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TECHNOLOGY MATURATION IN CLEAN SKY 2 FOR NEXT GENERATION SMR ENGINE

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Abstract

In the frame of the Clean Sky 2 programme Engines ITD, the activities within the WP2, Ultra High Propulsive Efficiency (UHPE) demonstrator, are tackling propulsion systems emissions for the Short & Medium Range Aircraft. An extensive technology maturation plan is ongoing to investigate and prepare technologies needed for the future generation of propulsion systems.

Keywords: propulsion, fan, compressor, turbine, combustor, gearbox, nacelle

1. Introduction

Future propulsion systems represent a generational architectural change and therefore offer many new opportunities from a technology perspective. Installation of larger fan systems at the front of the engine, relative to the size of the core, results in improved fuel consumption characteristics and an overall increase in the propulsive efficiency of the engine.

These fans will require new lightweight, multifunctional structures and materials, in parallel with optimisations of the engine core to improve engine thermodynamic efficiency and fuel burn characteristics. The large external diameter of the fan will require to reduce its rotational speed while the trend will be to increase rotational speed of the Low Pressure Turbine for high efficiency. These two opposite requirements will be achieved through high power reduction gearbox between the fan and the LP Turbine. In parallel, the nacelle will have to to evoluate towards either systems with short inlet or with systems with multifunctonal cowls.

The demonstration programme in ENG ITD WP2 includes a technology maturation plan dedicated to these key enabling technologies. The technology maturation plan will develop technologies and enablers, leverage essential knowledge and capabilities and de-risk the identified key technical gaps where further maturation & validation are required to maximize the impact of the WP2. The WP2 is structured in seven sub-work packages, each of them addressing technologies needed for the future engine. The Work Break Down structure of the WP2 is illustrated in figure 1.

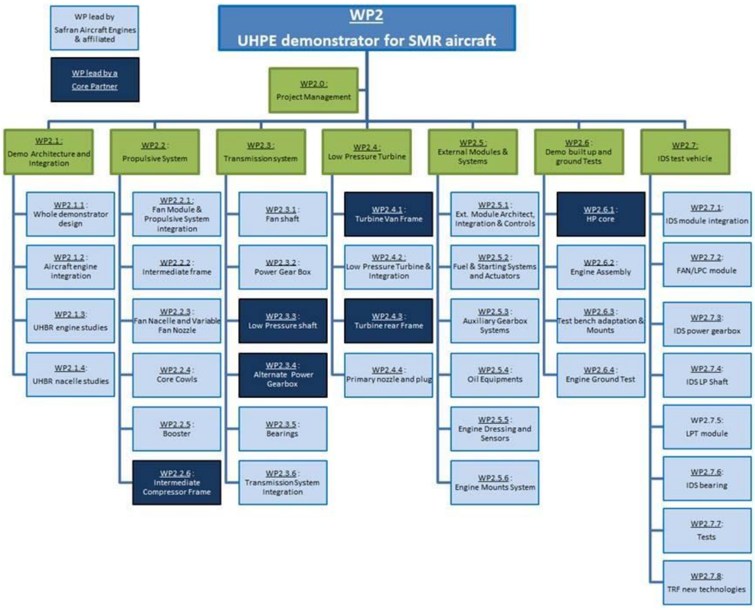

Figure 1 : WBS of ENG ITD WP2

2. Technology maturation plan

The next figure shows the technologies, which the WP2 is investigating, and how they match to the engine architectures, which were analyzed during the initial part of the Clean Sky 2 programme. Most of the results of the technology maturation are applicable to the three engine architectures.

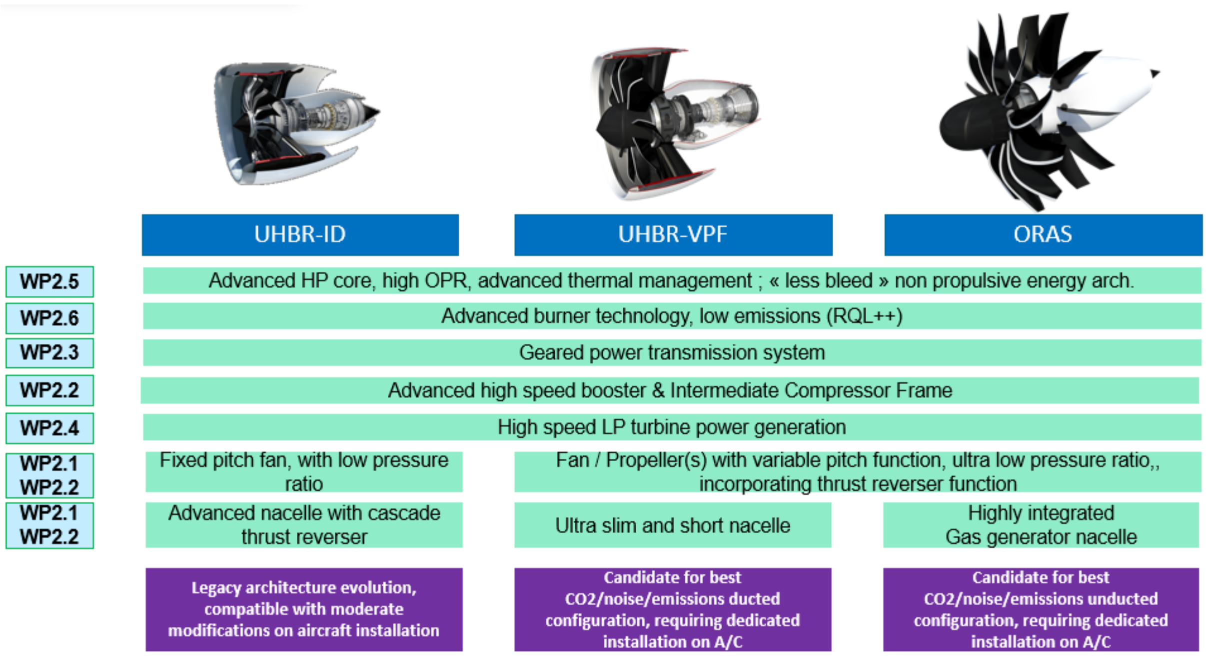

Figure 2 : WP2 technology mapping

The maturation for the gearbox components and the HP core technologies serves all three architectures. As far as the propulsive system is concerned, in particular the fan is characterized by a high by-pass ratio and evaluates from a fixed blade pitch, to a variable pitch blade and finally an actuated open fan.

As for the nacelle, the constraints differ with the engine architecture and the maturation in WP2 addresses sole the ducted Ultra High By-Pass Ratio Integral Drive (UHBR-ID) architecture.

The figure below illustrates how the maturation plan is contributing to support preparation of the engine demonstrator; they deliver test results, used to refine the assumptions and prepare for the design of components of the future engine demonstrator. More details on the progress and results are given in the next sections.

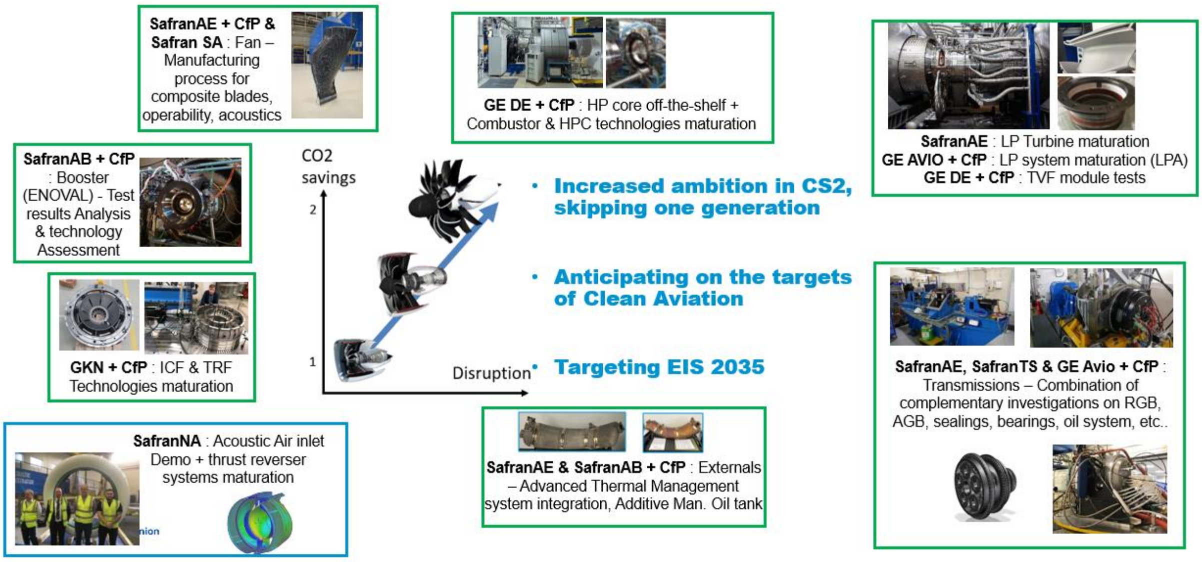

Figure 3 : Execution of the maturation plan for engine architecture consolidation

3. Technologies for LP front module

a. Fan blades

One way to improve the engine efficiency is to increase the mass of air ejected while liming its acceleration. This can be achieved by increasing the by-pass ratio. Engines with such architecture are characterized by large fan diameter and by the implementation of a gearbox that helps limiting fan speed with respect to the low pressure turbine. Also to increase efficiency, the fan blades can be characterized by variable pitch.

The manufacturing for the next generation of large fan blade are key, therefore Safran are working on the new processes needed to ensure compliance of the blade to the various requirements.

The choice of the composite technology and the associated manufacturing process will indeed be strongly affected by the criticality of the mass. Actually, with the given dimensions, the composite blade will be characterized by a hollow or a lightweight core. This core must be embedded and sealed inside the blade to avoid accumulation of fluids or environmental aging (in case of a lightweight material). This means that all the manufacturing process must be thought around the integration of such cores.

The manufacturing studies for the next generation of fan blade thus focus on two main axes:

- Comprehension of the link between manufacturing parameters and parts key characteristics through reduced scale manufacturing trials.

- Tuning of the LCM thermal and injection cycles in order to adapt to the new functional needs of next generation fan blades through panels and simplified manufacturing tests
  - Multi-components blades (composite hybridization, integration of low-density core materials)
  - New reinforcement pattern impacting permeability

A fan blade specimen of manufacturing trials is shown on the next figure.

Figure 4 : Fan blade advanced manufacturing

b. Intermediate compressor frame (ICF)

Within WP2, GKN is working on the Intermediate compressor frame (ICF); in particular, GKN are studying technologies for Innovative ICF Frame (composite/metal hybrid). The design phase of 1:1 test HW is now completed.

The test rig design has been analysed, reviewed and approved (see illutration on the next figure). Composite material coupon testing and feature testing have been performed to verify material data and the demonstrator manufacturing is initiated:

- Trial manufacturing of full scale part have been performed.
- Composite cure tools design are finalized and tool manufacturing is ongoing

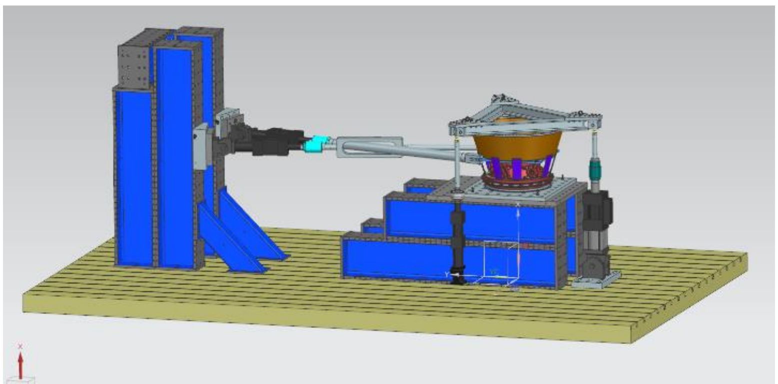

Figure 5 : Rig design for mechanical testing

c. Gearbox

Within WP2.3, Safran Transmission Systems and Avio Aero aim at maturing gearboxes breakthrough technologies for the next generation SMR engine. The technology maturation is carried out through component, sub-module and full scale module test campaign.

Safran Transmission Systems have tested various technologies of the gearbox at component level:

- The scavenge feature
- The oil dispenser
- The roller bearings
- The carrier

i. Scavenge feature test

The purpose of this test was to demonstrate the performances of a scavenge feature to reduce the power losses due to windage and churning effects. These features were tested in a subscale gearbox accounting for all relevant parameters (oil flows, temperatures, pressures, flight attitude, speeds). Seven designs were tested and their performances compared. The improvement of efficiency was confirmed. Those results helped the design team to down select the most promising design for the full scale gearbox.

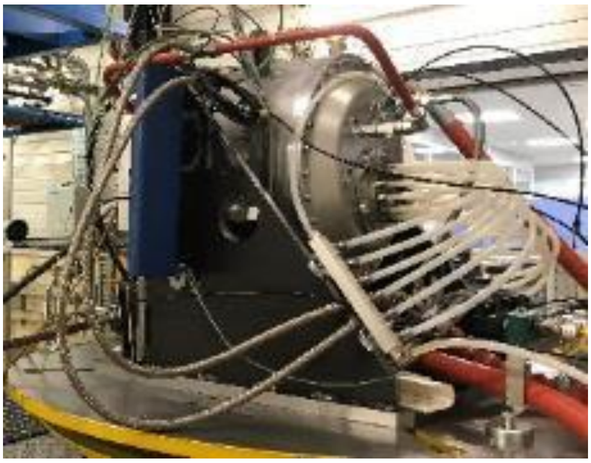

Figure 6 : Lubrication and scavenge test bench

ii. Oil dispenser test

The purpose of this test was to demonstrate the performances of an advanced oil manifold design and correlated associated numerical models to predict oil flow share within it. The oil manifoild was tested in dedicated full scale rig accounting for all relevant parameters (speed, oil flow, temperature, pressure). All test campaign was performed, representing about 100 rotating hours. Models showed good correlations to test.

iii. Roller bearing test

Mainly 3 types of tests have been performed

- Power losses and oil flow characterization
- Pressure field correlation
- Endurance test

These tests were run on a dedicated test bench (see the next figure). Roller bearings testing in endurance and critical phases have been successful and the thermal model has been correlated with tests.

Figure 7 : Planet bearing test bench

iv. Planet carrier test

The purpose of this test was to provide experimental characterization and data points to support the correlation of stress simulation. These tests were run on a component test bench, shown on the next figure. The comparison between the test data and the modelling results has been made and a good correlation has been found.

Figure 8 : Carrier test bench

The next figure show the maturation plan executed by Avio Aero in WP2. AviodriveX2 IDS full scale test campaign has been performed and has provided precious elements to support the improvement of calculation and predictive models, design methodologies and tools and to address the tech maturation roadmap.

i. Innovative materials for gearbox components

Reduction gearbox for next generation Short Medium Range engine applications shall be able to manage the full amount of power produced by the turbomachinery minimizing at the same time the power losses, the weight and the dimensions while guaranteeing an adequate level of robustness and safety.
One of the major technology areas to be investigated in order to address this challenge is relevant to the material mechanical properties: being able to rely on materials with improved mechanical performances (in particular in terms of strength to weight ratio) is fundamental to reduce weight and dimensions of the key gearbox components and so of the whole module.
Avio Aero, in WP2.3, focused on the development and the validation of new materials for high power gears and bearings: the material composition and structure as well as the manufacturing process are designed and tuned by Avio Aero that is supported for the validation test campaign by Clean Sky 2 partners.
While the activity is still on going, actual results are confirming the high expectations on the new materials under development.

ii. Full scale module validation

Integrating the new technologies into a full scale gearbox module to be tested at full power in a representative environment is a fundamental step to proper mature and validate them: in continuity with the activities started in Clean Sky 1 and exploiting the same test team and test facility. Avio Aero performed an extensive full-scale test campaign focusing on many different specific performance areas to verify and validate the integration at module level of the different technologies matured in Clean Sky 2. The purpose was to confirm that the behavior of the test gearbox as a module was in line with the design intent and to improve the engineering prediction and modelling tools thanks to the return from the test results.

Figure 9 : Maturation plan on gearbox components (Avio Aero)

4. Technologies for HP core

i. High Pressure Compressor aerodynamic

GEDE has designed and tested an advanced 3-stage HPC rear block configuration at the High-Speed Research Compressor (HSRC) facility of TU Munich.
The test results confirmed the predicted performance and the operability potential across various speeds and rotor tip clearance levels. Test data post-processing and analysis are still ongoing, including the interpretation of adv. time-resolved measurements from Fast response Aerodynamic Probe (FRAP) and hot-wires.

Post-test CFD simulations are being performed to compare with the test data.

Figure 10 : High-Speed Research Compressor (HSRC) Test Facility at CfP partner TU Munich, Germany

ii. Combustor

GEDE has completed combustor tests at DLR Cologne. Detailed NOX, CO, UHC (unburned hydrocarbons), smoke & dynamics data were measured at different rates (ground-idle, 7% and 85% ICAO). The detailed post-test assessment has been completed and a novel integrated damper design has been validated. CFD simulations were performed to complete the analysis, as shown on the next figure.

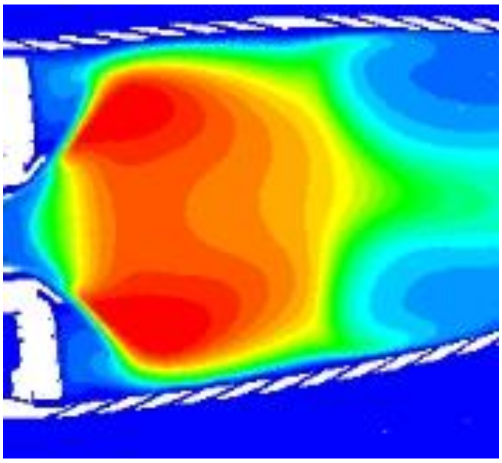

Figure 11 : Example of CFD-based mean mixture fraction distribution

5. Technologies for LP Turbine

a. Turbine Vane Frame (TVF)

GEDE has been investigating the aerodynamics of a next-generation TVF. TVF dual-spool test campaigns were performed, testing an initial baseline configuration as well as an optimized design. The test campaigns were conducted at TU Graz, showing good results

As for the TVF module (additive integrated TCF/TVF frame design); GEDE has completed all planned four sector print trials. Mechanical (TUHH/TUD) and aero thermal testing (TUD) has been completed at TU Hamburg and TU Dresden.

The lessons learned of these sector print trials have been implemented in a final 360 degrees design.

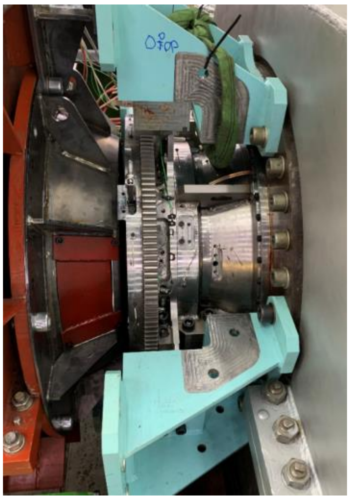

Figure 12 : 2-spool rig 2 assembly at TU Graz (FWD rig side completed with HPT)

b. 3-stage High Speed Low Pressure Turbine (HS-LPT)

Safran Aircraft Engines has built a full 3-stage HS-LPT to be tested at 1T in Villaroche (Safran Aircraft Engines premises). A picture of the installation is shown on the next figure.
A full test campaign is ongoing: 200 running hours have been performed to characterize the HS-LPT performance (performance, turbine mapping). Additional tests will be performed to include purge and Reynolds influence, turbulence measurement.

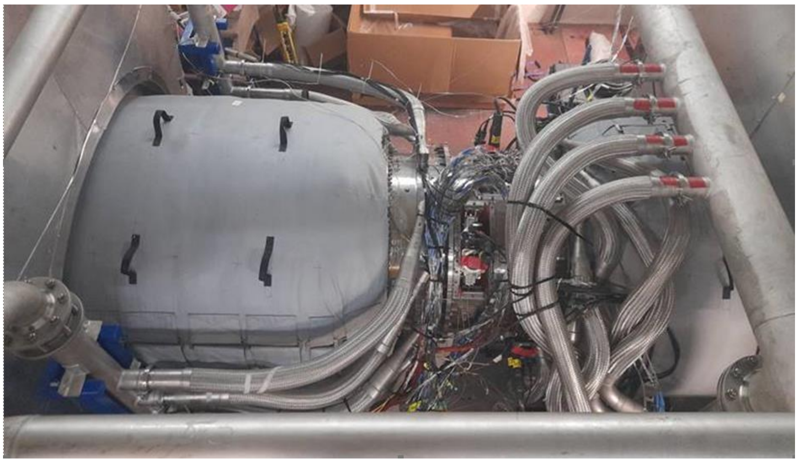

Figure 13 : TVF + full LPT rig (build 2) at 1T Villaroche

c. LPT clearance controls

The goal of the LPT clearance control activities performed in CleanSky2 program is to feed the optimization loop for the clearance control design. Safran Aircraft Engines has been working with partners through a CfP ACCENTO on experimental aspects and numerical approach to build the response surface used in the optimization loop. A flow-check test rig devoted to the impingement holes discharge coefficient characterization has been designed, manufactured and operated.
27 pipe configurations have been manufactured and tested with different operating conditions that leads to 408 tests points.

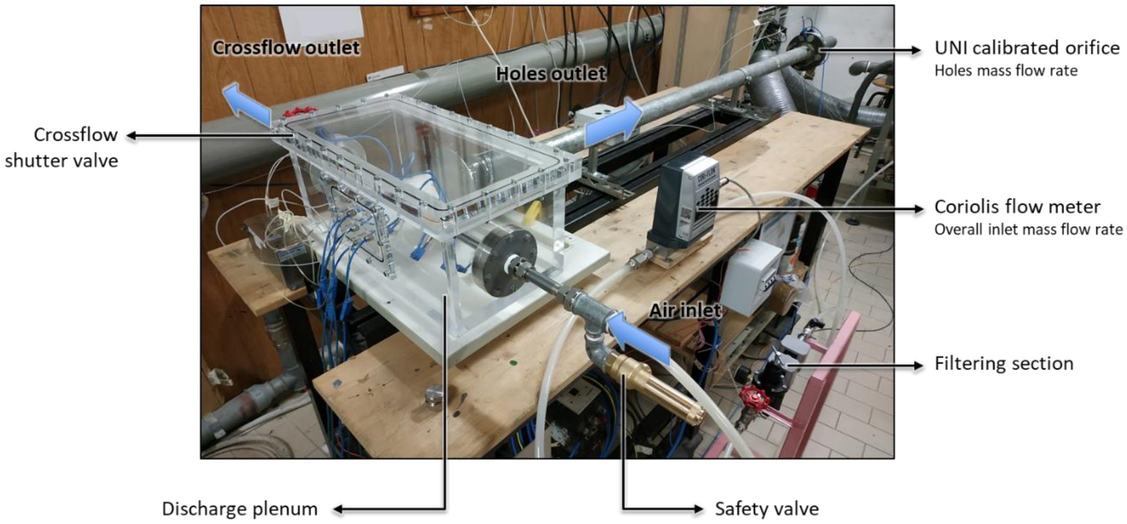

Figure 14 : Flow check rig installation

A post-processing tool has been developed to help the visualization, the comparison and the analysis of the results. This tool allows the user to:

- Visualize 2D results
- Check compliance between 2D results and average distributions
- Visualize and compare 1D average distribution
- Visualize and compare 0D average value
- Analyze influence of Reynolds, impact distance and hole number
- Interpolate result by Reynolds, impact distance or hole number
- Determine optimal drilling pattern

d. Turbine Rear Frame (TRF)

GKN has completed a 1:1 scale TRF mechanical test including new alloys and processes. The strength test resulted in a strut buckling failure mode, which compared well with pre-test predictions regarding mode shape and load level at failure. The TRF Mechanical test has been completed.

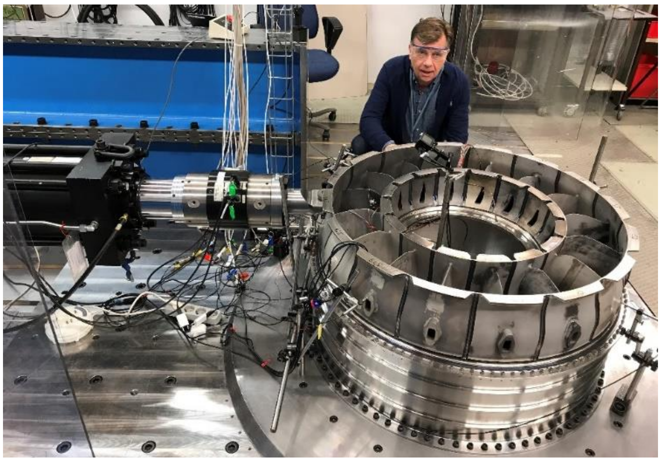

Figure 15 : Scale 1-1 TRF

6. Nacelle technologies

Safran Nacelle within WP2 has concentrated the effort reducing on air inlet length reduction with a higher acoustic performance than conventional inlet.

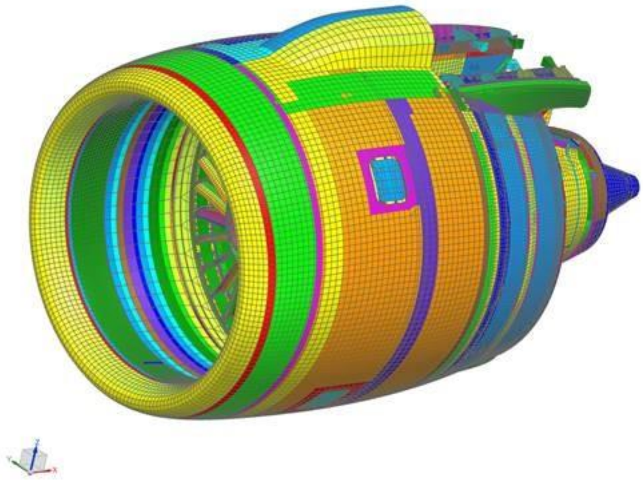

Figure 16 : 3D model of advanced nacelle components

The manufacturing of an acoustic demonstrator was successfully achieved, while the inlet structure design has been optimized and a weight reduction performed. In parallel, aero-acoustic analysis have been performed during the demonstrator preparation.

Figure 17 : Scale 1:1 short inlet nacelle demonstrator hardware

7. Conclusions

A broad technology maturation plan has been presented, which are part of the activity in ENG ITD WP2. This plan is supporting the preparation of a large scale engine ground demonstration.
Several technologies will reach TRL5 by completion of Clean Sky.

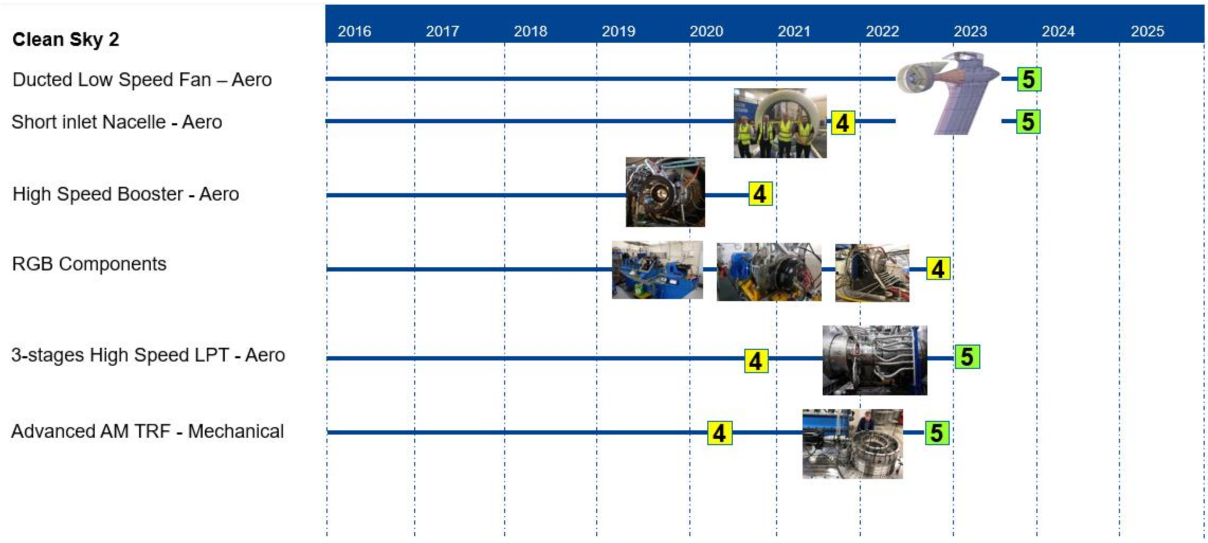

Figure 18 : TRL progress on key technologies studied in Clean Sky 2

At the end, there will be a transition phase toward Clean-Aviation; the plan will be articulated for Clean Aviation to leverage on the results provided by Clean Sky 2.

Abbreviations and Acronyms

A/C	Aircraft
CFD	Computational Fluid Dynamics
CfP	Call for Proposal
CS2	Clean Sky 2
ENG	Engines
FRAP	Fast response Aerodynamic Probe
HSRC	High Speed Research Compressor
ICF	Intermediate Compressor Frame
ITD	Integrated Technology Demonstrator
LP	Low Pressure
ORAS	Open Rotor And Stator
RGB	Reduction Gear Box
SMR	Short & Medium Range
TRF	Turbine Rear Frame
UHC	Unburned Hydrocarbons
UHBR-ID	Ultra High By-Pass Ratio Integral Drive
UHPE	Ultra High Propulsive Efficiency
VKI	Von Karman Institute
WTT	Wind Tunnel Test

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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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