33rd Congress of the International Council of the Aeronautical Sciences
ICAS 2022 – Stockholm, Sweden

OPEN FAN ENGINE ARCHITECTURE FOR NEXT GENERATION SMR

Christophe Diette
Safran Aircraft Engines
Rond Point René Ravaud, 77550 Moissy-Cramayel, France
christophe.diette@safrangroup.com

Abstract:

Within the frame of Clean Sky 2, the WP2, within the Integrated Technology Demonstrator (ITD) ENGINES, is preparing technologies needed by the future propulsion systems of an SMR aircraft. Two axes are considered to address the challenges; the first one consists in investigating engine architecture capable to meet the High Level Goals of Clean Sky 2 and beyond. The second axes focuses on the maturation of technologies to support or enable the engine architecture investigations and design.

This paper focuses on the investigations relative to the engine architecture and the selection of a champion architecture: the Open Fan. The first part of the article will present the maturation studies on the engine architecture. The second part will present the selected champion Open Fan architecture and the key opportunities and challenges. Finally, the synergy with the Clean Sky 2 Large Passenger Aircraft (LPA) platform 1 will be briefly described.

1. Introduction

The energy efficiency of aircraft has improved in leaps and bounds in past decades: today's aircraft are 75% more fuel (and CO2) efficient than aircraft from the early jet age. However, the growth of air transport require further more improvements to face the challenging environmental objectives. Among levers to reduce aircraft emissions, the propulsion is a key contributor to achieve or surpass the Air Transport Action Group's (ATAG) goals on the way towards Carbon neutrality by 2050.

Next generation propulsion systems will offer significant propulsive efficiency improvements through Ultra High By-Pass Ratios, low fan pressure ratios, however at the expense of a strong increase in engine diameter. Engines cores will work at higher temperatures and become smaller.

The next figure illustrates the evolution of the mapping regarding the engine architectures. Two main ducted engine architectures have been considered in Clean Sky 2: Ultra High By-Pass Ratio Integral Drive (UHBR-ID) and Variable Pitch Fan (VPF). Both architectures are geared engines; the VPF mainly distinguishes from the UHBT-ID by an increased by-pass ratio (above 20) and the introduction of actuation system for the fan blade. It is therefore an evolution with respect to the UHBR-ID, which has a by-pass ratio above 15 and fixed pitch fan blades.

On the parallel way, the unducted engine architectures offer the highest potential for CO2 reduction and therefore the highest impact. Clean Sky 2 has learned from experience in Clean Sky 1 and the Contra-Rotating Open Rotor (CROR), which has been ground tested in 2017. The CROR demonstrator cumulated 70 running hours on the test facility. The engine first started in May 2017 and the test campaign ended in December 2017 after completion of all test items. Engine disassembly started in September 2018 and the final tear down review took place in May 2019.

The inspection of every system and critical parts allowed Safran to have more information about the engine, the parts and systems behavior during the tests. The inspection helped to validate design choices and gave information to enhance design for a future engine or future similar system. The final tear down review was critical following the test campaign; it made possible to link observations about the parts to phenomena observed/recorded during the tests. The disassembly confirmed the very good behavior of the engine observed during tests and parts were in very good conditions. The resulting information and all of the validated technologies gave a reference to build on for future engine architectures.

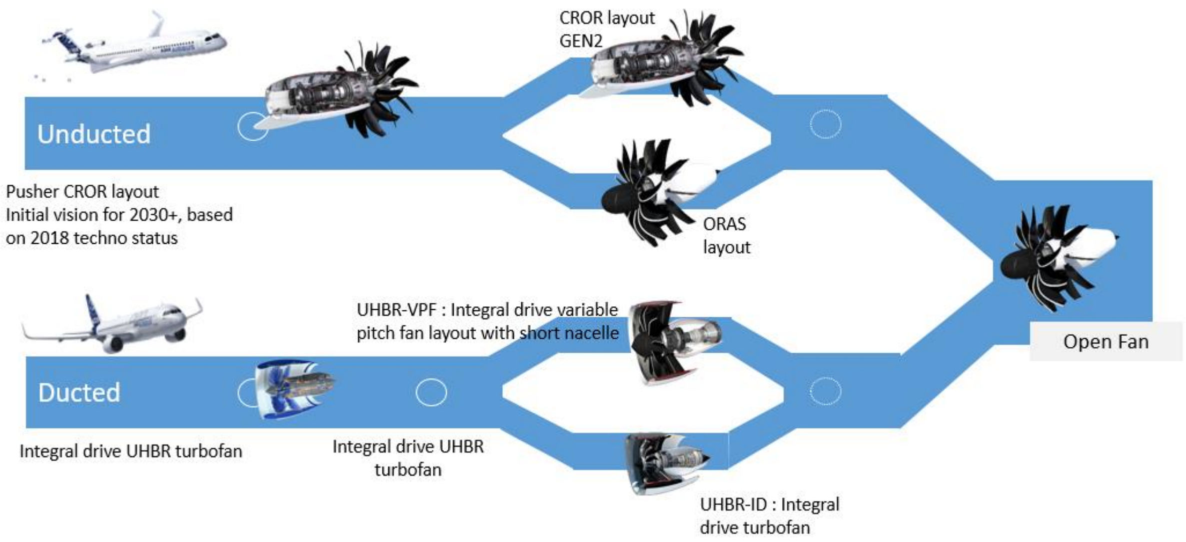

Figure 1 : Maturation path on propulsion systems architectures

The Open Rotor And Stator (ORAS) was then studied within Clean Sky 2, leveraging on the experience with the CROR demonstrator, searching for simplification and higher integration feasibility.

2. Engine architecture trade-off studies

Traditional ducted engine architectures, which could be available by the end of this decade, would deliver between 5 to 10 percent better fuel consumption and lower carbon emissions versus today's most efficient engines. An open fan architecture, that could enter service by the mid-2030s, would provide a 20 percent improvement. These numbers are at the propulsion system level only, based on the aircraft using conventional Jet A fuel.

The drawing on the next figure illustrates this trend. Thanks to Clean Sky 2, progress in engine integration studies and aircraft/engine installation studies lead to consider that conventional underwing engine installation limits the by-pass-ratio increase, unless losing a part of engine Fuel Burn (FB) benefit. Besides, analysis conducted to the conclusion that future expectations in terms of FB reduction, ie CO_2 reduction, would be higher in the next programme. Therefore, Safran Aircraft Engines has been shaking engines architectures, in Clean Sky 2, in order to identify the potentialities for the future generation of engines and aircraft. Among them, three were top ranked in 2019: the UHBR-ID, the VPF and the Open Fan.

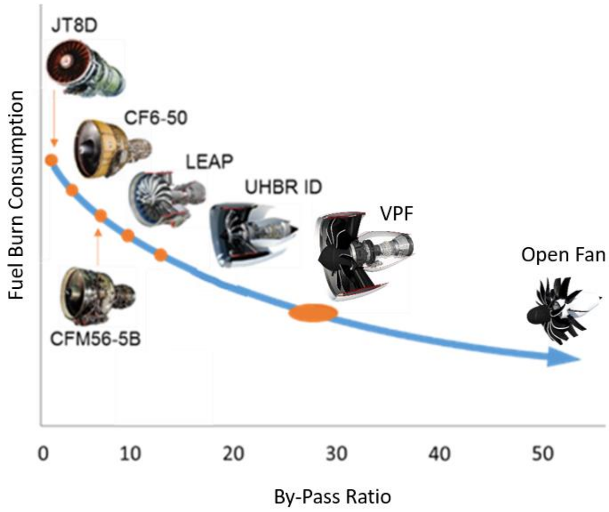

Figure 2 : Evolution of fuel burn consumption versus by-pass ratio

The selection criteria for innovative engine architectures must take into account the integration penalties and therefore analysis are also conducted to evaluate the impact on installation of those engines concepts.

The next figures illustrate possible installations, depending on the engine architecture. The UHBR-ID remains compatible with a classical Low Wing (LW) installation. The VPF with its increased by-pass ratio introduces new challenges and close studies with the airframer are necessary.

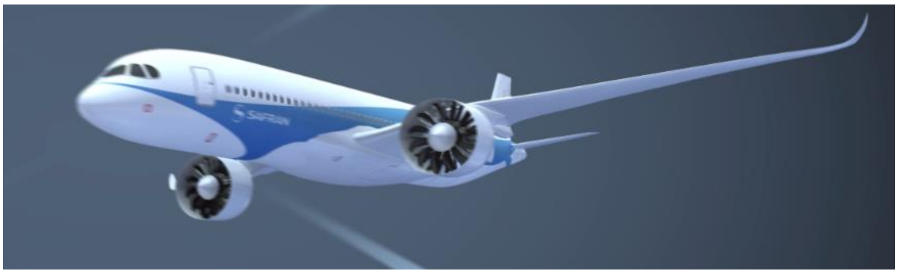

Figure 3 : UHBR-ID installation

Figure 4 : Possible VPF installation (example for illustration purpose – gull type wing)

Finally, studies in Clean Sky 2 show that an unducted engine architecture confirms the best potential for CO2 savings. The next illustrates also a preliminary concept of installation based on the CROR experience.

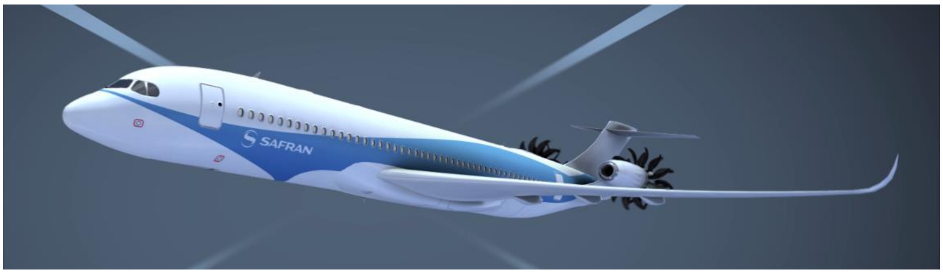

Figure 5 : Example of unducted engine (CROR-like) installation

Multiple maturation studies were performed to first mitigate UHBR integration risks & optimize the architecture:

- Engine operability, water & hail ingestion, Icing & windmilling
- Lubrication system architecture & Thermal management sizing
- Fan Pitch Actuation System (FPAS) architecture analysis
- Engine control logic trade studies
- Reverse thrust analysis
- Equipment's packaging analysis

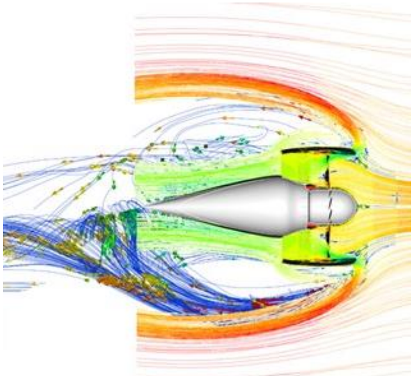

Figure 6 : Simulation of reverse flow (VPF)

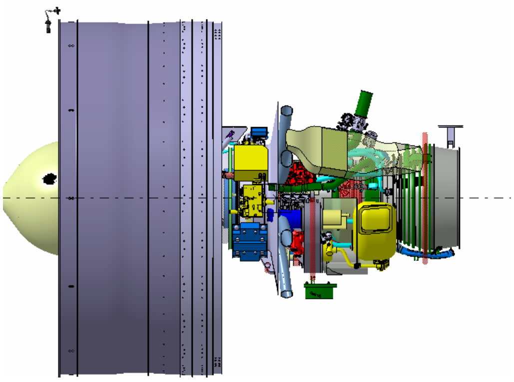

Figure 7 : VPF equipment packaging

On the same principle, multiple multidisciplinary studies were then performed with the unducted engines to consolidate architecture choice. The main analyses are listed herafter:

- Functional analysis & FMEA analysis initiated on each component and advanced systems
- Updated risk analysis and requirements for tech mat needs / test cards
- Maturation studies on modularity / maintainability
- Fuel burn exploration study
- Component efficiency design space, cross-discipline trade studies, component pre-sizing

In parallel, acoustics evaluation updates for community noise &cabin noise were performed based on previous available Wind Tunnel Test (WTT) results. The installation of propulsion systems based on experimental data was reassessed. And the comparison between different architecture configurations (ducted, unducted) was made.

Performance & integration assessment were performed in combination of architecture studies to release constraints on Aircraft design & operations. Typical criteria or area of optimization have been:
- Thrust optimization during ground & flight phases
- Architecture simplification & flexibility studies

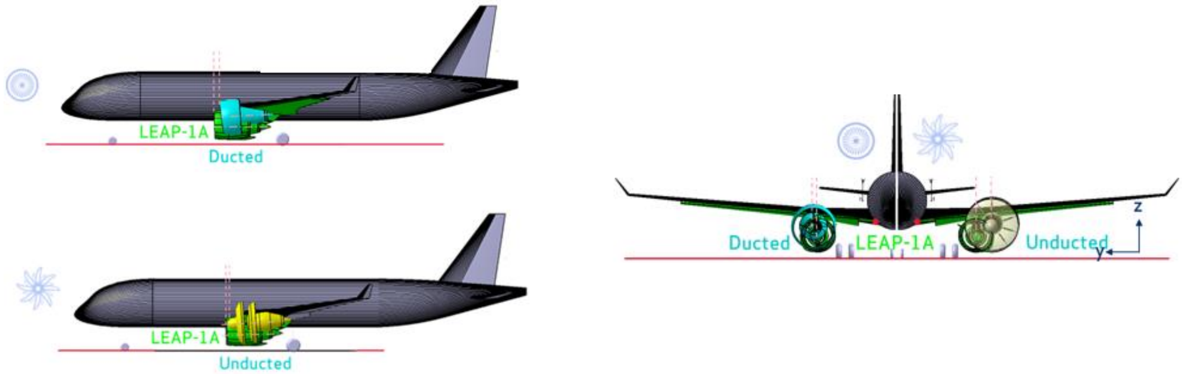

Figure 8 : Integration assessment for Open Fan engine architecture

The concept studies have identified a number of key enabling technologies, which need to be developed ahead of the engine design. Some of them are generic common technologies, which can serve in various engine architectures.

Based on this multidisciplinary approach, the architectures were ranked based on key success factor and finally the Open Fan has been selected to be demonstrated.

3. Champion engine architecture: the Open Fan

a. Key features

The next figure shows the Open Fan Propulsion System demonstrator. The open Fan is rotating clockwise when looking from the front.

Figure 9 : 3D view of the Open Fan

It is a geared engine, which enables to decouple the fan rotational speed from the booster and LP turbine. It has a single stage open (unducted) fan and OGV; both fan and OGV are actuated to optimize the operability. The reduction gearbox achieves high power and speed throughputs thanks to advanced gearing system and transmission architecture. The fan then rotates at low speed while Booster and LP turbine rotates at high speed. The HP core is compact at higher temperature.

b. Key installation drivers

The next figure illustrates some of the challenges of an increased by-pass ration engine, the external fan diameter becoming with the Open Fan twice the size of a LEAP engine.

Figure 10 : Installation challenges

Nevertheless the Open Fan Architecture is compatible with different types of installation onto an aircraft. The figure below illustrates three possible concepts of Open Fan installations on an SMR aircraft.

The first one is the High-Wing (HW) mounted: it is the most feasible due to the distance from the wing to the ground, which facilitates this installation. However, it induces more weight penalties, in particular, because the upper section of the fuselage needs to be strengthened.

The Rear-End (RE) fuselage installation offers several advantages, among them the opportunity for an ultra-efficient (laminar) wing. But as it was seen with the CROR project, additional weight penalties appear when considering an aircraft family: typically, the potential need to lengthen the fuselage will require more effort to rebalance the weight distribution.

Finally, the Low-Wing (LW) installation is the most convenient installation and becomes possible with the Open Fan architecture. This installation has been assessed and optimized. The passenger comfort is one the criteria, which are taken into account and there is no showstopper identified on cabin noise.

Figure 11 : Installation concepts for the Open Fan

The LW installation is therefore the most promising one and the primary target within Clean Sky 2. As shown on the next figure (given for illustration purpose), the installation must be closely studied with the airframe due to the potential impact on the wing.

Figure 12 : Example of a LW installation of the Open fan (illustration purpose)

4. Link with LPA

The scheme on the next figure describes the link with Large Passenger Aircraft (LPA) Platform 1 and the overall consistency within Clean Sky 2.

Both efforts in ITD ENG WP2 and LPA WP1.1 are coordinated. ITD ENG WP2 is working on defining a propulsion system capable to achieve ambitious fuel burn targets while LPA is supporting integration & installation studies to evaluate the integration of the solutions.

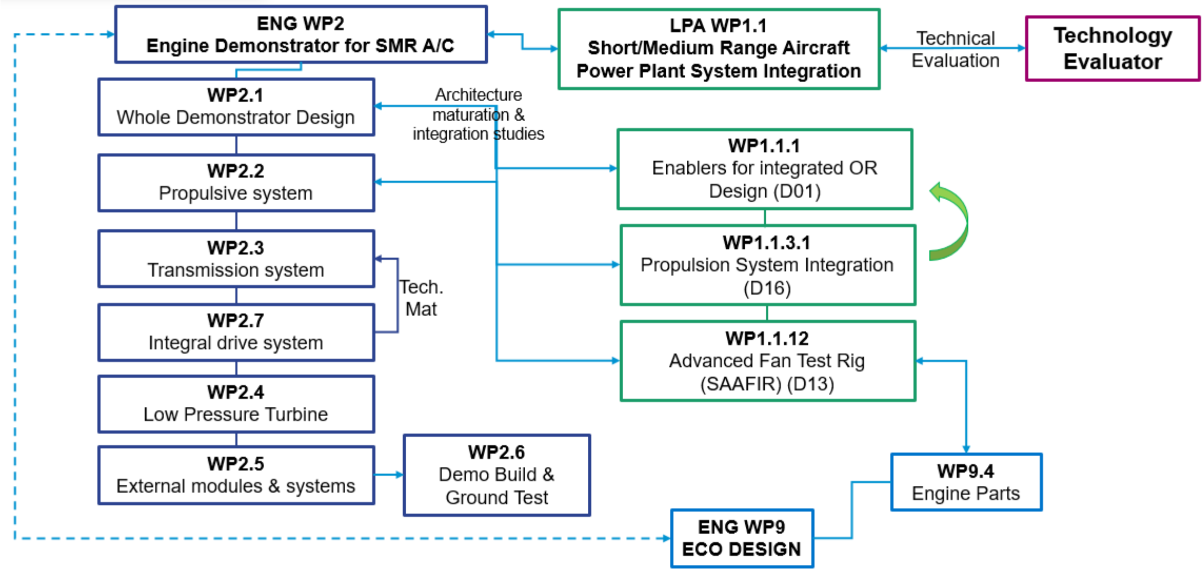

Figure 13 : Synergy between ITD ENG WP2 and LPA Platform 1

This collaboration within Clean Sky 2 is illustrated through the links between the work packages, in particular for the architecture studies.

5. Conclusions

The Clean Sky 2 programme is supporting a Technology maturation plan through modules & rigs ground demonstrations to prepare the design of a scale 1 Engine Ground Test Demonstrator. Multiple maturation studies have been performed to identify and select an innovative engine architecture capable to achieve 20% of CO_2 reduction: the Open Fan.
The key features of the GTD Engine will thus include a large open fan with a variable pitch, an integrated gearbox, a high-speed booster and a high-speed low-pressure turbine.

Clean Sky 2 is contributing to the preliminary design phase of the GTD Engine with the aim to validate the new engine architecture and the Low Pressure Modules

Abbreviations and Acronyms

CROR	Contra-Rotating Open Rotor
CS2	Clean Sky 2
BPR	By-Pass ratio
ENGD	Engine
FB	Fuel Burn
HW	High-Wing
ITD	Integrated Technology Demonstrator
LPA	Large Passenger Aircraft
ORAS	Open Rotor And Stator
RE	Rear End
SMR	Short & Medium Range
UHBR-ID	Ultra High By-Pass Ratio Integral Drive
VPF	Variable Pitch Fan
WP	Work Package
WTT	Wind Tunnel Test

Acknowledgment & disclaimer

This project has received funding from the Clean Sky 2 Joint Undertaking (JU) under grant agreement No 945541. The JU receives support from the European Union's Horizon 2020 research and innovation programme and the Clean Sky 2 JU members other than the Union.

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.

Contact

CS2-ENG/ WP2
Programme overview and structure | Clean Aviation (clean-aviation.eu)

Christophe DIETTE
christophe.diette@safrangroup.com
Tel: +33.6.43.55.13.06