Hybrid electric propulsion development for commercial aviation

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SUMMARY: Hybrid electric propulsion technologies can save fuel and optimize engine performance, helping the aviation industry reach its commitment of net-zero CO2 emissions from flight by 2050.

GE Aviation is committed to a more sustainable future of flight through the development of new, breakthrough technologies that improve aircraft engine fuel efficiency and reduce CO2 emissions. Hybrid electric-powered propulsion systems are key to this strategy. To that end, GE Aviation announced in 2021 a series of technology demonstration programs with hybrid electric capability, including research plans with NASA and through CFM International, a 50-50 joint company between GE and Safran Aircraft Engines.

With the announcement that NASA selected GE Aviation for its Electrified Powertrain Flight Demonstration (EPFD) project, GE is systematically maturing a megawatt (MW) class integrated hybrid electric powertrain to demonstrate flight readiness. Plans are to conduct ground and flight tests by the mid-2020s using a Saab 340B testbed, as well as GE's CT7-9B turboprop engines.

The partnership with NASA further advances GE Aviation's efforts to develop hybrid electric jet engine applications for single-aisle commercial aircraft. Including research studies beginning in 2009, GE Aviation has been deliberately maturing and testing components of a hybrid electric system for more than a decade –the motor/generator, converters and more. For example, GE engineers tested a motor-driven propeller in 2016 and an electric machine in altitude conditions in 2019. Eventually, the NASA demonstrator will lay the foundation for new GE Aviation engine designs and products with hybrid electric capability, with learnings to be incorporated in future technology demonstrations.

GE Aviation hybrid electric technology maturation

- **2015-2016: F110 engine power generation**
- **2016: First generation electric machine demonstration**
- **2017-2018: Power integration system test**
- **2019: Second generation electric machine ground and altitude test**
- **2020: Third generation power converter ground and altitude test**

Robust system ground and altitude maturation tests underway to demonstrate flight readiness

Also in 2021, GE Aviation and Safran Aircraft Engines announced the CFM RISE Program to demonstrate and mature a range of new, disruptive technologies for future engines that could enter service by the mid-2030s. Goals include reducing fuel consumption and CO2 emissions by more than 20 percent compared to today's most efficient engines, as well as ensuring 100 percent compatibility with alternative energy sources such as Sustainable Aviation Fuels and hydrogen. The program will also use hybrid electric capability to optimize engine efficiency while enabling electrification of many aircraft systems, incorporating learnings from the NASA EPFD effort.

CFM RISE technology demonstration program

Targeting more than 20% lower CO2 emissions

- Advancing open fan architecture
- Propulsive efficiency step change
- Same speed & cabin experience
- Ground and flight tests mid-2020s
- Advanced materials
- Hybrid-electric capability
- Additive manufacturing
- 100% SAF, hydrogen capability
- EIS by mid-2030s

Revolutionary Innovation for Sustainable Engines

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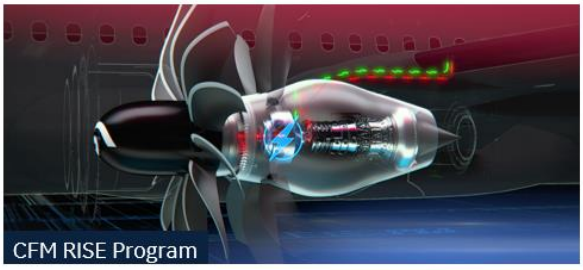
GE Aviation hybrid electric ground and flight test program

Flight demonstration mid-2020s

- Modified Saab 340B testbed powered by GE CT7 engines
- GE-Boeing partnership to support flight tests
- Feasibility and reliability of hybrid electric propulsion system

Future engine designs

- Hybrid electric compatible with Sustainable Aviation Fuel and hydrogen
- Demonstrator informs future GE engine product designs with hybrid electric capability



More electric future of aviation propulsion

RISE is a trademark of CFM International, a 50-50 joint company between GE and Safran Aircraft Engines.

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Aviation industry CO2 reduction goals

The aviation industry's climate impact of 915 million tons of CO2 emissions in 2019 represents about 2% of total human-induced CO2 emissions. However, the industry association Air Transport Action Group (ATAG) forecasts that distance traveled by paying passengers is expected to grow at a compounded growth rate of 3.1% a year from 2019 to 2050.

To address the global challenge of climate change, members of ATAG, including GE Aviation, have adopted the following targets to reduce CO2 emissions from air transport:

- Carbon neutral growth from 2020 through implementation of the International Civil Aviation Organization's (ICAO) Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA), a program where international aviation CO2 emissions beyond 2019 levels must be offset.
- Net-zero CO2 emissions by 2050. Meeting the long-term net-zero goal requires the industry to deploy revolutionary technologies to reduce emissions such as hybrid electric propulsion and to advocate for increased use and availability of alternative fuels, such as Sustainable Aviation Fuel (SAF) and hydrogen.

GE and CFM International are members of ATAG, with representation on its board of directors. ATAG works closely on aviation and environment issues with the International Civil Aviation Organization (ICAO), a United Nations specialized agency. GE Aviation is active in ICAO's Committee on Aviation Environmental Protection (CAEP), which assists the ICAO Council in formulating new policies and adopting new Standards and Recommended Practices (SARPs) related to aircraft noise and emissions and aviation environmental impacts.

The U.S. Aerospace Industries Association announced a similar commitment for commercial aviation manufacturers to work with airline customers and governments globally to achieve net-zero carbon emissions by 2050.

The European Commission is also on an ambitious trajectory to reduce CO2 emissions from flight. While governments work on legislative proposals, the European aviation industry issued Destination 2050, a report supported by GE Aviation, announcing a pathway to net-zero CO2 emissions by 2050 and a 55% reduction by 2030 compared to 1990 levels.

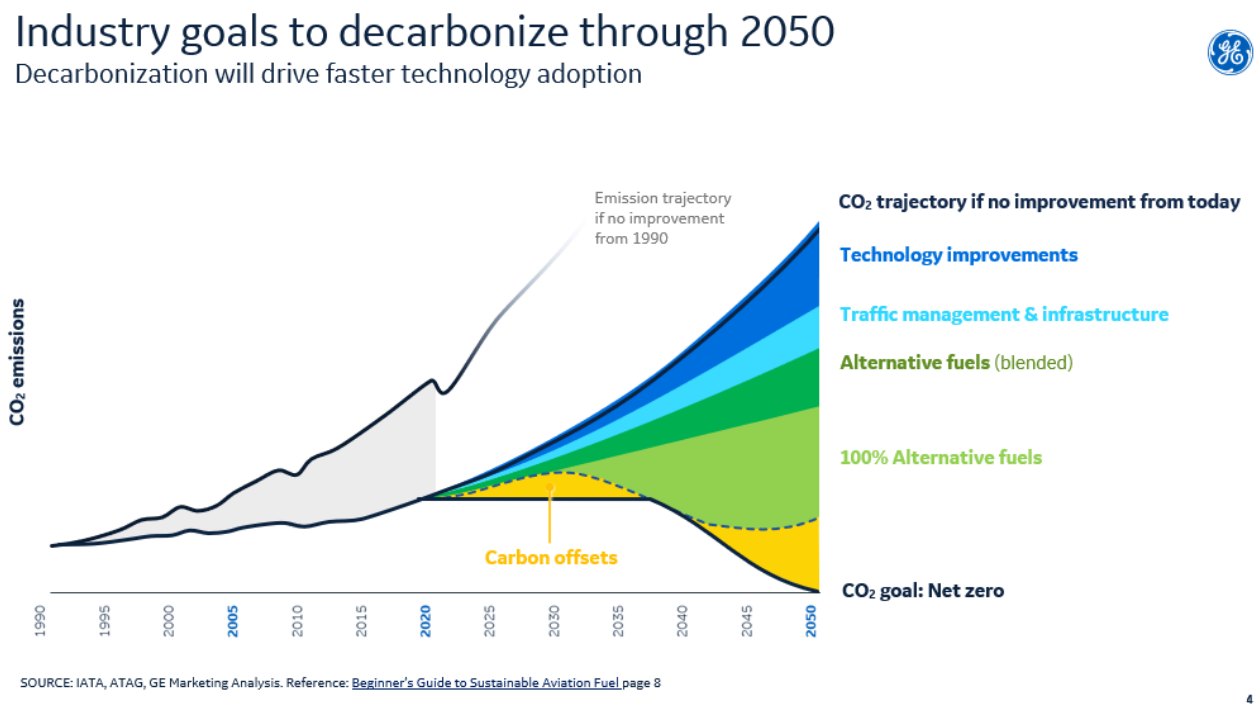
GE's goal is to be carbon neutral in our facilities and operations by 2030. Plans are to reach most of the progress toward the 2030 goal through absolute reductions of direct emissions and energy use achieved through:

- Energy efficient infrastructure investments;
- Reviewing purchasing strategies for their impact;
- Evaluating facility energy contracts for smarter power and energy sources;
- Using lean practices to identify and eliminate waste; and
- Exploring the use of SAF in engine test cells.

GE also announced an ambition to be a net zero company by 2050—encompassing not just GE's

operations, but also Scope 3 emissions associated with the use of our sold products.

To address this challenge to reduce CO2 emissions in flight, GE Aviation has embarked on multiple engine technology demonstrators to accelerate emissions-lowering technologies for aircraft propulsion. Examples include the CFM RISE* (Revolutionary Innovation for Sustainable Engines) Program in partnership with Safran Aircraft Engines and the EPFD project with NASA. Additionally, GE has been actively involved in assessing and qualifying SAF since 2007 and works closely with SAF producers, regulators, and operators to ensure that SAF can be widely adopted for use in aviation.



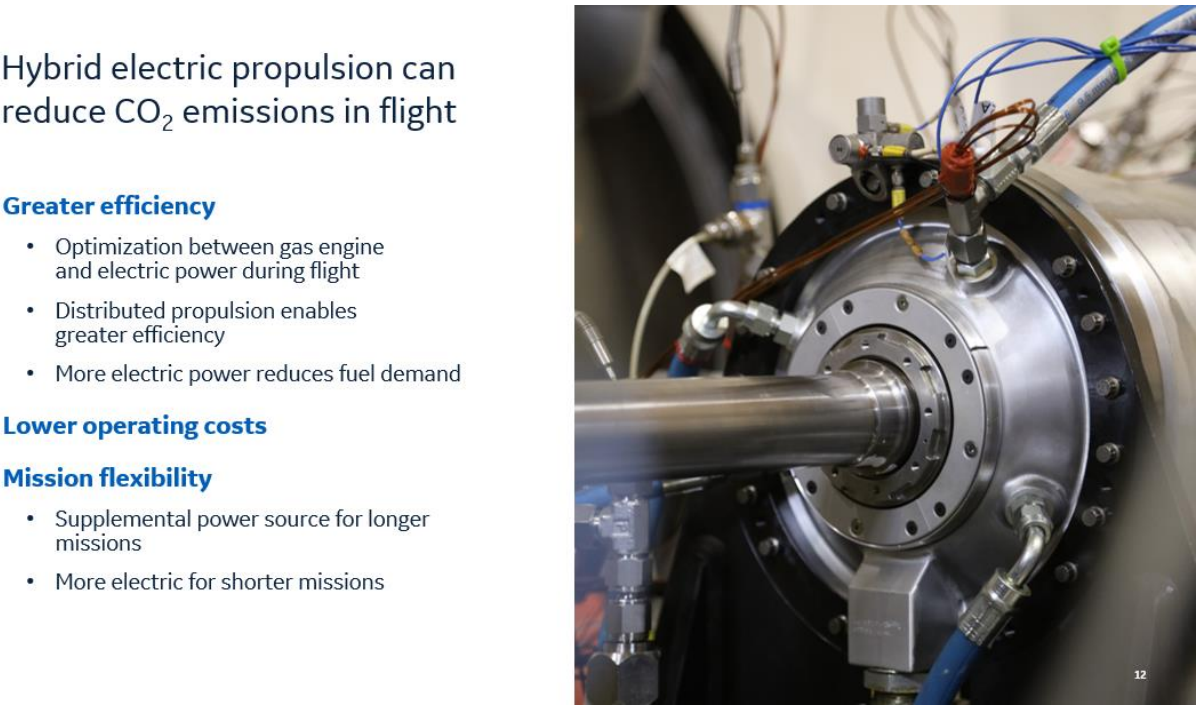
Electrified Powertrain Flight Demonstration (EPFD) project

On September 30, 2021, NASA announced a new research partnership with GE Aviation to launch a hybrid electric technology demonstrator program. Plans are to conduct ground and flight tests of a megawatt (MW) class hybrid electric propulsion system by the mid-2020s.

The hybrid electric technology will be flight tested with a modified Saab 340B testbed and GE's CT7-9B turboprop engines.

As part of NASA's EPFD project, a total $260 million will be invested by NASA, GE Aviation and partners over five years to accelerate the introduction of hybrid electric flight technologies for commercial aviation. After years of maturing individual components of a hybrid electric system—motors, generators and power converters—GE will systematically mature an integrated hybrid electric powertrain to demonstrate flight readiness for single-aisle aircraft.

Hybrid electric propulsion technologies that save fuel and optimize engine performance are key to GE's commitment to help develop a more sustainable future of flight. GE Aviation's ambition is for its products to have net zero emissions by 2050 and hybrid electric engines will help achieve this target. Hybrid electric technologies are highly compatible with SAF and hydrogen, as well as advanced engine architectures such as the open fan and new advanced engine core designs.



In partnership with NASA on the EPFD program, GE will also provide guidance and data to establish standards and certification and regulatory requirements for hybrid electric engines.

As the program has kicked off, GE Aviation announced in 2022 the selection of two companies to support its EPFD contract.

Boeing has been selected to support flight tests of the hybrid electric propulsion system. Boeing and its subsidiary Aurora Flight Sciences will provide GE Aviation with airplane modification, system integration and flight-testing services. That work includes nacelle manufacturing, flight deck interface design and software, aircraft-level performance analysis, and systems integration. Aircraft systems engineering and testing work will be based at Aurora's headquarters in Manassas, Va., with nacelle manufacturing taking place in its facilities in Mississippi and West Virginia.

BAE Systems has been selected to design, test and supply energy management components for GE. For this demonstration program, BAE Systems will provide the battery and related cabling used to store electricity and drive the motor/generator GE Aviation is building, controlled by GE's power electronics.

In addition to energy storage, BAE Systems will provide the high-integrity controls and cables for this demonstrator's power management system, which will be tested on CT7-9B turboprop engines. The company will also leverage its investment in aircraft electrification and expertise in flight-critical systems to provide guidance for flight certification requirements.

The EPFD contract builds on GE Aviation's extensive experience with hybrid electric systems and electrical power generation, as well as extensive research and flight component development capabilities at GE Research and GE Power. Key GE milestones include:

- **2009:** Participating in the Boeing Subsonic Ultra Green Aircraft Research (SUGAR) study. The NASA request was to identify aircraft technologies that would lower emissions and reduce fuel consumption for future aircraft flying after 2030. The team evaluated hybrid electric propulsion systems.

- **2013:** Opening the EPISCenter (Electrical Power Integrated Systems Center) in Dayton, Ohio, a dedicated facility for developing and testing electric power components and systems for aircraft.

State-of-the-art test and system integration facility

Electrical power systems headquarters: Dayton, Ohio (6 global facilities)
Specifications: End-to-end testing across power system, 155,000+ sq. ft., 2 high bays, 6 drive cells ~1,000-3,000 horsepower
Capabilities: Testing 6 aircraft electrical power systems simultaneously ... 15 megawatts of available power

Opened in 2013, GE's EPIScenter is a world-class, tier 1 test facility for hybrid electric systems

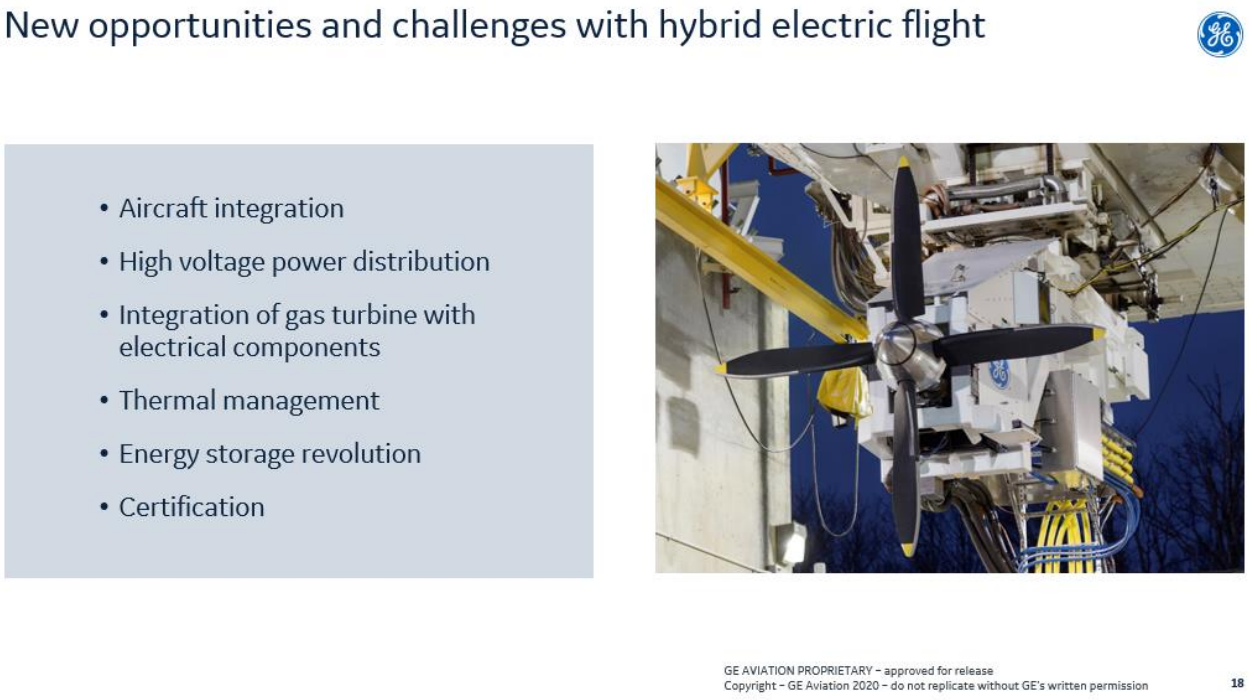
Source: GE Aviation

- **2015:** Successfully extracting one MW of electrical power with an F110 engine in a ground-level test cell, followed by a 2016 demonstration of MW power extraction at flight-representative altitude conditions.

- **2016:** Demonstrating an electric machine consisting of a MW class motor/generator, electrically powering an 11-foot diameter propeller on a test stand.

- **2019:** Demonstrating a MW class motor/generator at altitude conditions up to 36,000 feet at NASA's Electric Aircraft Testbed (NEAT) facility in northern Ohio. GE believes this to be the world's first power dense, MW and kilovolt class electric machine tested at flight-representative conditions.

Our systems business has designed and manufactured power conversion, distribution, and control systems for commercial aircraft for over 30 years. GE Aviation Systems continues to advance these products with technology including GE-developed silicon carbide transistors to increase efficiency, power density, thermal performance and reliability. These technologies are integral to the development of GE Aviation's hybrid electric powertrain demonstrator with NASA.

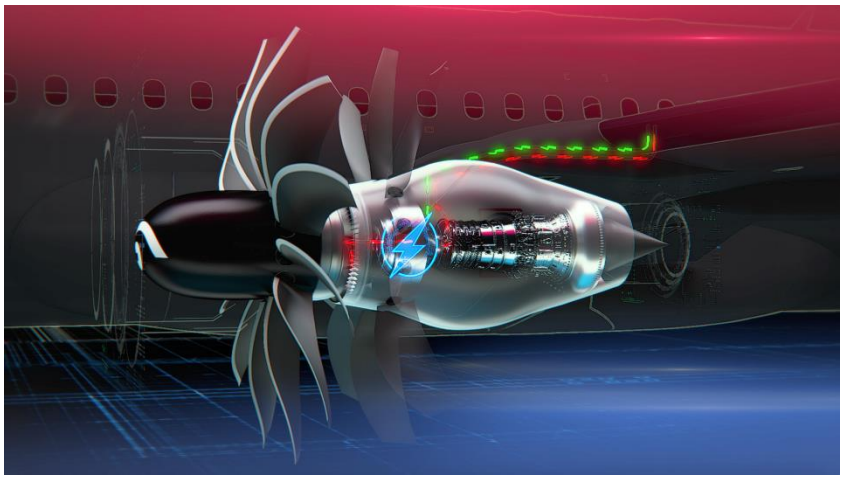


CFM RISE Program

GE Aviation and Safran in June 2021 announced the launch of a bold technology development program targeting more than 20 percent lower fuel consumption and CO2 emissions compared to today's engines. The CFM RISE (Revolutionary Innovation for Sustainable Engines) program will demonstrate and mature a range of new, disruptive technologies for future engines that could enter service by the mid-2030s.

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 CO2 emissions by more than 20 percent compared to today's most efficient engines, as well as ensuring 100 percent compatibility with alternative energy sources such as Sustainable Aviation Fuels and hydrogen.

Central to the program is state-of-the-art propulsive efficiency for the engine, including developing an open fan architecture. This is a key enabler to achieving significantly improved fuel efficiency while delivering the same speed and cabin experience as current single-aisle aircraft. The program will also use hybrid electric capability to optimize engine efficiency while enabling electrification of many aircraft systems.



The program is being led by a joint GE/Safran engineering team that has laid out a comprehensive technology roadmap including composite fan blades, heat resistant metal alloys, ceramic matrix composites (CMCs), hybrid electric capability and additive manufacturing. The RISE program includes more than 400 separate component, module and full engine builds. A demonstrator engine is scheduled to begin testing at GE and Safran facilities around the middle of this decade and flight test soon thereafter.

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