ICCM 23
INTERNATIONAL CONFERENCE ON COMPOSITE MATERIALS
BELFAST 2023
30 JULY – 4 AUGUST

Lifecycle Metric Integration in **Lamination Parameters** Design Space for **Structural Optimisation** of **Composite Structures**

Dr. ir. Julien van Campen

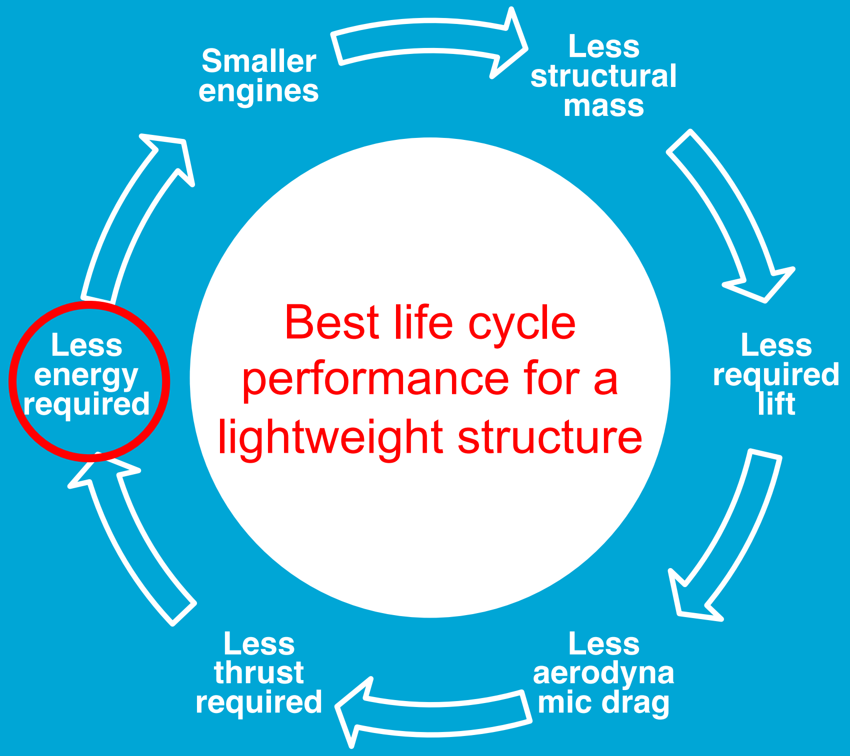
1 August 2023

TUDelft

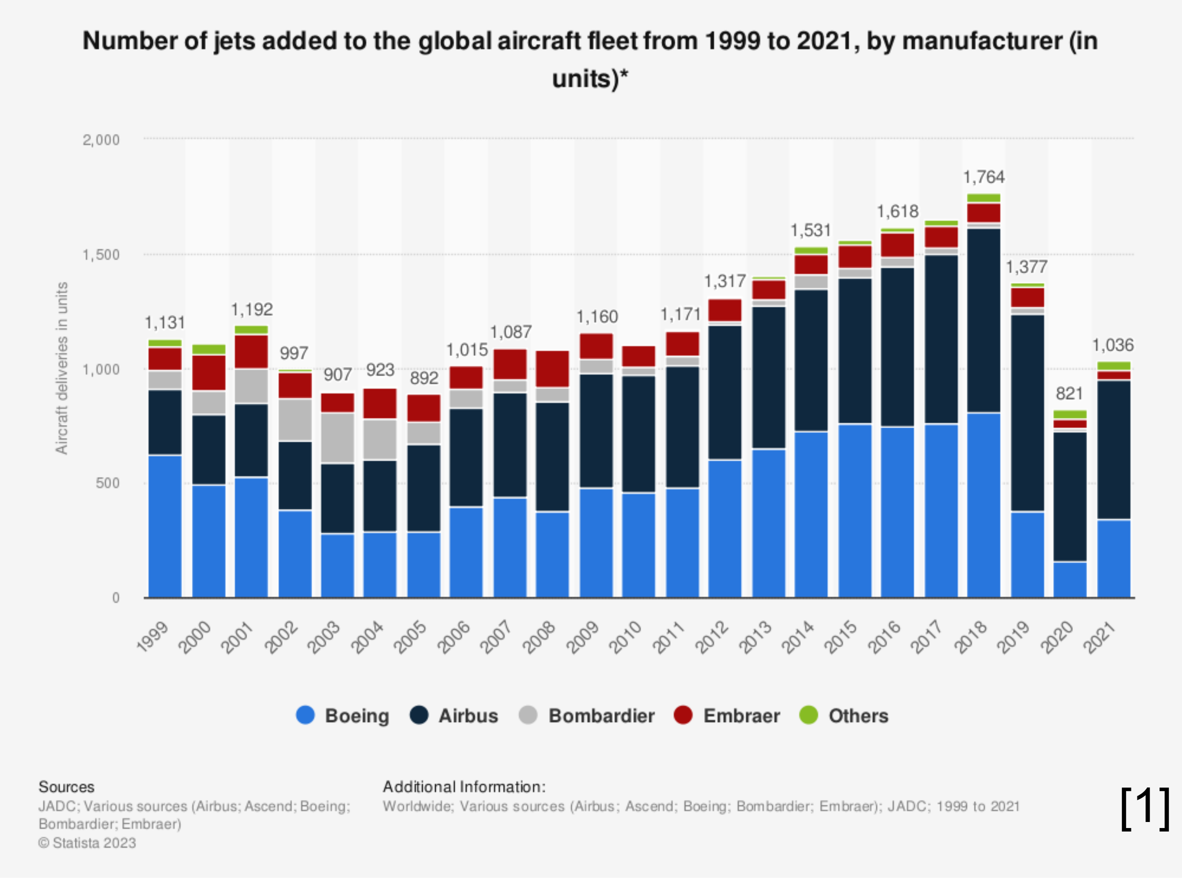
Photo by Chris Leipelt

https://www.reddit.com/r/pics/comments/pldog/photo_of_the_downwash_effect_from_a_passing_jet/

The importance of light-weighting in aviation



The number of decommissioned aircraft



[1]

New commercial aircraft 2022

- Airbus: 661
- Boeing: 542

Predicted growth per annum 4.3% for the next 20 years [2]

Estimated cummulative number of aircraft to be recycled between now and the year 2043 based on these numbers:

22,190

(assuming an average life span of 30 years)

Current state of the art at end-of-life aircraft:

- ±10 weeks to process a decomissioned aircraft
- Only a limited number of parts is reused / recycled
- Most of the airframe is scrapped

TU Delft

[1] Statista, https://www.statista.com/statistics/622779/number-of-jets-delivered-global-aircraft-fleet-by-manufacturer/
[2] International Civil Aviation Organisation (ICAO), United Nations, Future of Aviation, https://www.icao.int/Meetings/FutureOfAviation/Pages/default.aspx

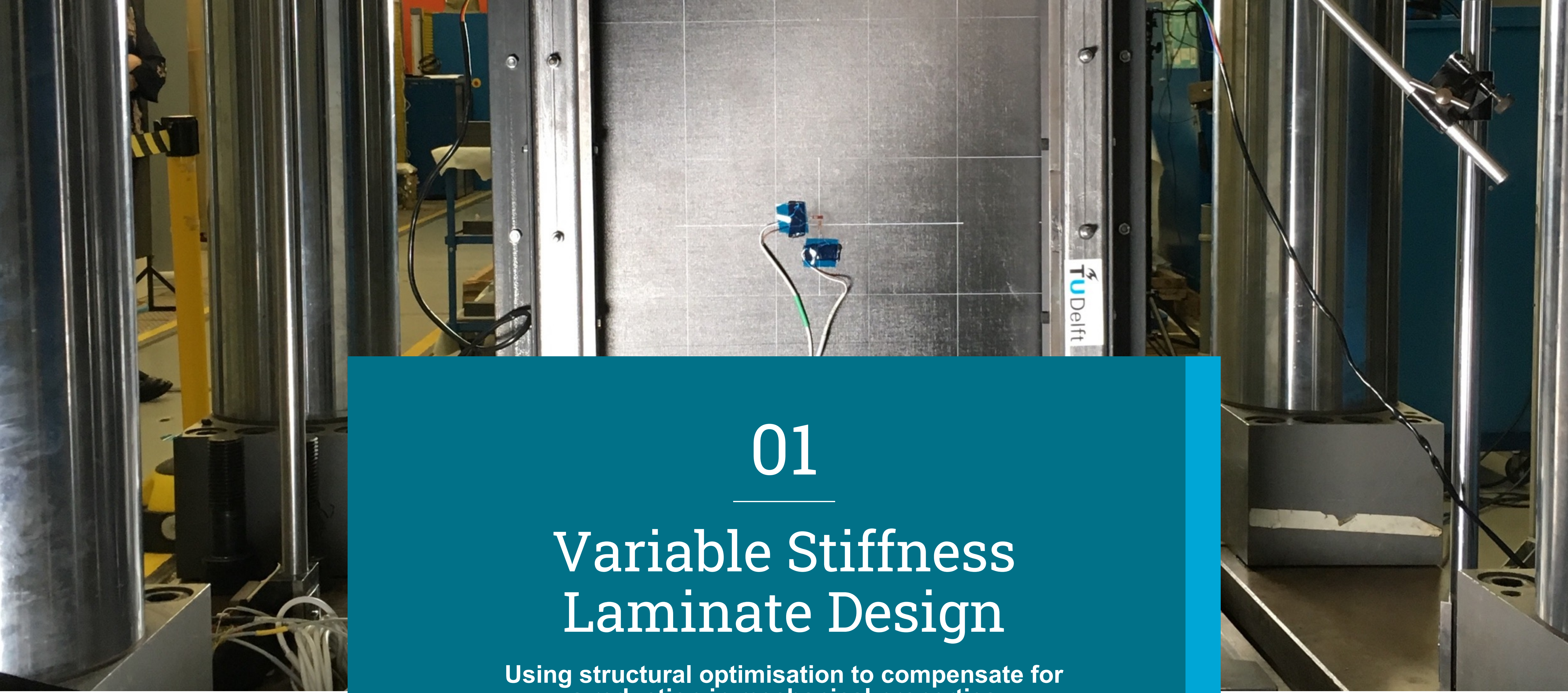
The energy transition and the growing number of decommissioned aircraft require that the paradigm that weight reduction automatically leads to better lifecycle performance of composite aircraft structures should be revisited.

TU Delft

Photo by Chris Leipelt

Presentation Contents

1. Variable stiffness laminate design
2. Life cycle metrics as a design constraint
3. Concept study
4. Discussion and outlook



01

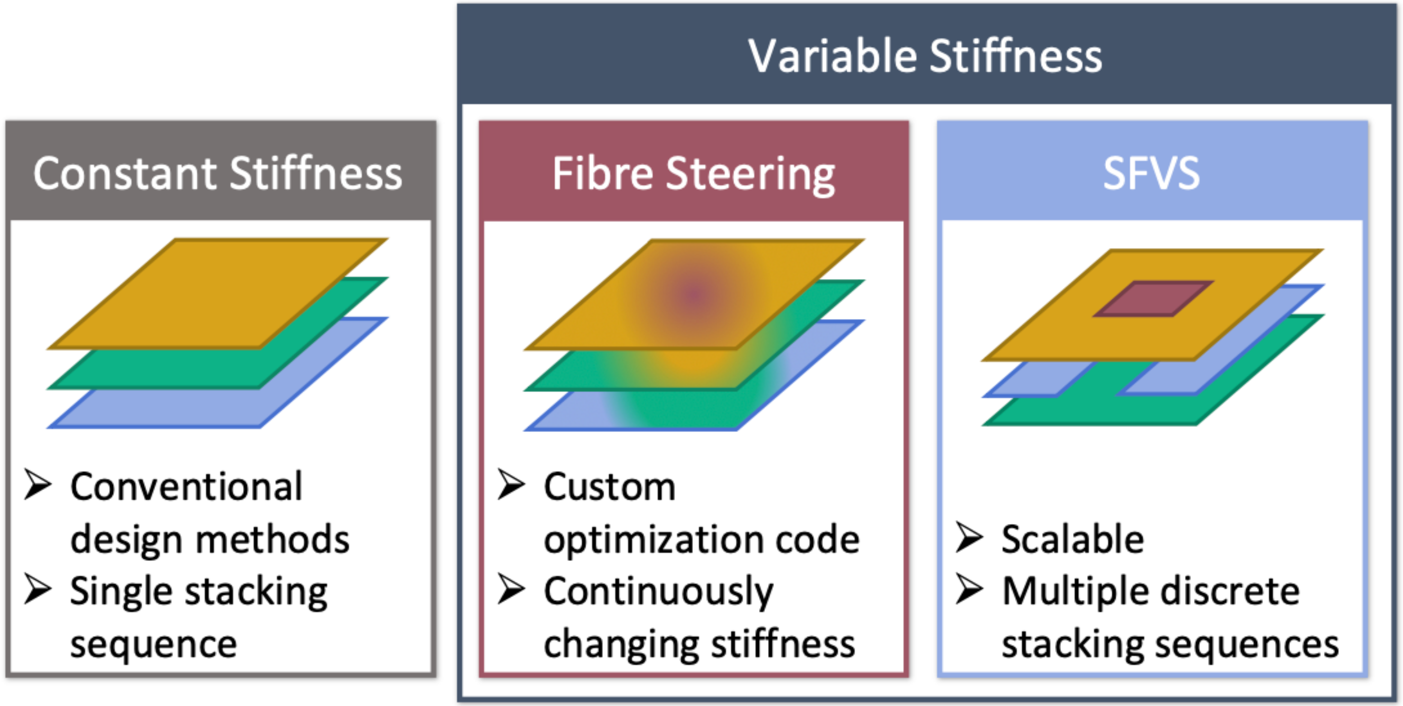
Variable Stiffness Laminate Design

Using structural optimisation to compensate for a reduction in mechanical properties

TUDelft

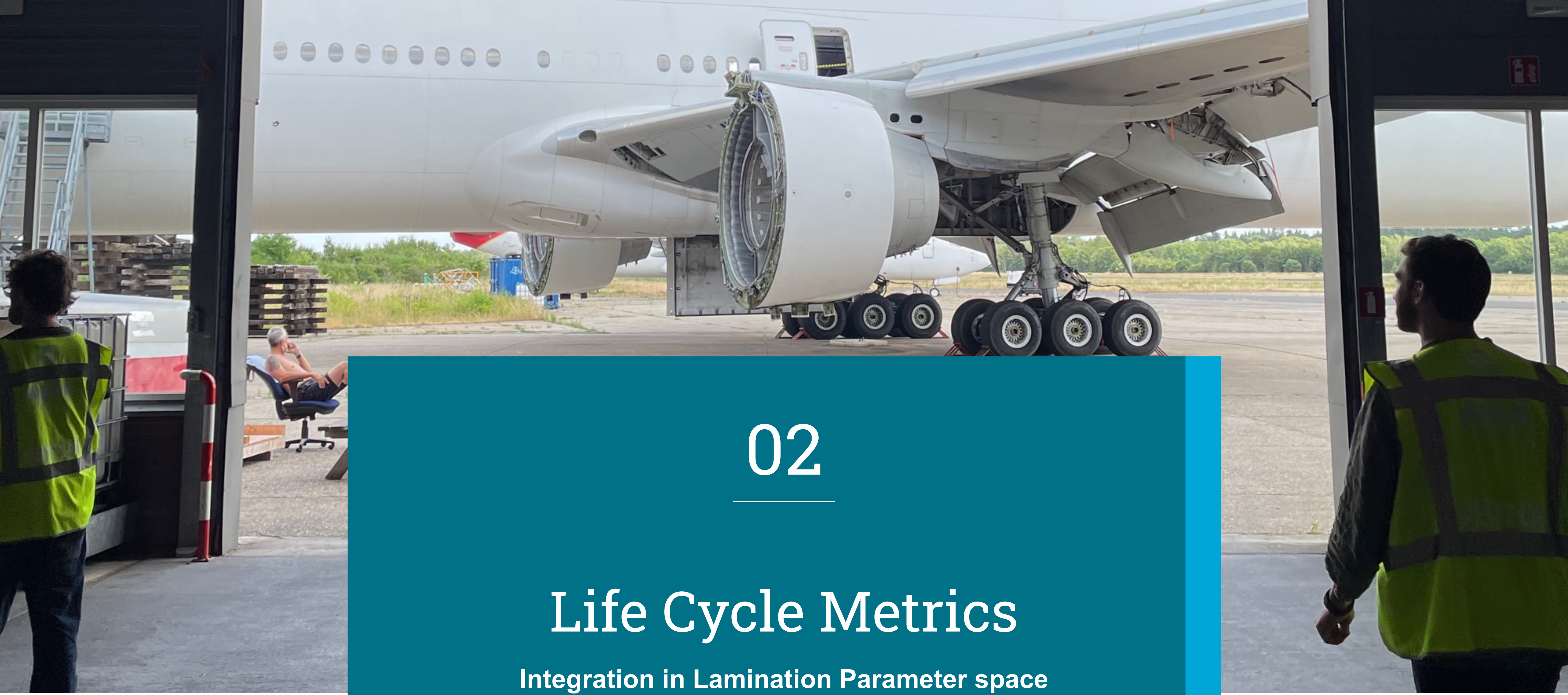
Variable Stiffness Laminate Design

Using in plane load redistribution to improve mechanical performance



Performance maximisation → Weight minimisation

[1] J.M.J.F. van Campen, M. Gomaa and T. Roepman, Straightening out the adoption of Variable Stiffness Composite Laminates in the Aerospace Industry, Proceedings of the 20th European Conference on Composite Materials, ECCM20, Lausanne, Switzerland, June 26-30, 2022



02

Life Cycle Metrics

Integration in Lamination Parameter space

TU Delft

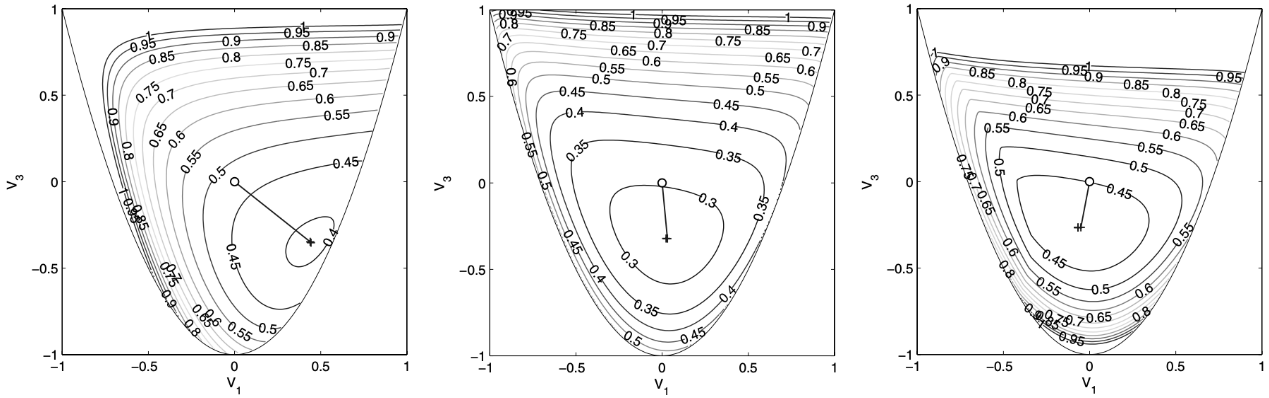
Using lamination parameters

$$\left(V_1^{\mathbf{A}}, V_2^{\mathbf{A}}, V_3^{\mathbf{A}}, V_4^{\mathbf{A}}\right) = \int_{-\frac{1}{2}}^{\frac{1}{2}} (\cos 2\theta, \sin 2\theta, \cos 4\theta, \sin 4\theta)\, d\bar{z}$$

$$\left(V_1^{\mathbf{B}}, V_2^{\mathbf{B}}, V_3^{\mathbf{B}}, V_4^{\mathbf{B}}\right) = 4\int_{-\frac{1}{2}}^{\frac{1}{2}} \bar{z}\,(\cos 2\theta, \sin 2\theta, \cos 4\theta, \sin 4\theta)\, d\bar{z}$$

$$\left(V_1^{\mathbf{D}}, V_2^{\mathbf{D}}, V_3^{\mathbf{D}}, V_4^{\mathbf{D}}\right) = 12\int_{-\frac{1}{2}}^{\frac{1}{2}} \bar{z}^2\,(\cos 2\theta, \sin 2\theta, \cos 4\theta, \sin 4\theta)\, d\bar{z}$$

Recycled material → Reduced strength & stiffness → Constraints in LP-space



a) Carbon/PEEK (AS4) - Tension
b) Carbon/Epoxy (IM6) - Compression
c) Boron/Epoxy (B5.6) - Compression

[1] S.W. Tsai, and H.T. Hahn, Introduction to Composite Materials, Technomic Publishing Co., Inc., 1980.
[2] S.T. IJsselmuiden, M.M. Abdalla, and Z. Gürdal, Implementation of Strength-Based Failure Criteria in the Lamination Parameter Design Space, AIAA Journal, 46, 2008, pp. 1826 – 1834, (doi: 10.2514/1.35565)

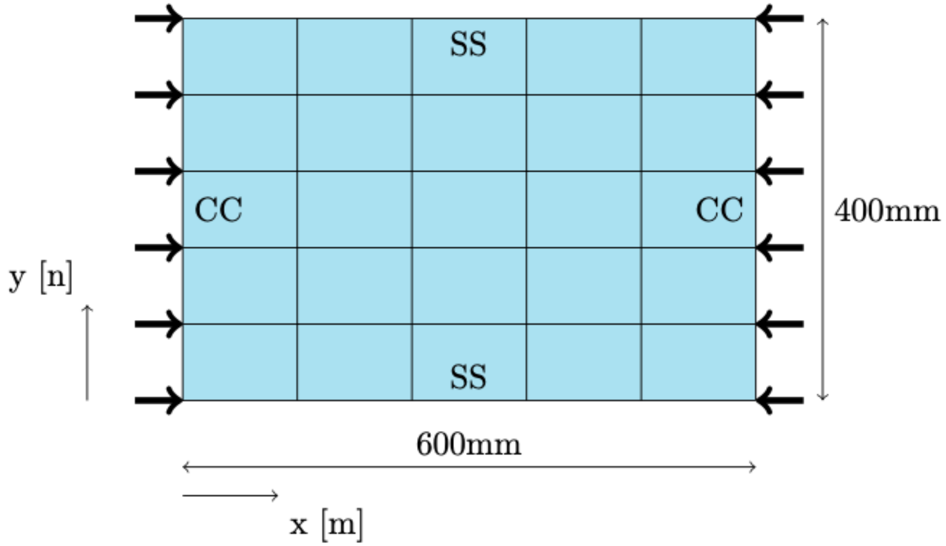
03

Demonstration of Concept

Case study: simply supported uniaxially compressed plate

TU Delft

Simply supported uniaxially compressed plate



$$Eb_C = wf_{PM} \bullet Eb_{PM} + wf_{RF} \bullet Eb_{RF}$$

$$wf_{PM} = \frac{m_{PM}}{m_{RF} + m_{PM}}$$

$$wf_{RF} = \frac{m_{RF}}{m_{RF} + m_{PM}}$$

$$E_C = E^{rw}{}_C + E^{m}{}_C = Eb_C \bullet (m_{RF} + m_{PM}) + SEC_C \bullet (m_{RF} + m_{PM})$$

$$SEC_{SFVS} = SEC_{process} * n_{regions}{}^{1/a}$$

Material	Young's modulus (GPa)	Tensile Strength (MPa)	Eb_C [MJ/kg]	SEC_C [MJ/kg]	w_{RF} [%]	w_{PM} [%]	E [MJ/kg]
Aluminium	70.1	324	-	38.6	-	-	230 / 26.7*
Composite A	30.2	276	392	600	40	60	-
Composite B	21.2	115	184.8	79	40	60	-

All values presented in this work are for demonstration purposes only.

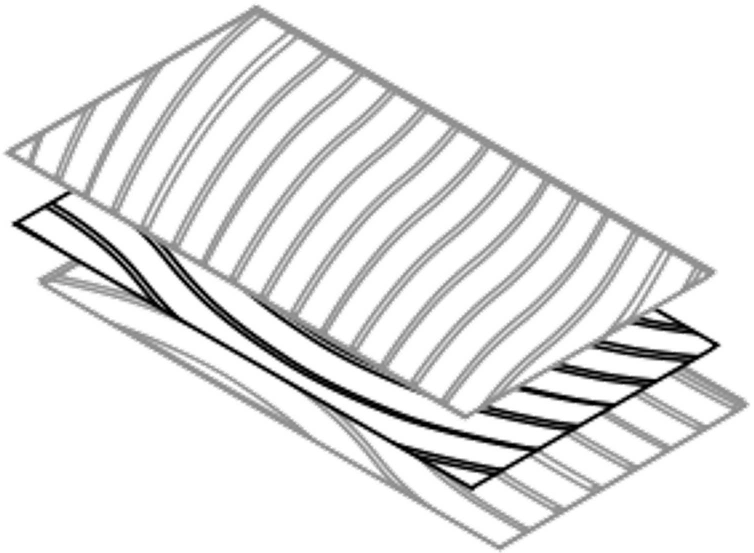
Eb_c: embodied energy of the composite (MJ/kg);
wf_{PM}: weight fraction of polymer matrix (-);
Eb_{PM}: emobodied energy of the polymer matrix (MJ/kg);
wf_{RF}: weight fraction of reinforcement (-);
Eb_{RF}: embodied energy of the reinforcement (MJ/kg);
m_{PM}: mass of the polymer matrix (kg);
m_{RF}: mass of the reinforcement (kg);
E_C: overall energy of the composite component (MJ);
$E^{rw}{}_C$: energy embedded in the composite raw materials (MJ);
$E^{m}{}_C$: energy needed to manufacture a composite component (MJ);
SEC_C: specific energy consumption of the manufacturing process (MJ/kg).

TU Delft

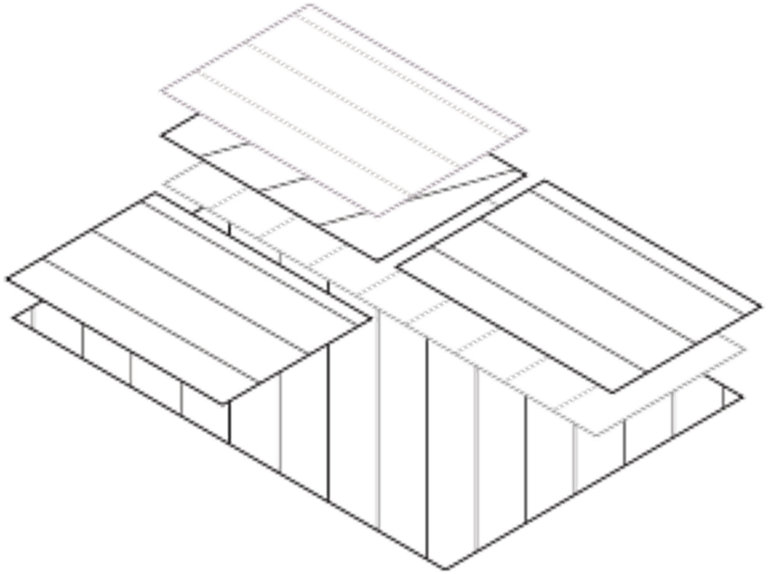
* Recycled aluminium

[1] V. Lunetto, M. Galati, L. Settineri and L. Iuliano, Sustainability in the manufacturing of composite materials: A literature review and directions for future research, Journal of Manufacturing Processes, 85, 2023, pp.858 – 874, (doi: https://doi.org/10.1016/ j.jmapro.2022.12.020)

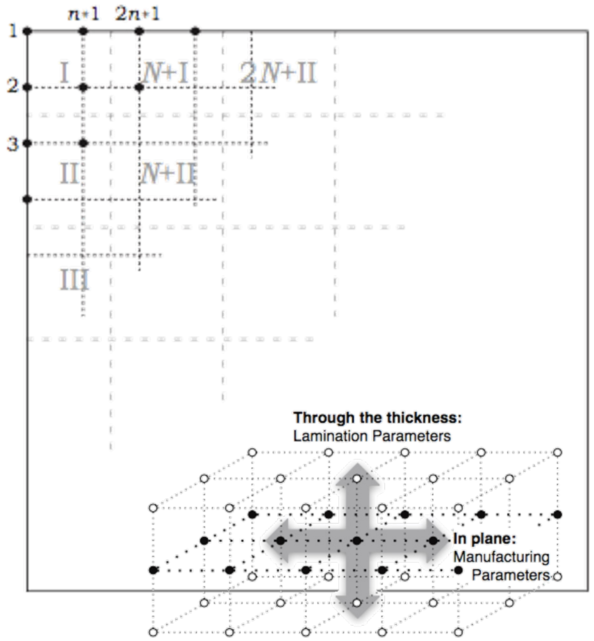
Straight-Fibre Variable Stiffness Laminates



Continuous fibre angle variation



Multi-patch laminate

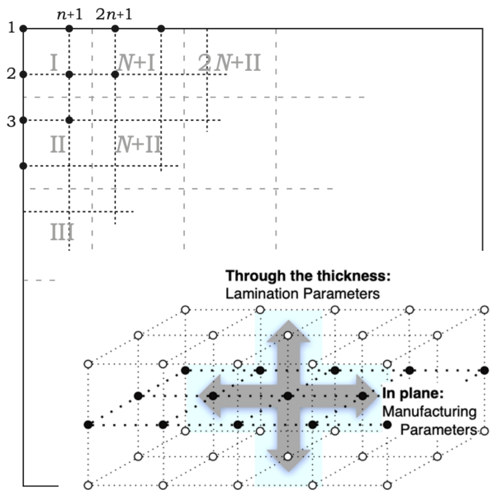


Straight-Fibre
Variable Stiffness
Laminate

SFVS

TU Delft

Results



Baseline aluminum panel, 2.0mm thick

Buckling load [kN]	Weight [kg]	E [MJ]
5.5351	1.296	298.08 / 34.99*

Composite A: Carbon fibre reinforced PEEK
Laser assisted AFP
Autoclave

Number of design regions [-]	Weight [kg]	E [MJ]			
		a = 2	a = 4	a = 6	a = 8
1	1.142	1133.00	1133.00	1133.00	1133.00
9	0.999	2190.03	1429.94	1256.22	1180.58
25	0.904	3065.95	1567.00	1281.68	1165.29
49	0.880	4040.53	1741.73	1354.84	1203.67
81	0.856	4960.45	1877.30	1404.59	1225.75
121	0.844	5900.10	2009.99	1456.79	1252.84
225	0.842	7909.80	2287.80	1577.01	1325.28

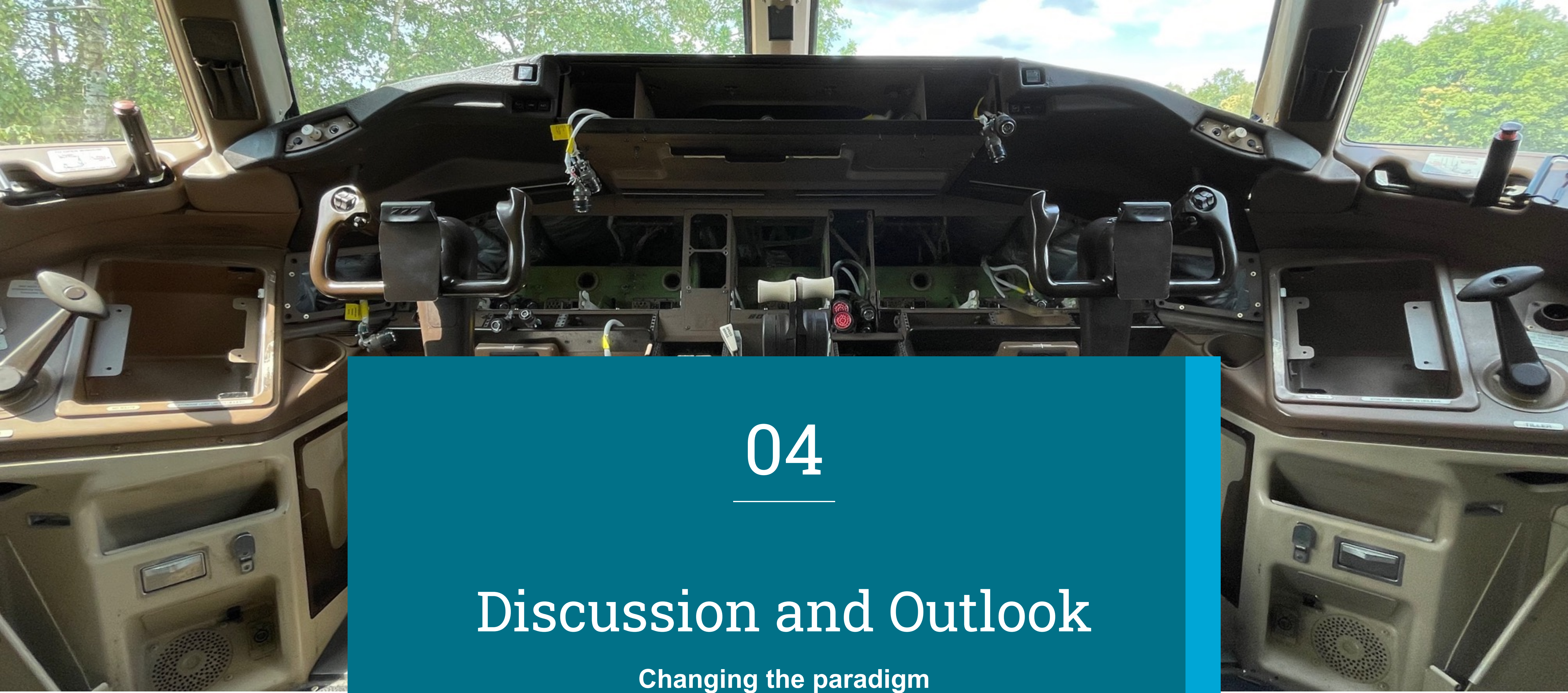
Composite B: Glass fibre reinforced PEEK
Hand lay-up
Thermo forming

Number of design regions [-]	Weight [kg]	E [MJ]			
		a = 2	a = 4	a = 6	a = 8
1	1.593	420.22	420.22	420.22	420.22
9	1.393	587.77	448.18	416.28	402.39
25	1.261	730.93	455.66	403.27	381.89
49	1.227	905.45	483.30	412.25	384.49
81	1.194	1070.02	503.83	417.03	384.19
121	1.177	1240.24	525.86	424.27	386.82
225	1.174	1609.99	577.57	447.05	400.82

$$SEC_{SFVS} = SEC_{process} * n_{regions}^{1/a}$$

$$[\pm\theta_1/\pm\theta_2/\pm\theta_3/\pm\theta_4/\pm\theta_5/\pm\theta_6/\pm\theta_7/\pm\theta_8]_s$$

Presented values are obtained by scaling ply thickness to match the buckling load



04

Discussion and Outlook

Changing the paradigm

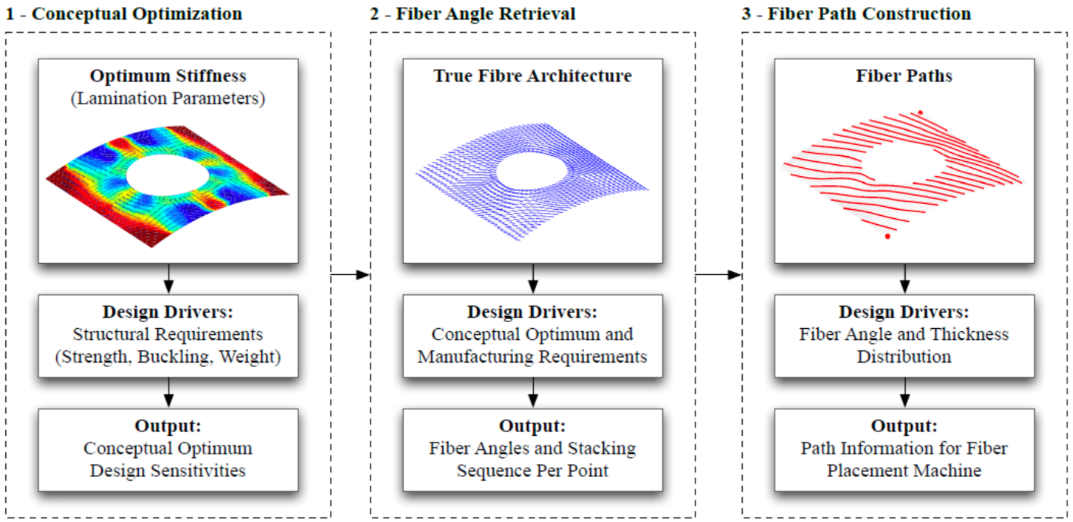
TU Delft

Discussion

- All values presented in this work are for demonstration purposes only
- The work presented is a preliminary study in this direction
- This study is limited to energy required for a composite component

- The energy required to manufacture the aluminium plate is lower than for either composite material
- The energy required to manufacture the composite B panel is roughly a third of that required for the composite A panel
- The results for composite B show that it should be possible to reduce the overall energy of a composite component by means of structural optimisation

- In follow-up work a full optimisation for a number of materials and production processes will be performed



S.T. IJsselmuiden, M.M. Abdalla, and Z. Gürdal, Optimization of variable-stiffness panels for maximum buckling load using lamination parameters, AIAA Journal, 48, 2010, pp. 134 – 143.

The choice of composite aircraft parts over alumium aircraft parts is to be considered carefully should the life cycle impact of light-weighting become less dominant in the future

TU Delft

ICCM 23
INTERNATIONAL CONFERENCE ON COMPOSITE MATERIALS
BELFAST 2023
30 JULY – 4 AUGUST

Thank you for your attention

Dr. ir. Julien van Campen
j.m.j.f.vancampen@tudelft.nl

TU Delft