESIGN?

Minimizing the environmental impact of the Aircraft's life cycle: production & operation, while maintaining functionality and economical viability.

HOW?

Geometrical optimization and material selection.

CONSTRAINTS

- Yield stress
- Buckling
- Aircraft's range

OPTIMIZATION?

UNCOUPLING MATERIAL CHOICE AND TOPOLOGY

- Optimal material minimizes Ashby's index for a rod in tension or compression: $\frac{\rho}{E}$
- Optimal topology minimizes: $f(V_f)V_f$

$$M = \frac{LhF}{\delta_{max}}\frac{\rho}{E}f(V_f)V_f \qquad (7)$$

USE OF ASHBY'S INDICES FOR ECODESIGN STRUCTURES OPTIMIZED THROUGH TOPOLOGY: CARBON FOOTPRINT EVALUATION

-New Ashby index that depends only on the vehicle being used: $\frac{\rho}{E} \times (CO^i_{2mat} + L_{veh} \times CO^i_{2veh})$

$$CO_2^{tot} = \frac{LhF}{\delta_{max}}\frac{\rho}{E}f(V_f)V_f \times (CO^i_{2mat} + L_{veh} \times CO^i_{2veh}) \qquad (10c)$$

Edouard Duriez, Joseph Morlier, Catherine Azzaro-Pantel, M. Charlotte. Ecodesign with topology optimization. Procedia CIRP, 2022, 109, pp.454-459. 10.1016/j.procir.2022.05.278. hal-03722152

SUSTAINABLE ALTERNATIVE MATERIALS?

PLA/Ramie

From *Potential of sustainable materials in wing structural design* PLA/Ramie is presented as an alternative reducing the environmental impact.

Its mechanical properties are argued to be poor in *Future aircraft wing structures using renewable materials.*

Solution: Adding nanocellulosic fibers (NCF). Nevertheless, the material becomes brittle. Other options should be proposed.

Thermosets fiber composites: Phenolic resins

Epoxy resins typically used due to their resistance to degradation and good mechanical porperties. A sustainable alternative could be Phenolic resins obtained from natural sources using non-toxic alehydes (glyoxal and furfural).

Bio-based carbon fibers

Naturally derived CF, they present similar mechanical and physical properties to conventional CF reducing its environmental impact. Acrylotirile is conventionally obtained petrochemically, which could be synthesied from glycerine in order to ensure its sustainablity.

Boegler, O., et al. *Potential of sustainable materials in wing structural design*. Bonn, Germany: Deutsche Gesellschaft für Luft-und Raumfahrt-Lilienthal-Oberth eV, 2015.
Kling, U., et al. *Future aircraft wing structures using renewable materials*. Deutsche Gesellschaft für Luft-und Raumfahrt-Lilienthal-Oberth eV, 2015.

SUSTAINABLE ALTERNATIVE MATERIALS?

	E (GPa)	σ_y (MPa)	ρ (kg/m³)
Fiber Material			
Ramie [1]	44	612	1450
Carbon fiber [2]	230	3530	1760
Matrix Material			
PLA + 3wt% NCF [3]	1.20	33	1220
Novolac furfural phenolic resin [4]	3.18	50	1250

Table 1: Material characteristics of naturally derived fiber and matrix materials from *Future aircraft wing structures using renewable materials*.

Material	E GPa	G GPa	σ_y MPa	ρ kg/m³
PLA+3%NCF/Ramie	8.7	5.5	124	1357
PLA+3%NCF/CF	40	27	540	1573
Phenolic Res./CF	42	27	543	1586
EpoxyRes./CF (Ref1)	75	47	550	1576
Al 6061 T6 (Ref2)	69	26	276	2700

Table 2: Ramie-fiber and carbon fiber composites input parameters and data for conventional CFRP and aluminum from *Future aircraft wing structures using renewable materials*.

Kling, U., et al. *Future aircraft wing structures using renewable materials*. Deutsche Gesellschaft für Luft-und Raumfahrt-Lilienthal-Oberth eV, 2015.

MASS CALCULATION?

The wing deformation leads to new aerodynamic forces and further wing deflection. Proposed iterative process of wing dimensioning for the corresponding load using “Tornado” FEM-beam model. (using Airbus A320neo as reference)

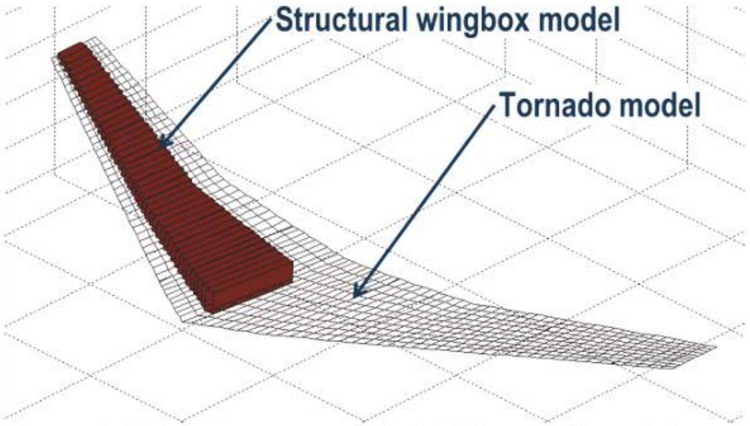


Figure 1: Finite element model with “Tornado”-mesh for aerodynamic calculations

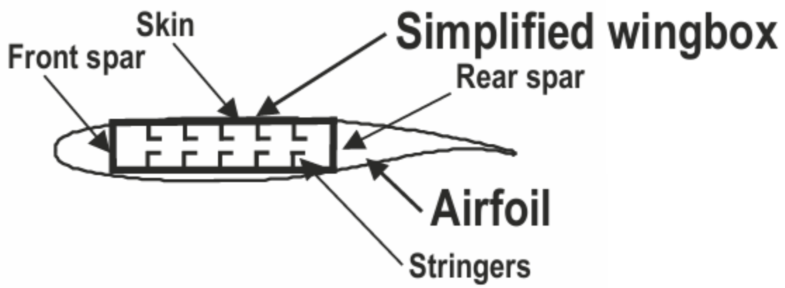


Figure 2: Definition of the wingbox for finite elements calculations.

Kling, U., et al. *Future aircraft wing structures using renewable materials*. Deutsche Gesellschaft für Luft-und Raumfahrt-Lilienthal-Oberth eV, 2015.

RESULTS

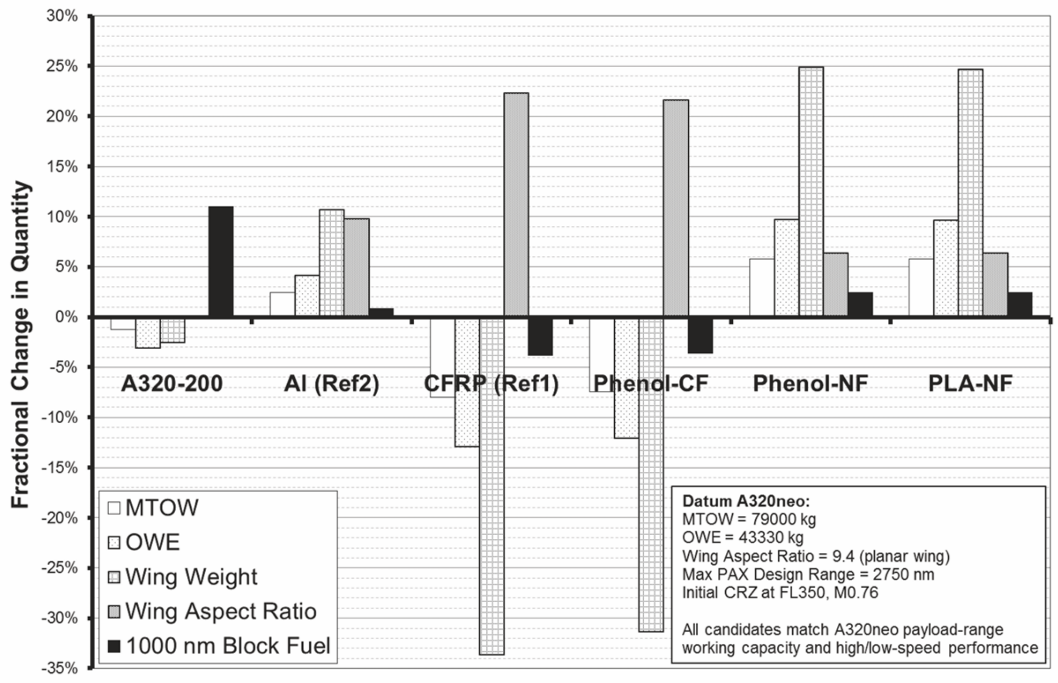
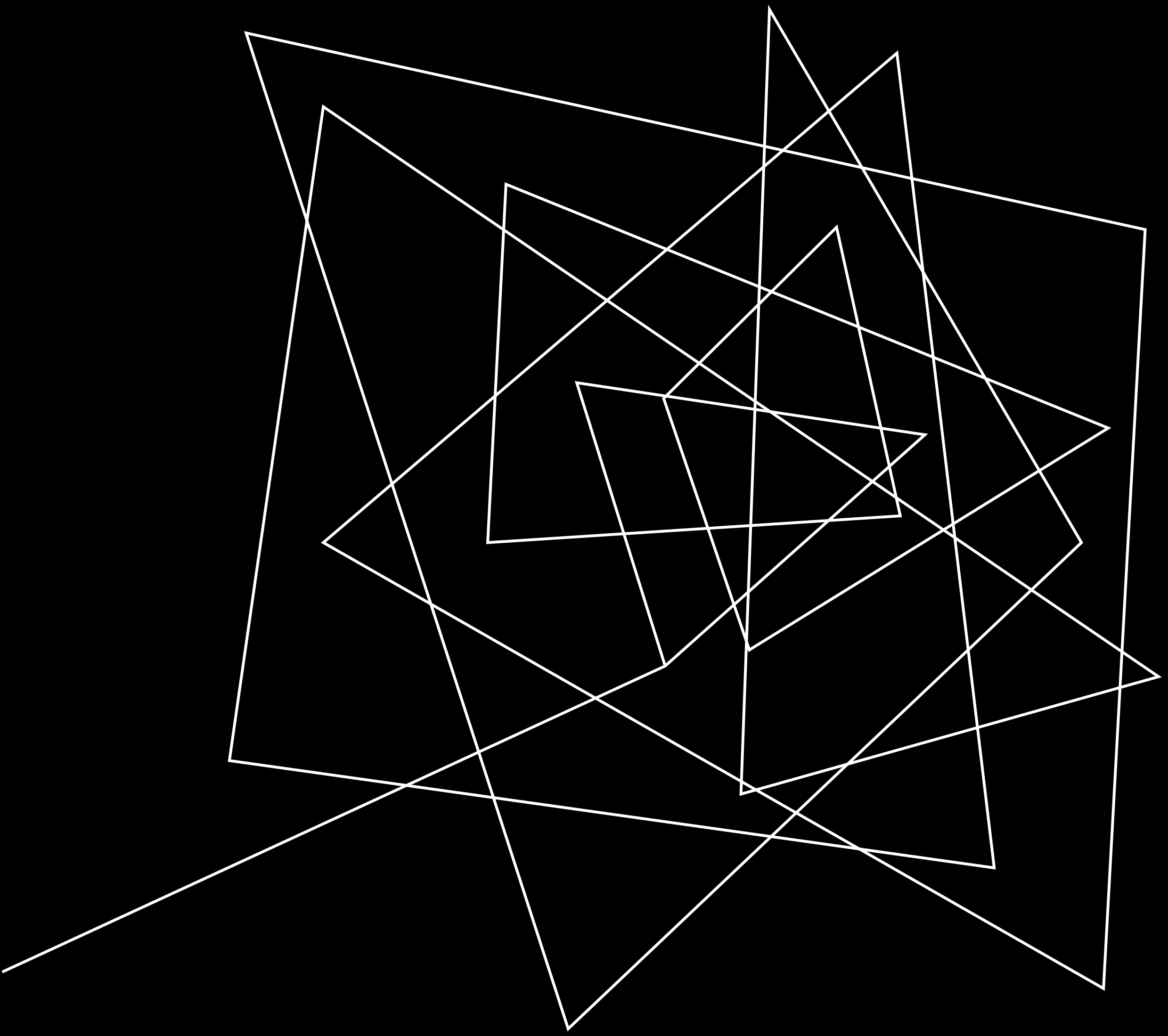


Figure 5: Parametric review between design candidates and the A320neo (datum) reference aircraft.

- Epoxy matrix materials present the best presults:4% reduction in 1000nm block fuel.
- Phenol-CF generates a similar outcome to CFRP.
- The wing with Phenol-CF presented buckling!
- Phenol-NF and PLA-NF increase the aircraft weight and produce more block fuel and costs.

Table 4: Parametric review between design candidates and the A320neo (datum) reference aircraft.

Aircraft Properties	*Unit*	*A320neo [datum]*	*A320-200*	*Al (Ref2)*	*CFRP (Ref1)*	*Phenol-CF*	*Phenol-NF*	*PLA-NF*
MTOW	kg	**79000**	-1.3%	+2.4%	-8.0%	-7.5%	+5.8%	+5.8%
OWE	kg	**43330**	-3.1%	+4.2%	-12.9%	-12.0%	+9.7%	+9.7%
OWE / MTOW	%	**54.9**	53.9	55.8	51.9	52.1	56.9	56.9
Aspect Ratio (planar)	-	**9.4**	9.4	10.3	11.5	11.4	10.0	10.0
Estimated W_{wing}	kg	**9379**	-2.4%	+10.7%	-33.6%	-31.4%	+24.9%	+24.7%
W_{wing} / MTOW	%	**11.9**	11.7	12.8	8.6	8.8	14.0	14.0
Estimated 1000 nm Block Fuel, M0.76	kg	**5740**	+11.0%	+0.9%	-3.8%	-3.6%	+2.5%	+2.4%



CONCLUSION FROM *FUTURE AIRCRAFT WING STRUCTURES USING RENEWABLE MATERIALS*

Sustainable composites with Ramie fibers are not a suitable option as they do not succed in reducing the wingbox weight. Phenolic resin with carbon fibers from renewable sources reduce the reference weight for A320neo and reduce the block fuel

OTHER INTERESTING WORK

Kumar, Dr Lakhan Patidar Dhananjay, Pankaj Pandey, and Lakhan Patidar. "Structural analysis of airplane wing using composite and natural fiber materials: A survey." (2023).

Gives an overall state of the art in the use of natural fiber composite materials and eventually focuses on glass fibers. Nevertheless, these fibers do not come from renewable sources.

“Throughout the course of this investigation, a number of different types of glass, including EGR glass, R glass, and S glass, were used. When exposed to a pressure of 0.005 MPa, the data suggest that S Glass is the material that is most capable of creating the highest amount of deformation as compared to the other options.”

OTHER INTERESTING WORK FOCUSED ON AIRCRAFT OPTIMIZATION RELATED TO ENVIRONMENTAL IMPACTS

- DATA-DRIVEN MULTI-RANGE MISSION-BASED OVERALL AIRCRAFT CONCEPTUAL DESIGN OPTIMIZATION Lijing Liu1, Dajung Kim1,2, Christian Reyner1 & Rhea P. Liem1 1The Hong Kong University of Science and Technology, Clear Water Bay, Hong Kong SAR 2Ecole Nationale de l'Aviation Civile, Toulouse, France.

"Studies the optimum aircraft size and configuration based on multi-range missions to take into account diverse operation conditions when designing aircraft. We adopted fuel economy as an objective function in the design optimization to consider the energy efficiency in multi-range missions."

OTHER INTERESTING WORK FOCUSED ON AIRCRAFT OPTIMIZATION RELATED TO ENVIRONMENTAL IMPACTS

- Henderson, Ryan P., Joaquim RRA Martins, and Ruben E. Perez. "Aircraft conceptual design for optimal environmental performance." *The Aeronautical Journal* 116.1175 (2012): 1-22.

"Develops an aircraft environmental design and optimisation framework for fuel burn (CO2) and LTO NOx emissions. The aircraft were also optimised for minimum direct operating cost for comparison purposes. All typical aircraft conceptual design disciplines, as well as propulsion and emissions, were integrated into this framework. Since the design space contained many local minima and was also discontinuous, the optimisations were performed using non-gradient based optimisers."

WHAT LINE OF WORK SHOULD WE FOLLOW?

- Research on materials that inherently produce the lowest carbon footprint while delivering acceptable performance.
- Optimizing the wing structure (wing span, etc) so that the efficiency is increased compared to already existing configurations in order to promote fuel saving.
- Key parameters to be optimized: range, Co2 footprint.