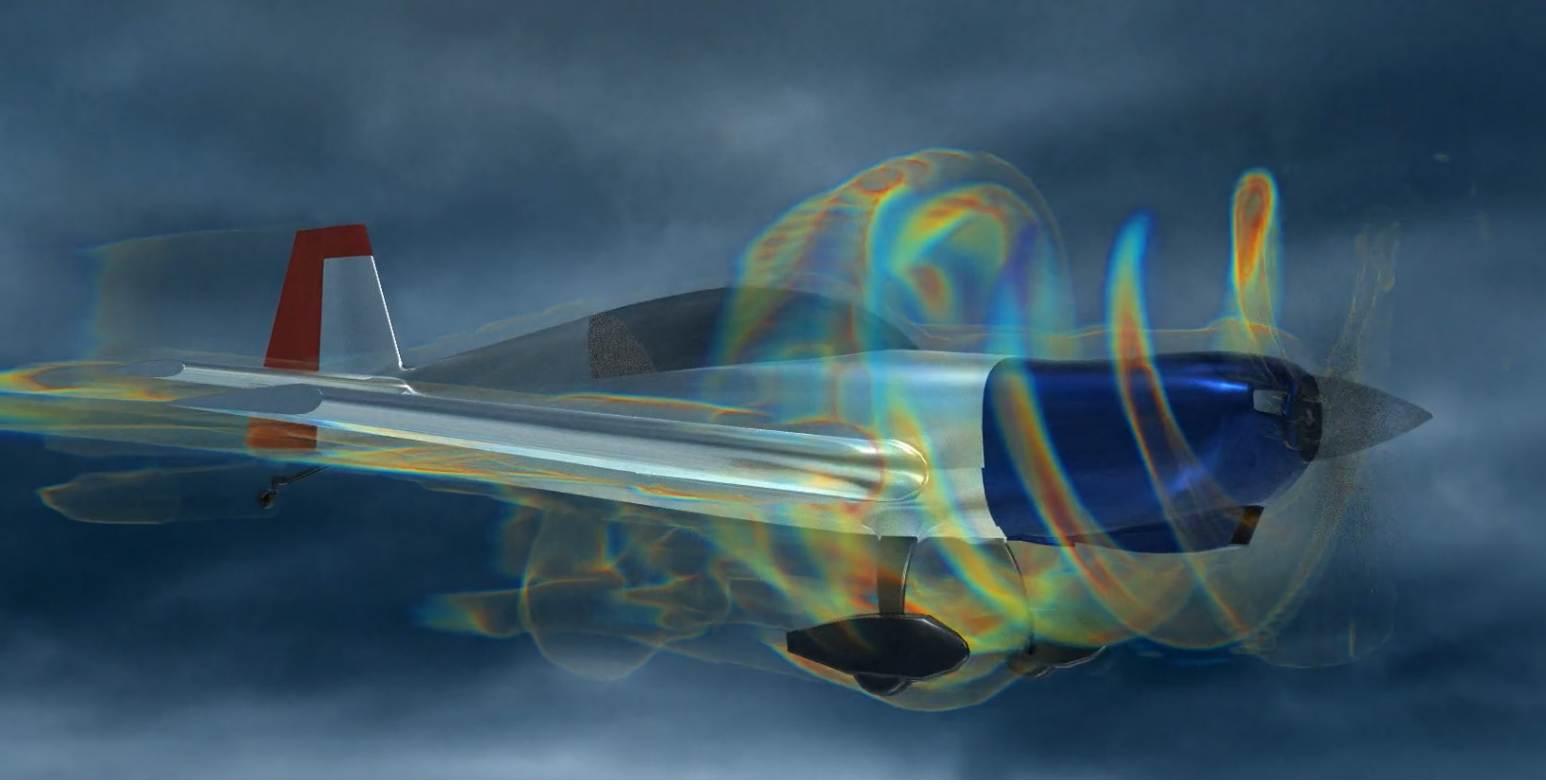

DIGITAL INDUSTRIES SOFTWARE

Shaping sustainable aviation with a digital twin

What it will take for the aeronautics industry to achieve climate neutrality by 2050

Executive summary
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 explores how these factors are transforming the design of next-generation aircraft and the aviation supply chain. Then it explains how leveraging digitalization using Simcenter™ software can support sustainability strategies that fit the world's timeline for the rise of green aircraft.

Introduction

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. Although 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 percent of the carbon dioxide (CO_2) and non-CO_2 emissions that fuels climate change.[1] 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).

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.

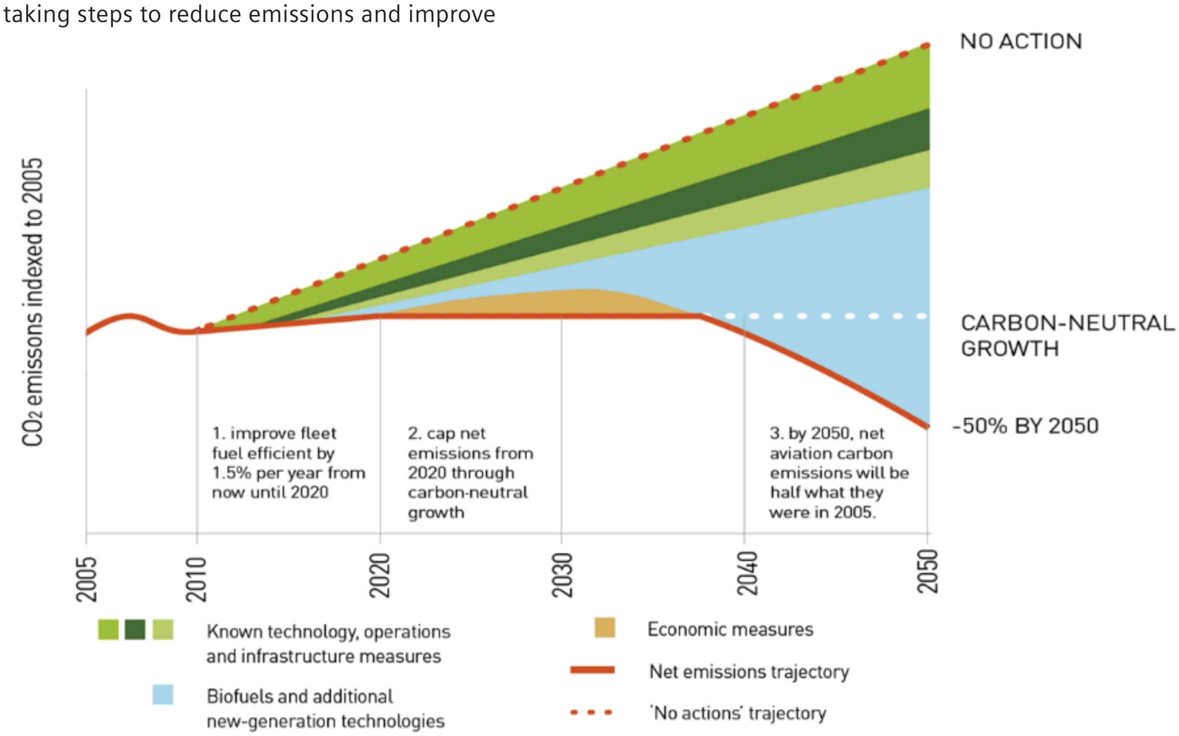

Figure 1. Meeting UNFCCC emissions goals will require the aviation industry to transition away from jet engines powered by hydrocarbons to drive propulsion systems with alternative energy sources that are climate-neutral. (Source: Aircraft technology roadmap to 2050, International Air Transport Association)

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, which was developed starting 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-pound force (lbf) thrust-class engines in the United States.

Although aircraft 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 the Rolls-Royce Trent 900 turbofan, which has a maximum certified capacity of 853 passengers and a range of 8,000 miles), there have been few fundamental changes to the original commercial aircraft configurations since the late 1950s. Aircraft pollute less due to advances in engine technologies and they are lighter due to the development of new materials, but in essence the aircraft configuration of the most modern commercial planes inherit their configuration from the Boeing 707.

It must be acknowledged that the incredible success of jet-engine-powered aircraft has transformed transportation (both for people and cargo), powered the global economy and connected societies. It is 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 years.[2]

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 emissions.[3]

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 five to 10 years.

For example, instead of using fossil fuels, synthetic fuels can be created using renewable energy sources by extracting hydrogen from water and carbon from CO_2 to produce a liquid fuel. Such synthetic fuels have the advantage of not containing impurities like sulfur, but they still release carbon into the atmosphere. However, its production might be climate-neutral.

Traditional aviation fuel is kerosene with an energy density of ~40 megajoules per kilogram (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 producing it using current technologies, hydrogen is more expensive than fossil fuels. The big advantage of hydrogen is 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 2035.[4]

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 a catastrophic explosion in the event of a crash, it takes 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 to 15 kilowatts per kilogram (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 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.

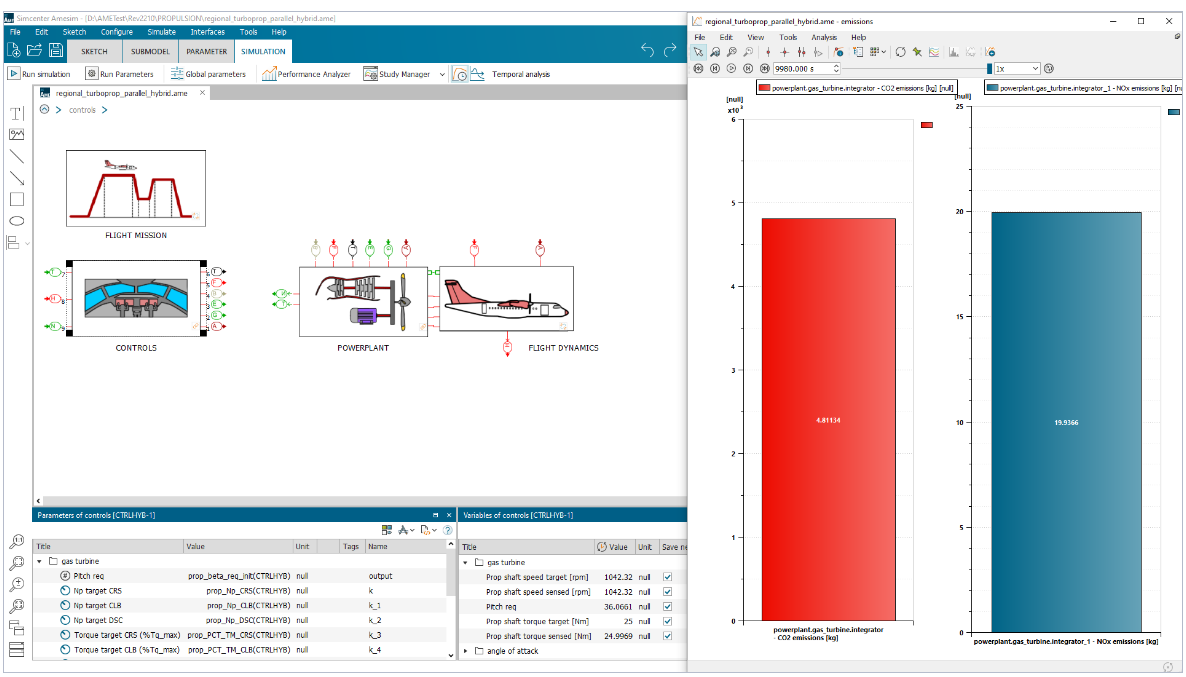

Figure 2. Using Simcenter Amesim allows engineers to perform tradeoff studies between different propulsion system configurations driven by a variety of energy vectors.

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 nonrecurring 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 associated with developing and deploying 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. However, smaller electric motor-powered aircraft used for shorter-range flights are much closer to coming online.

As just one example, Bye Aerospace[5] specializes in the design and manufacture of electric aircraft, including light aircraft for flight training. Bye Aerospace has two electric aircraft projects well underway targeting Federal Aviation Administration (FAA) aircraft certification, one being the two-seat eFlyer 2 training aircraft, which was designed using Siemens Digital Industries Software tools.

Digitally defining next-generation aircraft configurations

A key element in creating successful next-generation aircraft and propulsion systems is the use of digitalization and a digital twin, which is a virtual replica of a physical device that can be used to run simulations before the device is 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 such as Simcenter,[6] which is part of the Siemens Xcelerator portfolio,[7] the comprehensive and integrated portfolio of software, hardware and services.

Using Siemens Xcelerator reduces the complexity of product development not only by providing a portfolio of software, hardware and services, but also with a growing ecosystem of developers and partners and a marketplace for technology solutions that will evolve over time. Simcenter is a flexible, open and scalable portfolio of best-in-class predictive simulation and testing solutions that support scientists and engineers at every step in their development journey.

The Siemens Xcelerator portfolio and 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 secure certification. Using Simcenter provides essential proof of compliance data using both virtual and physical testing for the mission-critical certification process. Moreover, for distributed propulsion, Simcenter supports engineering decisions for optimal aerodynamic, electrical, thermal and structural integration.

Plus, Simcenter can help reduce risks associated with developing hydrogen fuel cells or hydrogen-fueled gas turbines. It addresses challenges related to storage, distribution and energy conversion. Moreover, by improving aerodynamics and structural performance, engineers can further reduce an aircraft's weight to improve overall efficiency and sustainability without compromising safety.

Figure 3. Simcenter helps build proof of compliance using virtual and physical testing artifacts.

Using Simcenter engineers can gain critical data and insights for aviation engineering processes to enable next-generation aircraft design. Engineers can successfully:

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

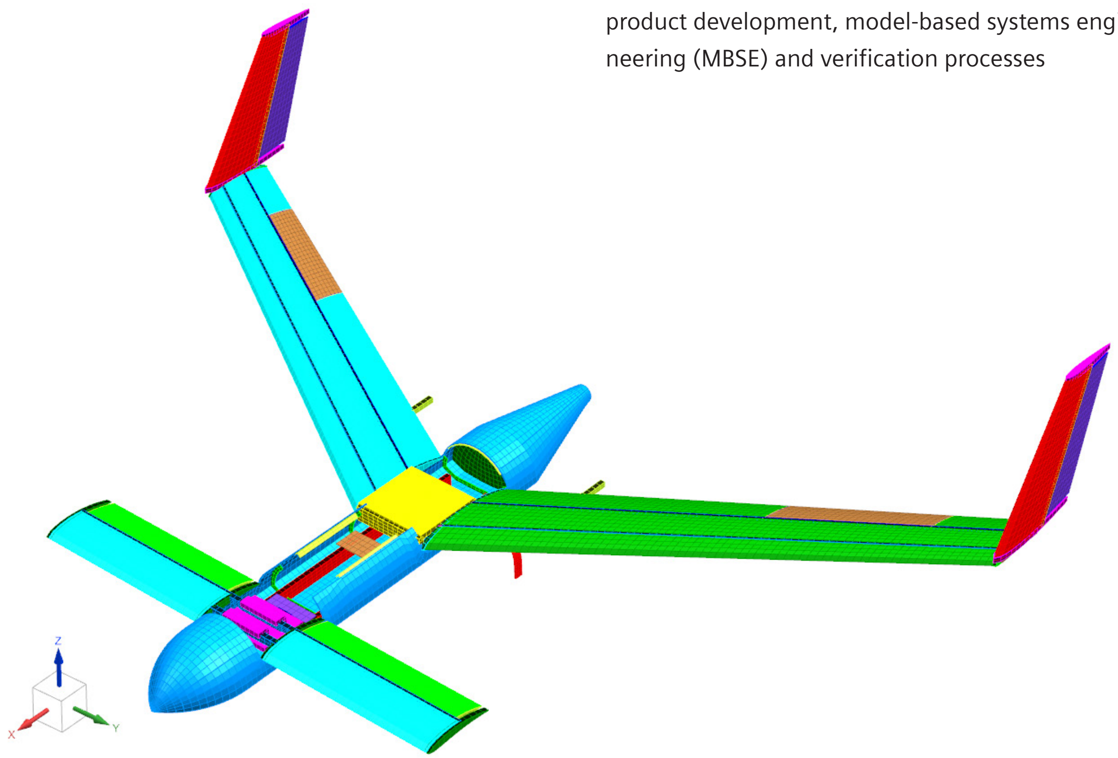

Figure 4. Simcenter models of new aircraft configuration enables engineers to analyze innovative aerodynamic and structural architectures.

Conclusion

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).

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

For more on this topic, read the white paper, "Innovate future aircraft: rethinking next-generation aircraft engineering."[8]

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