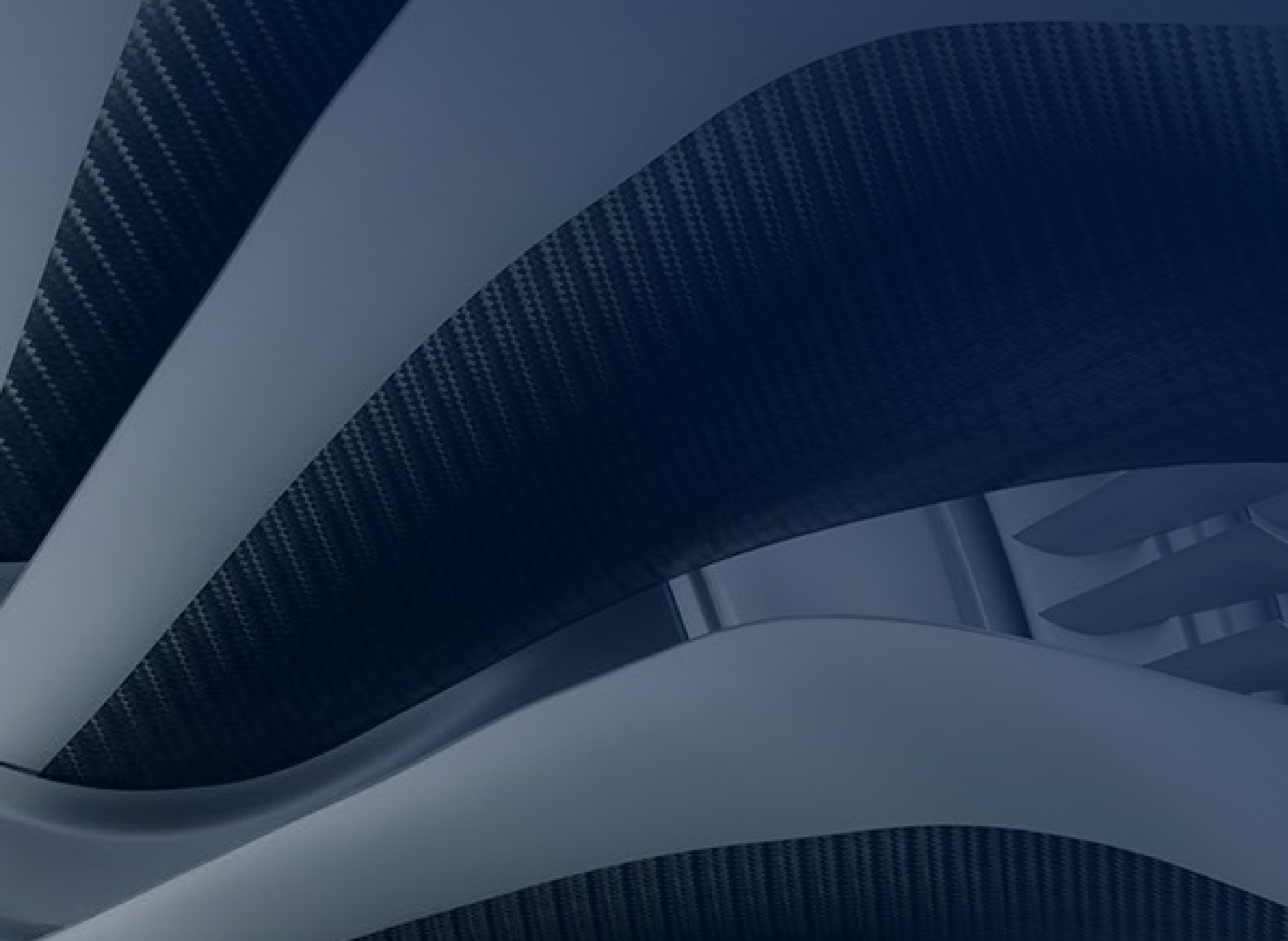
CFM RISE PROGRAM

REVOLUTIONARY INNOVATION
FOR SUSTAINABLE ENGINES



SECTIONS

FOREWARD

The CFM International **RISE (Revolutionary Innovation for Sustainable Engines)*** Technology Demonstration Program that was launched on June 14, 2021 is the manifestation of the deep commitment GE and Safran share for achieving ambitious goals for a sustainable future.
The program embodies CFM's mission to push the limits of innovation to develop, demonstrate, and bring to market breakthrough technologies that will advance the industry and protect the planet.

Building on four decades of investment that made our engines cleaner, quieter, and more efficient, the RISE Program accelerates the development of uncompromising new propulsion technologies that will pave the way for the next generation of aircraft and an ever more sustainable future.

Technologies matured as part of the RISE Program will serve as the foundation for the next-generation CFM engine that could be available by the mid-2030s. The program goals include reducing fuel consumption and CO_2 emissions by more than 20 percent compared to today's most efficient engines, as well as ensuring compatibility with alternative energy sources like Sustainable Aviation Fuels (SAF) and hydrogen to provide even further sustainability benefits. The program will deliver revolutionary performance all while maintaining the unrivalled CFM standards for reliability, asset utilization, and overall cost of ownership.

* RISE is a registered trade mark of CFM International, a 50/50 joint company between GE and Safran Aircraft Engines

RISE

BACKGROUND

With the RISE Program, CFM is driving a step change in aviation propulsion. Achieving ambitious sustainability goals will require uncompromising technologies capable of achieving levels of efficiencies beyond anything we have done before. The ultimate solution must not only build upon the safety, reliability, and operating economics of today's benchmark CFM56 and LEAP engines, but lay a solid foundation for the generation beyond.

Simply put, a sustainable future requires a propulsion system that can deliver the largest CO_2 reduction in aviation history, as well as meeting anticipated noise and emissions standards that will be set by the International Civil Aviation Organisation. From the beginning, CFM has continually pushed the envelope to develop advanced technologies that bring benefits to customers, both in terms of operating costs and reliability, as well as help reduce the emissions created by the aviation industry.

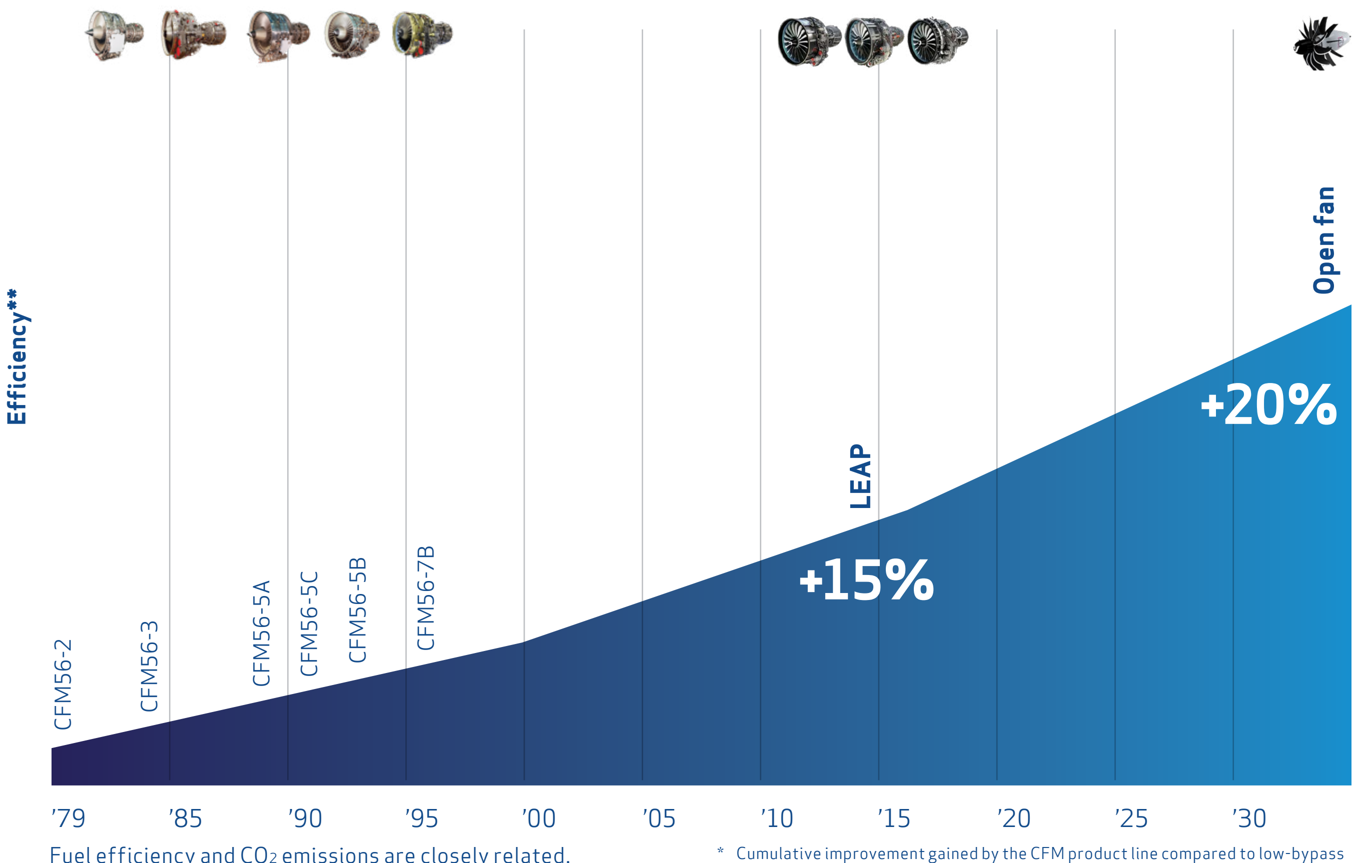
This paper details the targeted performance goals, the key technologies being demonstrated, and the development timeframe.

THE KEY TO A MORE SUSTAINABLE AVIATION FUTURE

Since the early 1980s, **CFM engine fuel consumption and CO_2 emissions have been reduced by 40* percent compared to the engines that they replaced as a result of technical innovation.** Future engines must accelerate improvements in these fields.

An open fan architecture could reduce fuel consumption and CO_2 emissions by more than 20 percent compared to today's most efficient engines.

CFM is also exploring other architectures. Each has limitations that cause them to fall short of the full propulsive efficiency gains required to achieve the full 20 percent improvement.



Fuel efficiency and CO_2 emissions are closely related, with a direct coefficient.

* Cumulative improvement gained by the CFM product line compared to low-bypass engines produced in the 1970s and 1980s.

** Engine contribution only

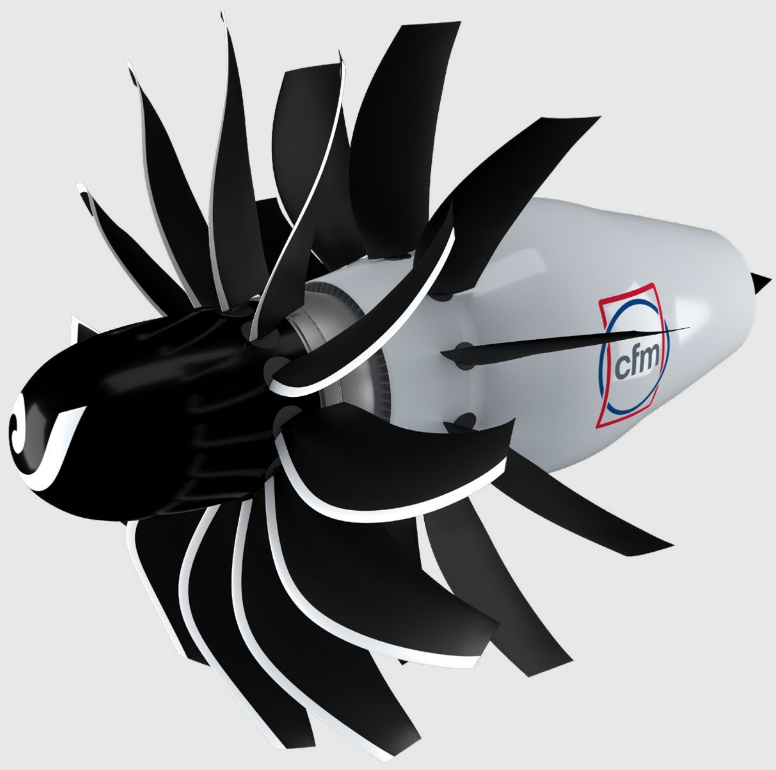
ENGINE ARCHITECTURE

The RISE Program is demonstrating foundational technologies that will allow CFM to define the optimum engine architecture to best meet the specifications and aircraft development schedule.

With more than a billion hours of experience, CFM has a unique understanding of how its products are used day-in and day-out. As a result, CFM products consistently serve as the industry benchmark for these two critical parameters.

An **open fan architecture** is the most efficient and sustainable option

- Step change in propulsive efficiency
- Improvements in thermal efficiency
- Integration of advanced systems.



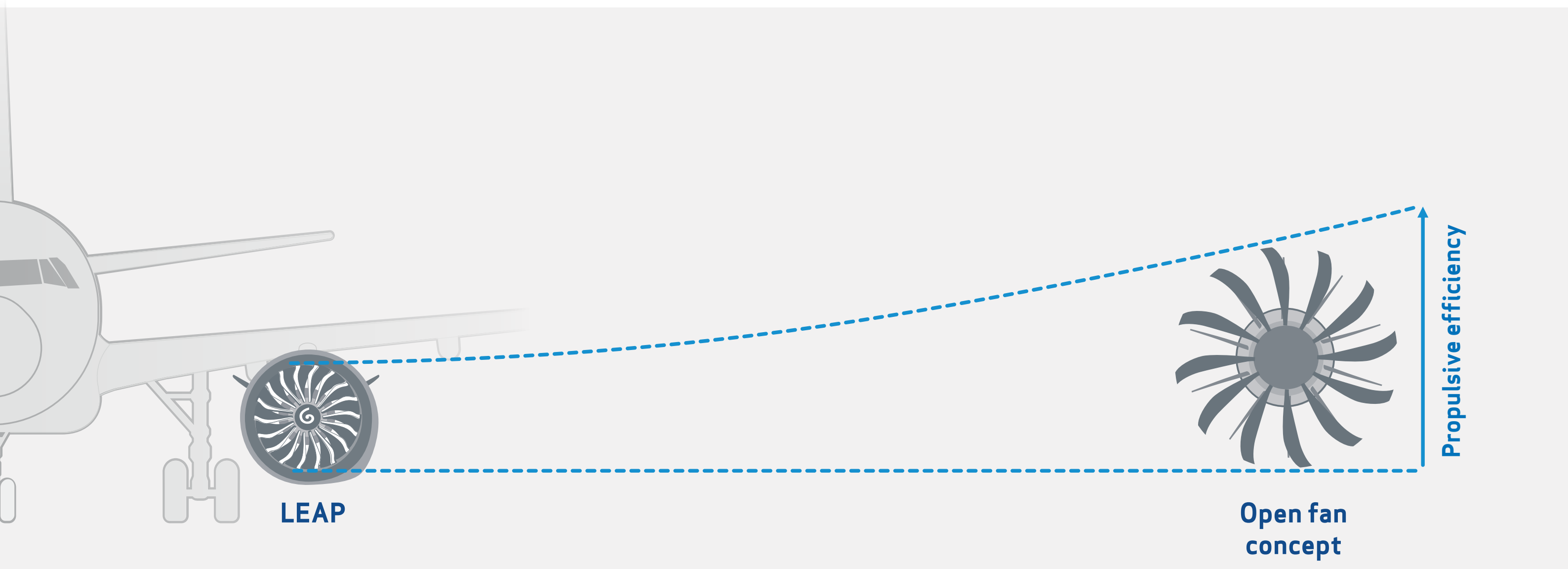
ADVANCING OPEN FAN ARCHITECTURES

The history of aviation propulsion tells us that all previous breakthroughs in efficiency were achieved by new technologies that allowed for a larger fan size and a higher bypass ratio.

The physics of propulsive efficiency – the measure of an engine's ability to create thrust using more air – require that, to achieve the highest level of fuel efficiency, you must propel the largest quantity of air at the lowest exhaust velocity.

The pursuit of ever-increasing propulsive efficiency has driven the growth of engine fan diameter in commercial jet engines over the past five decades. This progression is ultimately leading to open fan concepts.

Although high bypass architectures can be seen in the form of turboprops on slower flying and shorter-range regional aircraft today, the open fan architecture to be demonstrated as part of the RISE Program is nothing like a turboprop engine. This advanced, new generation open fan architecture will be able to fly at the same speed as current single-aisle aircraft (up to Mach 0.8, or 80 percent the speed of sound) with a noise signature that will meet anticipated future regulations.



For more information, see appendix about propulsive efficiency

A RICH HISTORY DEMONSTRATING OPEN FAN ARCHITECTURE

The engine industry has studied and demonstrated open fan architecture concepts for more than four decades.

One of the best examples is the GE36 Unducted Fan (UDF) on which Safran (Snecma the time) was also a development partner. The GE36 was initially flight tested on a Boeing 727 in 1986 and later flew to the 1988 Farnborough Airshow mounted on a McDonnell Douglas MD-80.

The initial drive to develop the concept came from a concern over very high fuel prices in the late 1970s and early 1980s. Projections at the time were for more than $5.00 U.S. per gallon (the equivalent of $16.80 today).

The GE36 was never introduced into commercial service primarily because oil prices fell substantially, and customer interest waned as a result. There was also a second challenge: the technology was not advanced enough to achieve acceptable noise levels.

However, many key technologies demonstrated with the UDF found their way onto new programs – the composite fan blade on the GE90, for example.

Since the 1980s, the industry has continued to develop the open fan architecture and has identified new technologies that are resulting in the improved efficiency, lower emissions, and lower noise we can achieve today.

More recently (2017), Safran Aircraft Engines ran a Counter-Rotating Open Rotor (CROR) engine through a European Clean Sky initiative to develop sustainable engines. GE's Avio Aero was a key partner in this demonstration program. The Sage2 open rotor demonstrator engine, which ran at Safran test facilities in Istres, included two counter-rotating, unshrouded fans. The engine achieved a double-digit improvement in fuel consumption and CO_2 emissions compared to today's most efficient powerplants, as well as comparable noise levels.

This test also demonstrated key technologies like multi-variable power control, a pitch actuation system advanced power gearbox integration.

The RISE program will use this experience and incorporate lessons learned into its future engine, regardless the architecture.

1988 - GE36 flight test

2017 - Safran CROR ground test

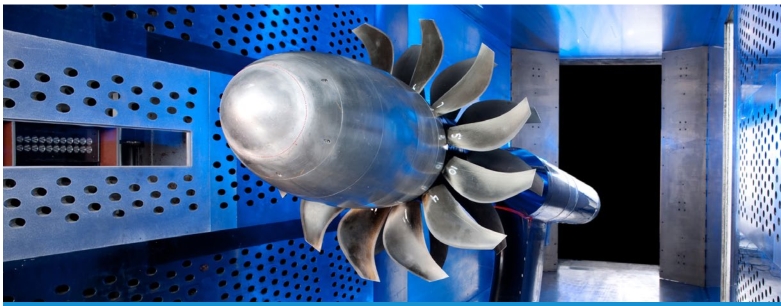
TECHNOLOGIES

Significant investments are being made to support the development of advanced foundational technologies and CFM has established a comprehensive roadmap with more than 300 separate component, module, and full-engine builds to test and mature technologies. Several rig tests have already been completed with promising results. CFM is on track for a full demonstrator engine ground test and flight tests by the mid-2020s.

The foundational technologies developed as part of this demonstration program can be incorporated into any type of architecture and will form the basis of any future CFM engine. They aim at further optimizing propulsive and thermal efficiencies, as well as integrate advanced systems.

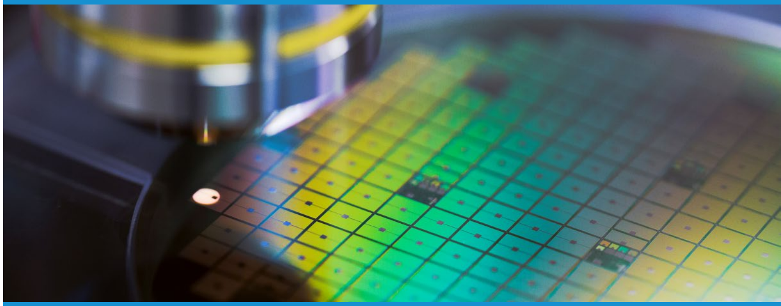
We have continued to advance the state of the art with carbon fiber composite fan technology since the GE90 first entered service in 1995. The RISE Program will benefit from more than 140 million flight hours of experience with composite fan blades on the GE90, GEnx, LEAP, and GE9X engine programs that all feature lightweight, highly efficient and durable fan blades. These are the only carbon fiber blades in commercial service.

These composite blades do not require a life limit.



Propulsive efficiency
Carbon fiber composite blades manufactured with a 3-D weaving process

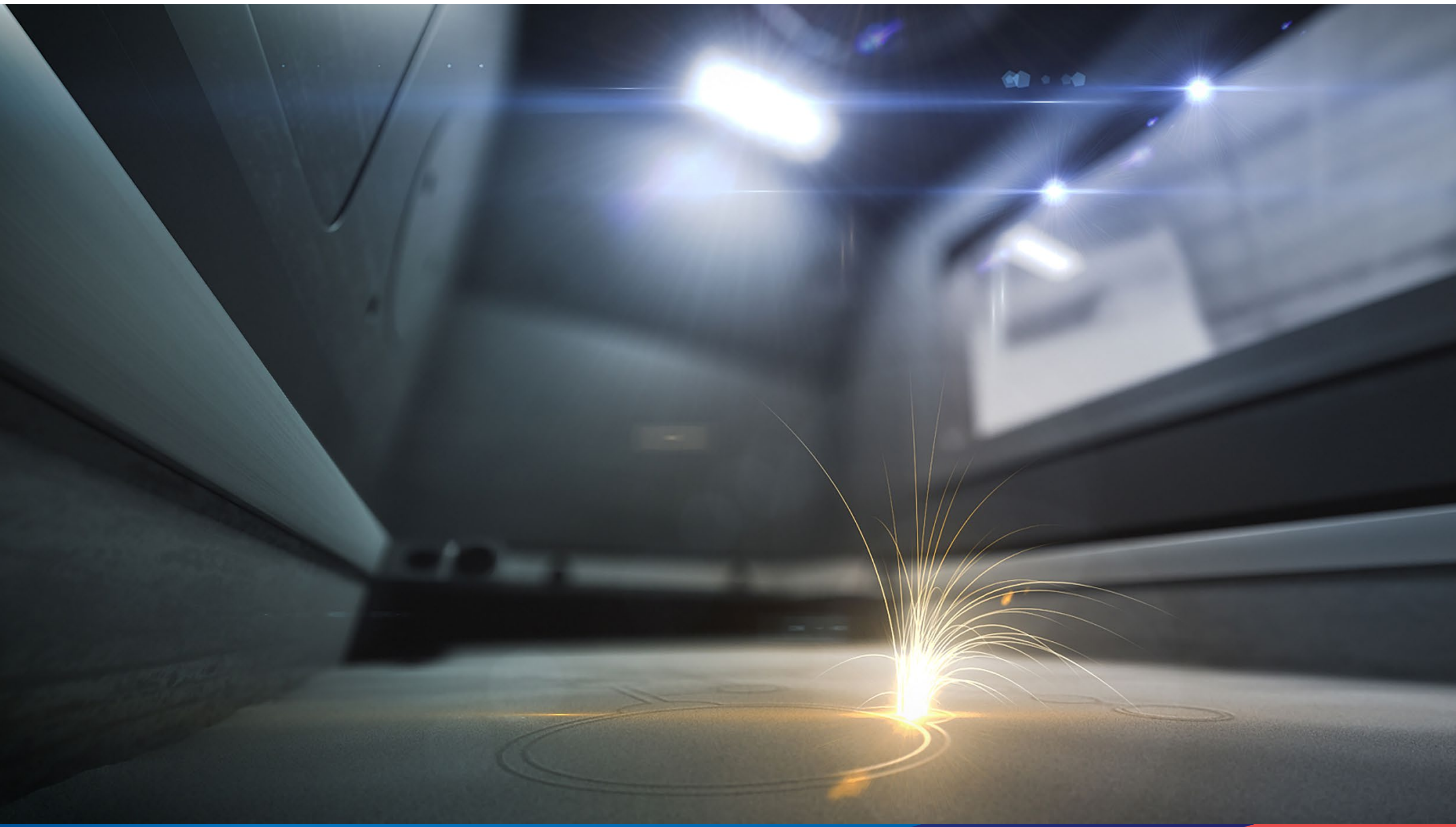
Thermal efficiency
Advanced metal alloys and ceramic matrix composites



Hybrid electric systems

Hybrid electric, the integration of gas-powered turbines and electrical-powered motors, is one of several key enabling technologies being matured to meet aviation industry goals to lower carbon emissions from air transport.

With the RISE Program, CFM is on track to be the first company to introduce hybrid electric in the single-aisle segment. GE and Safran are uniquely positioned to lead the industry's development of hybrid electric aircraft propulsion systems due to a legacy of electrical engineering expertise, world-leading experience in manufacturing, electrical power distribution and generation, and advanced materials research.



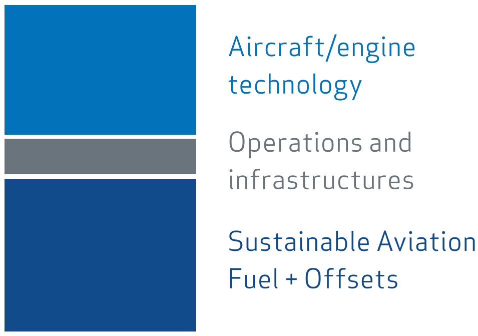
ALTERNATIVE ENERGY SOURCES

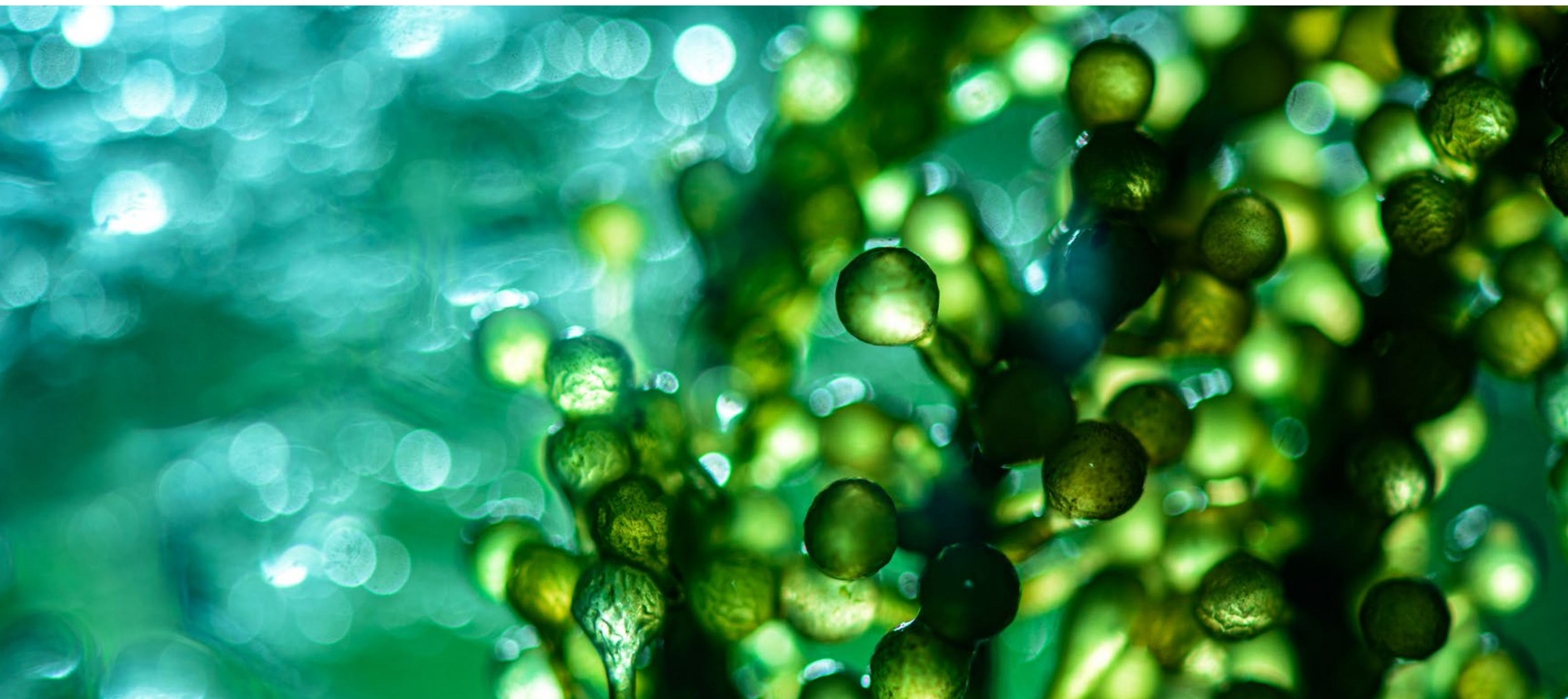
As part of the technology maturation program, the engineering teams will investigate the use of 100 percent Sustainable Aviation Fuels (SAF) and hydrogen.

Should these energy sources be approved by the aviation authorities, any future CFM engine will be compatible with the selected pathway(s).

CFM has done extensive ground and flight tests with SAF since 2006 and its customers have flown hundreds of thousands of commercial flights with the currently approved 'drop-in' SAF blends. We are working across the industry to assess the certification of 100 percent renewable fuels for current aircraft operating today with certified blends of up to 50 percent renewable fuels. Certification of 100 percent SAF would accelerate the reduction of CO_2 emissions for the fielded fleet when supported by global availability of synthetic fuels.

Contributors to meeting 2050 industry emission reduction goals





SUPPORTING RESEARCH PROGRAMS

CFM parent companies, GE and Safran Aircraft Engines, are committed to continuous investment to develop and mature new technologies. Their involvement in various research programs backed by government investment is crucial to ensuring the full maturation of the disruptive technologies required to meet industry sustainability goals.

For example, Safran Aircraft Engines and Avio Aero are among the main companies shaping how we could participate in the Clean Aviation European research program that will run from 2022 to 2028 and that includes ground and flight demonstrations.

GE Aviation works with NASA to advance technologies for aviation sustainability in addition to the Federal Aviation Administration (FAA), within the scope of the CLEEN (Continuous Lower Energy, Emissions and Noise) program.

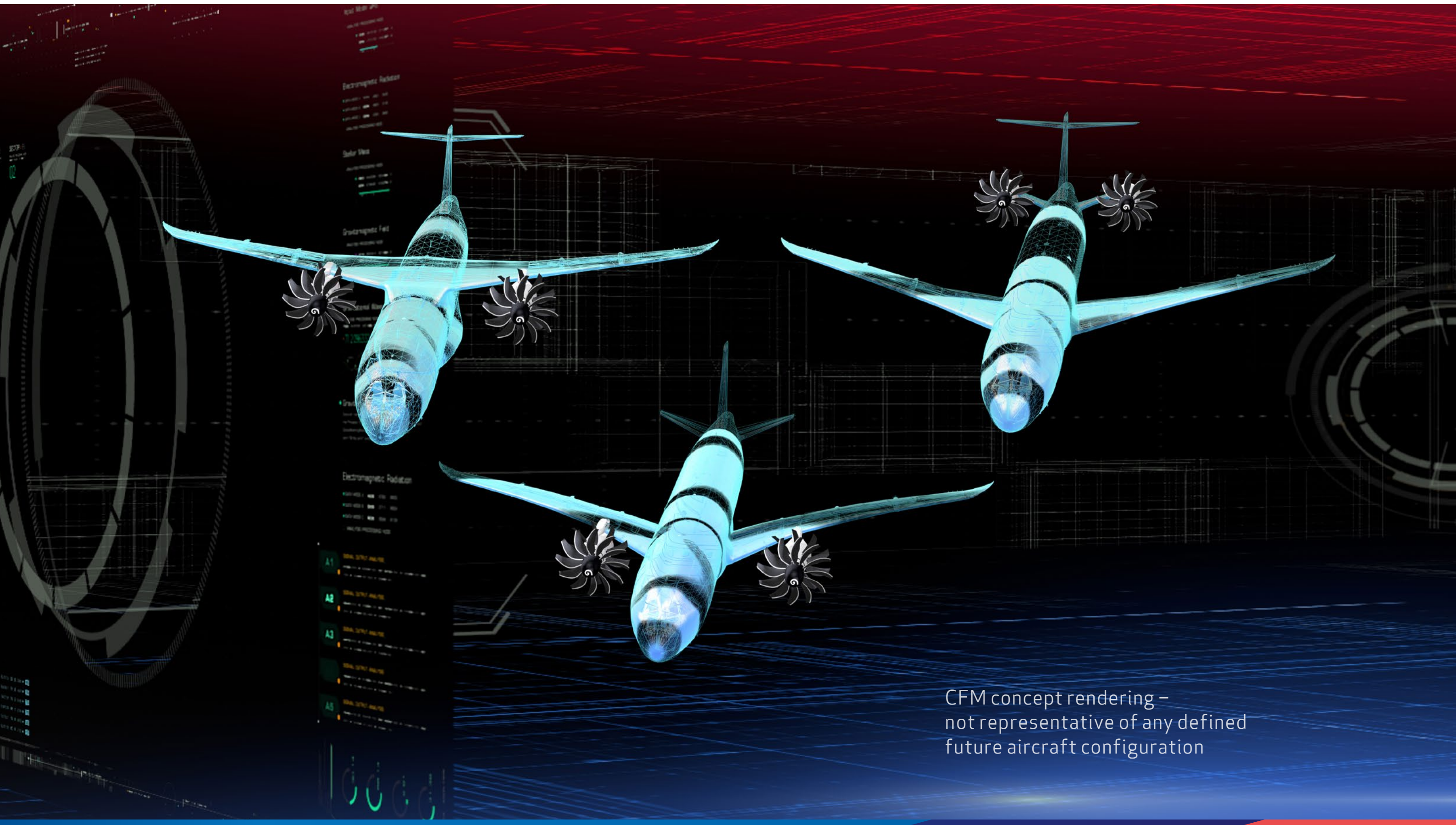
Both GE Aviation and Safran also have strong partnerships on technology development with national governments globally.

STRONG
technology development partnerships

AIRFRAME INTEGRATION

The technologies developed as part of the RISE program require closer integration with the aircraft manufacturers than ever before. Through a strong partnership with aircraft manufacturers, we can fully optimize installed performance of advanced architectures.

There are a variety of options for installing an open fan engine: under the wings in either a low- or high-wing configuration, or at the back of the aircraft.



CFM concept rendering –
not representative of any defined
future aircraft configuration

AVIATION INDUSTRY SUSTAINABILITY CONTEXT AND GOALS

The aviation industry was responsible for 915 million tons of CO_2 in 2019. While only 2 percent of the total human-induced CO_2 emissions, aviation is the fastest growing mode of transport, with aircraft traffic growth expected to triple carbon emissions by 2050, absent any advancements that decrease carbon production.

The International Air Transport Association (IATA), along with other industry partners, recognizes the need to address the global challenge of climate change and adopted the following targets to reduce CO_2 emissions from air transport:

- An average improvement in fuel efficiency of 1.5 percent per year from 2009 to 2020 (achieved)
- A cap on net aviation CO_2 emissions from 2020 (carbon-neutral growth)
- A reduction in net aviation CO_2 emissions of 50 percent by 2050, relative to 2005 levels

There will be many technology improvements introduced over the next decades to meet these ambitious goals, and the industry continues to explore more aggressive requirements.

WAY FORWARD

Discussions with aviation authorities have already started to ensure that all the relevant certification and regulatory elements are understood and agreed for open fan engines. CFM will proactively support the development of new certification methods as needed.

CONCLUSION

CFM has a clear ambition to achieve a step change in engine technology to address the longer-term sustainability of our industry. We also have a credible pathway to achieving that. Regardless of the path that aircraft manufacturers may take, the CFM RISE Program will demonstrate the foundational technology to address aircraft requirements and the development timeline. We are rising to the challenge.

APPENDIX

Propulsive efficiency

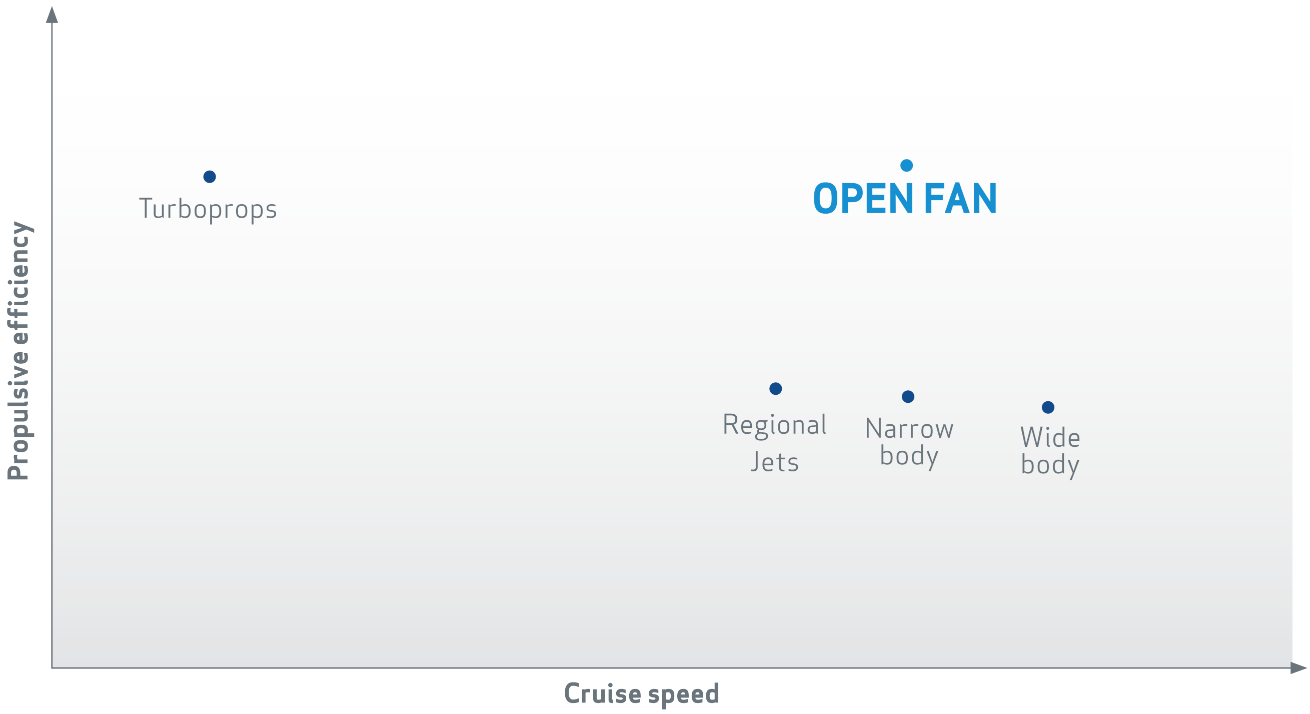
Propulsive efficiency reflects the proportion of the mechanical energy actually used to propel the aircraft.

Its formula is:

$$\eta_p = \frac{2}{1 + \frac{v_9}{v_0}}$$

Where v_9 is the exhaust velocity of the gases and v_0 is the aircraft airspeed.

The propulsive efficiency is maximized if the engine exhaust gas velocity is close to that of the aircraft. At the same thrust, it is more energy efficient to accelerate a large amount of air by a small amount than it is to accelerate a small amount of air by a large amount. Accelerating a large amount of air can be achieved by increasing the size of the fan blades. Open fan engines therefore provide much higher propulsive efficiency than traditional ducted engines.



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