Kick-off

By Álvaro Caridade

Life cycle of CFRP

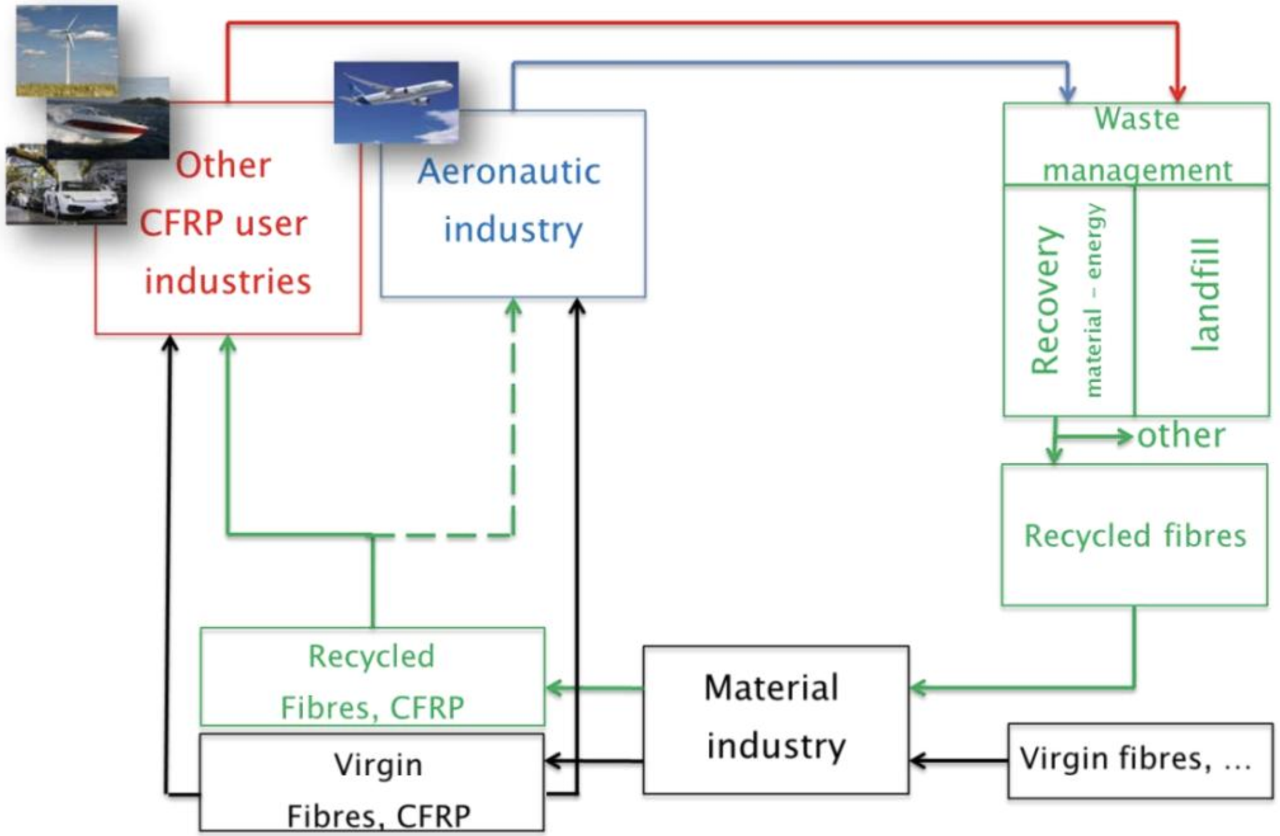


Figure 3: Simplified life cycle of CFRP (from SEARRCH project)

Phuong Anh Vo Dong. Multi-objective optimization for ecodesign of aerospace CFRP waste supply chains. Chemical engineering. Institut National Polytechnique de Toulouse - INPT, 2017. English. ffNNT : 2017INPT0034ff. fftel-04222345

Aerospace Industry's Environmental Challenge

- High use of **CFRP and composites** for weight reduction.
- **Growing CFRP waste** from both manufacturing and future end-of-life aircraft.
- **Key Problem**: **Recycling composites** like CFRP is still challenging—landfilling remains common.

Challenges in Recycling CFRP

Technological Barriers:

- **Heterogeneous nature** (fiber + resin) complicates recycling.
- **Thermoset composites** can't be remelted like thermoplastics.

Recycling Methods:

- **Mechanical**: Grinding—low-quality output.
- **Thermal**: Pyrolysis—damages fibers.
- **Chemical**: Best quality but expensive.

Current Industry Initiatives & Gaps

Initiatives:

- **AFRA** (Aircraft Fleet Recycling Association) promotes aircraft recycling.
- **PAMELA** (Airbus project) for end-of-life management.

Gaps:

- **High recycling costs** and **low-quality recyclates** limit commercial use.
- No strict **end-of-life regulations** for aircraft (unlike cars, electronics).

How this relates to our project:

•**Ecodesign Levers**:
choosing materials that are **easier to recycle** or **designing structures for easier disassembly** at the end of life (like modular wing components).

•**Structural Dynamics Implications**:
If recycled CFRP or alternative sustainable materials have **lower mechanical properties**, this could impact **modal behavior** (natural frequencies, damping ratios) and **aeroelastic stability** (flutter risks).

•**Future-Proofing Designs**:
Since **end-of-life regulations** for aircraft are expected to tighten, our work could anticipate these changes by incorporating **design-for-disassembly** or **design-for-recyclability** principles.

Why Explore Natural Fiber Composites (NFCs)?

•**Aerospace's Challenge**: High use of **CFRP** and **aluminum**, leading to environmental concerns.

•**Research Goal**: Assessing the **weight reduction potential** and **aeroelastic impact** of NFCs in wing design.

•**Focus Materials**: **Ramie**, **Hemp**, **Flax**, **Sisal** combined with **Epoxy** and **PLA**.

Future design options, from:

POTENTIAL OF SUSTAINABLE MATERIALS IN WING STRUCTURAL DESIGN

O. Boegler, U. Kling, D. Empl, A. T. Isikveren
Bauhaus Luftfahrt e.V., Lyonel-Feininger-Straße 28, 80807 München, Germany

Impact of NFCs on Wing Weight

Ramie Composites showed the **highest weight reduction**:

- **Epoxy/Ramie**: **14% lighter** than aluminum.
- **PLA/Ramie**: **12% lighter** than aluminum.
- **Hemp** and **Flax** composites **increased wing mass**.

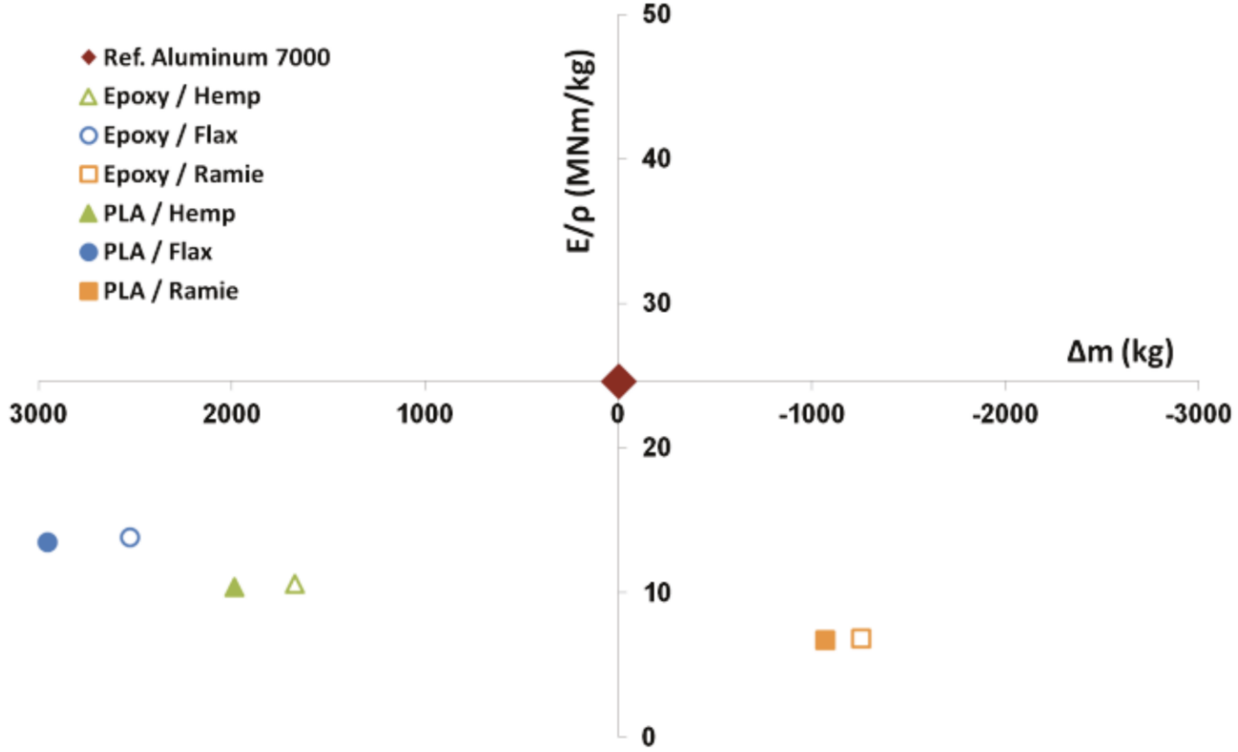
Balancing Weight and Mechanical Integrity

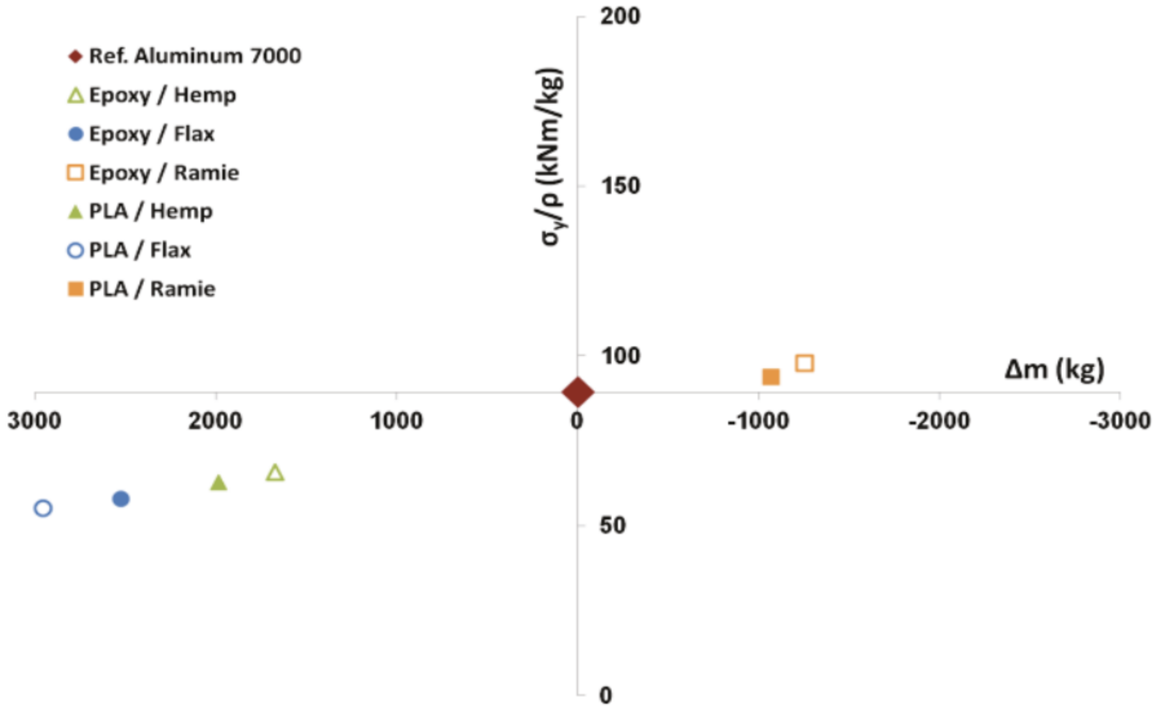
Ramie composites have **lower stiffness (E)** but **higher yield strength (σy/ρ)**.

•**Graph Insights**:

•*Lower E* can be compensated by *higher σy*.

•*Figures* show Ramie falls into the **“ideal design case”** for lightweight structures.





Sustainability and Economic Impact

- **Cost Savings**: Ramie is **cheaper** than aluminum and CFRP.
- **Lower CO2 Footprint**:

Ramie: 12,600-226,400 kg CO2 (vs. 97,100 kg CO2 for aluminum).

CFRP emissions are significantly higher than NFCs.

Challenges in Using NFCs for Wing Design

Aeroelastic Risks:

•Changes in **modal parameters** (natural frequencies, damping ratios).

•Potential **flutter** risks due to lower stiffness materials.

Need for Further Research:

•**Aeroelastic simulations** to assess flutter boundaries.

•Structural layout adjustments to maintain safety.

Conclusions & Future Directions

- **Ramie composites** offer **promising weight reduction** while maintaining mechanical integrity.
- **Hemp and Flax** increase wing mass and are **less suitable**.
- **Next Steps**:
  - Investigate **aeroelastic behavior** of wings with NFCs.
  - Develop **optimized structural layouts** to mitigate flutter risks.

Mechanical properties of composites, from:

SCIENCE CHINA
Technological Sciences

·Special Topic· Green Aviation Research
• Review •

September 2017 Vol.60 No.9: 1301–1317
doi: 10.1007/s11431-016-9094-y

Environmental analysis of innovative sustainable composites with potential use in aviation sector—A life cycle assessment review

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Table 2 Exemplary comparison of tensile properties (strength and Young's modulus) of composites reinforced with synthetic, biological and recycled fibres. Data has been obtained from scientific literature and technical data sheets

Composite [a)]		Fibre content (wt%)	Tensile strength (MPa)	Young's modulus (GPa)	Comments [b)]	Source [c)]
Fibre	Matrix					
CF IM (UD)	EP	67[d)]	2860	160	Prepreg	TDS Hexcel M21 [20]
CF HM (UD)	EP	67[d)]	1000–1600	135–175		ACP composites [21]
CF HM (fabric)	EP	58[d)]	350–600	70–85		ACP composites [21]
E-GF (UD)	EP	74[d)]	1000	40		ACP composites [21]
E-GF (fabric)	EP	66[d)]	440	25		ACP composites [21]
AF (fabric)	EP	53[d)]	480	30		ACP composites [21]
rCF (Random non-woven)	EP	37[d)]	207	25	Compression moulding	Shah2016 [22]
rCF (Random non-woven)	EP	37[d)]	245/263	27/32	MD/CD	TDS ELG Carbiso M [23]
rCF (Aligned non-woven)	EP	52[d)]	422	80	Prepreg	Shah2016 [22]
rCF (Aligned non-woven)	EP	29[d)]	282	44	SMC	Shah2016 [22]
Flax (UD)	EP	65	330	35	Prepreg	TDS Lineo Flaxpreg [24]
Flax yarn (aligned)	PP	72	321	29	Filament winding	Pickering2016 [25]
Flax yarn (aligned)	EP	~31	160	15	Hand lay-up	Pickering2016 [25]
Flax yarn (aligned)	EP	45	133	28	Autoclave	Pickering2016 [25]
Flax (fabric)	EP	~50	104	10	Prepreg	Pickering2016 [25]
Flax (random)	PLLA	30	99	9	Film stacking	Pickering2016 [25]
Jute (fabric)	UP	35	50	8	RTM	Pickering2016 [25]
Ramie (fabric)	EP	~48	~120	~12	Hot compaction	Gu2014 [26]

a) CF=carbon fibre, GF=glass fibre, AF=aramid fibre, rCF=recycled carbon fibre, UD=unidirectional, EP=epoxy, PLLA=poly(lactic acid), UP=unsaturated polyester; b) MD=machine direction (non-woven), CD=cross direction (non-woven), SMC=sheet moulding compound, RTM=resin transfer moulding; c) TDS=technical data sheet; d) calculated from given fibre volume content.

Another study:

Deutscher Luft- und Raumfahrtkongress 2015
DocumentID: 370118

FUTURE AIRCRAFT WING STRUCTURES USING RENEWABLE MATERIALS

U. Kling, D. Empl, O. Boegler and A. T. Isikveren
Bauhaus Luftfahrt e.V., Willy-Messerschmitt-Straße 1,85521 Ottobrunn, Germany

Results:

- **CFRP (Carbon Fiber Reinforced Polymer) with epoxy matrix** showed the best results, with a **4% weight reduction** for a 1000 nm mission.

- **Phenol-CF (Phenolic Carbon Fiber)** performed similarly to conventional CFRP, showing promise as a sustainable alternative.

- **Natural fiber composites (Phenol-NF & PLA-NF)** led to increased wingbox weight and higher block fuel consumption (2-3% increase compared to the A320neo), making them less favorable.

- **Buckling issues** were observed in the wing design using Phenol-CF, highlighting a limitation in structural performance.

Conclusion

- **Ramie fiber composites are not ideal** for primary load-bearing aircraft structures due to weight penalties.
- **Future advancements** in processing and mechanical enhancements may improve **natural fiber composites** for niche applications.
- **Sustainable carbon fibers from renewable sources** are a promising alternative if they can match conventional carbon fiber properties.
- **Optimizing laminate fabrication** with active load considerations may further reduce weight.
- **Increasing aspect ratio for planar wings** could improve aerodynamics while staying within regulatory limits.
- **Incorporating winglets or non-planar wings** may help optimize aircraft efficiency with sustainable materials.

Buckling analysis of sandwich composites with lightweight core:

Buckling and free vibration behavior of cenosphere/epoxy syntactic foam sandwich beam with natural fibre fabric composite facings under mechanical load

Sunil Waddar[1], Jeyaraj Pitchaimani[1,*], Mrityunjay Doddamani[1], Ever Barbero[2]
[1]Department of Mechanical Engineering, National Institute of Technology Karnataka, Surathkal, India
[2] Mechanical and Aerospace Engineering, West Virginia University Morgantown, WV, 26506-6106, USA
DOI: 10.1016/j.compositesb.2019.107133

Buckling & Vibration Analysis:

- Investigated the buckling and free vibration response of **sisal fabric/epoxy skin** with a **syntactic foam core** (experimentally & numerically).

- **Global buckling** was observed **without skin delamination or wrinkling.**

Weight Reduction:

- **Untreated cenosphere/epoxy foam: 15.81% weight savings** compared to neat samples.

- **Treated cenosphere/epoxy foam: 14.61% weight savings**, with **better stiffness** due to improved adhesion.

Buckling Load & Frequencies:

- **Higher filler loading → Increased buckling load & natural frequencies.**
- **Treated cenosphere composites perform better** than untreated ones.
- **Natural frequencies decrease** as axial compressive load increases.
- **First natural frequency reaches a minimum at critical buckling load** and then increases exponentially due to geometric stiffening.

Challenges & Considerations

✅ Pros:

✔️ Lighter than aluminum & CFRP → Fuel savings

✔️ Good buckling & vibration properties → Structural efficiency

✔️ Sustainable & recyclable → Reduces aerospace waste

⚠️ Cons:

❌ May have **lower mechanical properties** than CFRP (needs reinforcement)

❌ Long-term **moisture resistance & fatigue behavior** must be validated

❌ **Fire resistance & regulatory approvals** for aviation use

MDO

Composite Structures 280 (2022) 114875

Contents lists available at ScienceDirect

Composite Structures

journal homepage: www.elsevier.com/locate/compstruct

Multi-disciplinary design optimization of composite structures: A review

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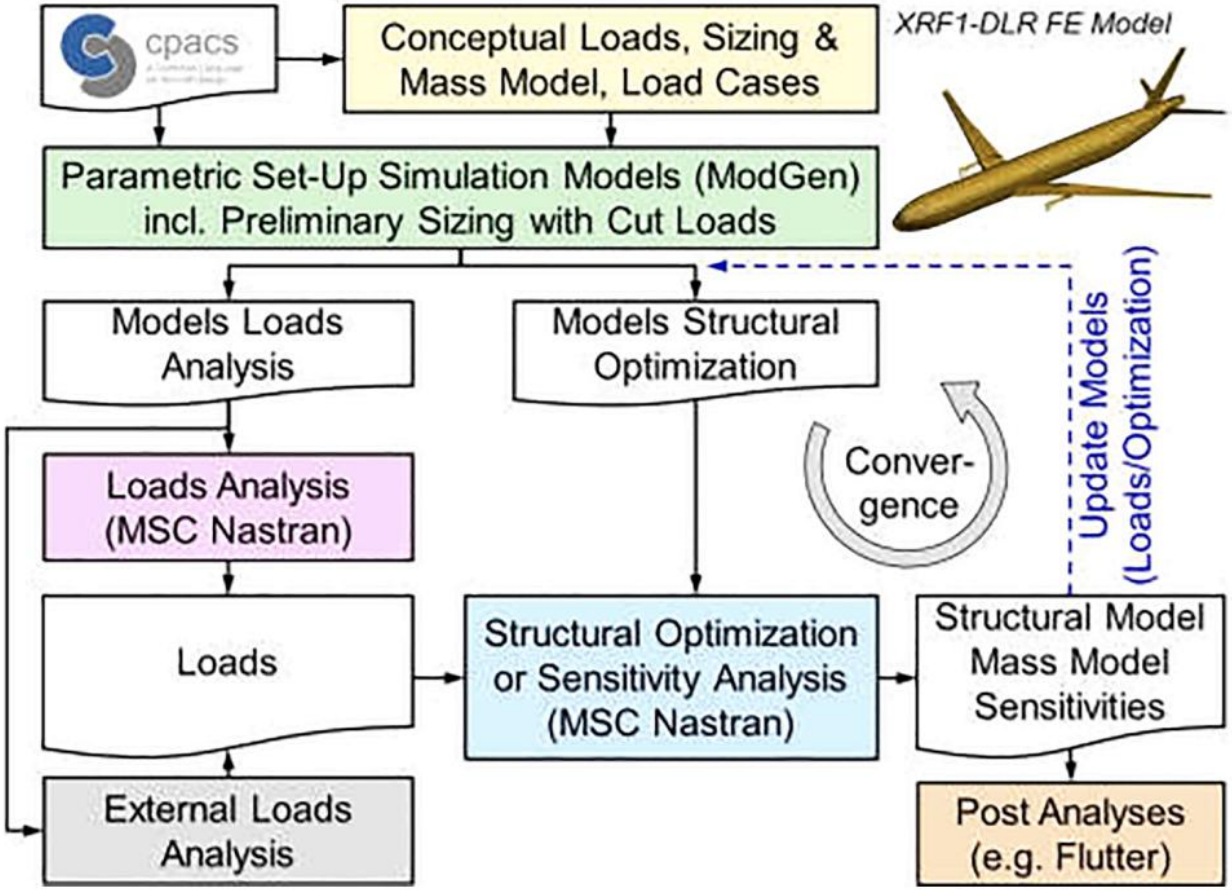
Aeroelastic design proccess



1. Increasing Use of Fiber-Reinforced Composites

- Lightweight and high-strength properties are driving increased use in aerospace, automotive, and structural applications.
- Composite materials are replacing traditional materials, but their **complex nature makes optimization difficult**.

2. Challenges in Optimization

- Conventional optimization relies on **domain-specific expertise**, leading to **suboptimal designs** when considering multiple performance parameters.
- Iterative methods are **time-consuming and inefficient**.
- **Conflicting design requirements** make it hard to achieve the best overall performance.

3. Role of Multidisciplinary Optimization (MDO)

- MDO **integrates different engineering disciplines (aerodynamics, structures, materials, etc.)** to find optimal solutions.
- Advances in **software and computational power** allow parallel processing of multiple parameters, improving design efficiency.
- The **genetic algorithm (GA)** is identified as an effective approach due to its computational efficiency.

4. Applications and Future Potential

- **Aerospace industry** has successfully implemented MDO for optimizing aircraft structures.
- **Automotive and structural engineering** have **less research in MDO**, presenting a **huge potential** for advancing design methods.
- **Future research** should focus on expanding MDO into new industries and refining optimization techniques.

Structural and Multidisciplinary Optimization (2023) 66:150
https://doi.org/10.1007/s00158-023-03600-1

INDUSTRIAL APPLICATION PAPER

Multidisciplinary structural optimization of novel high-aspect ratio composite aircraft wings

Spyridon Kilimtzidis[1] · Vassilis Kostopoulos[1]

Received: 2 May 2022 / Revised: 26 December 2022 / Accepted: 19 May 2023 / Published online: 20 June 2023

1. Importance of High-Aspect Ratio Airframes

- **Increase aerodynamic efficiency** by reducing **induced drag**.
- **Further weight reduction** achieved through **composite materials**.
- However, **structural flexibility introduces challenges** like **geometric nonlinearities and aeroelastic couplings**.

2. Challenges in Design & Optimization

- **Low-fidelity models**: Fast but lack accuracy, missing complex effects.
- **High-fidelity models**: Accurate but computationally expensive.
- **Need for a hybrid approach** that balances **cost and accuracy**.

aerospace

Article

Sustainability-Driven Design of Aircraft Composite Components

Angelos Filippatos [1,*], Dionysios Markatos [1], Georgios Tzortzinis [2], Kaushik Abhyankar [2], Sonia Malefaki [1], Maik Gude [2] and Spiros Pantelakis [1]

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* Correspondence: angelos.filippatos@upatras.gr

Table 2. Structural and sustainability requirements.

	Current State	Target State
Structural requirements	• Reference geometry. • Reference mass.	• No damage should occur. • Geometrical dimensions can be increased in specific thickness ranges up to 12.5%. • Stiffness loss shall be minimized.
	• No damage to the component should occur. • Effort is significantly below damage initiation for typical loading conditions. • Typical loading conditions (bending, tensile, torsion, and shear). • Boundary conditions are fixed-free, with restricted translational, rotational DOFs. • Safety Factor (SF) of 2.0. • Recycled materials from aeronautical structures. • The main structural stiffness should remain the same.	
Sustainability requirements	• No sustainability requirements at current state.	• Three (3) different recycled materials. • Identify the relationship between stiffness loss and efforts to recycle proportion. • Identify the relationship between mass increase, material selection, and sustainability index.

- “

From the analysis focusing solely on structural performance, it is evident that opting for recycled composites is impractical. This reasoning stems from the resultant lower weight and the necessity to augment weight when utilizing recycled composites to attain equivalent properties to virgin composites. This reality persists due to the inherent downgrading of recycled fibers during the recycling process and the absence of effective methods for reprocessing recycled fibers.

“

Eco-composites in aviation

Outlook on ecologically improved composites for aviation interior and secondary structures

Jens Bachmann[1] · Xiaosu Yi[2] · Hugh Gong[3] · Xavier Martinez[4,5] · Gabriel Bugeda[4,6] · Sergio Oller[4,6] · Konstantinos Tserpes[7] · Eric Ramon[8] · Christophe Paris[9] · Pedro Moreira[10] · Zhengping Fang[11] · Yan Li[12] · Yanfeng Liu[13] · Xiaoqing Liu[14] · Guijun Xian[15] · Jianfeng Tong[16] · Jiahu Wei[13] · Xufeng Zhang[16] · Jin Zhu[14] · Songqi Ma[14] · Tao Yu[12]

Received: 28 February 2017 / Revised: 6 March 2018 / Accepted: 17 March 2018 / Published online: 24 April 2018

Eco-compass project:

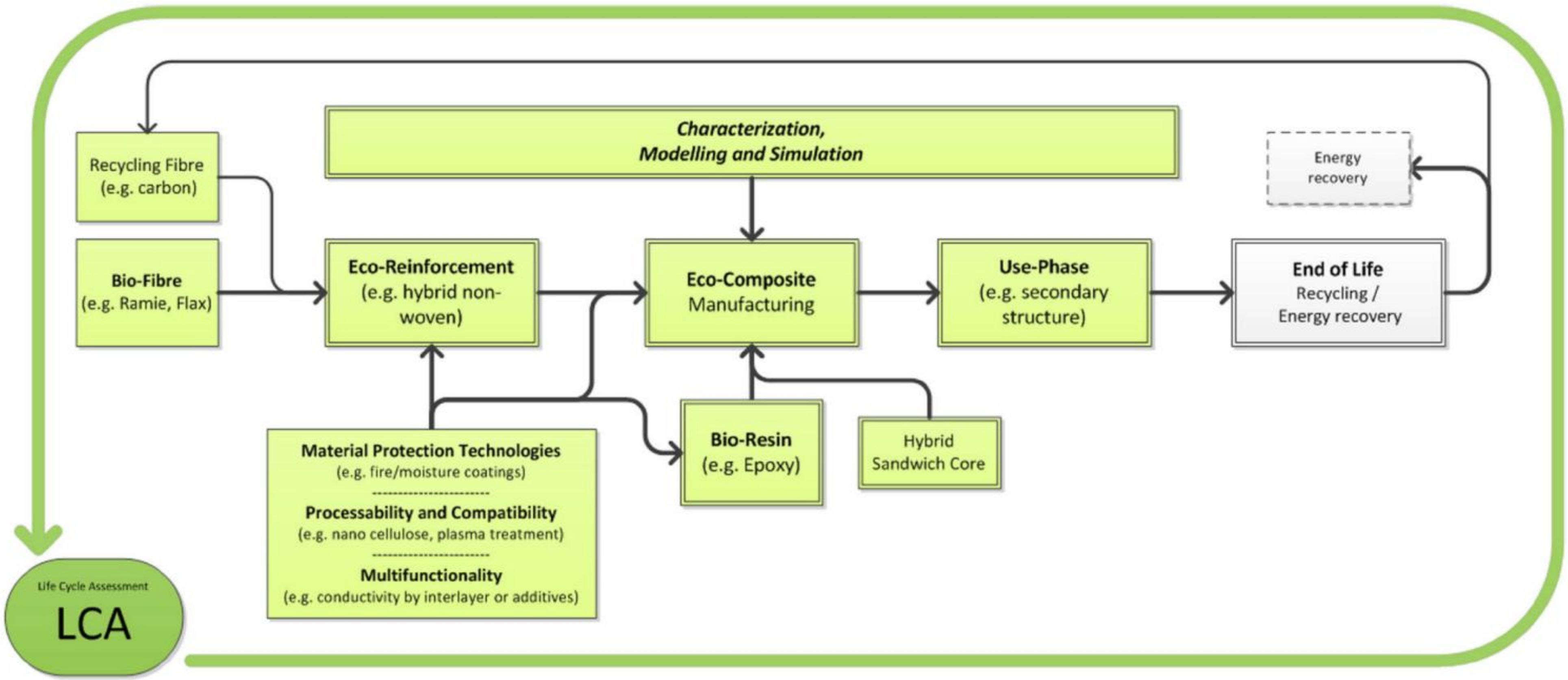


Fig. 2 Simplified circular flow diagram for ECO-COMPASS tasks

Pure bio-composites made of bio-fibres (e.g. flax, ramie) and bio-resin (e.g. epoxy) will be evaluated in parallel with a new approach that aims to combine valuable recycled carbon fibres and bio-fibres in a hybrid non-woven.

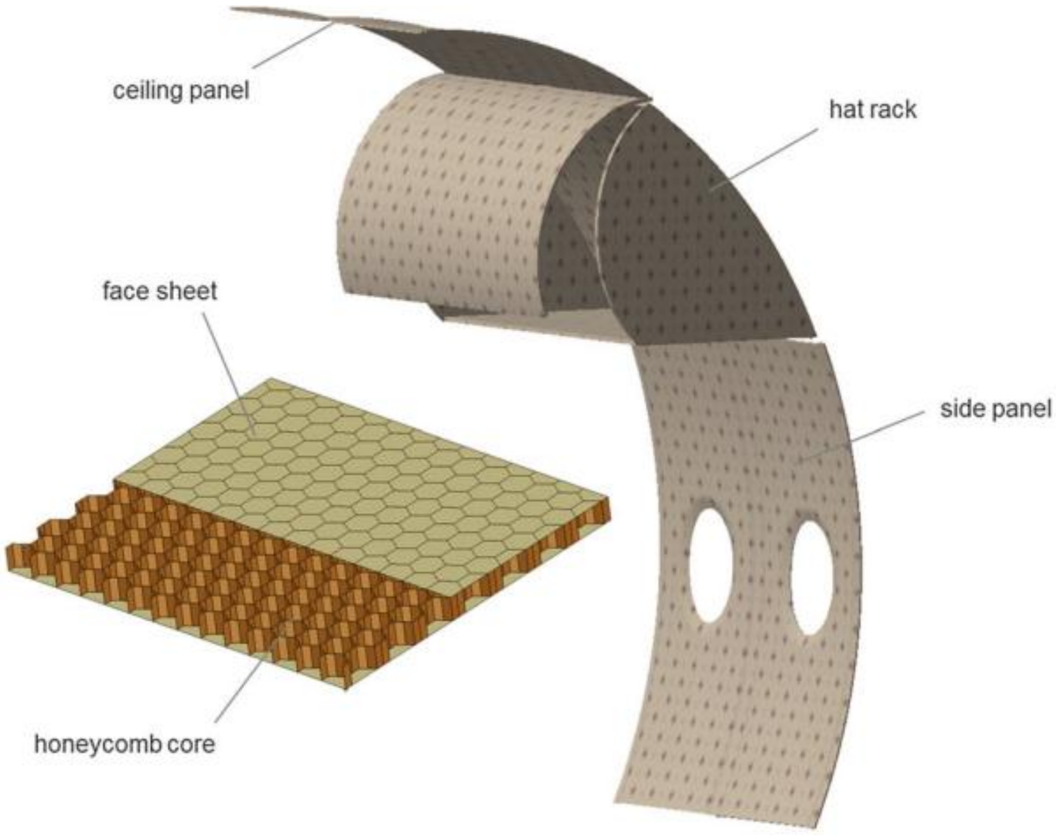
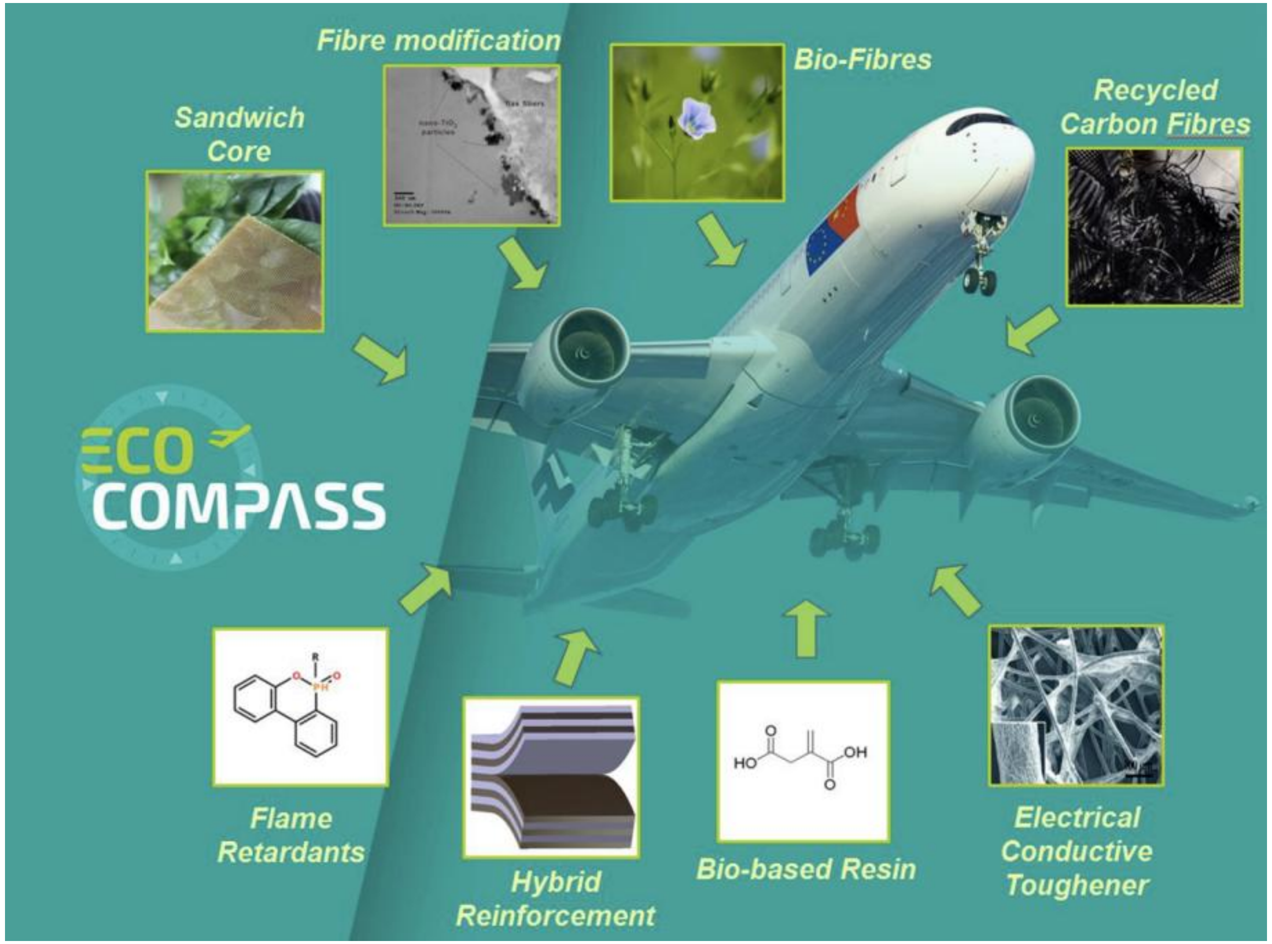


Fig. 3 Examples for interior sandwich parts

ECO-COMPASS Project

•Aims to **combine research** to **develop eco-friendly composite materials** for **secondary structures and aircraft interiors**.

•Focuses on **bio-based/recycled reinforcements, resins, and sandwich cores**, assessing their **aviation applications**.



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A review on green hybrid composites – (Glass-Sisal-Bamboo) for aircraft structural applications

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Case Study: Use of Bio-Composites in Reputed Aerospace Companies

8.1 Airbus

- **Partnership with CSIR (South African Council for Scientific and Industrial Research)** to explore **bio-composites** for **interior design replacement**.
- Focus on **natural fibers** like **flax, hemp, kenaf, and sisal**, cultivated in **South Africa** due to:
  - **Low cost**
  - **High biodegradability**
  - **Low density & recyclability**
  - **Non-abrasiveness**
- Research on **nanotechnology** to **improve resin-fiber bonding**.
- Implemented **flax fiber** in the **Airbus X3 high-speed helicopter demonstrator**.

8.2 Boeing

- Developing **bio-composite sandwich panels** to **replace cabin sidewalls**.
- Uses **halogen-free flame retardant agents** to improve **fire resistance of flax fibers**.
- Fabrication process: **Vacuum bag molding**.
- Strict **FAA (Federal Aviation Administration) and EASA (European Aviation Safety Agency) screening & approval** for compliance.

Conclusion

- **Hybrid green composites** (e.g., **bamboo, sisal, glass fibers with biopolymers**) show **high tensile, compressive, flexural, and impact strength**.
- **Superior mechanical properties** compared to **natural fiber-only or synthetic-natural fiber hybrids**.
- **Ongoing research** is needed to optimize green hybrid composites for **future aerospace applications**.

Contents lists available at ScienceDirect

Composites Part C: Open Access

journal homepage: www.elsevier.com/locate/composites-part-c-open-access

Mechanical analysis of a carbon fibre composite woven composite laminate for ultra-light applications in aeronautics

Nicholas Fantuzzi [a,*], Antoine Dib [a], Sajjad Babamohammadi [a], Silvio Campigli [b], David Benedetti [c], Jacopo Agnelli [c]

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[c] Carbon Dream SpA, Via Fausto Melotti 16, Barberino Tavarnelle, 50028, FI, Italy

Findings on ULCC

- The **Ultra-Light Carbon-Based Composite (ULCC)** presents a promising advancement for the **aeronautical industry**, offering **higher stiffness** and **lower density** compared to conventional **T300/Epoxy** and **T1000/Epoxy** materials.

Higher stiffness & lower density → Improved structural performance

Finite Element Analysis (FEA) → Validates feasibility & mechanical superiority

Potential Benefits:

- **Reduced aircraft weight** → Lower fuel consumption
- **Enhanced performance** → Better structural efficiency
- **Economic impact** → Cost savings & sustainability

Comments on the research so far:

- This initial research provided me with a solid understanding of the problem and the broader industry context relevant to our research project. I was able to explore various studies on **new composite materials, material comparisons, life-cycle analysis, structural testing, and MDO**. However, I found less **research on aeroelastic behavior and its impact on aircraft modal parameters**. This gap highlights the need for further investigation into how these advanced materials influence the **dynamic response and stability** of aircraft structures.