



Fun4Design

D4.2 – Conference disseminating parametrized test-benchmark

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Abstract

Deliverable D4.2, titled “*Conference Disseminating Parametrized Test-Benchmark*”, as part of WP#4 of the Fun4Design project, aims to present two different parametric studies, with an emphasis on mechanical components such as an A-Pillar structure and a hat-stiffened panel. These numerical studies were presented at two International Conferences.

This deliverable provides a brief introduction to the conference papers and includes the presentation slides.

Keywords: Numerical studies, Parametric, A-Pillar, Hat-Stiffened panel, Conference papers

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Proposal Title (ΕΛ)	Σχεδιασμός βιώσιμων μηχανικών συστημάτων από πολλαπλά υλικά με προσανατολισμό στις λειτουργίες
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Department	DEPARTMENT OF MECHANICAL ENGINEERING AND AERONAUTICS
Non-beneficiary Collaborating Organization(s)	TU DRESDEN
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1 INTRODUCTION

The submitted conference papers focused on disseminating the outcomes of the Fun4Design project. In **MO9**, the conference paper (C1), titled: *“Investigation of Structure Property-Function (SPF) Relations in A-Pillar Frame Design”* was presented at the [Tenth International Conference on Engineering Failure Analysis \(ICEAFX\)](#). This research focuses on exploring and establishing Structure-Property-Function (SPF) relationships integrating Environmental Impact for Sustainable Design. Three design configurations for the base profile of the A-Pillar were investigated using automotive materials and compared with the reference case through a 3-point bending Finite Element (FE) model. For each simulation, both mechanical and non-mechanical properties were predicted, examining how the A-pillar shape and material configuration affect performance and environmental impact

In **M15**, the conference paper (C2), titled: *“Sustainability analysis and comparison of thermoplastic and thermoset aircraft component designs”* was presented at the [“Towards Sustainable Aviation” Summit \(TSAS2025\)](#). This research was conducted on a hat-stiffened panel by developing a simulation model using Finite Element Analysis to determine its mechanical properties under multiple material combinations suitable for aerospace applications and typical loading conditions. Different material configurations were tested numerically with emphasis on the sustainability design. Particularly, Response Surface Model from ANSYS provided the desired metrics for I) Performance, II) Cost; III) Environmental Impact; IV) Circularity and V) Social Impact. Taking the above into account, thermoplastic fiber-reinforced polymers (when hydrogen was considered as fuel) provide more sustainable results when equal weighting was applied, whereas thermosets (also with hydrogen as fuel) appeared more sustainable when environmental impact was prioritized.

Details of the Conference Presentations can be found in **Annex 1** and **Annex 2**.

ANNEX 1: Conference Presentation (C1)

Investigation of Structure-Property-Function (SPF) Relations in A-Pillar Frame Design

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Fun4Design proposal

Title: Function-oriented, Multi-material Design Of Sustainable Mechanical Systems
Acronym: Fun4Design
Duration: 2023-2025
Call: Basic Research Financing (Horizontal support for all Sciences), National Recovery and Resilience Plan (Greece 2.0)
Type of Call: Funding New Researchers - RRF: Basic Research Financing (Horizontal support for all Sciences)
Coordinated by: Department of Mechanical Engineering and Aeronautics, University of Patras
Non-beneficiary Collaborating Organization: Technische Universität Dresden, Germany
Proposal Objectives:

1. Develop methodologies for the **structural design of sustainable mechanical systems**
2. Integrate **sustainability and recyclability** considerations into the early design phase of hybrid components
3. Create a **decision-making tool utilizing state-of-the-art machine learning algorithms** to enhance the acceptance and implementation by design engineers during the concept design phase

Fun4Design Workpackages (WPs)

WP.2: Analysis of **main and secondary functions** for representative geometries in **a-pillar structure** [1]

- A-pillar Geometry
- Material choice

Rob-structure: Polyamide (PA) with glass fibers (GF), Composite layer, GF laminate in PA matrix, Local reinforcements, Steel: HCT500X, Base profile, Steel: HCT500X

WP.3: Physically-based investigations of Structure-Property-Function (SPF) relationship

Structure ↔ SPF relations ↔ Function
Property ↔ Stiffness, Mass

- Different 3D geometries
- Different multifunctional materials
- Safety Factor (SF)
- Lightweight
- Environmental Sustainability

WP.5 & 6: Development of a GUI-tool Using ML-algorithm for Sustainable Design

Objective

- Establishing a common interface between Structure, Property and Function (SPF) for automotive applications to enable design using multifunctional materials, employing a fundamental standardization unit.

Test case: A-pillar structural component with multifunctional materials

Can we achieve a target level of sustainability without disturbing the structural performance of a component?

Requirements	Target State
Structural	<ul style="list-style-type: none"> • The outer geometrical dimensions of the structure should remain the same • No damage occur ($1.5 < SF < 2.5$) • Mass in specific range (340 gr-680gr)
Environmental Sustainability	Identify relationship between material properties and functional requirements

Design and methodological approach

A-pillar Base Design → Structural Support → torsional stiffness, bending stiffness, natural frequencies, Protection, Visibility → mass, Composite materials, thickness of composite, energy absorption, obstruction angle → Safety factor, Lightweight, Environmental Sustainability

FAST method

- FAST (Function Analysis System Technique) method significantly contributes to defining, analyzing, and understanding product functions
- This method discerns higher-order, lower-order, and intermediate primary and secondary functions.

Design Methodology Summary

List of Requirements (01-06) → **Draft Solution** (01-06)

- Validation: Compared results according to the original requirements
- Rank the scenarios: Assess the structural performance
- Run the scenarios: Perform post-process analysis
- Create the parametric space: Perform parametric FEM simulations

Describe the problem: Represent the a-pillar component as abstract functions
Develop the model: Parametrize the model, Validate the nominal scenario

Structure-Property-Function (SPF) Relations

Isotropic: Steel (DP500), Aluminum 6111 T8x, Magnesium Aluminum AZ91D
Anisotropic: Composite, epoxy/glass fiber, woven fiber, biaxial

Structure (Target: No damage occur) → Properties (Stiffness, Mass, CO2 footprint) → Functions (Structural, Lightweight, Environmental Sustainability)

Model parametrization and design scenarios

A-pillar base geometry modifications: GO_REF, G1, G2, G3

Representation of material inputs and thickness variation: External thickness, Internal thickness

Material modification (see Appendix A)	Material
M ₀	Steel (DP500) (TUD)
M ₁	Aluminum 6111 T8x
M ₂	Magnesium Aluminum AZ91D
C ₁	Composite, epoxy/glass fiber, woven fiber, biaxial

FEM simulation model

Mesh discretization

- 30,000 hexahedral elements in base profile
- Element size = 1.5 mm

Boundary & Loading Conditions

- 3-point bending
- 2 fixed supports and input load of 650 N

Applied loading conditions:

- Bending

Analysis

- Static analysis
- Modal analysis

Parametric FE model

- Input geometry
- Define material properties
- Extracted results (bending stress, strain energy, modes)

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Results for Structural performance

3D a-pillar base geometries

GO_REF, G1, G2, G3

Material properties

M ₀	Steel (DP500)
M ₁	Aluminum 6111 Tbx
M ₂	Magnesium Aluminum AZ91D

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Results for Structural performance

Properties to Functions

— Steel (DP500) — Aluminum 6111 Tbx — Magnesium Aluminum AZ91D

Reference, Structural, Target State, Mass High Low

- All running geometries (Reference, rectangular, semi-circular, and trapezoidal) using three different materials (steel, aluminum, and magnesium aluminum) satisfy the structural function but not the lightweight function.
- Structural & Lightweight functions are satisfied only for the reference geometry using all materials. For other tested geometries, these functions are satisfied only when using aluminum and magnesium aluminum.

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Results for Environmental sustainability

Properties to Functions

— Steel (DP500) — Aluminum 6111 Tbx — Magnesium Aluminum AZ91D

Reference, Structural, Target State, CO2 footprint (kg)

- Structural & Lightweight & Environmental Sustainability functions:** These functions are satisfied using the reference geometry for all materials. However, for rectangular, semi-circular, and trapezoidal shapes, these functions are specifically achieved using Aluminum 6111 Tbx and Magnesium Aluminum.
- Structural & Environmental functions:** These functions are only satisfied for semi-circular shapes with a variation in thicknesses from 2.3 mm to 2.7 mm (indicated in the green area).

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Conclusions

Structural-Property-Function (SPF) relations was investigated for each alternative a-pillar design:

- Structural function of the base a-pillar was preserved:
 - Same outer geometrical dimensions of the structure
 - Safety factor within limits (1.5<SF<2.5)
 - Mass in specific range (340gr-680gr)
 - Different geometry and material data were compared and discussed
- Different geometry configurations always influence
 - structural,
 - lightweight and
 - environmental sustainability functions
- Composites impacts structural function,
 - New design configuration leading to mass minimization

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Future Work – A-pillar Conceptual Design and Sustainability

- Dataset of materials with described SPF-relationships
- Effect of recycled materials on SPFs
- Development of a GUI-tool for Sustainable index prediction

Simulation of full geometry in a-pillar design

Performance + Costs + Society + Environment + Circularity = Sustainable product

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Website: Fun_4_Design_IDEAS.upatras.gr

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ANNEX 2: Conference Presentation (C2)

Boundary Conditions, Loads and Parametric Design

Parametric Design			Requirements	
Constraints	Variable	Parameters	Structural	Sustainability
Safety Factor: between 1.15 - 1.5	Thickness of skins: 3 - 8mm	Total Deformation	Minimization of Total Deformation	Minimization of costs
	Thickness of stringer: 3 - 8 mm	Mode I Eigenfrequency	Maximization of Mode I Eigenfrequency	Minimization of environmental impact
		Mass of skin	Safety Factor: 1.15 - 1.5	Maximization of circularity
	Crown Width: 35-55 mm	Mass of stringer	No damage should occur	Minimization of social impact

Use Phase	CFRP		CF/PEEK	
	CFRP	CF/PEEK	CFRP	CF/PEEK
N/A	57,285	57,285	57,285	57,285
Kerosene	597057,285	597057,285	597057,285	597057,285
Hydrogen	57,285	57,285	57,285	57,285
N/A	190,983	262,193	190,983	262,193
Kerosene	4155,033	4226,223	4155,033	4226,223
Hydrogen	7480,983	7552,183	7480,983	7552,183

Environmental Impact (CO₂ Footprint per kg):

- CFRP: 1.5
- CF/PEEK: 1.5

Cost (€ per kg):

- CFRP: 1.5
- CF/PEEK: 1.5

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Circularity Performance Assessment

Circularity Performance is assumed to be independent of the geometrical alterations, but dependent on material choices.

Material Type	Quality Reduction after recycling
CFRP	18.38 %
CF/PEEK	27.78 %

$$CIRC = 1 - \left(\frac{p}{\sum_{i=1}^n p_i} \right) \left(\frac{E_{recycled} - E_{virgin}}{E_{virgin}} \right)$$

$p = \frac{V_m}{V_{total}}$: Volume fraction of material divided by the number of materials that cannot be recycled

Configuration		CIRC
Skin Material	Stringer Material	
CFRP	CFRP	0.032
CF/PEEK	CF/PEEK	0.445

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Social Impact Assessment

Social Life Cycle Assessment (S-LCA) is a methodology to assess the social impacts of products and services across their life cycle (e.g. from extraction of raw material to the end-of-life phase, e.g. disposal) ⁴

The S-LCA framework calls upon a stakeholder approach where the potential impacts on different stakeholder categories are considered.

ANSYS sLCA tool is used to obtain social hotspots related to the components' materials and the nations from which have been sourced.

Best Case Scenario	Social Impact Categories					Social Level
	CFRP	CF/PEEK	CFRP	CF/PEEK	CFRP	
Plants	0	0	0	0	0	0
Construction	0	0	0	0	0	0
Society	0	0	0	0	0	0
Land Use/Change	0	0	0	0	0	0
Climate Change	0	0	0	0	0	0
Total score	0	0	0	0	0	0

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Optimization Procedure

Response Surface Models from ANSYS to Simulink.

Full factorial design to obtain the multiple geometrical variations of the considered configurations / material combinations.

Response Surface Model provided the desired metrics for I) Performance, II) Cost & III) Environmental Impact; IV) Circularity & V) Social Impact were imported manually into the dataset, as they are independent of the geometry, but dependent on the material.

Normalization of the metrics followed, and the Sustainability Index was calculated for an equal weights scenario.

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Sustainability Assessment Results Overview Equal weights

Sustainability Ranking	Material Configuration & Use Phase	SI
1	CF/PEEK-CF/PEEK (use phase: Hydrogen)	0.75 ± 0.03
2	CF/PEEK-CF/PEEK (use phase: Kerosene)	0.65 ± 0.03
3	CFRP-CFRP (use phase: Hydrogen)	0.55 ± 0.04
4	CFRP-CFRP (use phase: Kerosene)	0.46 ± 0.04

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Sustainability Assessment Results Overview Emphasis on Environmental Impact

Sustainability Ranking	Material Configuration & Use Phase	SI
1	CFRP-CFRP (use phase: Hydrogen)	0.89 ± 0.01
2	CF/PEEK-CF/PEEK (use phase: Hydrogen)	0.80 ± 0.02
3	CFRP-CFRP (use phase: Kerosene)	0.37 ± 0.04
4	CF/PEEK-CF/PEEK (use phase: Kerosene)	0.34 ± 0.04

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Conclusions

- Currently, thermoset fiber-reinforced polymers are utilized for structural parts of aircrafts; ongoing research indicates that a shift to thermoplastic fiber-reinforced polymers could prove a more sustainable practice.
- To transit from eco-driven to sustainability-driven design, an aggregated sustainability metric is utilized as a design and optimization parameter for aircraft components and structures, involving performance, environmental, economical, circular economy, and social impact considerations.
- We suggest that design configurations with the 'best' balance among the above criteria, when comparing these two material groups, are offering the possibility to account for sustainability considerations from the early design stage.
- Thermoplastic fiber-reinforced polymers (when hydrogen is considered as fuel) provide more sustainable results when equal weighting is applied, while thermosets (when hydrogen is considered) appear more sustainable when environmental impact is prioritized.
- Use phase dominates the lifecycle impact; hydrogen-powered aircraft proves to be more viable
- Further research should focus on reducing the cost and environmental impact of thermoplastic composites and advancing hydrogen technologies; also the effects of NO_x and contrails should be considered.

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