Bringing Manufacturing into the MDO domain using MBSE

Presentation subtitle

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What is GKN Aerospace

What do we do:

As a Tier 1 supplier we design and built aircraft components such as tails, flaps and fuselage sections

What is out position in the MDO process:

For major OEM's we get involved once the main aircraft configuration has been frozen. Aerodynamics and main structural interfaces are fixed.

For UAM start-ups we develop complete components from design to manufacturing

How does the MDO process affect us:

We use MDO to define and size design concepts for UAM components

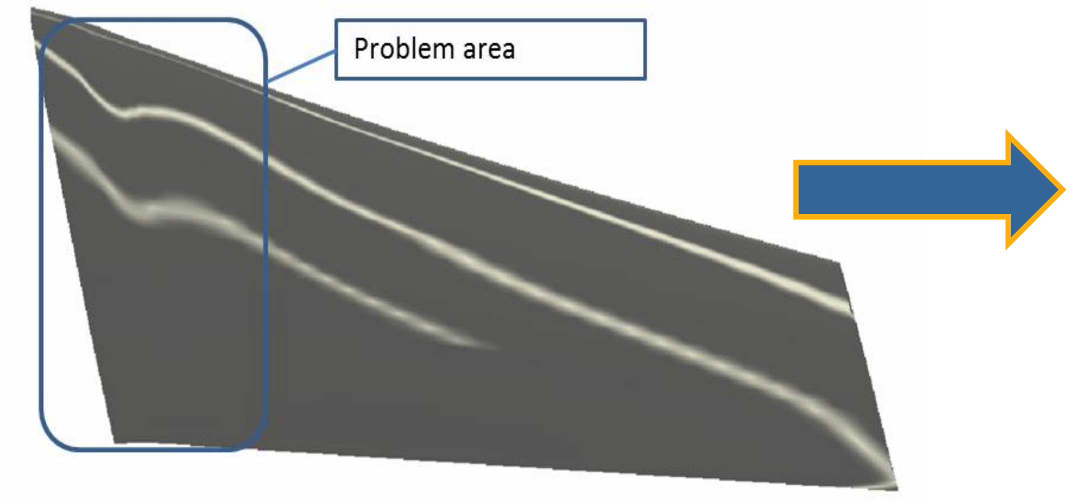
We regularly have to disappoint customers because weight and cost targets defined using a MDO process are not achievable

Why is it important to consider manufacturing in MDO

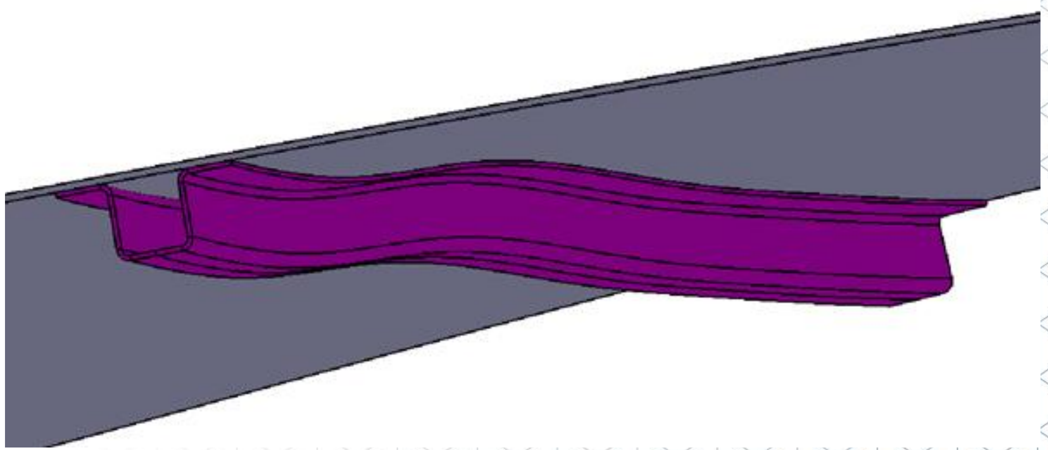
- **Projects need to be profitable for a company to be financially healthy**
- **We need to predict manufacturing cost and risk associated with a design to ensure a project will be profitable**

Example: Aerodynamic optimization influencing manufacturability

Thinning of the airfoil at the root to avoid transonic shock



Difficult stringer core extraction



Why is it important to consider manufacturing in MDO

- **Projects need to be profitable for a company to be financially healthy**
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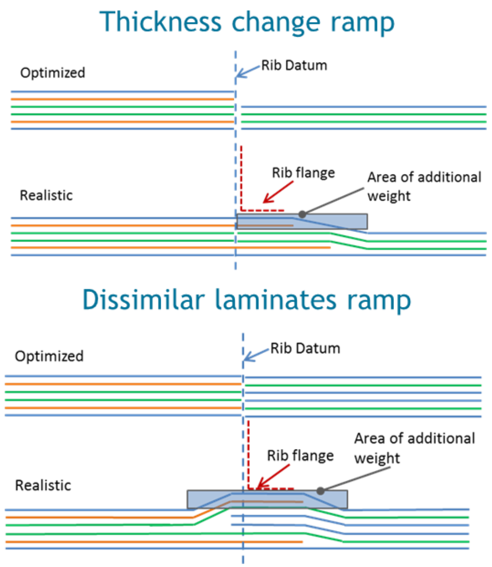
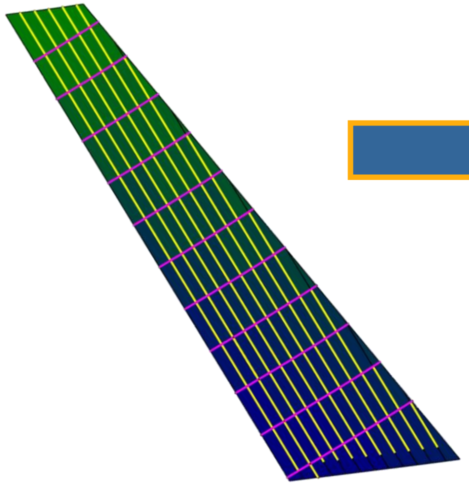
Example: Structural optimization introducing ramps resulting in weight and cost increase

Different lay ups as a result of structural optimization result in ramps





Ramps introduce a weight increase of 3.5%. This results in a reduction of profit of 35%

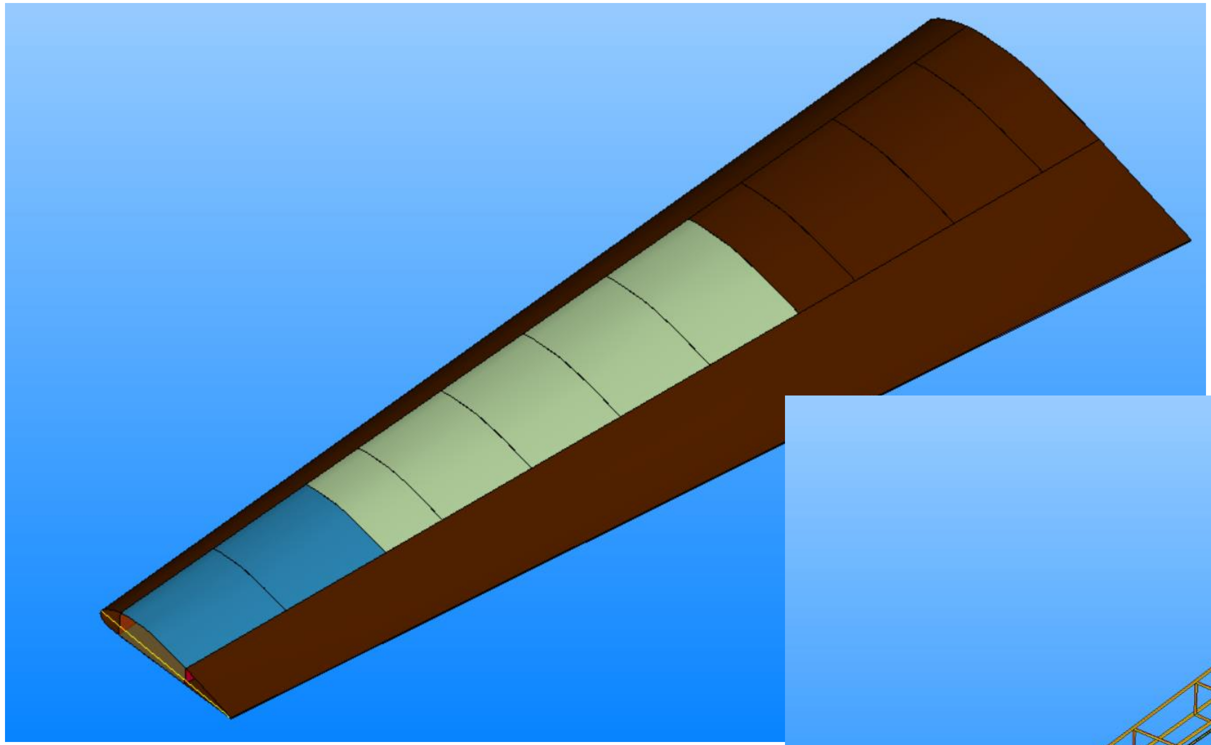
	Symbol	Thickness ramps	Orientation ramps	Units
Skin weight without ramps		60.21	60.21	kg
Total possible ramp length	L_r	61548	61548	mm
Ramp percentage	R_p	75%	20%	
Flange width	w_f	40	40	mm
Extra ramp width	w_a	5	5	mm
Ramp ratio	RR	20	20	
Average ramp thickness	t_r	0.5	0.5	mm
Density	ρ	1500	1500	kg/m3
Effective ramp width	w_{eff}	50	50	mm
Total ramp volume	V_r	1154022	307739	mm3
Total ramp weight	W_r	1.73	0.46	kg
Weight percentage		2.87%	0.77%	

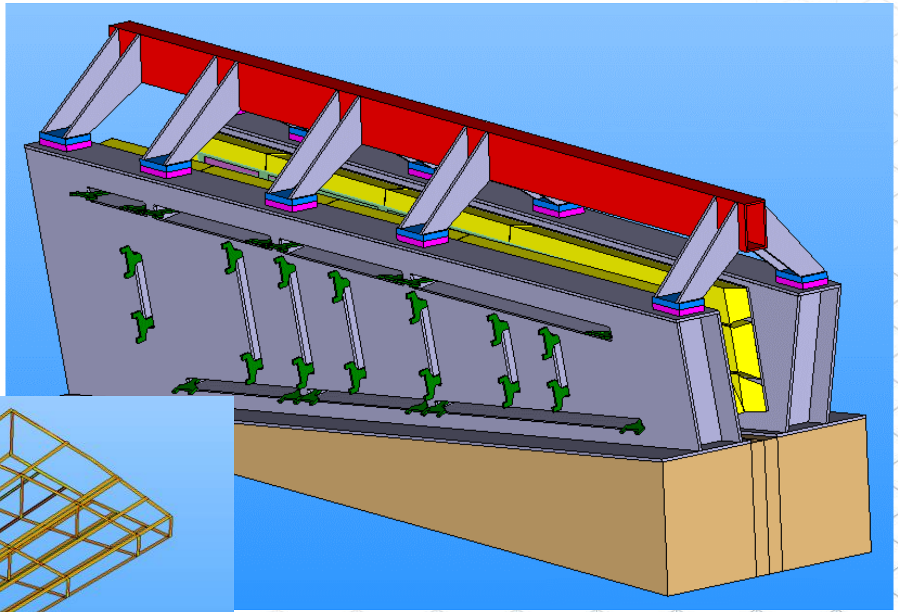
What do we need to enable considering manufacturing in MDO

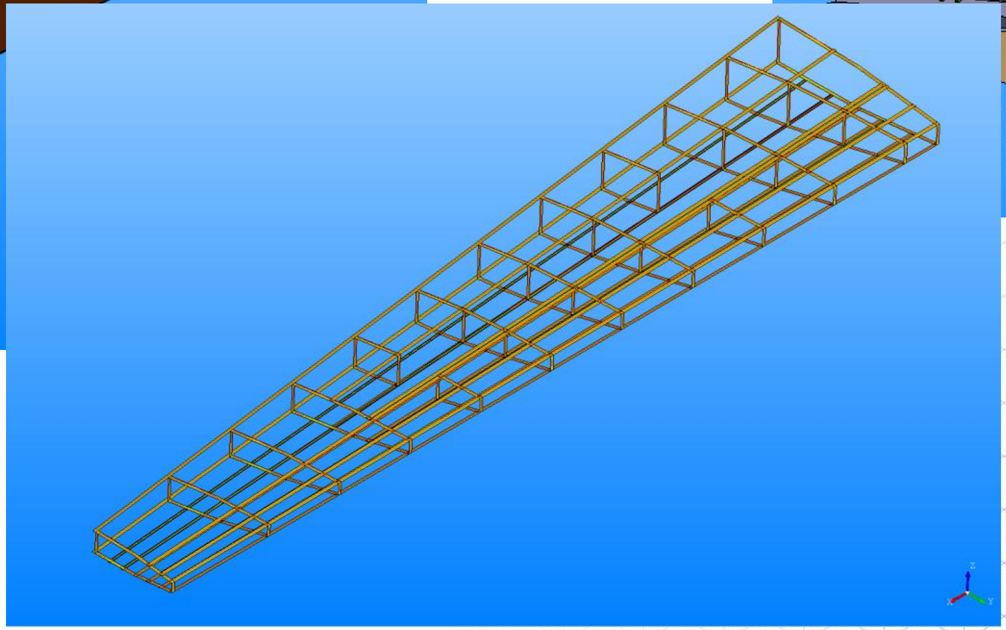
- Models of the system of interest including the manufacturing system
- Models of requirements
- Quantification methods for manufacturing aspects
- Analysis modules analysing manufacturability aspects
- Optimization routines that can handle non-continuous design variables

What do we need to enable considering manufacturing in MDO

- **Models of the system of interest including the manufacturing system**

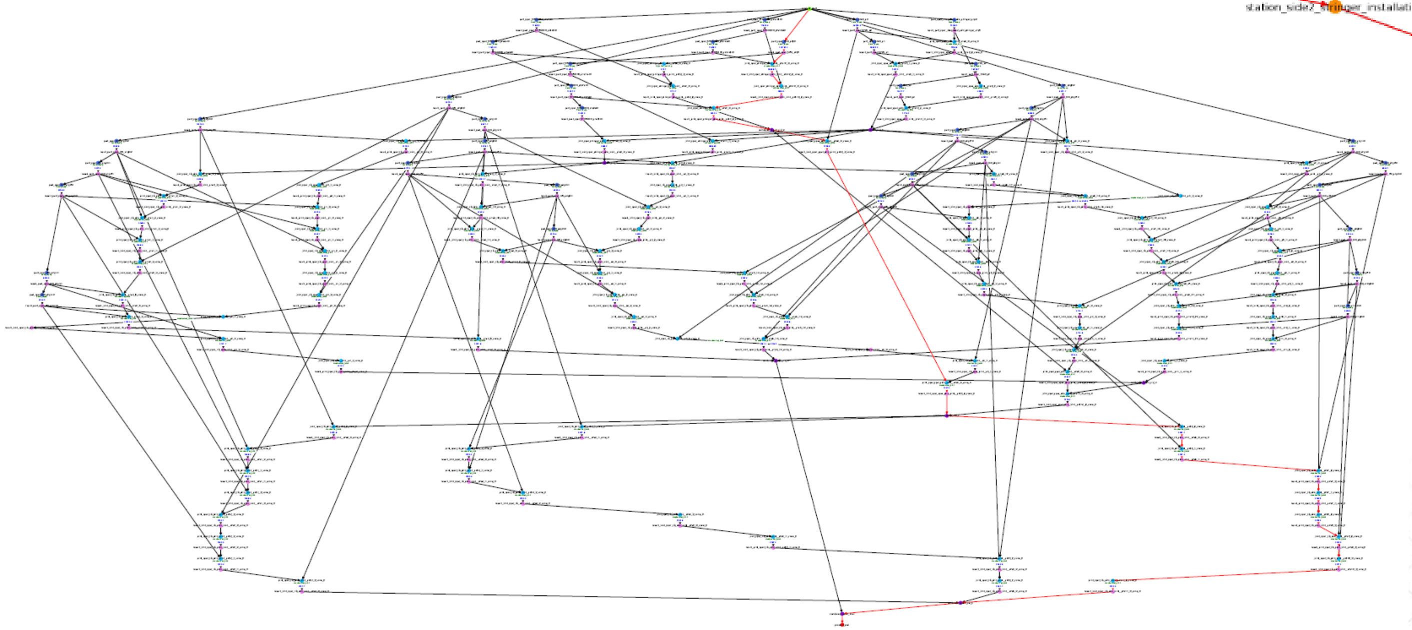


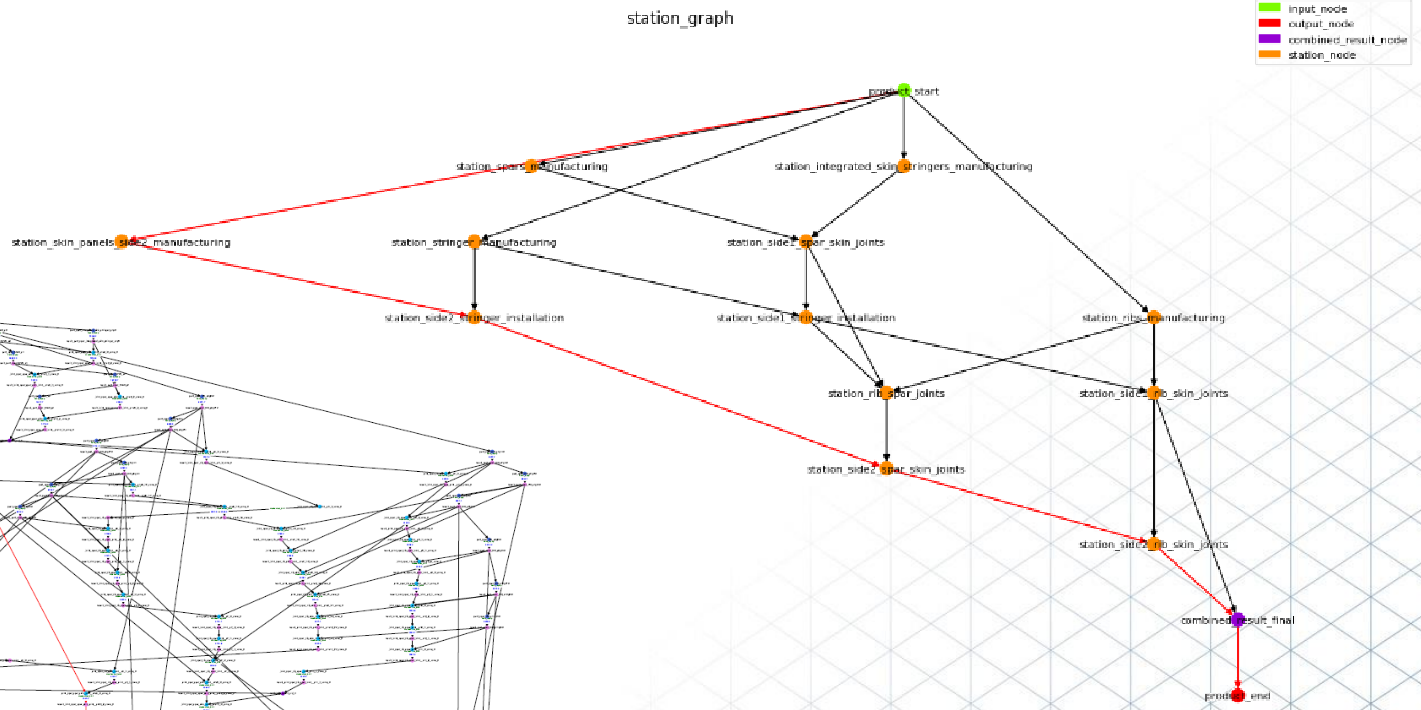




What do we need to enable considering manufacturing in MDO

- **Models of the system of interest including the manufacturing system**





What do we need to enable considering manufacturing in MDO

- **Models of requirements**

Requirements overview

Below you`ll find an overview of all requirements in the design study.

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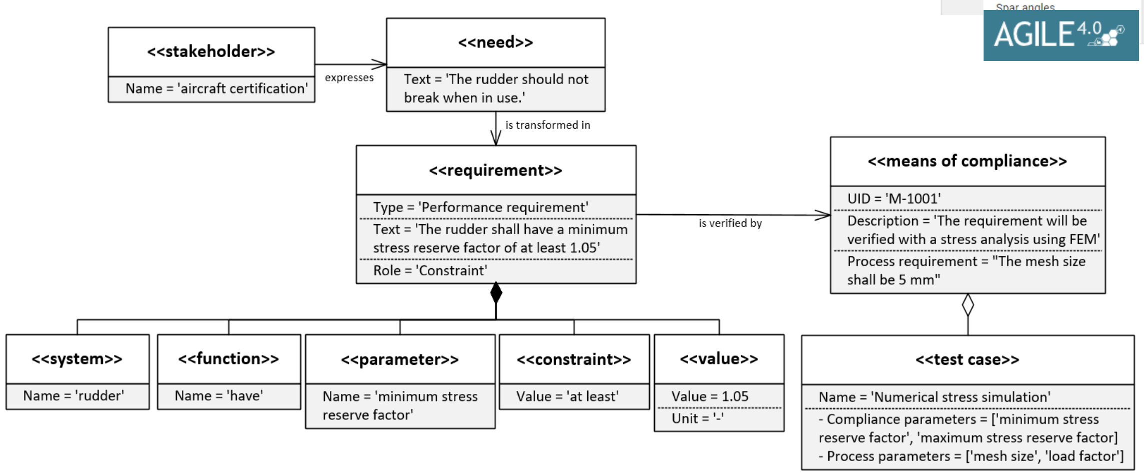
Requirement	ID	Text	Priority	Type	Parent/source requirement	User needs	Version
Rib pitch	R-0005	The flap shall have a rib pitch of minimal 250 mm	Medium	Design constraint		Manufacturability	1.0
Flap balanced lay-ups	R-0038	The flap shall have balanced lay-ups	High	Design constraint		Manufacturability, Design method maturity	1.0
Flap symmetrical lay-ups	R-0039	The flap shall have symmetrical lay-ups	High	Design constraint		Manufacturability, Design method maturity	1.0
Flap manufacturability	R-0041	The flap shall be manufacturable	High	Design constraint		Manufacturability	1.0
Spar angles	R-0043	The spars shall have an angle between the spar web and the spar flange of at least 90 degrees	High	Design constraint	Flap manufacturability	Manufacturability	1.0

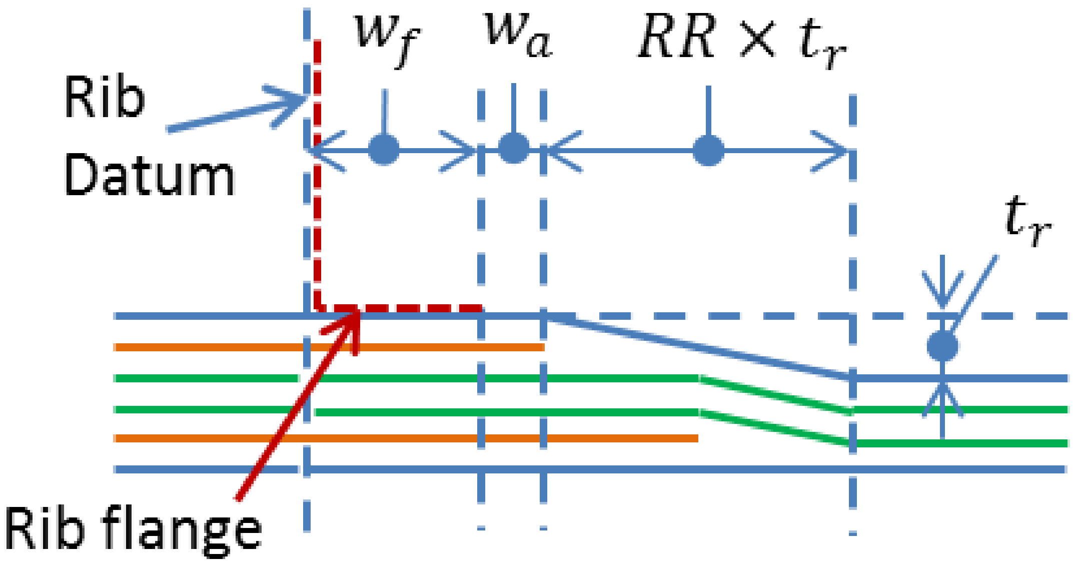


What do we need to enable considering manufacturing in MDO

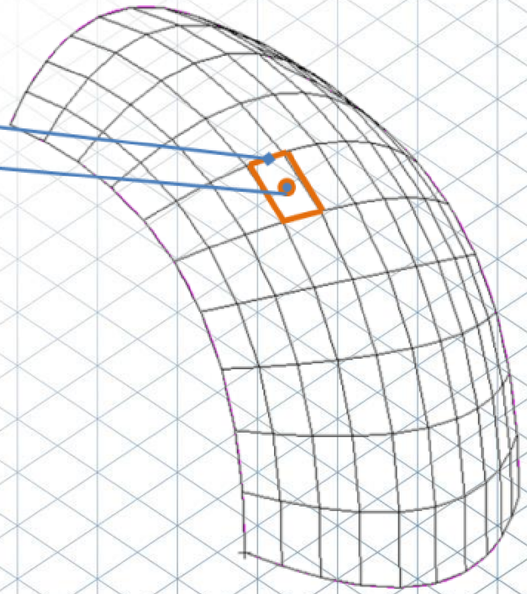
- **Models need to be:**
  - Easy to use
  - Accessible through an open API
  - Visually inspectable
  - Use a standard ontology

What do we need to enable considering manufacturing in MDO

- **Quantification methods for manufacturing aspects**
  - Standard geometrical quantification → sizes and weights
  - Complexity quantification → surface curvatures, ramp lengths
  - Preferable simple quantification methods



1. Calculate area of element
2. Measure κ_g in middle point
3. Calculate I_g of element
4. Repeat for each element
5. Sum all element I_g to get surface I_g



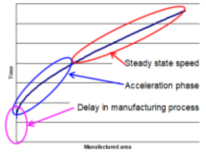
What do we need to enable considering manufacturing in MDO

- **Analysis modules analysing manufacturability aspects**

Open source manufacturing cost tool

Implementing an existing method modeling Manufacturing methods using a combination of (sub-)processes

$$t = \tau_{overall} \cdot \sqrt{\left(\frac{A_{total}}{v_{overall} \cdot \tau_{overall}} + 1\right)^2 - 1}$$



Process variables are adjusted to take into account part complexities such as double curvature

$$\tau_{overall} = \tau_0 + b_n \cdot \sum_{n}^{NoOfSharpConnections} I_{sharp}$$

$$v_{overall} = \frac{v_0 \cdot A_{flat} + v_{single} \cdot (A_{single} + A_{double}) + v_{double} \cdot A_{double} + V_d}{\left(A_{flat} + A_{single} + 2 \cdot A_{double} + \sum_{n}^{NoOfCurvedConnections} A_n\right)}$$

Where

Single curvature

$$v_{single} = \frac{v_0}{1 + \left(\frac{v_0}{c_n}\right) \cdot \sum_{i}^{NoOfSurfaces} I_{n_i}}$$

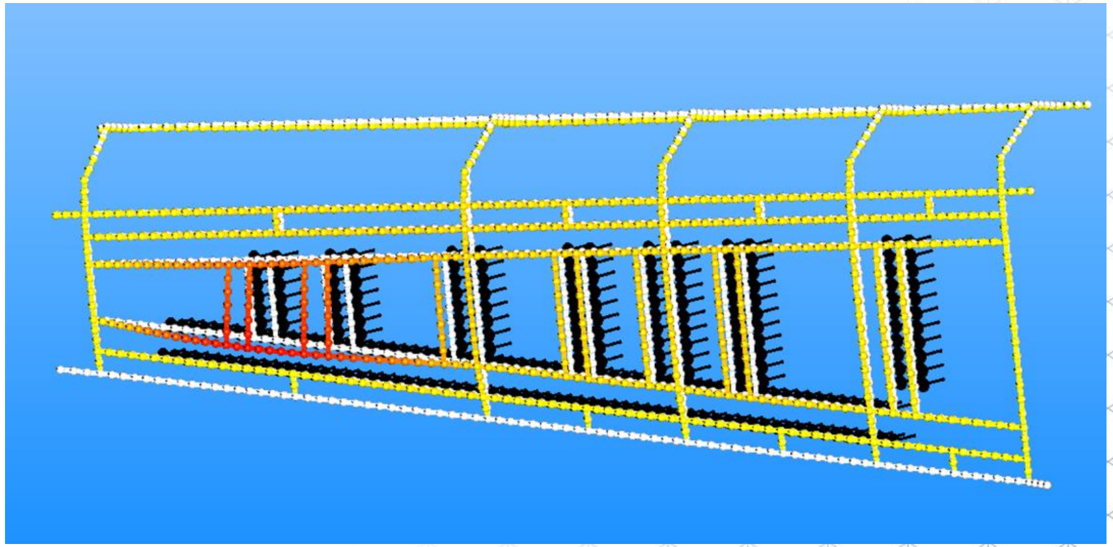
$$I_n = \iint_{surface} \kappa_n ds$$

Double curvature

$$v_{double} = \frac{v_0}{1 + \left(\frac{v_0}{c_d}\right) \cdot \sum_{i}^{NoOfSurfaces} I_{g_i}}$$

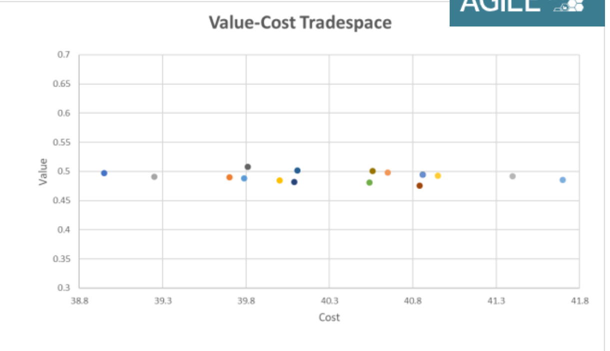
$$I_g = \iint_{surface} \kappa_g ds$$

Tooling stiffness analysis



Supply chain cost value optimization tool

Manufacturing and Supply Chain Options		Cost	Total Value	
ID	SC Proposal			
1	1 S-1	38.94962	0.497168	Supply Chain Option 1
2	2 S-1	39.69962	0.490455	
3	3 S-1	39.24962	0.491144	
4	4 S-1	39.99962	0.484432	
5	5 S-1	39.78962	0.488016	
6	6 S-1	40.53962	0.481305	
7	7 S-1	40.08962	0.481995	
8	8 S-1	40.83962	0.475284	
9	1 S-2	39.80886	0.507578	Supply Chain Option 2
10	2 S-2	40.55886	0.500865	
11	3 S-2	40.10886	0.501554	
12	4 S-2	40.85886	0.494842	
13	5 S-2	40.64886	0.498427	
14	6 S-2	41.39886	0.491715	
15	7 S-2	40.94886	0.492405	
16	8 S-2	41.69886	0.485694	
Min		38.94962	0.475284	
Max		41.70	0.51	



What do we need to enable considering manufacturing in MDO

- **Optimization routines that can handle non continuous design variables**

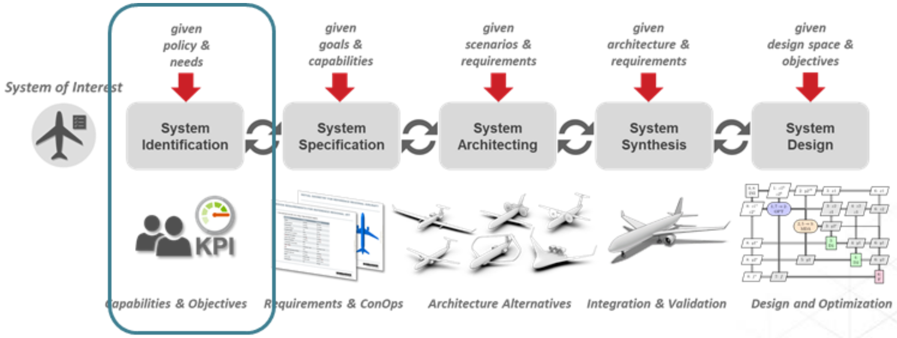
???

How do we implement this at GKN

- **At GKN Fokker we use a system model which is geometry centric but also encompasses manufacturing aspects built using Parapy**
- **Manufacturing model includes assembly and mono part manufacturing models**
- **Different manufacturing analyses can be fed using data from the models, structural analyses also fed from models.**
- **Experimenting with these tools in EU projects like Agile 4.0 and Defaine before application in "real" projects**

What are the current achievements, Agile 4.0 workflow

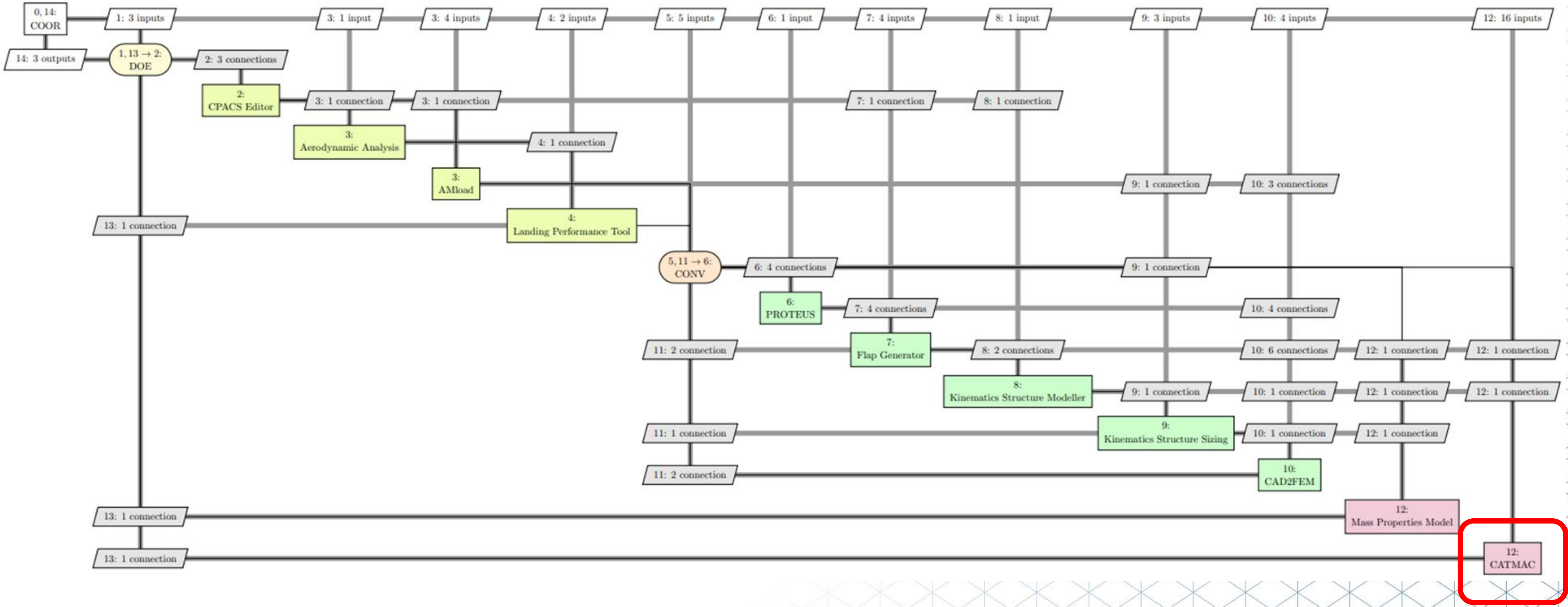
- For Agile 4.0 MDO we are running a Design Of Experiments with manufacturing cost estimation in the loop, no optimization yet
- Start with modeling requirements



Need	ID	Text	Stakeholder	Linked to requirements?	Derived requirements
Design input	N-0006	Needs design inputs (loads, OML,etc.)	Flap manufacturer (FM)	Yes	OEM supplies OML, Aircraft integration
Weight and CG limits	N-0008	Needs to be in the weight limit and min/max CG	Flap manufacturer (FM)	Yes	Flap weight
KC's measurability	N-0009	Needs to be able to measure (KC's)	Flap manufacturer (FM)	Yes	Flap KC's, Flap KC's FM
Product delivery time	N-0010	Product needs to delivered on time	Flap manufacturer (FM)	Yes	Flap delivery, Flap delivery dates
Flap shape	N-0011	Flap needs to be of a certain shape	OEM	Yes	Flap planform, Flap OML deviation
Flap delivery time	N-0012	Flap needs to delivered on time	OEM	Yes	Flap delivery, Flap delivery dates
Flap costs	N-0013	Flap needs to be within budget	OEM	Yes	Flap manufacturing costs
		Flap needs to be as light as			Flap weight, Material

What are the current achievements, Agile 4.0 workflow

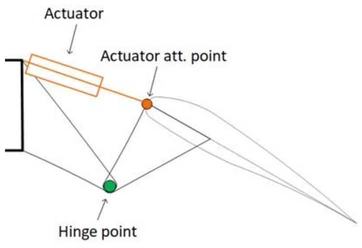
- Working though all the steps in the Agile 4.0 collaborative environment we get a DOE workflow



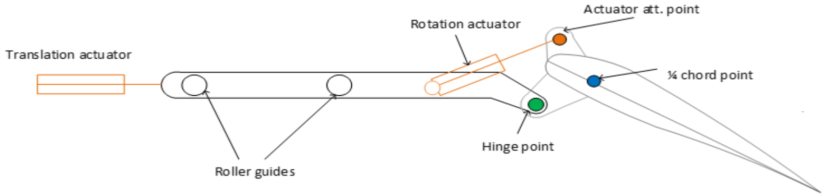
What are the current achievements, Agile 4.0 workflow

- We look at different flap types and sizes

Dropped hinge



Smart Flap

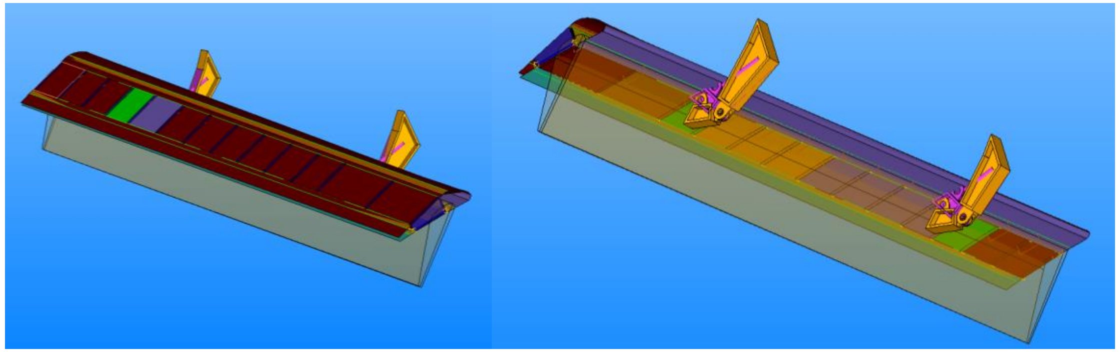


ID	chord	translation	rib pitch	man. Method	mechanism type		weight [kg]	cost [$]	landing dist [m]
1	0.15	0.3	150	advanced	dropped hinge		27.97	11573.32	2874.18
2	0.35	0.3	150	advanced	dropped hinge		85.98	18389.76	2942.85
3	0.15	0.7	150	advanced	dropped hinge		35.76	12438.36	2190.01
4	0.35	0.7	150	advanced	dropped hinge		74.39	18197.02	2039.54
5	0.15	0.3	500	advanced	dropped hinge		28.85	6683.34	2874.18
6	0.35	0.3	500	advanced	dropped hinge		99.17	14417.12	2942.85
7	0.15	0.7	500	advanced	dropped hinge		34.18	7377.99	2190.01
8	0.35	0.7	500	advanced	dropped hinge		94.95	14938.16	2039.54
9	0.25	0.5	325	advanced	dropped hinge		55.15	10903.49	2472.61
10	0.15	0.5	325	advanced	dropped hinge		33.67	8338.80	2408.23
11	0.35	0.5	325	advanced	dropped hinge		96.88	15752.86	2467.51
12	0.25	0.3	325	advanced	dropped hinge		56.30	10868.82	2824.22
13	0.25	0.7	325	advanced	dropped hinge		59.98	11543.13	2405.46
14	0.25	0.5	150	advanced	dropped hinge		52.73	14634.10	2472.61
15	0.25	0.5	500	advanced	dropped hinge		52.57	9622.19	2472.61
16	0.15	0.3	150	advanced	smart flap		32.05	12029.44	2874.18
17	0.35	0.3	150	advanced	smart flap		80.84	17261.78	2942.85
18	0.15	0.7	150	advanced	smart flap		34.49	12211.64	2190.01
19	0.35	0.7	150	advanced	smart flap		78.37	17129.30	2039.54
20	0.15	0.3	500	advanced	smart flap		30.38	6809.72	2874.18
21	0.35	0.3	500	advanced	smart flap		79.58	11999.39	2942.85
22	0.15	0.7	500	advanced	smart flap		34.78	7475.57	2190.01
23	0.35	0.7	500	advanced	smart flap		73.93	11463.81	2039.54
24	0.25	0.5	325	advanced	smart flap		49.44	9550.13	2472.61
25	0.15	0.5	325	advanced	smart flap		37.94	8786.14	2408.23
26	0.35	0.5	325	advanced	smart flap		79.96	13094.87	2467.51
27	0.25	0.3	325	advanced	smart flap		53.59	10313.74	2824.22
28	0.25	0.7	325	advanced	smart flap		57.91	10884.21	2405.46
29	0.25	0.5	150	advanced	smart flap		52.42	13843.61	2472.61
30	0.25	0.5	500	advanced	smart flap		47.42	8318.89	2472.61

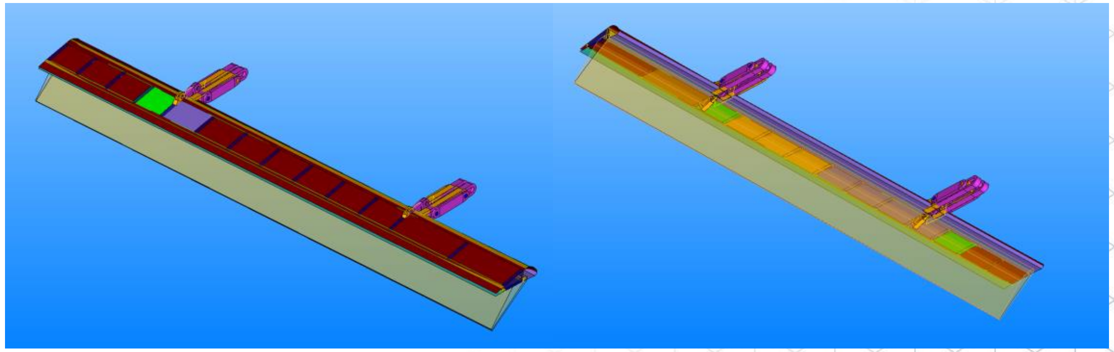
What are the current achievements, Agile 4.0 workflow

- It is important to visualize the flap models for inspection

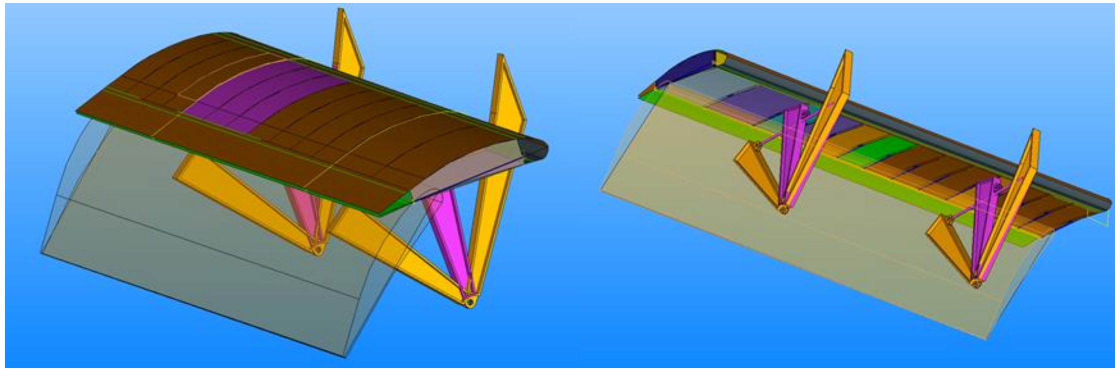
Experiment 1; Dropped, min. chord, min. translation



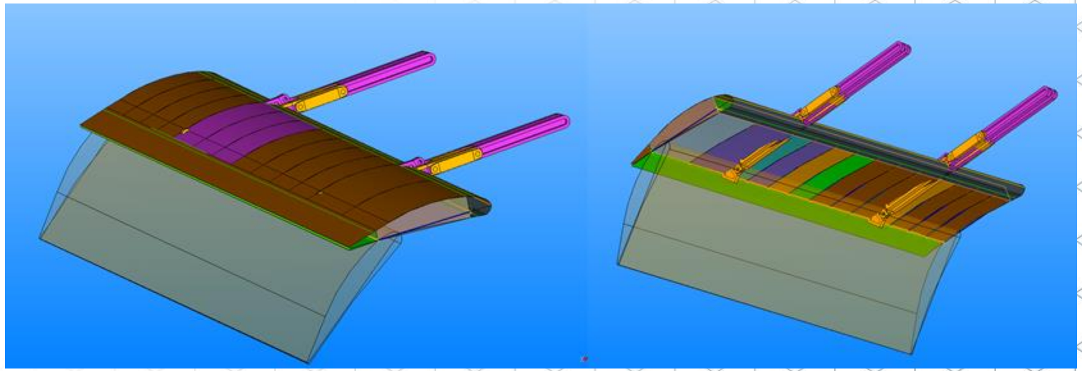
Experiment 16; Smart, min. chord, min. translation



Experiment 8; Dropped, max. chord, max. translation



Experiment 23; Smart, max. chord, max. translation



What are the current achievements, Agile 4.0 workflow

Achievements:

- Showcased the use of tools developed within the AGILE 4.0 project
- Automatically set up a Design of Experience Work Flow using AGILE 4.0 tools
- We’ve shown it is possible to include manufacturing cost in a DOE flow

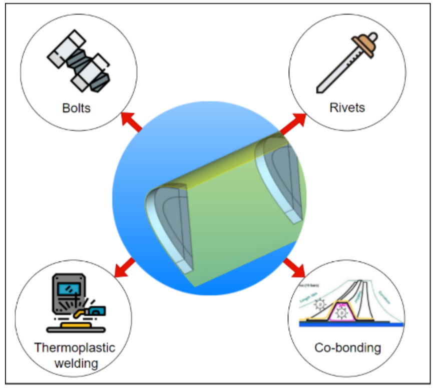
Next steps in Agile 4.0

- Improve robustness of workflows
- Move towards optimization

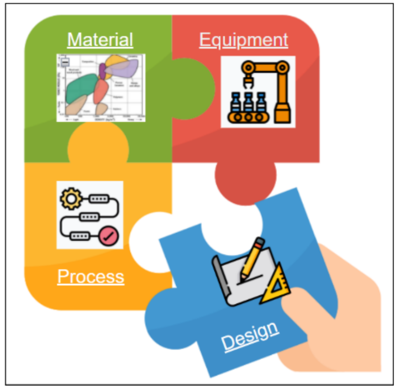
What are the current achievements, manufacturing model linked to geometric design model

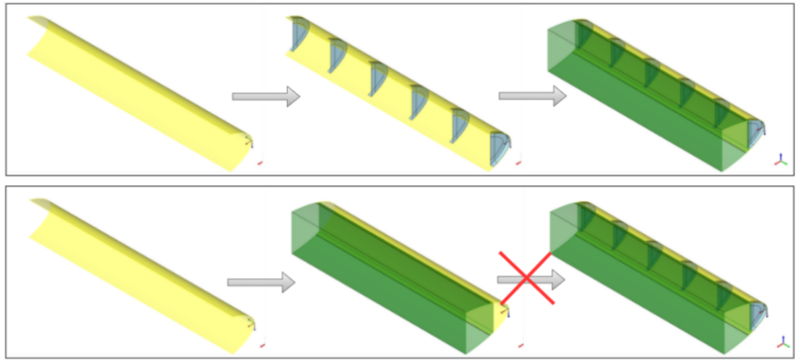
Model considerations

1. Joint information



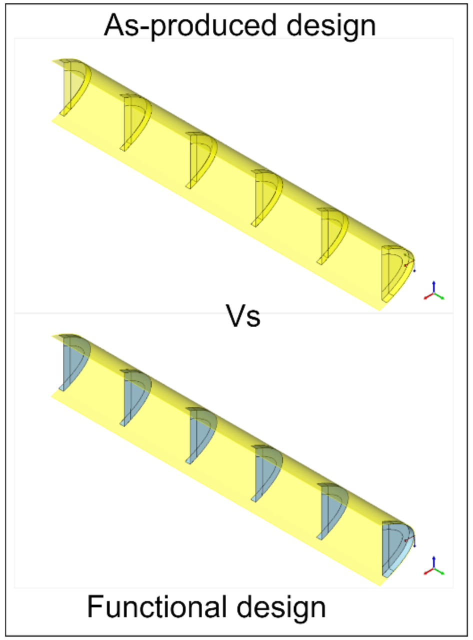
2. Product Compatibility



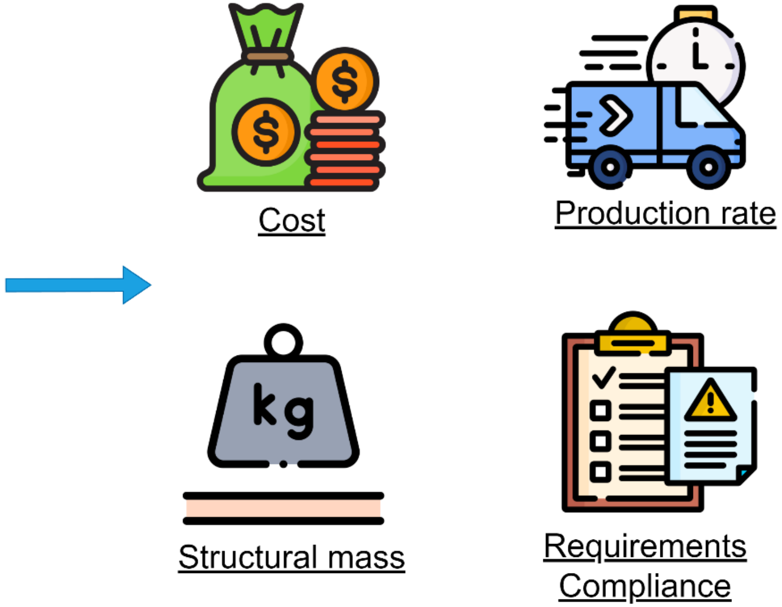


3. Assembly Sequence

4. Part Integration



Source: GKN Fokker Aerostructures

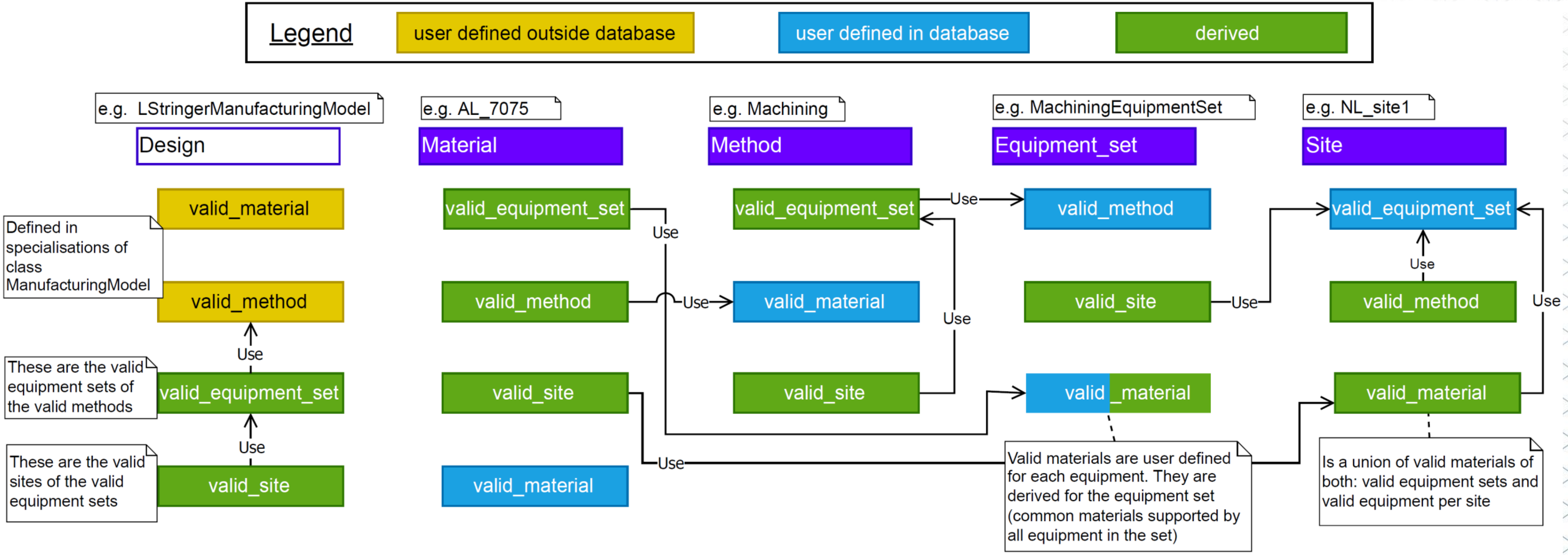


Production considerations

Parameters of interest

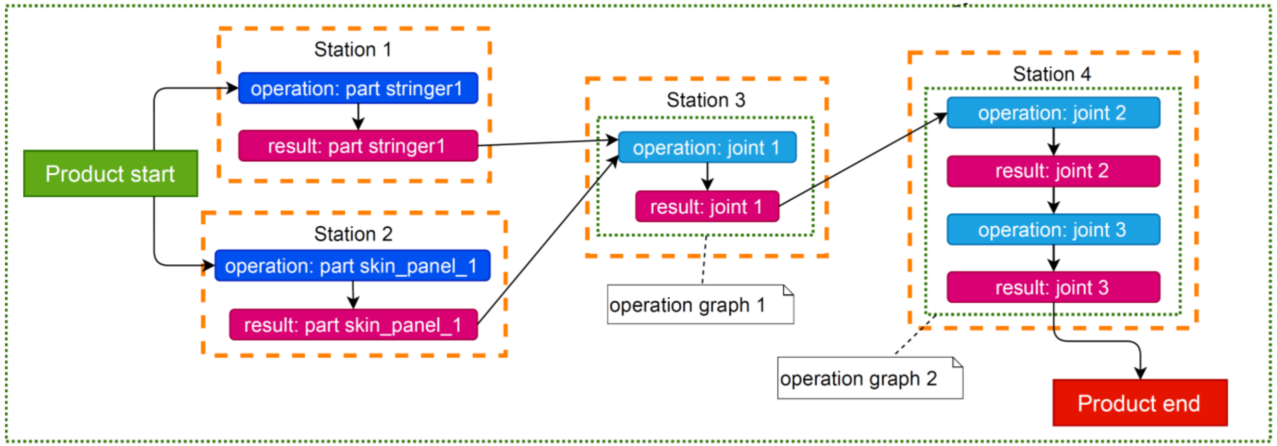
What are the current achievements, manufacturing model linked to geometric design model

Compatibility requirements, what material, production method combinations are valid

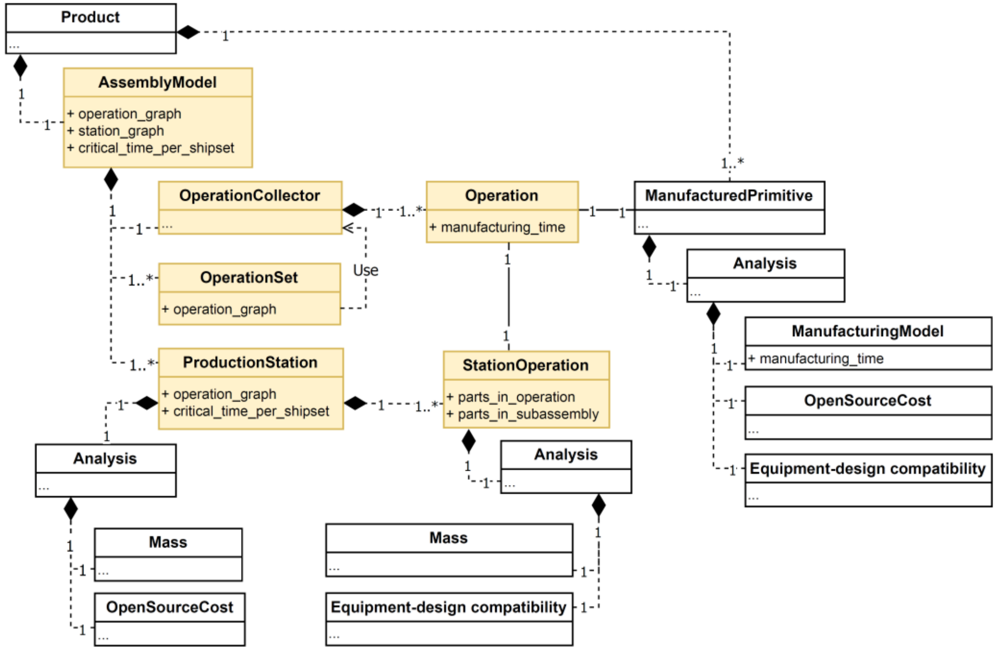


What are the current achievements, manufacturing model linked to geometric design model

Assembly sequence and what is done in what station

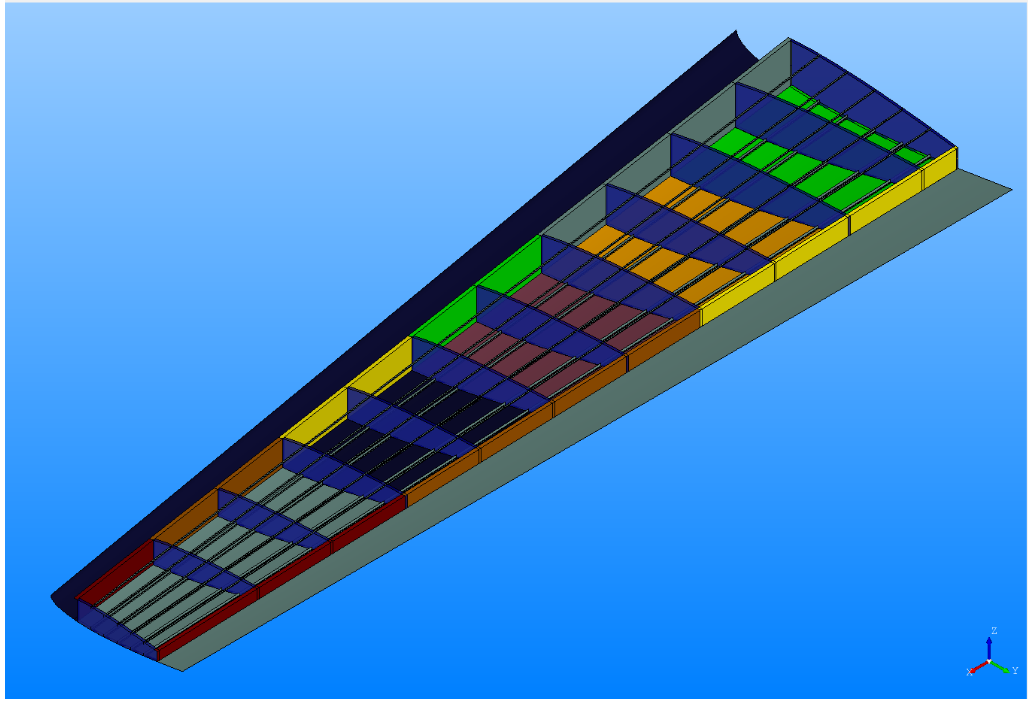


Linking the assembly model to the product

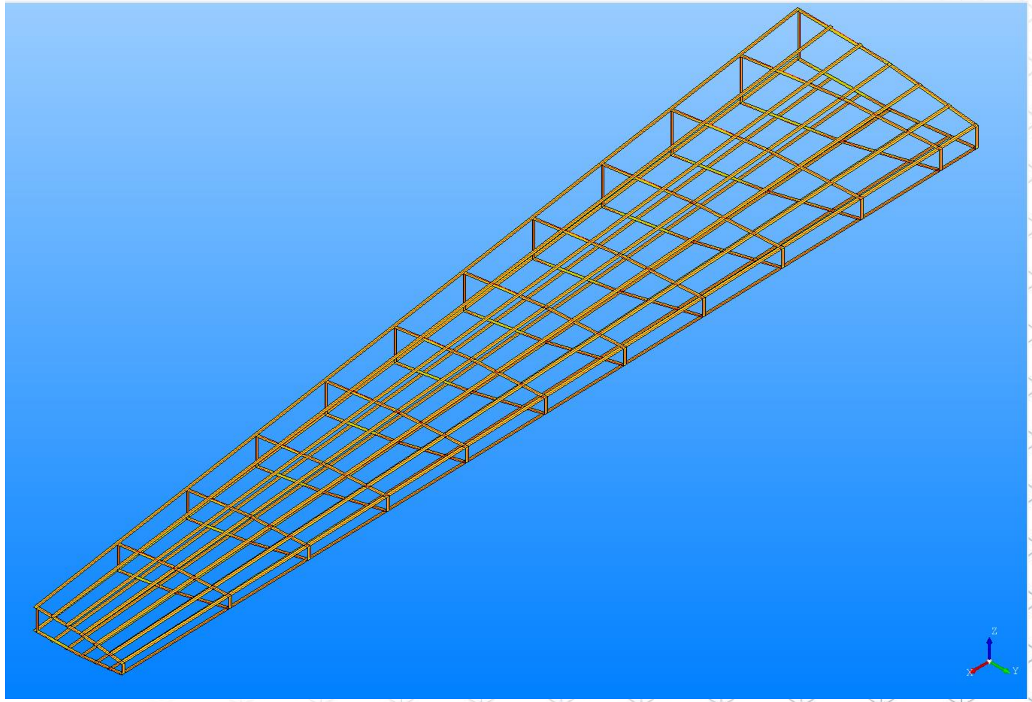


What are the current achievements, manufacturing model linked to geometric design model

Geometric representation of parts

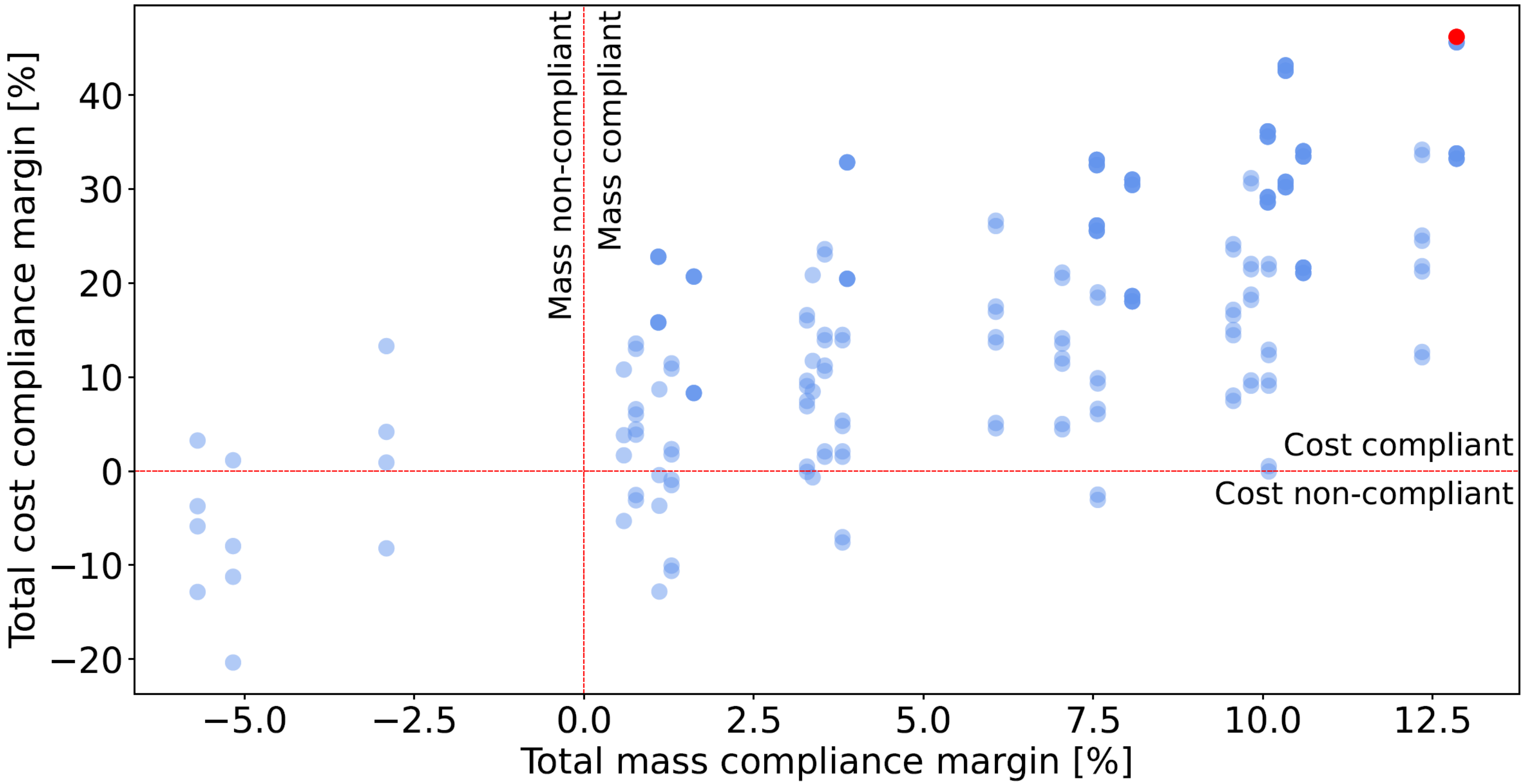


Geometric representation of joints



What are the current achievements, manufacturing model linked to geometric design model

Overview of different manufacturing strategy results (Work In Progress)



What is the way forward, what do we want to achieve

The ultimate goal is to be able to explore aircraft component design spaces and represent them in simplified models to quickly respond to customer requests

The response given will be weight, cost and manufacturability for a safe aircraft component

To ensure the responses are reliable we want to use high fidelity methods. Comparable to current certification tools

To enable the exploration of the design spaces all tools must be automated and interfaces between tools must be clear. This will require clear ontologies for the models used by the tools.

Building the design spaces will require multiple optimization steps and algorithms. We need methodologies that can handle the nature of our manufacturing problems

To really take manufacturing into account we need, besides the currently used cost tools, true manufacturability models and the associated analysis tools

Questions

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