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Hybrid Laminar Flow Control ready for Series Application

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Abstract

A competitive HLFC series application for the next generation of long-range Aircraft is shown. The system is applied to the outer leading edge and upper cover part of the wing where the drag reduction potential is highest. Small scale demonstrators (SSD) and a ground-based demonstrator (GBD) were built to show technical feasibility, functionality and cost-effective series near TRL 4. A demonstrator-based assessment of weight and cost compared to a conventional aircraft has been carried out, showing the capability of HLFC technology for future long-range aircrafts.

1. Introduction

A major objective of the Clean Sky 2 project "HLFC-WIN" [1] is to push HLFC technology towards a competitive series application for the next generation of long-range Aircraft. The geometrical boundary conditions that have been agreed on for the project are to primarily focus on the outer wing between the engine pylon and the wing tip. Furthermore, it has been agreed that the wing leading edge, structural/aerodynamic interfaces and the wing box upper shell are mainly contributing to the drag reduction potential (Figure 1 - dark & light green). The chosen, highly modular design approach with 4 similar leading-edge segments is a major enabler for low development effort. A no-pipe design with distributed small compressor units that can be integrated in the leading-edge structure has been chosen to save weight and create redundancy.

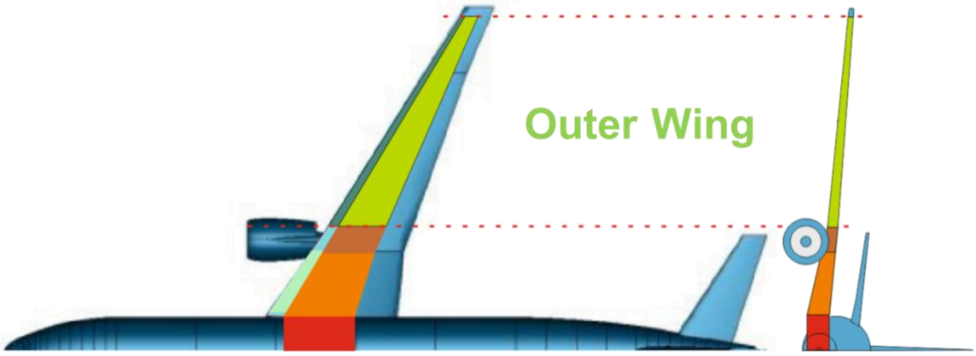

Figure 1: Outer Wing of laminar XRF1

Several demonstrators have been and are built with increasing complexity. With cost and weight estimations derived from these demonstrators an overall assessment shows the potential of HLFC for future long-range aircrafts.
The approved TRL3 and the expected TRL4 level at the end of the HLFC-WIN project indicate that the chosen technical solutions are well established and acceptable from a certification point of view.

2. HLFC System and Demonstrators

To provide the required suction at the outer wing, the four similar wing segments are each subdivided into 2 segments, resulting in 8 very similar submodules (Figure 2). This enables the verification of the design and system approach by

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building one representative small and relatively cost-efficient submodule together with its joining interfaces. In the assessment chapter, the results are virtually transferred to the other 7 submodules.

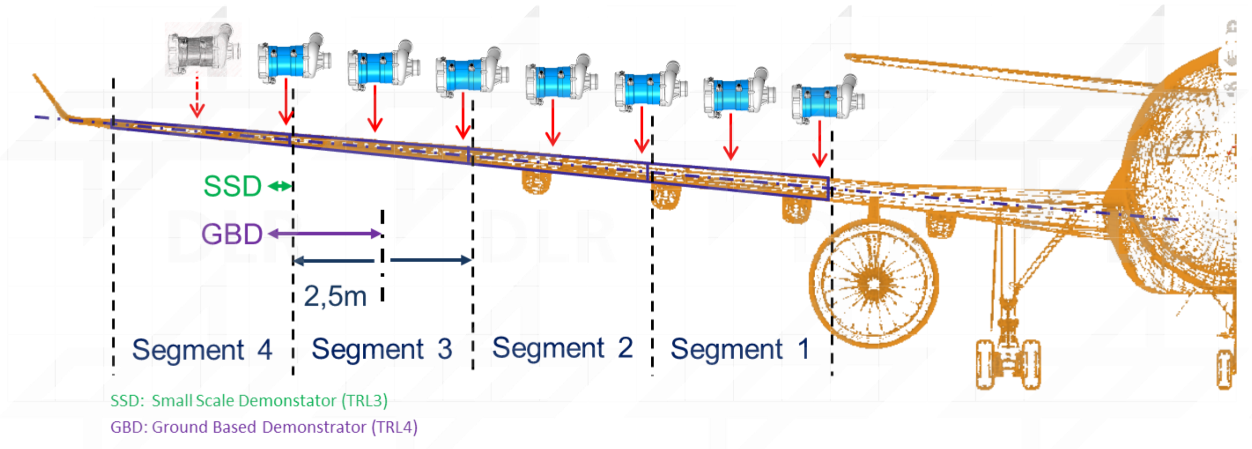

Figure 2: Segments and Demonstrators

A submodule consists of a suction rib with an internal compressor, a 2,5m span Krüger flap and the dedicated mechanism. Two submodules build up a 5m leading-edge segment with a continuous laser drilled Titanium suction glove and an inductive WIPS system at the critical wing areas (Segment 2 and 3).

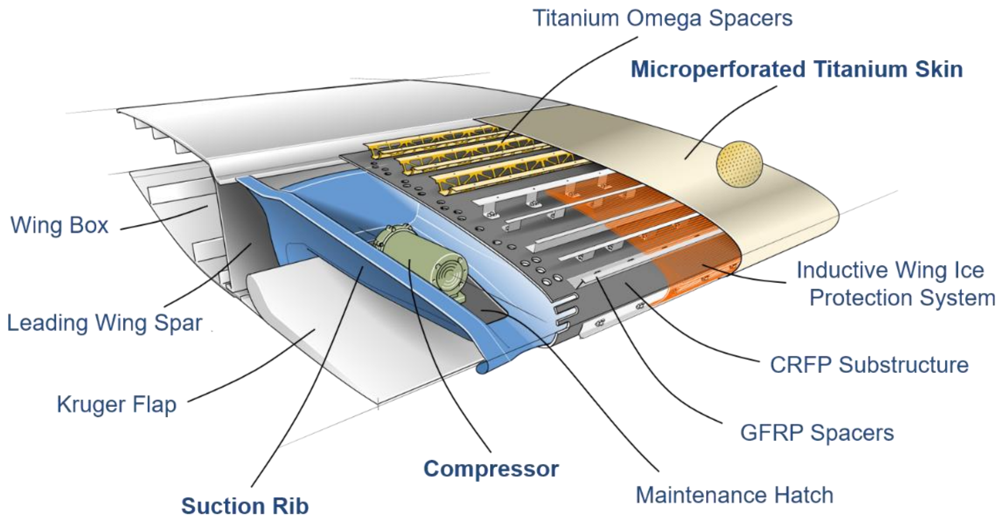

Figure 3: Suction rib SSD / Submodule

In order to check the technical feasibility of the modular approach, a combination of 3 small-scale demonstrators has been designed, built and tested. Furthermore, a ground-based demonstrator has been designed and will be built and tested within the remaining project time. The Suction Rib SSD has been used to verify the compressor integration, the "Spanwise Flow" SSD allowed to analyze the spanwise flow conditions in the suction glove and with the "Interface" SSD the "Plug and Fly" leading edge to box joint concept has been verified. The ground-based demonstrator is adding a representative wing complexity (tapering) and also includes the wingbox structure. In addition, all relevant electrical systems and their routings are part of the demonstrator.
Figure 3 represents the setup used in the suction Rib SSD and gives a good overview on the HLFC concept and its components. The suction rib contains the compressor and is connected to the spanwise cavity between the CRFP substructure and the microperforated titanium skin. This cavity distributes the suction from the suction rib in spanwise direction. The titanium skin is held in position by a set of spacers which are made from titanium respectively GFRP. The titanium spacers are omega spacers and deliver high stiffness and enable high positioning precision. This is important for the interface between titanium skin and wingbox, which in turn is highly important for the chordwise

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subsequent laminarity. At the leading-edge region, the spacers are made from GFRP to prevent their heating by the inductive wing ice protection system (inductive WIPS).

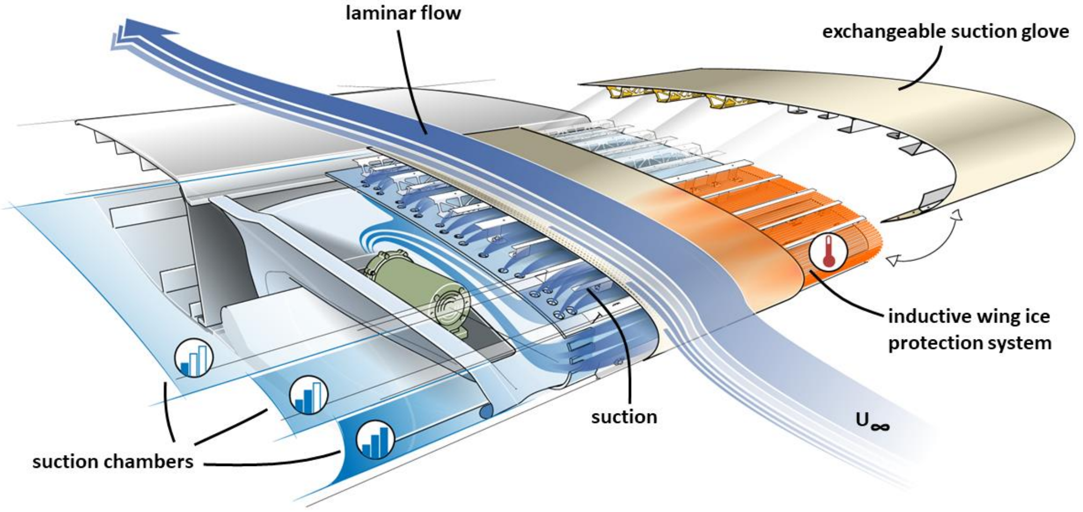

Figure 4: Suction rib submodule – Functionality and Features

Figure 4 shows major functionalities and features of the HLFC System, being the variable suction, the inductive WIPS and the exchangeable suction glove.

Variable Suction

In this setup 2 of the spacers are airtight and thus divide the cavity in chordwise direction into three chambers. This was a first concept to create variable suction according to the needs for the HLFC working properly and at the same time being energy efficient. Within the project AERNNOVA improved and industrialized their laser titanium drilling technique such that they are able to generate locally adapted drilling patterns with different hole densities, which in turn enables variable suction without the chambers. Therefore, the chambers will not be seen in the GBD.

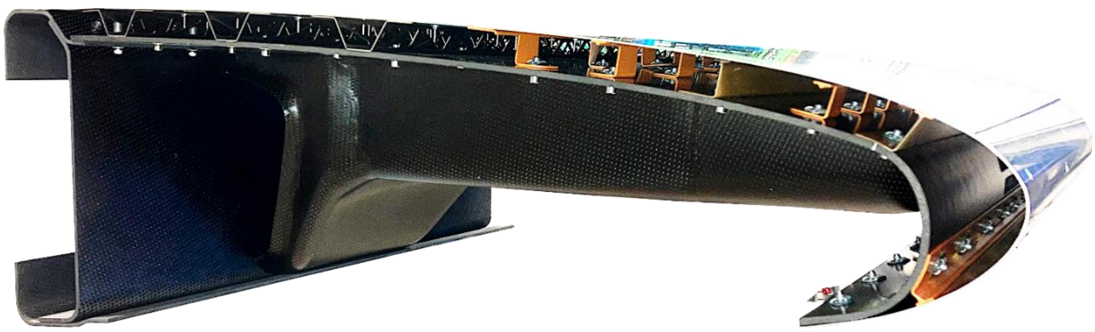

Figure 5: Suction Rib Small Scale Demonstrator

Inductive Wing Ice Protection

The suction system in the leading-edge is the core technology of the HLFC-WIN approach and therefore a WIPS that minimizes blocking of suction skin is a consequent strategy. The contact free induction-based heating of the perforated suction skin also offers a new perspective for an efficient maintenance concept because the coils and the suction skin are independent modules that can be exchanged individually when necessary. The current status is that it is sufficient, when only the segments 2 and 3 are equipped with a WIPS.

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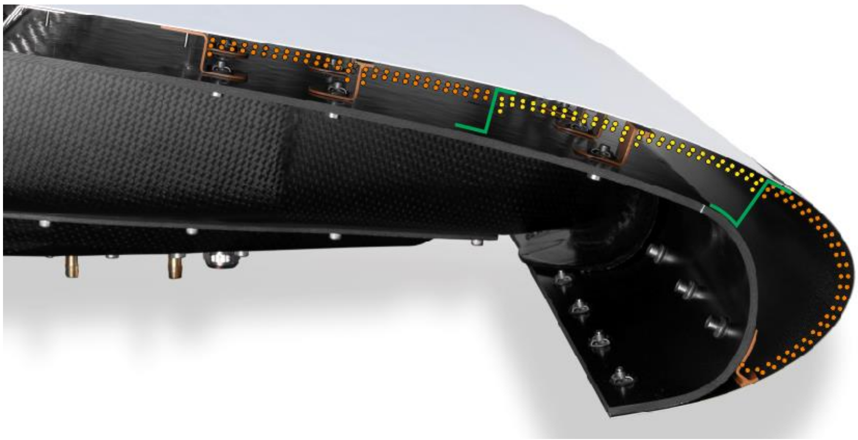

Figure 6: Example: Double Layer Installation of the coils system

Heating and flow characteristics for different coil configurations (example in Figure 6) have been investigated on experimental and simulation level with a quite positive result. The ICEPASS campaign where an inductive WIPS demonstrator wing will be tested in an Ice Wind Tunnel will provide a further matured understanding of the advantages and disadvantages of the new approach.

Suction Glove

The exchangeable suction glove allows for easy maintenance and if necessary replacement of the titanium skin which reduces aircraft downtime. At the same time, it allows maintenance and/or exchange of the WIPS system.

2.1 Suction Rib Small Scale Demonstrator

Figure 5 shows the Suction Rib SSD [2], [3]. It represents a 2D extrusion of the leading-edge cross section between Segment 3 and 4 and as such a submodule without the complexity of the wing tapering. In spanwise direction a demonstrator length of 800mm has been chosen to keep a compact size and be cost efficient on one hand and still be able to show the major Suction Rib features in full size on the other hand. In order to focus on the new elements of the HLFC-WIN approach the wing box is only represented by a dummy structure.

The assessment of the Suction Rib SSD prototype manufacturing provides a substantial basis for the estimation of a future HLFC wing leading-edge with distributed compressors. In addition, maintenance aspects can be investigated by analyzing the effort to check and maintain the rib integrated compressor and the effort to exchange the suction glove.

2.2 Supporting Small-Scale Demonstrators

An additional feasibility analyses of the Suction Rib concept and the “Plug and Fly” glove has been done on two additional small-scale demonstrators. They are used for concept verification but are not suitable for subsequent assessment and will not be regarded subsequently. Even though the setups of the Spanwise Flow and the Interface SSDs were highly improvised they proved the feasibility of the HLFC-WIN approach in two areas that are highly critical from a technical point of view.

Spanwise Flow SSD

Main target of the Spanwise Flow SSD is to validate the internal flow conditions in the suction glove. This is necessary because the distance of the distributed compressors is 2,5m and adequate suction also needs to be established in between the compressors. The setup of the Spanwise Flow SSD is highly improvised and only suited to replicate the aerodynamic flow conditions.

Interface SSD

The “Plug and Fly” suction glove is a major aspect of the HLFC-WIN concept and keeping the very tight tolerances at the wingbox interface is very challenging. The “Interface” SSD [4], [5] proved, that the newly developed “Plug and Fly” mechanism works as intended and that it can be manufactured with a certifiable series production setup.

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2.3 Ground-Based Demonstrator (GBD)

Space allocation is an important aspect and that is why the outer side of segment 3 (2,5m) and a small portion of the inner side of segment 4 (0,5m) have been selected to demonstrate all relevant structural and system related HLFC-WIN features. To enable a laminar flow length of up to 60% in chord direction at the upper wing, it is necessary to stay within challenging step, gap and waviness tolerances at the leading-edge, the leading-edge to box interface and also at the upper skin of the wingbox. It is also planned to extend the surface smoothness analyses to representative wing deformations that are related to operational conditions by applying representative load conditions to the wing box. Typical maintenance scenarios like the exchange of the suction glove will also be part of the analyses.

Figure 7: CAD data of the Ground Based Demonstrator

System Components of the GBD

Main System Components for the GBD are the Compressors, the Krüger flap Highlift System and the Inductive WIPS. Compressor and WIPS system data are derived from the SSD assessment.

Krüger Flap Highlift system

Metallic kinematic ribs and other elements of the Krüger flap highlift system are still under development. Uncertainties with respect to possible future certification rules that may demand 3 kinematic ribs for every high lift flap and the strategic decision to go for a “Scissor” kinematic instead of a presumably simpler and lighter “Gooseneck” kinematic make it difficult to come up with a result that can directly compete with the currently established slat approach that is mainly based on just two kinematic support structures.

Figure 8: Krüger Highlift System

DOI: 10.13009/EUCASS2023-647

On the other side the Krüger flap is an essential aspect of the HLFC-WIN approach because it is used as shielding against insects when it is deployed during takeoff and landing. Given these uncertainties it does not seem appropriate to use the current level of development for a cost assessment but the level of detail that can be seen in figure 8 is sufficient for a preliminary assessment of the masses.

3. Weight Assessment

This chapter addresses the weight assessment based on the Small Scale SSD and GBD. First a mass breakdown for the demonstrator components is carried out. Then for both a strategy for upscaling in terms of spanwise and chordwise dimensions and laminate thickness is presented. Then those masses are extrapolated. A linear extrapolation regarding geometry and laminate thickness has been chosen. This approach has been chosen because only rough estimation is intended and the outer wing shows mainly a simple tapering and a homogeneous distribution of laminate thickness without any massive local load introduction areas (e.g. no landing gear or pylon attachment).

3.1 Weight Assessment based on Suction Rib SSD

The following sections describe the assumptions and estimations and the show resulting weight distribution for the HLFC system on one wing based on the Suction Rib SSD.

Mass breakdown on structural components of the suction Rib SSD
Figure 9 shows all hardware components of the Suction Rib SSD and their respective mass shares. As expected the structural CFRP leading-edge skin and the porous Titanium suction skin are dominating the mass breakdown. The mass share of the suction rib structure (21,5%) is also very prominent but has to be seen in the context, that the spanwise width of the 800mm demonstrator is not representative. The components shown in Figure 9 sum up to an overall mass of 14,2 kg.

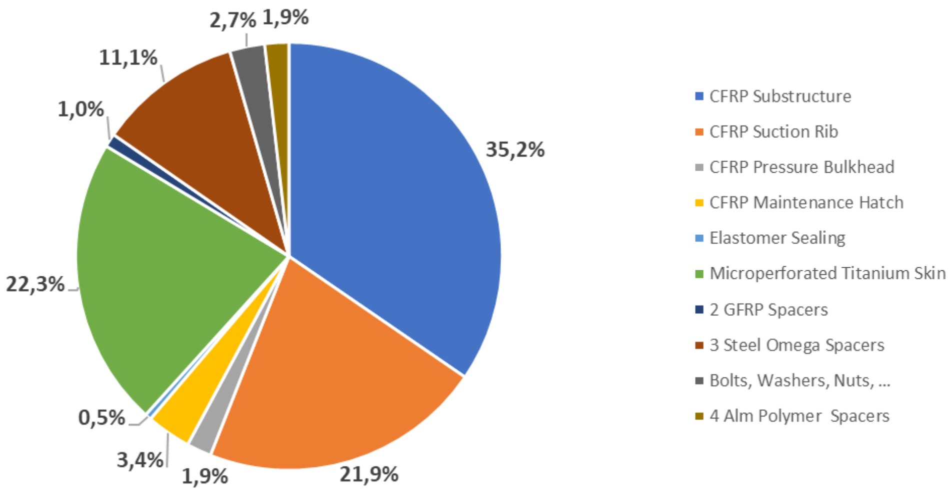

Figure 9: SSD Mass breakdown (wingbox dummy not included)

DOI: 10.13009/EUCASS2023-647

	Inboard	Segment 1	Interface 3/4	Segment 2	Interface 2/3	Segment 3	SSD	Segment 4	Outboard
Spanwise Position	0	2,5	5	7,5	10	12,5	15	17,5	20
Normalized unwound lenght	2,67		2,11		1,54		1		0,45
Geometry scaling factor		**2,39**		**1,83**		**1,27**		**0,73**	
Normalized laminate thickness	1,57		1,35		1,18		1		0,84
laminate thickness Scaling Factor		**1,43**		**1,26**		**1,09**		**0,93**	

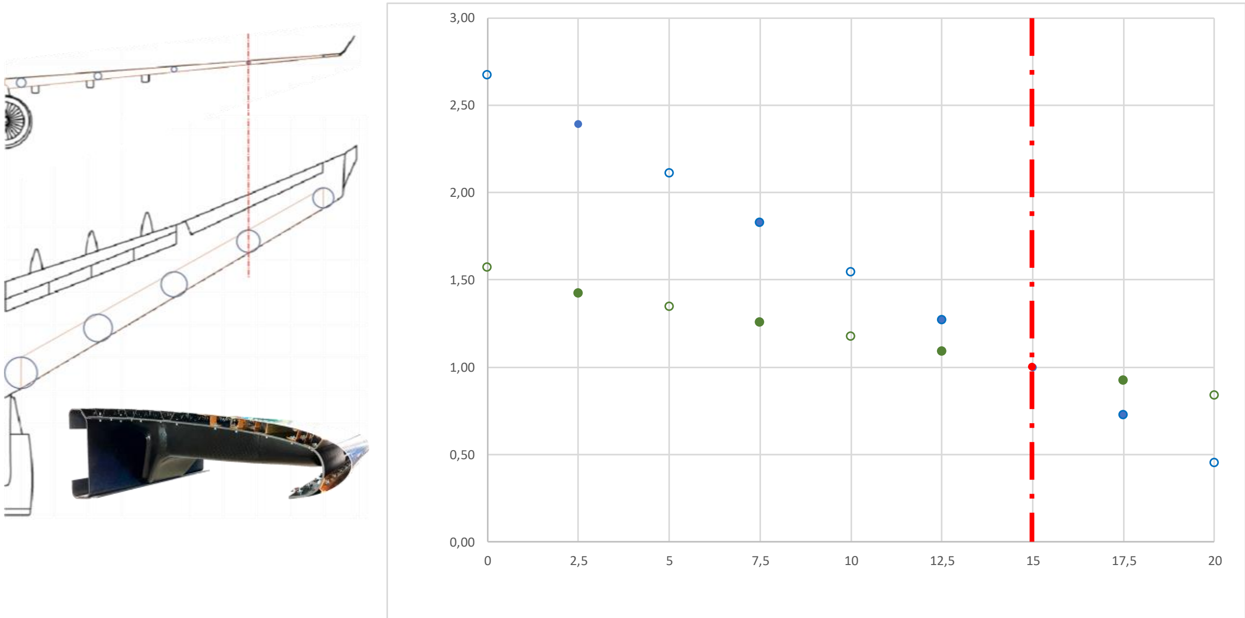

Figure 10: Segment positions and scaling factors for Suction Rib SSD extrapolation

Structure upscaling

The Suction Rib based estimation of the outer wing is based on a linear extrapolation of the demonstrator results derived from the geometry of the XRF1 wing at the interface of the segment 3 and 4. For the geometry scaling factor, wing thickness and chordwise length of the leading edge have been derived from wing drawings (Figure 10).

The provisional laminate dimensioning of the non-tapered Suction Rib SSD has been made in a very early stage of the project and was mainly based on former experiences. Even though it seems that these first suggestions are accurate enough to get a good understanding of the different interdependencies.

Table 1 shows the factors which have been applied to scale up the Suction Rib SSD results to the outer wing. For all continuous components there is a spanwise size adaption from the 800mm demonstrator to a 5000mm segment.

Table 1: Upscaling for SSD structural components

	Factor	spanwise scaling 5m / 0.8 m	chordwise scaling depending on segment	laminate thickness scaling depending on segment	other
Components	CFRP Substructure	x	x	x	
	CFRP Suction Rib		x	x	2 for segment 1-3 & 1 for segment 4
	CFRP Pressure Bulkhead		x	x	2 for segment 1-3 & 1 for segment 4
	CFRP Maintenance Hatch		x	x	2 for segment 1-3 & 1 for segment 4
	Sealing	x	x		
	Titanium skin	x	x		
	4 Polymer spacers	x	x		replaced by GFRP-Spacers
	2 GFRP Spacers	x	x		4 additional spacers
	3 Steel omega spacers	x	x		density: titanium/steel (4.5/7.9)
	Bolts/Washers/Nuts	x	x		

DOI: 10.13009/EUCASS2023-647

Chordwise scaling and laminate thickness is accounted for with the dedicated factors, depending on the average segment chord length and laminate thickness estimation. For the Suction Ribs a size and laminate thickness adaption has been applied but dependent on the segment one (Segment 4) or two (Segment 1-3) Suction ribs are considered. The Suction Glove components will only be adjusted geometrically because the thickness of the components remains unchanged. The improvised ABS 3D printed spacers are replaced by GFRP. In a comparable way the sheet Steel spacers are transferred into Titanium spacers. This results in the structure weight distribution shown in Figure 11 and a total weight of roughly 490 kg.

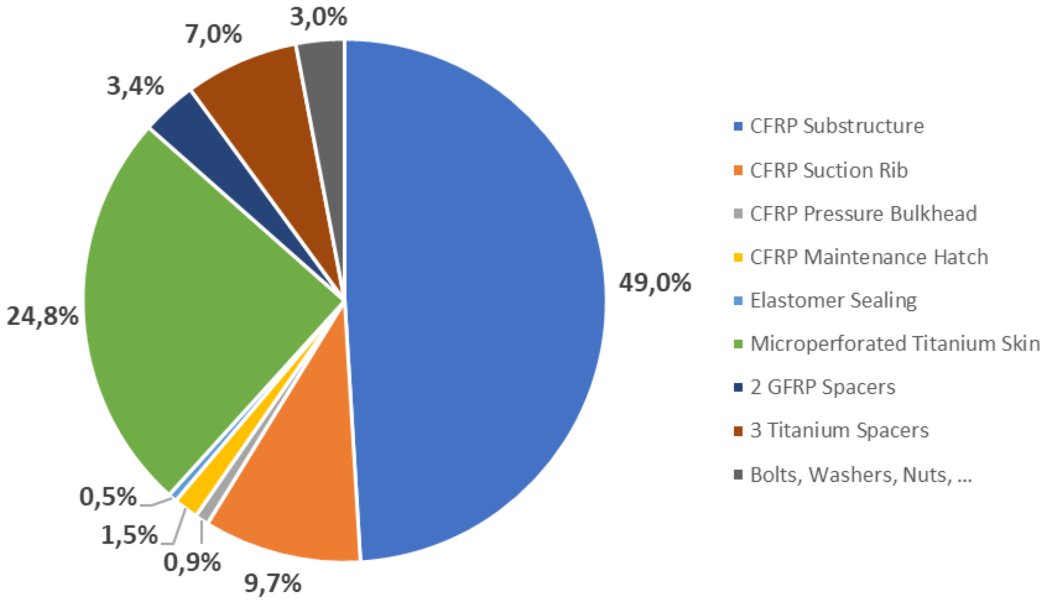

Figure 11: Outer Wing Structure Mass breakdown

System – Compressors

Each of the Suction Ribs will host one compressor. To account for the special demands like high altitude and limited installation space, the Company SAFRAN was tasked to design a compressor with sufficient power. It is planned that only one physical compressor design will be used for all Suction Ribs and that the required suction power can be adapted to the individual requirements of the four segments.

According to the SAFRAN study the expected mass of the compressor and its integrated control unit is 11,4 kg. For the assessment a 10% margin for mounting elements will be used, which means a total weight of 12.5 kg per unit and 87.5 kg on the complete outer wing.

System – Inductive WIPS

A double layer coil setup shown in Figure 6 should be able to provide 22,5 kW/m² inductive heating power which is expected to meet the WIPS demands. For the upscaling, only the coil length had to be adapted and an estimation of the inverter weight had to be included resulting in the masses shown in Table 2. Because of the yet unvalidated system a mass penalty of 50% was added. Resulting in a total weight of 123,3 kg.

Table 2: Inductive WIPS weight estimation

	No. of Segments	No. of Wires	Copper Crossection	Length	Copper Density	Closing of Coils	mass penalty	single coil/ inverter mass	Overall mass
Units	-	-	mm²	mm	kg/m³	%	%	kg	kg
Coil 1	4	40	2	5000	8960	15	50	5,9	23,7
Coil 2	4	36	2	5000	8960	15	50	5,3	21,3
Coil 3	4	48	2	5000	8960	15	50	7,1	28,4
Inverter	4							12,5	50,0
Overall Inductive WIPS Weight									**123,3**

DOI: 10.13009/EUCASS2023-647

3.2 Weight Assessment based on GDB CAD data

Since the GBD is not yet manufactured, the weight assessment is based on the detailed GBD CAD model. Similar to the SSD data, the upscaling approach then delivers a weight approximation for the outer wing. Compressors and inductive WIPS are regarded exactly the same way and are thus not mentioned in the GBD section.

Mass breakdown on Structural Components of the GBD

In this early stage of the project only preliminary CAD data of the resulting 3m span GBD will be considered for the assessment because at the time the GBD hardware is still under construction. To simplify upscaling of the CAD data, the GBD model is reduced to the more representative submodule segment 3b, which is estimated to 85% of the mass of the full CAD model. The part belonging to section 4a, which is built to demonstrate the segment to segment interface is not regarded. The CAD model of the wingbox upper shell is in a final stage and can directly be used for the assessment. The derived masses can be found in Figure 12. For the lower shell an assumption has been made that its weight is about 90% of the weight of the upper shell.

	Segment 3b + 20% Seg. 4a		**Segment 3b (85%)**	
Segment length	3000	mm	2500	mm
HLFC-WIN GBD LE	**42,4**	**kg**	**36,1**	**kg**
Fixed Leading Edge Structure	23,9	kg	20,4	kg
Suction Glove	18,5	kg	15,7	kg
HLFC-WIN GBD Wingbox	**181,7**	**kg**	**154,5**	**kg**
Upper Cover	65,6	kg	55,7	kg
Stringer	9,6	kg	8,2	kg
Lower Cover (90% UC)	59,0	kg	50,2	kg
Front Spar	20,3	kg	17,2	kg
Rear Spar	17,3	kg	14,7	kg
Ribs	4,9	kg	4,2	kg
Clips, Shear Ties, Angle Ribs	5,1	kg	4,3	kg

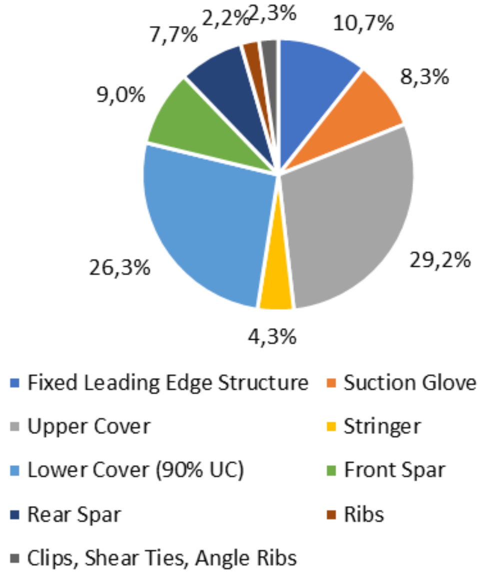

Figure 12: CAD data of the Ground Based Demonstrator and Adaption to Segment 3b

Structure upscaling

To derive the full outer wing estimation from the preliminary Ground-Based Demonstrator CAD data the CAD results have been assigned to the middle of segment 3b and than extrapolated to the other segments. The scaling factors for the geometry and the laminate thickness are based on the same assumptions that have been made for the Suction Rib small-scale demonstrator. The following factors have been applied to scale up the GBD CAD data to the outer wing. For all continuous components there is a size adaption from 2500mm (span of Section 3b) to a 5000mm segment. The Suction Glove will only be adjusted in size because the thickness of the components remains unchanged.

DOI: 10.13009/EUCASS2023-647

	Segment 1		Segment 2		Segment 3a		Segment 4	
	Segment 1a	Segment 1b	Segment 2a	Segment 2b	Segment 3a	GBD	Segment 4a	Segment 4b
Spanwise Position	1,25	3,75	6,25	8,75	11,25	13,75	16,25	18,75
Normalized unwound length	2,22	1,97	1,73	1,49	1,24	1	0,76	0,51
Geometry scaling factor	**2,1**		**1,61**		**1,12**		**0,63**	
Normalized laminate thickness	1,42	1,34	1,25	1,17	1,08	1	0,92	0,83
laminate thickness Scaling Factor	**1,38**		**1,21**		**1,04**		**0,87**	

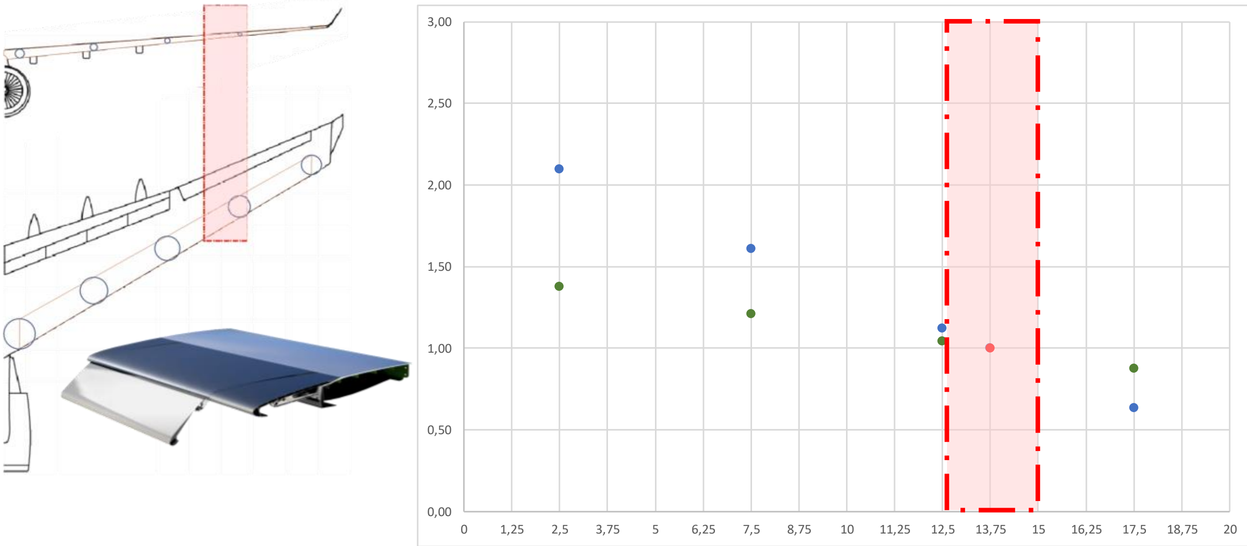

Figure 13: Segments and Scaling Factors for GBD extrapolation

Table 3: Upscaling GBD Structural Components

	Factor	spanwise scaling 5m / 0.8 m	chordwise scaling depending on segment	laminate thickness scaling depending on segment
Components	Fixed Leading Edge Structure	x	x	x
	Suction Glove	x	x	
	Upper Cover	x	x	x
	Stringer Upper Cover	x	x	x
	Lower Cover (incl. Stringer)	x	x	x
	Front Spar	x	x	x
	Rear Spar	x	x	x
	Ribs	x	x	x
	Clips, Shear Ties, Angle Ribs	x	x	x

With the formerly introduced factors an outer wing mass of about 440kg can be estimated for the HLFC leading edge structure and a mass of 2120 kg for the Wing Box

Krüger Highlift System

Even though, the current data of the Krüger Highlift System are very preliminary, the available masses have been scaled up by applying a scaling rule that is derived from the XRF1 slat mass distribution. The slat mass distribution of slat 2-7 (blue dots in Figure 13) has been normalized to the position of the GBD at 13,75m. The summed-up mass of all slats is 231 kg (baseline XRF, slats 2-7). By dedicating CFRP to the Krüger flap, Aluminium to the 3 kinematic ribs and a Steel/Al mixture to the gearbox and motor, the mass of the Krüger 6 assembly can be estimated in the order of 153 kg. The summed-up CFRP Krüger flaps have a weight of 263 kg when being upscaled to the outer wing. Applying the upscaling approach to the mass of the complete outer wing high lift system results in a weight of 1388 kg (Figure 14. Furthermore, the currently considered motors and also the scissor mechanism may be subjected to a mass increase if stronger motors or other materials need to be applied.

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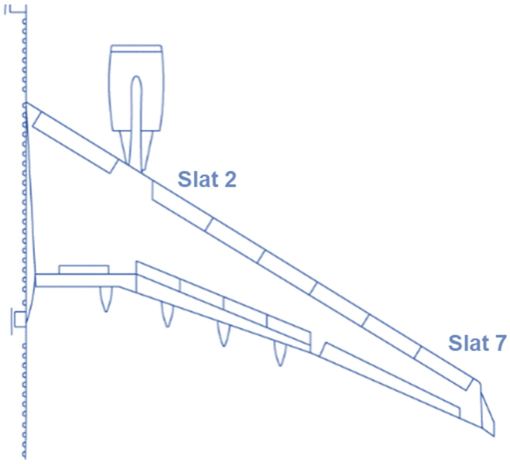

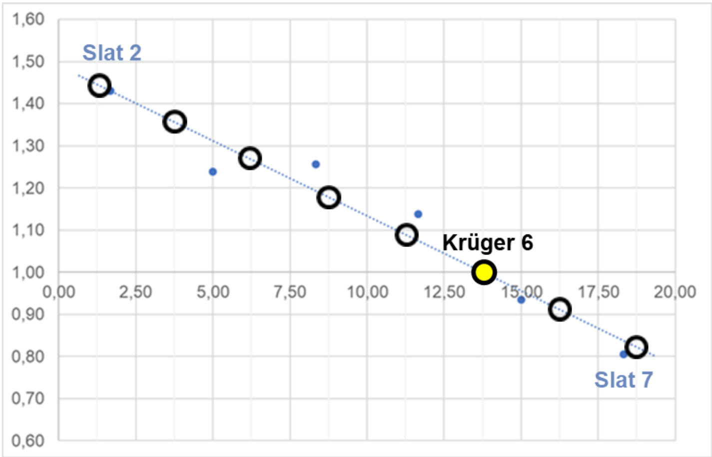

Krüger 6		
component	mass	unit
Krüger Flap	29	kg
Kinematic Rib	52	kg
Gearbox	72	kg
total mass	153	kg

	Position [m]	Factor		
Krüger 1	1,25	1,45	**221,2**	**kg**
Krüger 2	3,75	1,36	**207,5**	**kg**
Krüger 3	6,25	1,27	**193,9**	**kg**
Krüger 4	8,75	1,18	**180,3**	**kg**
Krüger 5	11,25	1,09	**166,6**	**kg**
Krüger 6	13,75	1,00	**153,0**	**kg**
Krüger 7	16,25	0,91	**139,4**	**kg**
Krüger 8	18,75	0,82	**125,7**	**kg**
			1387,6	**kg**

Figure 14: Upscaling of Krüger Highlift System

3.3 Conclusion - Weight Assessment

Between the estimated outer wing leading edge mass of 490 kg extrapolated from the Suction Rib SSD data and the 440 kg derived from GBD data is a difference of 50 kg. From a structural point of view the major difference in the GBD and Suction Rib SSD approaches is, that for the GBD the housing of the compressor is not designed as a load bearing, structural member of the fixed leading edge. The reason for this is, that the high number of kinematic ribs for the Krüger flaps were sufficient to carry the complete leading-edge structure, whereas the suction rib as built in the Suction Rib SSD is designed to carry leading edge loads.

4. Cost Assessment

This chapter addresses the cost assessment based on the Small Scale SSD and GBD

4.1 Cost Assessment for structure components based on SSD

Table 4: Cost Indices for Outer Wing Leading Edge Cost Assessment (Suction Rib SSD based)

	Part Production	Assembly	total
CFRP skin	450 €/kg	135 €/kg	585 €/kg
CFRP Omega Rib	720 €/kg	216 €/kg	936 €/kg
CFRP Pressure bulkhead	450 €/kg	135 €/kg	585 €/kg
CFRP Maintenance hatch	450 €/kg	135 €/kg	585 €/kg
Elastomer Sealing	150 €/kg		150 €/kg
Titanium skin	2077 €/kg		2077 €/kg
GFRP Z-spacers	350 €/kg	105 €/kg	455 €/kg
Titanium Omega spacers	500 €/kg	150 €/kg	650 €/kg
Bolts/Washers/Nuts/…	1500 €/kg		1500 €/kg

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To transfer the identified weights to a cost-based assessment it is necessary to dedicate cost indices to the different structural and system components (Table 4). These cost indices should represent an established series production status. A cost index of 450 €/kg has been applied for all standard CFRP components and because of the lower raw material costs 350 €/kg have been applied for standard GFRP components. As the manufacturing trials have shown, the more complex CFRP Omega Rib structure requires a higher manufacturing effort. To address this extended effort, an increased cost index of 720 €/kg has been applied. The laser drilled Titanium skin can be considered as a major enabler for future HLFC concepts and with a large margin for cost improvement when the technology is applied on an industrial scale. A cost index of 2077 €/kg is derived from the very rough assumption, that 500.000€ should be an adequate margin for a complete airliner wing. The remaining cost indices are based on experiences and will not have a noticeable impact on the overall assessment. A margin of additional 30% cost to cover assembly related effort has also been added to some of the components. The overall cost sums up to 492,000 €.

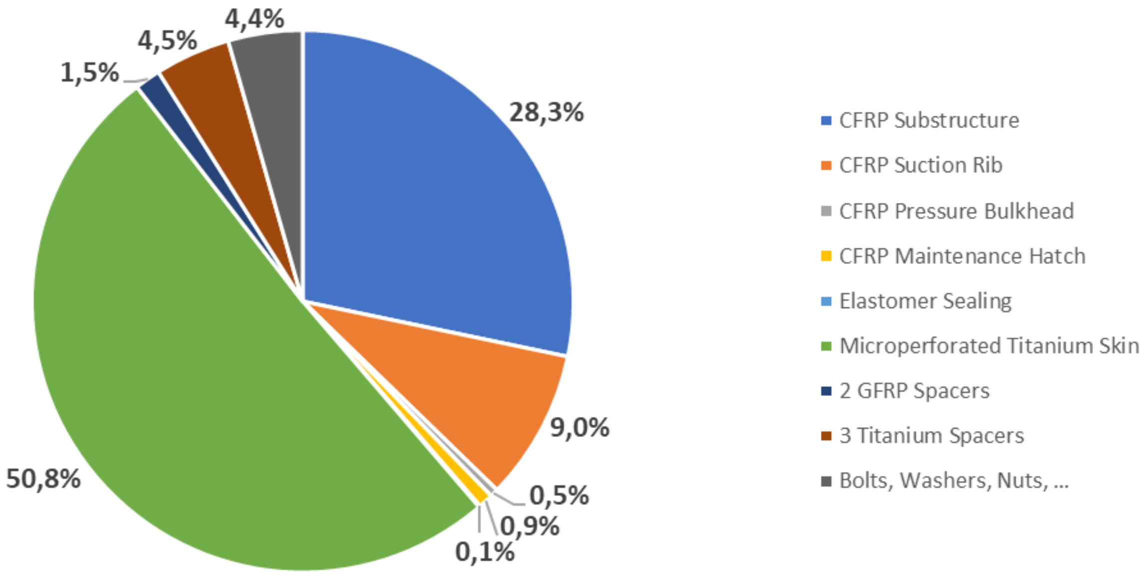

Figure 15: Suction Rib SSD based Cost Distribution

Even though the assessment is mainly suited for a very first orientation, Figure 12 shows that the components that can be dedicated to the suction system account for around 75% of the leading-edge costs. The CFRP omega ribs can be considered as part of the structural leading edge and also part of the suction system but a more detailed analyses wouldn't change the global picture in a significant way. The laser drilled Titanium skin is a dominating factor and it can be expected that an even more cost-efficient process can be applied towards the end of the project.
It is also important to point out that the cost increase during manufacturing enables a laminar flow related drag reduction for the entire time the aircraft is operated.

4.2 Cost Assessment based on GDB CAD data

The cost indices (Table 5) that have been dedicated to the different structures and systems are based on experiences for a fully settled and partly automated series production scenario. The laminar upper shell has to meet tight surface tolerances that would not allow bolting through the outer surface in the laminar area. The resulting increased level of structural integration leads to a relatively costly component production but provides also a cost advantage during assembly. The huge size of the upper and lower shell will demand cost intensive layup equipment (Automatic Fibre Placement (AFP) Machines). This has been acknowledged by increased cost indices.
The majority of CFRP components has been rated as "average" from a production point of view with an additional cost factor of 30% for the assembly.
The suction glove cost index is based on the results of the Suction Rib SSD where the glove hardware has been manufactured as a prototype.
In case of the compressor cost index the assumed worse case cost of 12.500€ have been divided by the weight of 12,5 kg for the compressor unit (11,4 kg plus 10% mounting devices).
At the current state of the project the maturity level of the Krüger Highlift System and the inductive WIPS are too low to dedicate a cost index.

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Table 5: Cost Indices for Outer Wing Leading Edge and Wingbox Cost Assessment (GBD based)

	Part Production/weight	Assembly/weight	total/weight
	€/kg	€/kg	€/kg
Fixed Leading Edge Structure	450	135	135
Suction Glove	1390		0
Laminar Upper Cover	750	225	225
Stringer	450	135	135
Lower Cover (90% UC)	550	165	165
Front Spar	450	135	135
Rear Spar	450	135	135
Ribs	450	135	135
Clips, Shear Ties, Angle Ribs	450	135	135
Compressor	997		
Krüger Highlift System			
Inductive WIPS			

Figure 16 shows the expected cost share of the different structural and system components without the Krüger Highlift System and the WIPS. To simplify the diagram, spar masses and some other minor items have been added up.

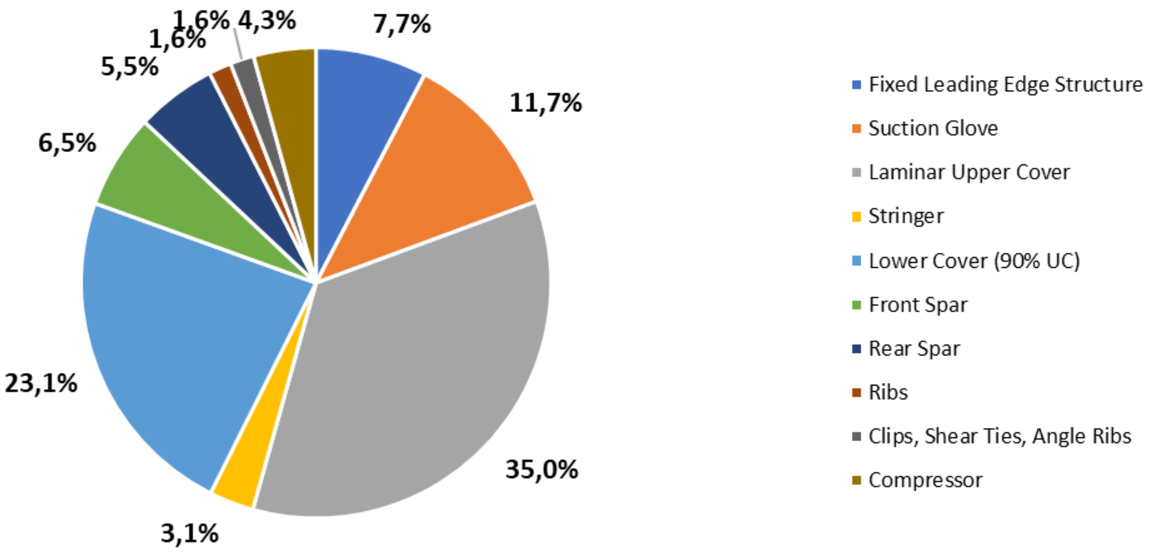

Figure 16: Cost Distribution for Leading Edge, Wingbox and Compressors

Compressor and suction glove cost, which mainly represent the suction system cost, have an overall share of 16% but would drop down to less than 10% under the quite likely assumption, that the cost indices for the highlift system and the WIPS are above 1000 €/kg.
It is also worth mentioning, that according to the XRF1 wing breakdown the chosen boundary conditions for the outer wing assessment only cover around 25% of the full wing. With respect to the high-level objective of the HLFC-WIN project, to increase competitiveness of a HLFC system in a long-range aircraft scenario these preliminary results are very promising.

5. Summary

The purpose of comparing the weight shares shown in Figure 18 is to identify a first tendency towards what can be expected from the HLFC-WIN approach. It is also important to bear in mind, that the different sources of the assessment and the applied scaling methods have individual levels of maturity and will need further refinement.

Suction System
The suction gloves and the compressors are the core elements of the suction system and the dedicated assumptions for the mass can be considered as relatively mature. From a global aircraft point of view the expected suction system mass

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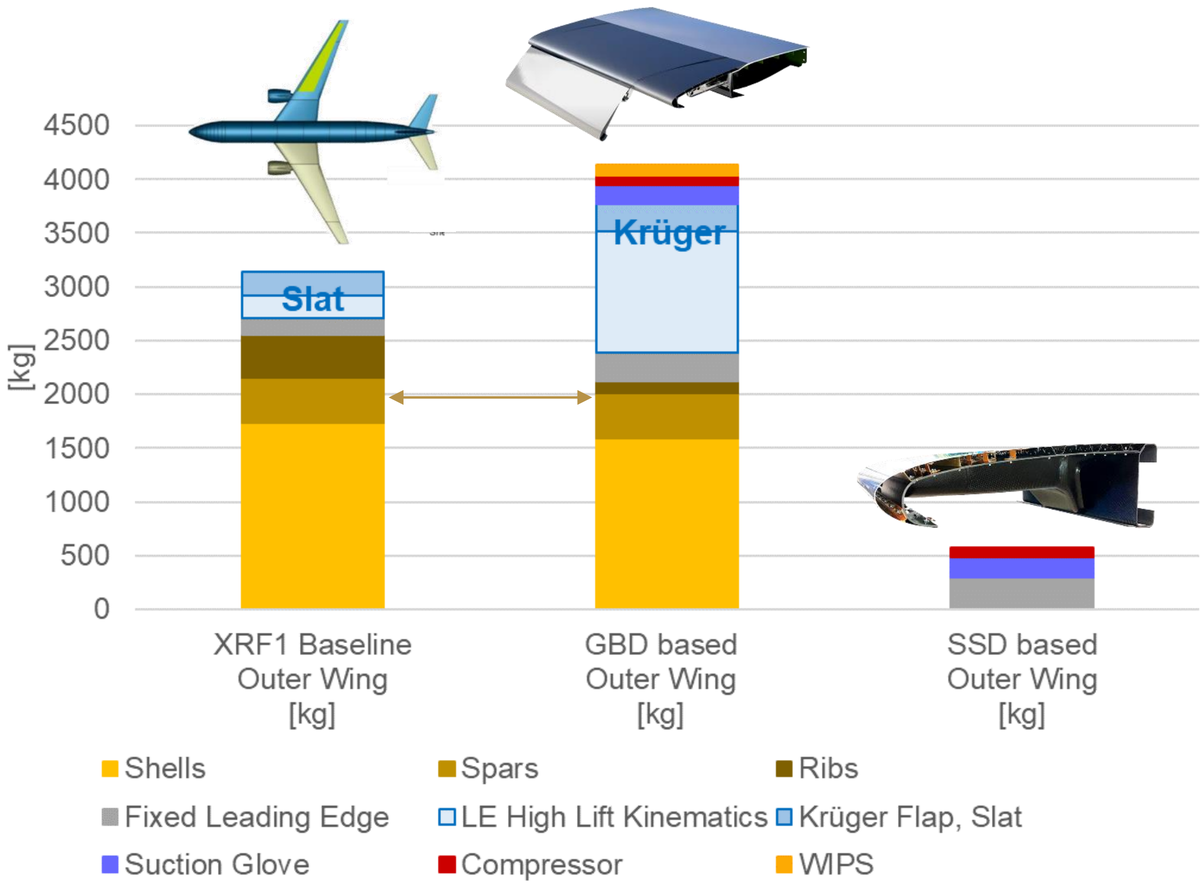
would be less than 2% of the global XRF1 wing mass. The breakthrough in CNC laser drilling and relative affordable compressor technology can be considered as the major enablers for the success of the HLFC-WIN approach.
Costs of the compressor units are highly dependent on their production rate and since this type of compressor seems to be well suited for fuel cells, an even wider field of application and in turn lower cost than the estimated can be expected.
CNC Laser drilling is also constantly improving and new laser generations will further decrease heat impact and the related disadvantages. Furthermore, multi head laser drilling might also bring a boost in machining speed and efficiency.



Wing Ice protection System (WIPS)
The innovative inductive WIPS has mainly been chosen because it avoids unnecessary suction blocking in the critical area of the leading edge. The WIPS does not play a crucial role neither from a cost nor from a weight point of view but is essential for the airworthiness. Towards the end of the project the inductive WIPS is expected to be at a TRL 4 which also means that weight and cost aspects as well as certification aspects have been fully understood and demonstrated.

High Lift System
The decision to investigate and demonstrate a Scissor kinematics in HLFC-WIN was driven by a strategic reason which is to analyse an alternative to the Gooseneck kinematics that has been applied in the EU FP7 project AFLONEXT. With respect to the highlift kinematics, the target of HLFC-WIN is to fully understand the complex interaction of the different structural members and to find a highly compact solution. Comparing the weights of a Scissor Krüger with a conventional slat highlift system is misleading because of the very different certification (three versus two support tracks) and also powertrain (hydraulic versus electric) boundary conditions. Apart from the kinematics the aerodynamic components themselves (outer wing slat 231kg and Krüger flap 263kg) are in a comparable range. Here it is important to point out that the innovative HLFC-WIN Krüger flap will be manufactured in a very cost-efficient thermoplast filament winding technology, and that the flap, especially from a size point of view, is also designed to allow effective insect shielding when deployed.

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6. Conclusion

The approach to combine hardware prototype and CAD model data for the preliminary assessment of the HLFC-WIN status proved to be successful and provides a solid framework for further investigations and analyses. The upcoming results of the very detailed Ground Based Demonstrator hardware will be a very significant step-up in data maturity and will add aspects like system installation mass and effort. Apart from the Krüger kinematics and its strategic boundary conditions there is a very clear indication that the HLFC-WIN project will be able to prove that HLFC technology is ready for future long-range aircrafts and that weight and cost related risks are well under control.

Innovative industrial, high-quality CNC laser drilling capabilities and affordable and compact high-performance compressor units may be the dominating enablers for the vastly improved applicability of a HLFC System. To a lesser extend the inductive WIPS may also contribute to the efficiency of the HLFC system by avoiding blocking of the suction holes.

Easy and simple maintenance is another strategic goal of the HLFC-WIN project. The solution was to enable quick replacement of all components of the suction system in case the functionality is limited by surface irregularities (e.g. dents from hail strikes) or blocked micro-perforation.

Other elements of the HLFC-Win approach like e.g. the suction rib structures where mainly developed to remain within a well-known and easy to certify regime in order to ensure the route to higher TRLs.

Eco design does also play a significant role and the investigated manufacturing methods and materials will be down selected to be as environmentally friendly as possible.

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