Sustainability and Climate-Neutral Aviation

What will it take for the aviation industry to achieve carbon neutrality by 2050?

This white paper reviews the technical and environmental differences between jet engines powered by kerosene and some of today's leading alternative propulsion systems. It continues to explore how these factors are transforming the design of next-generation aircraft and the aviation supply chain as we know it. Then, it explains how digitalization supports sustainability strategies that fit the world's timeline for the rise of sustainable aircraft.

The United Nations Framework Convention on Climate Change (UNFCCC) has put all the world's industries under the microscope, but none more so than transportation. While much of the attention around greenhouse gas emissions focuses on automobiles, there is another huge contributor to the problem looming just over our heads.

Globally, aviation currently accounts for 4.9% of the CO2 and non-CO2 emissions adversely impacting climate change1. The industry is already taking steps to reduce emissions and improve aircraft fuel efficiency, but to meet goals set forth by the Paris Agreement of carbon neutrality by 2050, those efforts won't be enough (Figure 1).

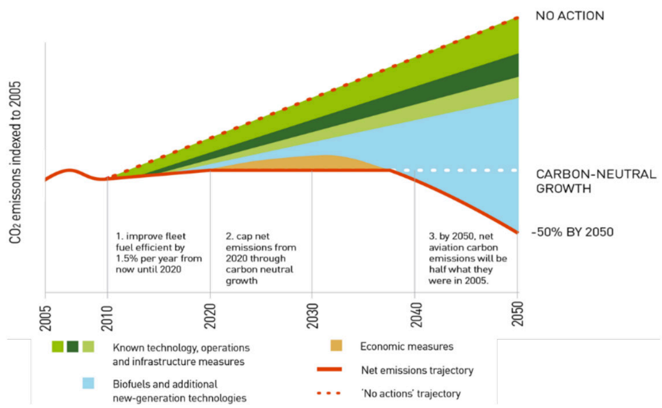

Figure 1. Meeting UNFCCC emissions goals will require that the aviation industry transition away from jet engines powered by hydrocarbons to drive propulsion systems fueled by alternative energy sources that are climate neutral. (Source: [Aircraft Technology Roadmap to 2050, IATA](#))

It's now clear that carbon-neutral aviation will be achieved through alternative fuel sources such as biofuels and electric power, which will require a complete architectural redesign of today's aircraft.

The Evolution of Today's Aircraft Configurations

The term "aircraft configuration" can refer to an aircraft's aerodynamic layout, including the relative size and shape of the body, wings, and associated control surfaces. It also includes the organization of the aircraft's interior space, such as the number and arrangement of passenger seats.

Many factors affect both aspects of an aircraft's configuration, the most important of which is the way its engines are powered. To date, the most significant advances in airplane design have been driven by the invention of the jet engine, the development of which commenced in the 1930s.

The most successful of the early commercial jet airliners was the Boeing 707, which first flew in December 1957. The initial, 145-foot-long 707-120 was powered by four Pratt & Whitney JT3C turbojet engines, which were the first 10,000 lb force (lbf) thrust-class engines in the United States.

Although jet engines have grown more powerful over the years resulting in larger aircraft that can carry more passengers over longer distances (the Airbus A380, for example, which is powered by four Engine Alliance GP7200 or Rolls-Royce Trent 900 turbofan, has a maximum certified capacity of 853 passengers and a range of 8,000 miles), there have been few changes in fundamental commercial aircraft configurations since the late 1950s – while advances in engine technology have made them less emissive and new structures have made aircraft lighter, in essence even the most modern commercial planes inherit their configurations from the Boeing 707.

It must be acknowledged that the incredible success of jet-engine-powered aircraft has transformed transportation (both people and cargo), powered the global economy, and connected societies. It is currently estimated that approximately 500,000 people are in the air at any one time, with around 6 million flying somewhere every day. Furthermore, the most recent estimates suggest that demand for air transport will increase by an average of 4.3 percent per annum over the next 20 years2.

All of this is due to the power density offered by jet engines. In fact, some people refer to jet engines as being "the kings of power density." However, it also must be acknowledged that the power density of jet engines comes at a high cost in the form of carbon and other emissions3.

Next-Generation Aircraft Propulsion Systems

Governments and people are becoming increasingly aware of the forthcoming problems associated with climate change, and this has driven extensive research into alternatively fueled aircraft propulsion systems over the last 5 to 10 years.

As opposed to using fossil fuels, synthetic fuels can be created using renewable energy sources by extracting hydrogen from water and carbon from CO2 to produce a liquid fuel, for example. Such synthetic fuels have the advantage of not containing impurities like sulfur, but they still release carbon into the atmosphere. However, their production can be climate neutral.

Traditional aviation fuel is kerosene with an energy density of ~40 MJ/kg. But the highest energy density fuel is hydrogen, which is also the simplest chemical component known to exist. Due to the way it is produced, and the relative inefficiencies of its production using current technologies, hydrogen is more expensive than fossil fuels. The big advantage of hydrogen is that the waste product from burning it in aircraft engines is water. According to a recent report from the European Commission, hydrogen-powered planes could enter the market as soon as 20354.

Hydrogen is very light compared to kerosene and—with an energy density of ~120 MJ/kg—packs three times as much power per unit of mass. However, in addition to the problems associated with storing liquid hydrogen that come with the potential for catastrophic explosion in the event of a crash, four times the volume of kerosene to achieve the same result.

Alternatively, hydrogen fuel cells can be used to generate the electricity used to power electric or hybrid-electric motors. The main advantages of electric aircraft are lower noise and zero emissions during flight, although the manufacturing and recycling of batteries must be factored into the overall environmental impact assessment. The main disadvantage is electric motors don't provide anywhere near the same power density as jet turbines. For example, the current state-of-the-art in electric motors used for aircraft propulsion deliver power density on the order of 10-15 kW/kg, though this is expected to increase in the future as new materials and techniques become available.

New Energy Sources Will Disrupt the Aviation Industry

Although every alternative to kerosene-powered jet engines has its own issues, environmental concerns dictate that aircraft must transition away from fossil fuels. This will, of course, disrupt the aviation industry.

The power density offset of alternative energy sources results in the need for more stored energy in the form of batteries or hydrogen fuel cells, with the latter also requiring cryogenic systems to store liquid hydrogen.

These new power sources will also result in revolutionary new aircraft configurations since the power source will be stored in the body of the plane rather than the wings (as it currently is with kerosene-fueled aircraft). Additionally, in the context of efficient flight, future aircraft may have very long, slender wings, which would be more prone to a fluttering type of phenomena.

Another possibility is a blended wing aircraft in which the wings and fuselage are blended into a single entity. In this case, the entire aircraft provides the lift required for flight, which is why this design is also referred to as a "flying wing." A big advantage of a flying wing configuration is that the increased fuselage space can be used for carrying payloads, including cargo and passengers along with batteries and/or hydrogen fuel cells.

Of course, all these developments will also affect ground-based infrastructure like airports and airport terminals, which will have to be modified to accommodate the new physical configurations and support new fueling requirements like the high-voltage/high-current electric charging stations to charge battery-powered aircraft.

None of this will be cheap or easy. Using a standard commercial jet liner as a very loose proxy, creating a new aircraft from design proposal to flight will take at least 10 years, cost many billions of dollars in non-recurring expenses (NRE) on the aircraft itself, and require the entire component supply chain to be redefined.

This represents a nearly complete overhaul of the entire aviation industry. When combined with the rigorous testing and certification processes required to develop and deploy a new commercial aircraft, this means that long-haul carbon-neutral airliners probably won't be seen in the skies until the 2040s or later. Having said this, smaller electric motor-powered aircraft used for shorter-range flights are much closer to coming online.

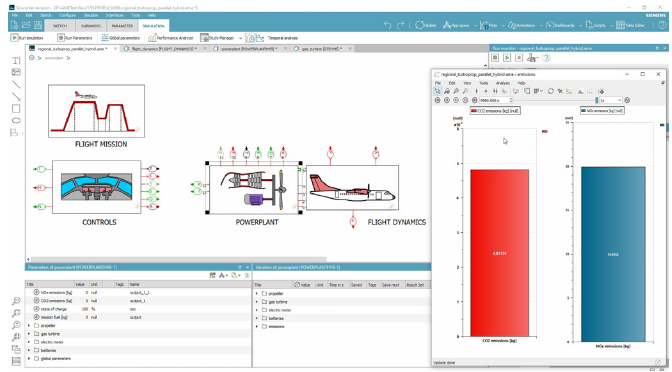

Figure 2: Simcenter Amesim allows engineers to perform trade-off studies between different propulsion systems configurations driven by a variety of energy vectors.

As just one example, Bye Aerospace5 specializes in the design and manufacture of electric aircraft, including light aircraft for flight training. At the time of this writing, Bye Aerospace has two electric aircraft projects underway that are advancing toward Federal Aviation Administration (FAA) aircraft certification, one being the two-seat eFlyer 2 training aircraft, which was designed using tools from Siemens.

Digitally Defining Next-Generation Aircraft Configurations

A key element in creating successful next-generation aircraft and propulsion systems is the use of digitalization and digital twins, which are virtual replicas of physical devices that can be used to run simulations before actual devices are built and deployed.

Unfortunately, deploying new propulsion technologies and integrating them into existing aircraft can be difficult for companies that are new to this arena. To address this, Siemens offers tools and technologies like Xcelerator6 and Simcenter7.

Siemens Xcelerator reduces the complexity of product development by providing a portfolio of software, a growing ecosystem of developers and partners, and a marketplace for technology solutions that will evolve over time. Part of the Siemens Xcelerator portfolio, Simcenter is a flexible, open, scalable portfolio of the best predictive simulation and test applications that provide critical data and engineering insights for scientists and engineers at every phase of the aviation engineering process.

With Simcenter, next-generation aircraft engineers can:

- Predict aircraft performance using comprehensive digital twins
- Make engineering decisions earlier in the concept phase
- Gain early insights into integrated aircraft behavior
- Optimize designs and innovate faster and with greater confidence
- Interconnect and manage scalable models for Agile product development, model-based systems engineering (MBSE), and verification processes

Digitalization tool suites like the Siemens Xcelerator portfolio and the Siemens Simcenter simulation and testing solutions provide an integrated design environment for multi-disciplinary aerospace engineering teams, helping them model, analyze, and test the impact of alternative energy sources and propulsion on future aircraft configurations.

From the component level to the entire integrated aircraft, Simcenter supports electric and hybrid-electric system design using Agile product development and engineering. The simulation and testing solutions help reduce overall development costs and streamline the process of securing necessary certifications.

Simcenter reduces the risk of developing hydrogen fuel cells or hydrogen-fueled gas turbines by allowing multi-disciplinary aerospace engineering teams to simultaneously address challenges related to energy storage, distribution, and conversion as well as electrical, thermal, and structural integration from a single, comprehensive environment. It also enables the modeling of lighter airframes with improved aerodynamics, allowing design teams to make iterative engineering decisions that optimize overall efficiency and sustainability without compromising safety (Figures 3, 4).

Figure 3. Simcenter models of new aircraft configurations allow engineers to analyze innovative aerodynamic and structural architectures while producing artifacts needed for certification.

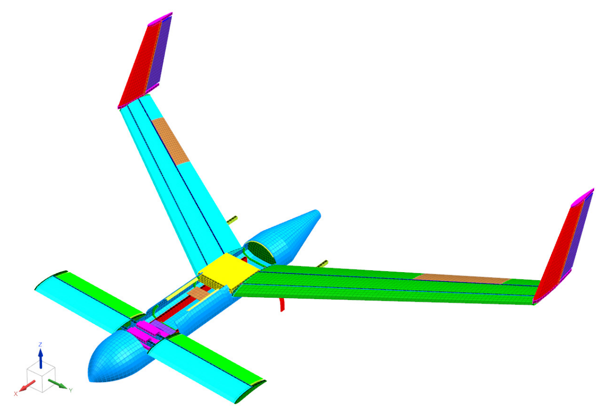

Figure 4. Simcenter helps build proof of compliance using virtual and physical testing artifacts.

Models created in Simcenter can also be used for virtual testing that combines with physical test procedures to provide essential proof of compliance data for the mission-critical certification process. For instance, mechanical engineers at the German Aerospace Center use Simcenter for the modeling and simulation of battery-powered eVTOL aircraft like the Volocopter VoloCity, which allows for the urban air taxi to be certified before first flight (Video 1).

Video 1. *Engineers at the German Aerospace Center use Siemens Simcenter to create data-driven modal models that allow sustainable aircraft like the Volocopter VoloCity urban air taxi to be certified before first flight.*

Sustainable Flight Starts Now

Now is the time to start preparing for a sustainable aviation industry, which requires a pincer movement of technology and environmental social governance to achieve the objectives laid down by organizations like the UNFCCC and the International Air Transport Association (IATA).

Xcelerator and Simcenter from Siemens supports the digitalization efforts the aerospace industry must undergo to achieve more sustainable air travel.

For more on this topic, read Innovate Future Aircraft: Rethinking Next-Generation Aircraft Engineering

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