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# CLEAN-SKY 2 LARGE PASSENGER AIRCRAFT PLATFORM 1 ADVANCED ENGINE AND AIRCRAFT CONFIGURATIONS

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## Abstract

In order to pursue the ambition to reduce the environmental footprint of the aircraft industry, the EU commission and the industry launched the program called Clean Sky 2, which started in 2014 and still runs until end of 2023. Among the programs covered by this framework, the largest one is the Large Passenger Aircraft under Airbus Commercial Aircraft lead.

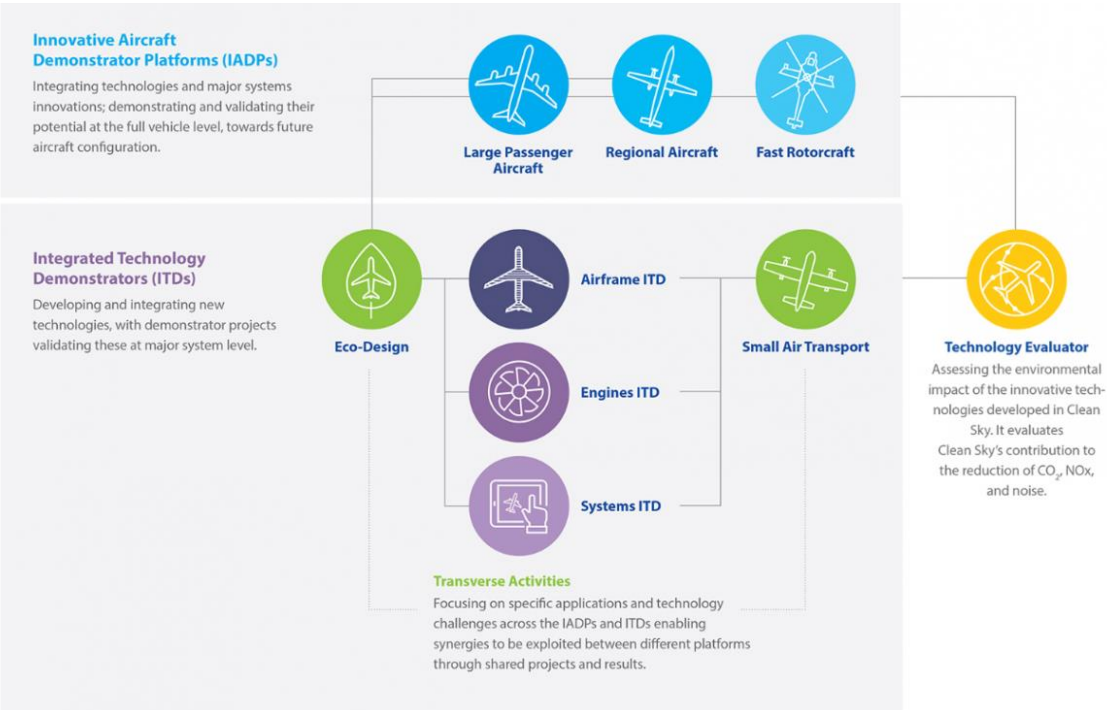


Figure 1: overall Clean-Sky framework

**Keywords:** Clean-Sky 2, Large Passenger Aircraft, Platform 1

## 1. Abbreviations and Acronyms

| | |
|---|---|
| AFC | ACTIVE FLOW CONTROL |
| ALM | ADDITIVE LAYER MANUFACTURING |
| BF | BLOCK FUEL |
| BLI | BOUNDARY LAYER INGESTION |

| | |
|---|---|
| CA | CONSORTIUM AGREEMENT |
| CDR | CRITICAL DESIGN REVIEW |
| CFP | CALL FOR PROPOSAL |
| CP | CORE PARTNER |
| CFRP | CARBON FIBER REINFORCED PLASTIC |
| CS2 | CLEAN SKY 2 |
| CS2DP | CLEAN SKY 2 DEVELOPMENT PLAN |
| CSJU | CLEAN SKY JOINT UNDERTAKING |
| DAS | DATA ACQUISITION SYSTEM |
| DEP | DISTRIBUTED ELECTRICAL PROPULSION |
| DLR | GERMAN AEROSPACE CENTER |
| DMU | DIGITAL MOCK UP |
| FTD | FLIGHT TEST DEMONSTRATOR |
| GBD | GROUND BASED DEMONSTRATOR |
| H2020 | HORIZON 2020 |
| HTP | HORIZONTAL TAIL PLAN |
| IA | INNOVATION ACTION |
| IADP | INNOVATIVE AIRCRAFT DEMONSTRATOR PLATFORM |
| ITD | INTEGRATED TECHNOLOGY DEMONSTRATOR |
| HEP | HYBRID ELECTRIC PROPULSION |
| HLFC | HYBRID LAMINAR FLOW CONTROL |
| HTP | HORIZONTAL TAILPLANE |
| H/W | HARDWARE |
| LPA | LARGE PASSENGER AIRCRAFT |
| LTS | LIEBHERR TRANSPORTATION SYSTEM |
| MEMS | MICRO-ELECTROMECHANICAL SYSTEMS |
| MFT | MISSION FLIGHT TESTS |
| MIL | MILESTONE |
| MW | MEGAWATT |
| NLF | NATURAL LAMINAR FLOW |
| NRC | NON RECURRING COST |
| OBS | ORGANISATION BREAKDOWN STRUCTURE |
| OGV | OUTER GUIDE VANES |
| ORAS | OPEN ROTOR AND STATOR |
| PBS | PRODUCT BREAKDOWN STRUCTURE |
| PCE | PRECOOLER EXCHANGER |
| PDR | PRELIMINARY DESIGN REVIEW |
| PMC | PROJECT MANAGEMENT COMMITTEE |
| PMO | PROJECT MANAGEMENT OFFICE(R) |
| QFT | QUALIFICATION FLIGHT TESTS |
| RC | RECURRING COST |
| RFC | REQUEST FOR CHANGE |
| RIA | RESEARCH AND INNOVATION ACTION |
| RPM | ROTATION PER MINUTE |
| RR | ROLLS ROYCE |
| SAAFIR | SIMULATOR OF AERODYNAMIC AND ACOUSTIC FAN INTEGRATION |
| SFD | SCALED FLIGHT DEMONSTRATOR |
| SME | SHORT & MEDIUM ENTERPRISE |
| SMR | SHORT & MEDIUM RANGE AIRCRAFT |
| SPD | STRATEGIC PLATFORM DEMONSTRATOR |
| SR | SHORT RANGE |
| TA | TRANSVERSE ACTIVITY |
| TE | TECHNOLOGY EVALUATOR |
| TRL | TECHNOLOGY READINESS LEVEL |
| UHBR | ULTRA HIGH BYPASS RATIO ENGINE |

| | |
|---|---|
| UHPE | ULTRA HIGH PROPULSIVE EFFICIENCY |
| WBS | WORK BREAKDOWN STRUCTURE |
| WCCP | WING CLOSED COUPLE PYLON |
| WP | WORK PACKAGE |
| WTT | WIND TUNNEL TEST |
| XDC | CROSS DEMONSTRATORS CAPABILITIES |

## 2. Large passenger aircraft:

The focus of the Large Passenger Aircraft IADP (called also LPA), is on large-scale demonstration of integrated technologies at aircraft level. This is done in three distinct 'Platforms':

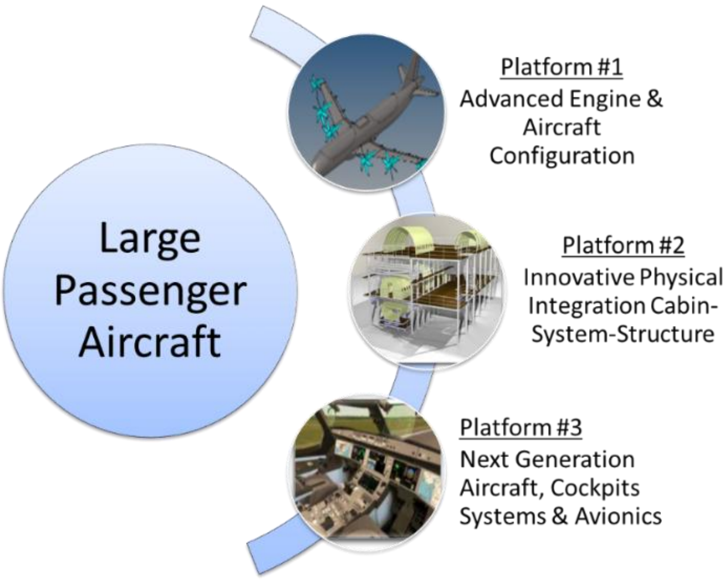


Figure 2: Large Passenger Aircraft structure

**Platform 1 - "Advanced Engine and Aircraft Configurations"**

It aims at integrating the most fuel efficient propulsion concepts into compatible airframe configurations, for the next generations of short and long range aircrafts and also studying laminarity as well as new radical aircraft configuration concepts.

**Platform 2: "Innovative Physical Integration Cabin – System – Structure"**

Platform 2 aims to develop, mature, and demonstrate an entirely new, advanced fuselage structural concept in alignment towards next-generation cabin-cargo architectures, including relevant aircraft systems.

**Platform 3 - "Next Generation Aircraft Systems, Cockpit and Avionics"**

Platform 3 will develop and demonstrate the next generation cockpit and avionic suite. It shall integrate and validate all functions and features which are emerging from a number of research programs into a disruptive new concept. The ultimate objective is to build a highly representative ground demonstrator of the future cockpit for large commercial aircraft.

Finally, LPA (or Large Passenger Aircraft) contributes to Clean Sky 2 environmental and socio-economic targets. In explicit terms:

- It will facilitate benefits for the environment in terms of reductions of CO2 emissions per passenger-kilometer as well as NOX and noise emissions,
- It will allow the entire European aviation value chain to jointly collaborate on integrated platforms,
- It will enhance European industrial leadership and its recognition as innovative, sustainable and competitive,

- It will target aircraft technology breakthroughs for which the market scale will lead to substantial long term investments and high technology jobs in Europe,
- It will de-risk the development of technologies and so ensure safety and security,
- It will align European research and innovation strategies and promote efficient research, technology development and demonstration.

We remind that the overall net funding of LPA is around 500M€ over 2014 to 2023 period.

## 3. Platform 1 – Advanced Engine & Aircraft Configuration dimensions:

In a nutshell, Platform1 includes:
- 22 Core Partners and Leaders across Europe
- 16 Demonstrators linked to either engines and/or aircraft configurations
- 305 MEUR funding at Completion incl. Call for Proposals

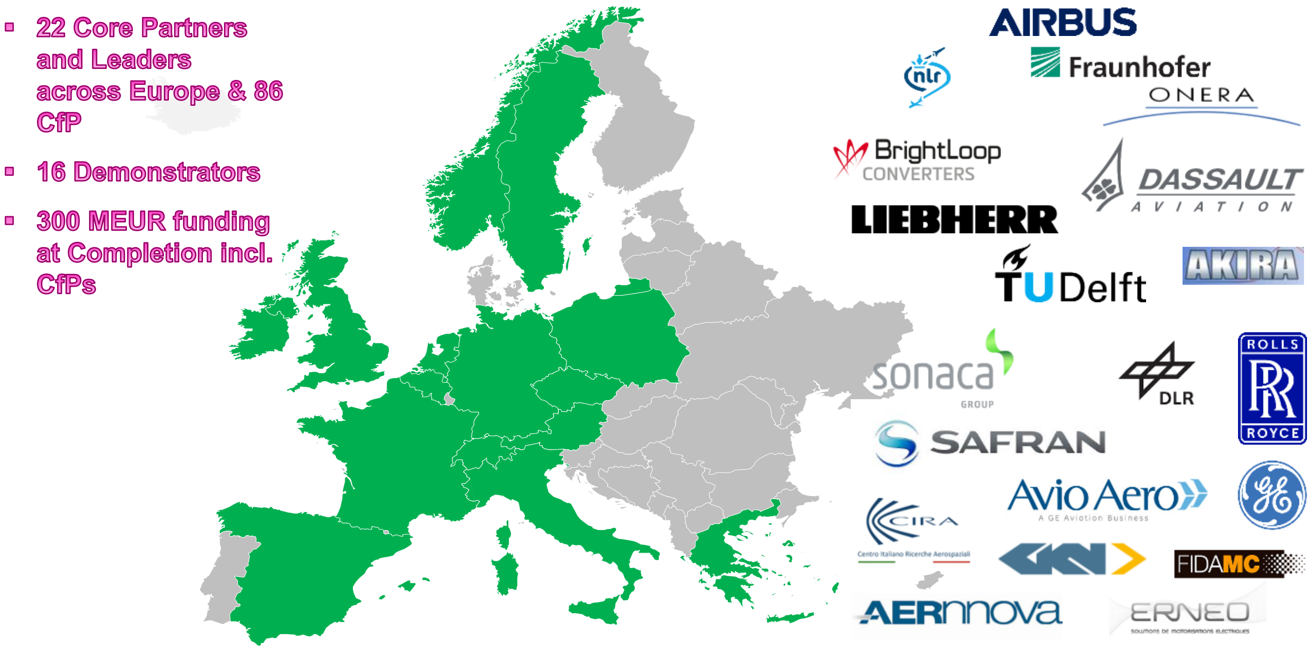


Figure 3: Platform 1 partnership overview

There are also 86 Call for Proposals that have been launched via 11 waves, between 2014 and 2020 (Wave 01 to Wave 11), and that contribute to 30% of the overall funding. Winners for those Call for Proposals are SMEs, research institutes, Universities, etc… spread across Europe, and are not listed in this chart.

Each partner brings along its expertise and his willingness to be part of the game to develop technologies that will make the difference, and contribute to the Clean Sky 2 environmental top level objectives

## 4. Platform 1 streams:

Platform 1 is about Advanced Engines, and also about Aircraft configurations: it is divided into 4 streams that are described hereafter.
Note that the conference presentation will provide an overview on the 16 demonstrators and in particular partners involved, main objectives, achievements and next steps.

### 4.1 Stream 1: Engine Design & Integration: n+1

It covers Ultra High Bypass Ratio (UHBR) Engines with an entry into service before 2030 with 4 demonstrators:
- Ultrafan Flight Test Demonstrator (FTD) including associated techno-bricks like Precooler Counterflow or optimized bleed with Jet pump
- Simulator of Aerodynamic and Acoustic Fan IntegRation (SAAFIR) including associated technobricks like Wing Close Coupled Pylon, Advanced Thrust Reverser unit or acoustic liner
- We have also active vibrations control

- And finally Non Propulsive Energy

### 4.1.1 D10 - Ultrafan® FTD

Let’s recall that the UltraFan® Engine developed by Rolls-Royce is a geared turbofan with a 15:1 bypass ratio and a diameter of 140” very close to the diameter of an A320 fuselage, providing substantial Efficiency improvement vs first Generation Trent Engines.

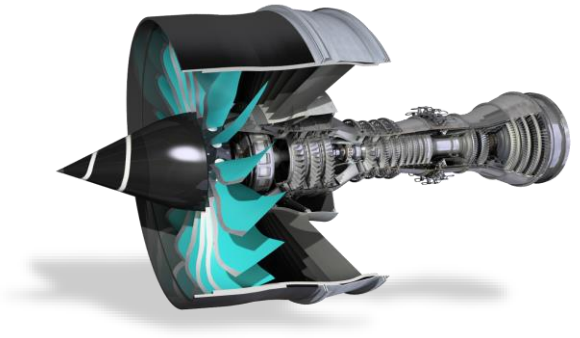

Figure 4: RR UltraFan® Engine

The objective of this demo is to:

- Deliver integration solution for flight test demonstration of the Rolls-Royce UltraFan® engine (via a Boeing 747 RR test A/C),
- Develop integration technologies & capabilities (nacelle, pylon) for the UltraFan® FTD and (optimized bleed, PCE counter flow) for future products.

Figure 5: Nacelle components assembly in Airbus Nantes facility

So far, all CDRs for A/C conversion and Nacelle components have been performed and we are aiming to the first Engine to test in 2022 in Derby RR facilities (UK).

### 4.1.2 D12 - Active Vibration Control

The goal of this demonstrator is to develop new technologies and design process for acoustic and vibration comfort for business jets and in particular:

- Actives technologies to control engine noise/vibration and fuselage vibration,
- Aero-vibro-acoustic model to tackle cabin acoustic comfort from new aerodynamic configurations,
- Cockpit and cabin noise reduction.

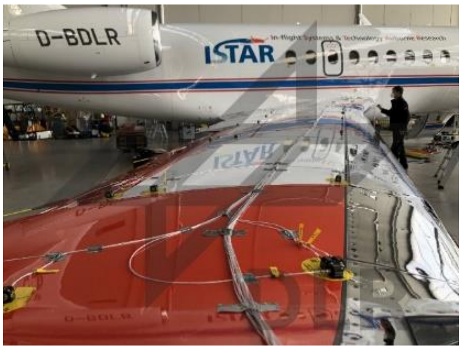


Figure 6: DLR Falcon test aircraft

To that extent, a first ground test campaign for modes identification on DLR Falcon aircraft has been completed with next step to perform Ground test campaign for active vibrations controls on the same aircraft.

### 4.1.3 D13 - UHBR SR Integration

The objective of this demonstrator is to improve UHBR integration on a short and medium range aircraft as far as aero-acoustics, aerodynamics and aero-elastics issues are concerned, and therefore reduce the uncertainty of the noise and aerodynamic performance prediction linked to the close coupled UHBR engine.

The idea was, to use a representative Engine fan and to put it in a Wind Tunnel for testing.

This becomes SA²FIR: Simulator of Aerodynamic and Acoustic Fan IntegRation with following purposes:

- De-risk fan noise of future installed configuration,
- Acquire a better understanding of UHBR related acoustic sources,
- Acquire validation data for numerical acoustic prediction tools,
- Increase maturity of design tools for aerodynamic, aero-acoustic and aero-elastics issues,
- Improve understanding of physical interactions between airframe & engine (in particular with fan blades).

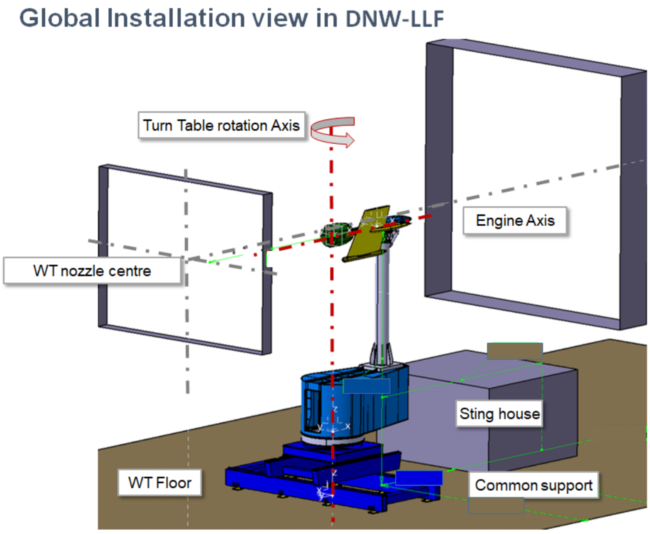


Figure 7: DNW test rig set up

Regarding the progress made until now, SAAFIR test rig Hardware Critical Design Review was performed and we are now focusing on delivering SAAFIR rig to DNW and launch the Wind Tunnel Test.

(Note that we have also additional techno-bricks attached to this demo such as: Wing Close Couple Pylon, innovative Thrust Reverser Unit, Acoustic liners)

### 4.1.4 D15 - Non Propulsive Energy:

We remind that an Engine has to provide the thrust for the Airplane but also the energy onboard (for instance to supply all the systems with electrical power).

Non Propulsive Energy = Energy required onboard the aircraft for other purposes than thrust generation.
During the ground and decent phase, in order to supply sufficient energy to the airplane, the Engine has to run at higher idle RPM than desired for flight management.
Therefore, from a purely energetic standpoint, it is more optimized to get the APU (Auxiliary Power Unit) supply energy to the plane during such phase rather than the Engine in order to improve at the end the fuel burn efficiency and aircraft operability.
The in-flight use of the APU, with re-light capability at altitude and increase reliability is essential.

Figure 8: APU concept

The objective of this demo is to validate such a concept on a ground bench test.

Up to now, APU components are under manufacturing to enable start of a ground demo power sharing test in 2023.

## 4.2 Stream 2: Engine Design & Integration: n+2

It covers 5 demonstrators link to Engines with an entry into service beyond 2030:
- Enablers for Open Rotor,
- Active flow control,
- Boundary Layer Ingestion,
- Common technologies for future Engines, but it is essentially Open rotor,
- Finally cross demonstrator capabilities focused around aero-acoustics.

### 4.2.1 D01 - Enablers for Integrated Open Rotor Design

Let's remind that the bypass ratio of an Open Rotor can be drastically increased versus classical turbofan Engine in particular by playing on the size of the propeller.

Therefore, purposes of this demo are mainly:
- To capitalize the findings and acquired Open Rotor knowledge,
- To explore further Open Rotor Engine integration concepts,
- To progress on certification aspects.

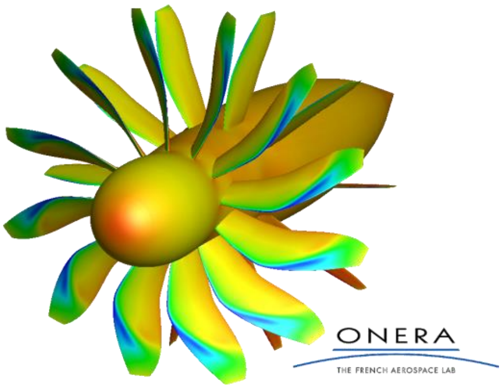


Figure 9: Open Rotor and Stator concept

In term of achievement, we can mention that Pylon structure, fuselage and Engine interfaces have been investigated and the next step is to finalize all studies and increase the maturity at architecture level by 2023.

### 4.2.2 D11 – Active Flow Control:

The bigger the Engine (in diameter), the more efficient. But then there is an integration problem as a bigger Engine can impact the slat geometry and therefore reduce their span.

The main consequence is a loss of lift: this can be compensated by using active flow control.
The purpose is to redirect air bleed from the Engine over the wing thanks to an innovative actuator.

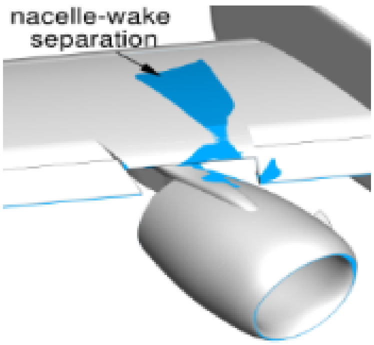


Figure 10: Active Flow Control principle

The airflow is redirected above the wing leading edge and this phenomenon regenerates lift by improving the boundary layer.

The purpose of this demo is to test different actuators in order to optimize the mass flow required.

### 4.2.3 D14 – Boundary Layer Ingestion:

Boundary Layer Ingestion concept enables to recover the energy of the boundary layer in the engine at low speed. This effects enables to use less thrust power.

The effect is increased at the rear fuselage position.

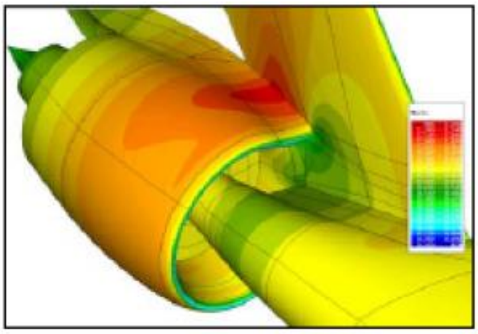

Figure 11: Boundary Layer Injection possible Layout

The goal of this demo was therefore to understand the potential and feasibility of the BLI technology.

### 4.2.4 D16 - Techno bricks for future engines

The goal is to develop key common enabling technologies for future propulsion systems for 2030+
Such as Acoustics, Aerodynamics, Sealing, Additive Layers Manufacturing applied to Airfoil optimization, Thermal Optimization, Manufacturing technologies.

This approach is done through:

- Partial rig testing,
- Architecture and Engine Integration studies.

This demo has strong Synergies with open rotor demonstrator D01.

Figure 12: Testing facilities for low pressure system in Poland

In term of progress, we can mention that the Low Pressure Turbine rig architecture has been finalized and we are aiming to execution of tests of Low Pressure Turbine demonstrator in 2023

### 4.2.5 XDC - Cross Demo Capabilities:

The intention of this demo is to Develop and demonstrate various numerical and experimental methods for:

- Aerodynamics,
- Aeroacoustics,
- Aeroelastics.

And thus applicable to all types of propulsion systems (e.g. UHBR, OR, BLI) integration.

Figure 13: Flow Optical Monitoring testing on DLR Falcon

In term of achievement, we can mention for instance that an innovative optical flow measurement has been completed on DLR Falcon and one of the next step is to finalize MEMS development.

## 4.3 Stream 3: Laminarity

This stream is looking to further develop the technologies developed in Clean Sky 1 with BLADE (Breakthrough Laminar Aircraft Demonstrator in Europe) on Natural Laminar Flow (NLF), and also pursuing the development of the technologies related to Hybrid Laminar Flow Control (HLFC). Here we are investigating HLFC technologies on tails, and on Wing, but also NLF on Horizontal TailPlane.

### 4.3.1 D04 – HLFC on HTP ground based demo:

We remind that HLFC technology enables to implement laminarity on high sweep angle profiles flying at mach above 0,82 by using a titanium leading edge with tiny holes to perform boundary layer suction

The goal of this demo is to:

- Develop a manufacturing process for an HTP equipped with HLFC leading edge,
- Manufacture of a Ground Based Demonstrator to be tested functionally.

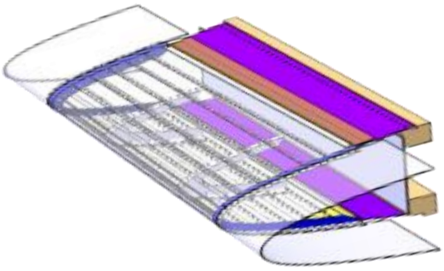

Figure 14: HLFC HTP schematic

In terms of progress, the assembly of the final Ground Based Demonstrator (GBD) has been completed by end of 2021 and a good maturity level has been achieved in October last year.
The main next step is to finalize the test of this Large-Scale Demo (GBD).

### 4.3.2 D05 - NLF on HTP

This Demo specifically focused around Natural Laminar Flow on HTP for business jet, just because the operational flight level of business jet enables to have NLF instead of HLFC

And therefore the goal of this demonstrator is to:

- Define specific architecture and its design principles that enable an NLF business jet HTP,
- Validate the concept with elementary physical components (manufacturing feasibility and environmental/mechanical durability),
- Define and validate serial-type manufacturing processes compatible with the surface quality requirements of an NLF bizjet HTP.

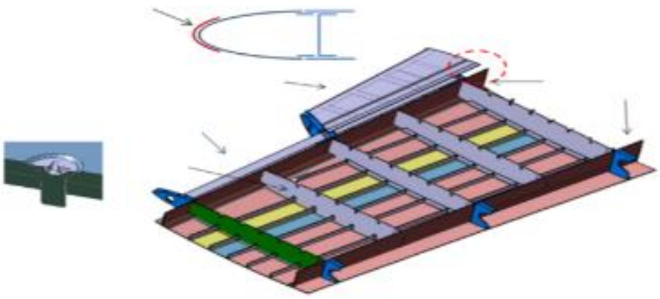

Figure 15: NLF HTP schematic

Main next step is in particular to mature solutions to ensure anti-erosion protections compatible with laminar requirements.

### 4.3.3 D06 - HLFC on Wing ground based demo:

The concept here is based on laminar profile with an HLFC leading edge and a Krueger flap device to provide both low speed performance and also anti-contamination function.

The main goal is to develop and validate an innovative and simplified HLFC concept to be applied and integrated on a long range wing.
It is also to Design and Manufacture a representative Ground Based Demonstrator.

Figure 16: HLFC Wing DMU

This will, at the end, enable to validate industrial aspects including NRC/RC assessment

So far, we can mention that manufacturing of this Ground Based Demonstrator (GBD) has started and main next step is to finalize its assembly to perform functional tests.

## 4.4 Stream 4: Radical Aircraft Configuration

We will find here:

- The Advanced Rear End demonstrator that develops new rear end concept and new manufacturing technics,
- Hybrid electrical propulsion is also a key technology contributing to the CS2 Top Project Objectives,
- The Scale Flight Demonstrator (SFD) that will allow disruptive ideas to be tested and de-risked at a lower cost,
- Finally the Distributed Electrical Propulsion that is derived from the SFD.

### 4.4.1 D02 - Advanced Rear End

The concept here is focused around what we call an Advance Rear End with forward sweep angle and laminar tail that mainly enable drag reduction and therefore fuel burn reduction because the HTP efficiency is increased.

The goal of this demonstrator is to deliver:

- Innovative Digital Mock-Ups and Technical Definition Dossiers of an Integrated Advanced Rear End,
- Innovative manufacturing process through components prototyping,
- Full component Structural/Systems/Industrial demonstrator (enabling a very high rate of aircraft production).

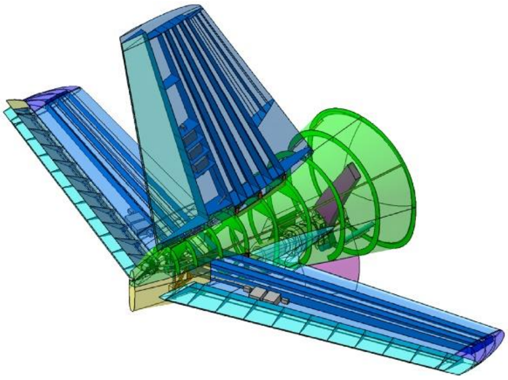

Figure 17: Advanced Rear End Schematic

Regarding the main achievements, we can mention that the full CFRP integrated upper skin has been delivered and the main next step is to perform the Rear fuselage upper shell assembly.

### 4.4.2 D03 - Scaled Flight Demonstrator

The initial question behind that demonstrator was how to avoid modifying a full scaled aircraft for any in flight test demonstration in order to drastically reduce the costs.

The objectives of the demo are therefore to:

- Demonstrate that the overall full scale aircraft behavior can be obtained with a dynamically scaled model,
- Assess the quality of data that can be gathered through Scaled Flight Testing.

Finally, we want to perform the validation of Scaled Flight Testing as viable means to de-risk disruptive aircraft technologies and aircraft configurations to high TRL.

Figure 18: SFD First Flight

On this demonstrator, the first flight has been performed on the 30$^{th}$ of March and the qualification flight test campaign has been completed with 6 flights in total. The next step is to perform the mission flight test in Italy in order to compare dynamic parameters between SFD and a typical short range aircraft.

### 4.4.3 D08 - Distributed Electrical Propulsion FTD

Following the launch of SFD, the question was: could we make it evolve to demonstrate the viability of a radical aircraft configuration like a Distributed Electrical Propulsion?

This is why this demo has 2 main objectives:

- Industrial assessment of Distributed Electrical Propulsion configuration,
- De-risk a Distributed Electrical Propulsion configuration in order to get knowledge on dynamics and control of such an aircraft.

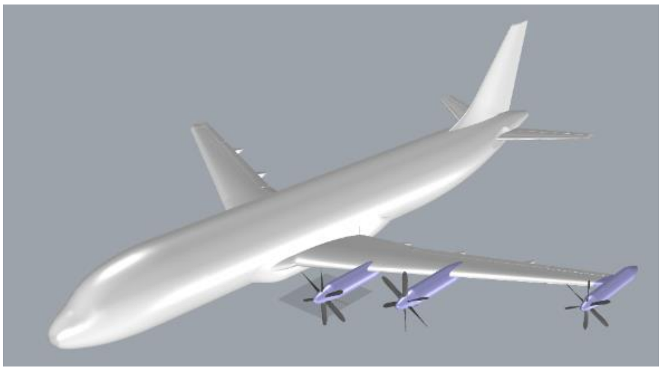

Figure 19: DEP DMU

So it is logically derived from the previous demonstrator SFD.
Currently, the manufacturing is ongoing and the main next step is to perform its WTT in DNW during summer 2022 before going to flight test in 2023.

#### 4.4.4 D09 - Hybrid Electrical Propulsion

This demonstrator has been proposed by RR to learn about hybrid electrical propulsion by combining a gas turbine with an electrical generator and an electrical motor

It therefore has the following objectives:

- Develop technology bricks for hybrid electrical propulsion,
- Demonstrate a hybrid electric propulsion system in the MW range,
- Validate the performance, control, and safety concept of the overall system by simulation & functional integration testing,
- Prepare the technology bricks to the Zero Emission Aircraft.

Figure 20: Power generation system installation in Bristol

Today all tests have been completed in particular for the power generation system in Bristol. And now RR are looking to further analyze the results and disseminate the main outcomes.

## 5. Conclusions

We remind that these demonstrators are contributing toward our research effort in the overall partner's consortium.

The 2 remaining years of CS2 will in particular focused on operational phase but also dissemination of the results and achievements of each demonstrator.

This phase is also a transition phase toward Clean-Aviation by providing articulation between some platform 1 demonstrators and pillar currently proposed in Clean-Aviation such as:
- D01 & Ultra Efficient Propulsion Systems for Short and SMR Aircraft
- D08 & Electrical Distribution Solutions for Hybrid Electrical Regional Aircraft

- D08 & Innovative Wing Design for Hybrid Electrical Regional Aircraft
- D08 & Aircraft architectures & technology integration for aircraft concepts ranging from regional to SMR applications
- D09 & Multi-MW Hybrid-Electric Propulsion

Finally, CS2 framework will have shown the strength and creativity of European parternship.

## 6. Acknowledgment & disclaimer

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The results, opinions, conclusions, etc. presented in this work are those of the author(s) only and do not necessarily represent the position of the JU; the JU is not responsible for any use made of the information contained herein.

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