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DLR strategy towards zero-emission aviation

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Abstract

This paper illustrates DLR´s approach to the ambitious climate goals described in the European Green Deal, aiming at climate-neutral aviation by 2050. Aviation is an integral part of our society and global mobility. It contributes to inter-cultural exchange and creates economic growth. However, aviation is undergoing one of the most radical transformation processes in its entire history. The end result should and will be climate-friendly air transport, as the consequences of climate change require resolute action. In order to achieve this goal, the growth of air transport must be decoupled from environmental pollution over the next 20 years. Current forecasts indicate that air transport could become climate-neutral by 2050, and this paper describes a path towards this goal. To do this, aeronautics research in DLR approaches aircraft and air transport as a complete system, taking an open-minded approach to the various technologies, evaluating and integrating them into this system.

Keywords: European Green Deal, zero-emission aviation, strategy, aeronautics research

1. Introduction

In the future, aviation will continue to connect the world's people, cultures and economic regions. For this to remain possible, a comprehensive transformation is necessary, because by the middle of the century, the economy and society are to be climate-neutral within the framework of the European Green Deal [1]. Only with a thorough commitment to research and development can growth in aviation be uncoupled from its environmental impact. To that end, DLR has presented an aviation strategy that sets out a research path to achieve climate-neutral flight [2]. The basis for this is the development of significantly more efficient aircraft that require less than half as much energy as today's models. To achieve this, they must become significantly lighter and more aerodynamically efficient. New sensor systems and innovative flight controls will both also play a key role here.

If they are to rely solely on energy from renewable sources in the future, aircraft will have to adopt climate-friendly propulsion concepts and sustainable fuels tailored to their range and size. DLR is conducting comprehensive research into the optimal combination of low-emission aircraft engines, energy-efficient aircraft technologies and a low-emission air transport system. In this way, DLR is positioning itself as a virtual manufacturer to deliver an accelerated energy transition in aviation; some 25 of its institutes and facilities are conducting research in this area. Thanks to its expertise and capabilities, as well as a unique research infrastructure, DLR has a broad understanding of aviation and all the tools needed to make it fit for the 21st century. DLR is taking on the role of architect – from fundamental research right through to applications – working in close coordination and in cooperation with the aviation industry and the wider economy. The new aviation strategy sets out the challenges that must be overcome in the coming years and decades to pave the way for zero-emission air transport. Evolutionary approaches are just as necessary as the consistent use of revolutionary technologies.

The following Figure 1 illustrates what has been achieved by aviation so far; and what can probably be achieved with conventional technologies as assessed by the DLR overview projects EXACT and KuuL. DLR follows its vision of zero-emission aviation by the end of the first half of the current century.

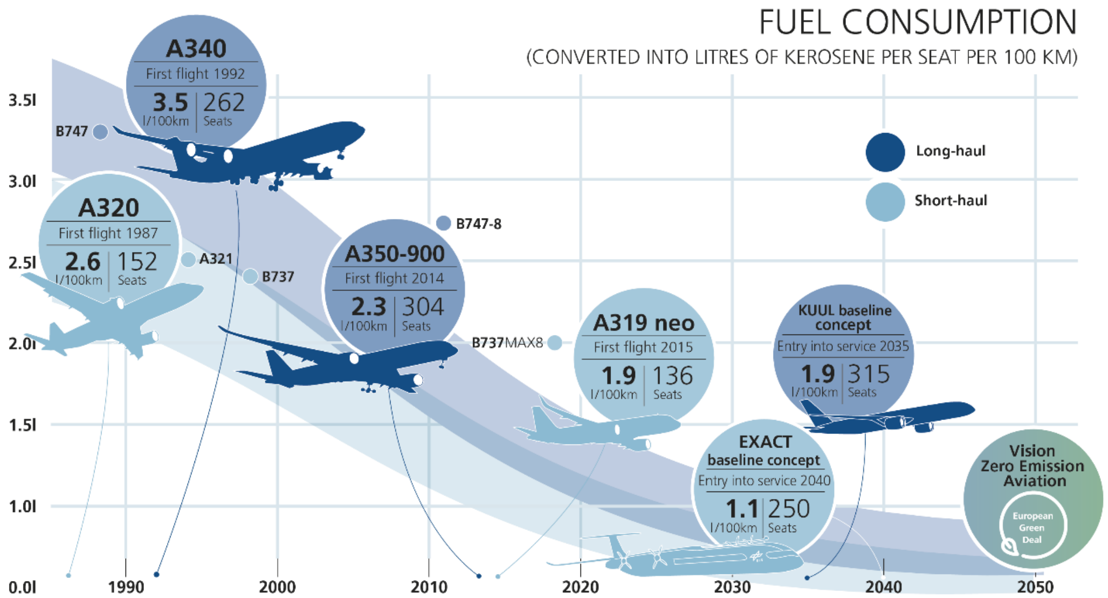

Figure 1. Air transport emissions per passenger per 100 kilometres have fallen continuously over recent decades. New aircraft concepts, such as those being developed as part of DLR's EXACT and KUUL projects, promise further potential emission cuts.

2. The need for new approaches

Air traffic is doubling in volume every 15 years. At present, every generation of aircraft is only seeing an increase in efficiency of approximately 15 percent over a comparable period of time. Air transport emissions have numerous undesirable effects and need to be reduced urgently – a goal that cannot be achieved by simply refining today´s aircraft. Revolutionary new technologies are also needed to counter the environmental impact of aviation. While steps are being taken to significantly increase the eco-efficiency of individual aircraft, a globally sustainable supply chain, in all its complexity, including existing production processes, materials and aspects of the infrastructure, must also be considered. Ground-breaking and immediately available solutions for zero-emission air transport do not currently exist due to the immense technological challenges they entail, particularly with regard to the energy and power density of alternative propulsion systems.

Even after the COVID-19 pandemic, it is clear that air traffic will grow again over the longer term. This makes an important question all the more urgent: How can the growth of air traffic be decoupled from its environmental impact?

The following Figure 2 illustrates the effects required to decouple the CO2 emissions; from their unrestrained growth to the levels prescribed by the European Green Deal.

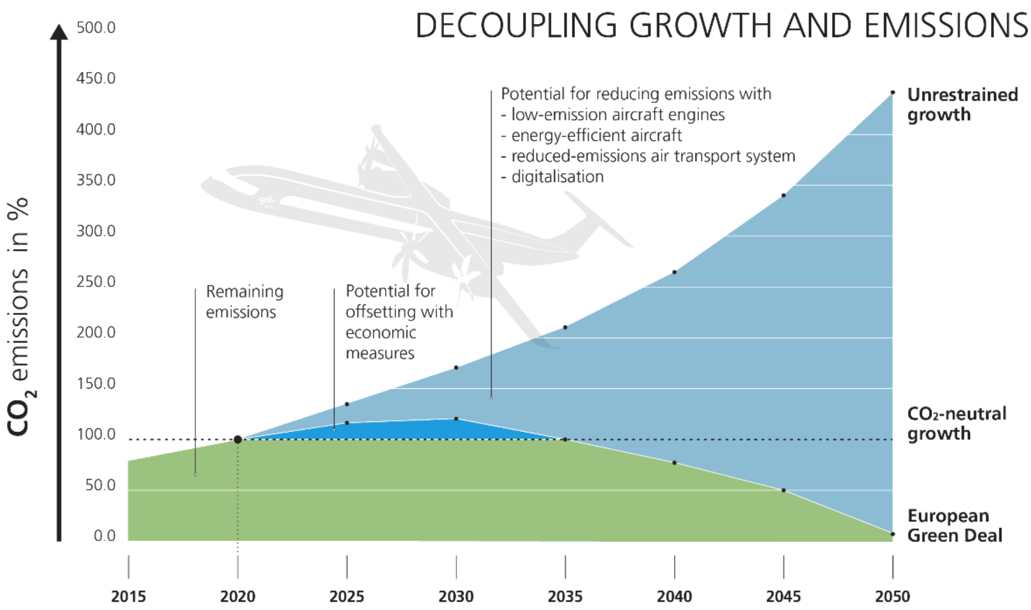

Figure 2. Despite the COVID-19 pandemic, exponential traffic growth is set to return in the medium term. If the world is to move towards climate-neutral air transport, associated emissions need to be decoupled from the exponential increase in air traffic volume.

DLR believes that decoupling the growth of air transport and its environmental impact is indeed possible. However, aviation affects the environment in a number of ways, so a nuanced approach is necessary and some terms should be used in a differentiated way:

- *Emissions* are understood to mean both the release of certain, usually harmful, substances and intangible disruptive factors such as noise. The effects of these emissions are referred to as immissions.
- The vision of *zero-emission aviation* represents an ideal that can only be approached asymptotically. While actual zero emissions are unlikely to be achieved, technologies and operational processes will be geared towards achieving this as far as is possible.
- *Environmentally sustainable aviation* considers all possible emissions but does not commit to a figure of absolute zero for the emissions in question.
- *Climate-neutral aviation* balances the climate impact of all carbon dioxide and non-carbon dioxide effects so that aviation no longer makes a net contribution to global warming. Noise is not taken into account for these purposes.
- The concept of *carbon-dioxide-neutral aviation* only considers carbon dioxide emissions as a simple, established and measurable variable that can be offset by various technical and market-based mechanisms. However, research shows that carbon dioxide emissions are only responsible for approximately one third of the climate impact of air transport.
- *Carbon dioxide equivalent* is a measure that enables emissions of different greenhouse gases to be compared on the basis of their global warming potential. For that purpose, quantities of other gases are converted into the equivalent amount of carbon dioxide with the same global warming potential.
- The concept of *sustainability* is an umbrella term for the aforementioned target concepts and also takes societal aspects into account.
- In this context, the *system boundaries* define the area in which the air transport system is considered and separate it from its surroundings. Opportunities for action can only be harnessed within the system boundaries; the influences of the surrounding environment are simply considered as peripheral conditions.

3. DLR vision and mission

Given the challenge of achieving climate-neutral aviation, aeronautics research at DLR has set itself the ambitious goal of a largely emissions-free air transport. Driven by this vision, it is harnessing its deep expertise to shape progress towards making air transport as sustainable as possible.

3.1 Vision – zero-emission aviation

With its comprehensive, interdisciplinary range of expertise, DLR can help to shape the transformation in line with the European Green Deal. However, the implementation of climate-neutral aviation requires the transfer of research results to the development of new aircraft and transport products in order to achieve market diffusion across the entire fleet. DLR is playing an active role in shaping this transfer by advising and supporting policymakers and industry.

By focusing on a vision of zero-emission aviation, DLR aeronautics research is pursuing an extremely ambitious goal. Even if absolutely emissions-free aviation is unlikely to be technically feasible, it makes sense to strive for a largely climate-neutral air transport system. This applies not only to the individual technologies and energy carriers, but also to their entire lifecycles and combined effect on the whole air transport system. Reducing emissions and the climate impact of aviation to almost zero requires major developments in the areas of sustainable aviation fuels, new energy carriers and aircraft concepts and components, as well as alternative propulsion solutions and their operational implementation with climate-optimised flight routes. This goal must be coupled with political, legislative and social drivers to combine environmental implementation with economic feasibility. The energy transition in aviation requires a wide range of investments in development, certification and infrastructure, as well as support through political decision-making at national and international level.

3.2 Mission – DLR as a virtual manufacturer

DLR is developing multi-scale and multi-fidelity technologies, methods and processes to provide solutions for an aviation system with the lowest possible emission rate. Its aeronautics researchers take an integrated approach to identifying solutions. DLR always considers aircraft and air traffic, with all their respective interrelationships, as an overall system. This system expertise enables DLR to take on the role of a virtual manufacturer (Virtual OEM), thereby involving other participants in aeronautics research, the aviation industry and the wider economy. In doing so, DLR brings together the expertise from its aeronautics, space, energy and transport research programmes, as well as the cross-sectoral areas of digitalisation and security.

4. Potentials for emission reduction

In order to fully exploit the potential for minimising emissions, evolutionary aeronautical technologies to reduce aerodynamic drag and aircraft weight must be pushed to the limits of what is technically feasible, alongside research into revolutionary propulsion technologies. This will make it possible to significantly reduce energy consumption, which, in addition to the direct decrease in emissions, will enable the use of alternative propulsion concepts. The use of sustainably produced kerosene will also play a decisive role, as it can be used for all classes of aircraft and can be implemented over a relatively short timescale.

The reduction in emissions that can be achieved by 2050 through the use of the various technologies is shown in the following Figure 3. The following assumptions apply to this figure:

- The reduction in carbon dioxide emissions serves as an easily measurable indicator. Noise and the climate impact of non-carbon-dioxide effects are not considered here. Although these non-carbon-dioxide emissions are actually responsible for most of the climate impact, they are associated with considerable uncertainty and can also be mitigated with climate-optimised flight routes, improved propulsion technologies and the use of sustainable energy carriers.
- In addition, a technology maturity level of TRL 6 is considered as a target value in order to

distinguish technological potential from product and market developments, as these can no longer be influenced by research. As a result, product strategies and the often considerable delays in the market launch and penetration of new technologies are not taken into account.
- The underlying traffic scenario is based on the statistics of the International Council on Clean Transportation (ICCT) for 2019, with 7 percent regional aircraft, 51 percent short- and medium-haul aircraft (mainly comprising narrow-body aircraft) and 42 percent long-haul aircraft (mostly wide-body aircraft). [3]
- It is also assumed that fuel cells can only be used for regional aircraft due to their low power density and that hydrogen combustion is only possible for short- and medium-haul aircraft due to the large increases in volume and weight resulting from integrating a hydrogen tank.
- The potential of the various Sustainable Aviation Fuels (SAF) to reduce carbon dioxide is 100 percent for hydrogen in fuel cells and hydrogen combustion and 80 percent for the combustion of sustainably produced kerosene. The fact that hydrogen combustion also produces climate-affecting nitrogen oxides in addition to water vapour must be considered.
- The potential for carbon dioxide reduction using energy-efficient technologies in the airframes, engines and flight trajectories amounts to a total of 3.4 percent per year. This corresponds to a 64 percent reduction of carbon dioxide by 2050.
- At present, air traffic is experiencing a temporary reduction due to the COVID-19 pandemic. However, a full recovery is expected.
- For all technology scenarios, it was assumed that sustainably produced kerosene and hydrogen will be available in sufficient quantities by 2050, so these are not a limiting factor.

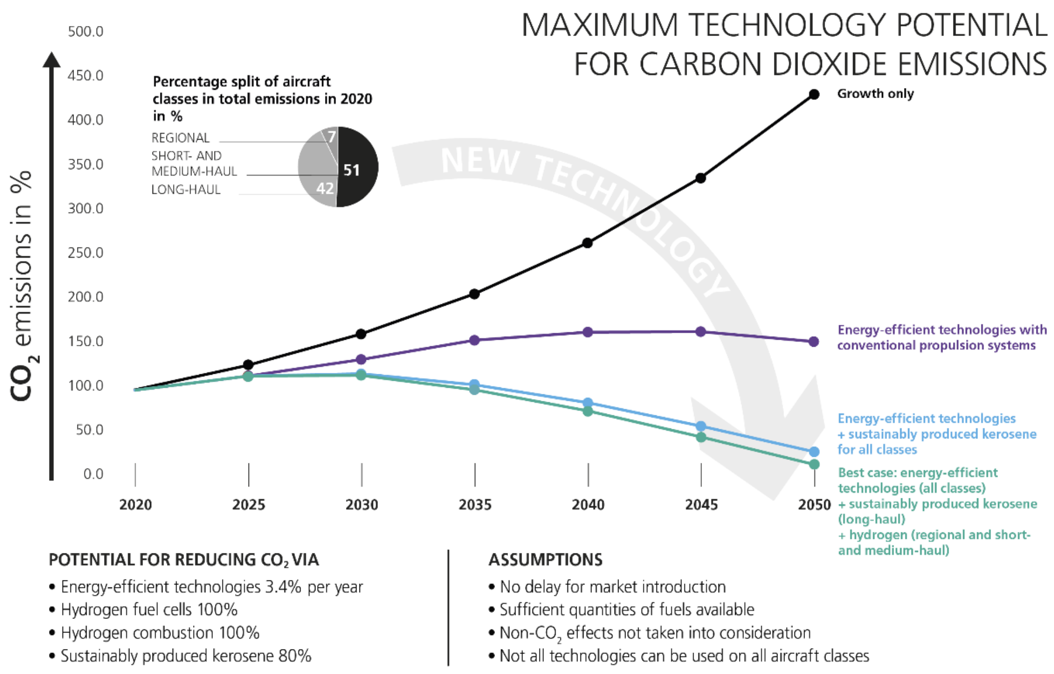

Figure 3. Aircraft emissions can be decoupled from the growth of air traffic through a combination of energy-efficient technologies and sustainably produced kerosene and hydrogen.

Four key insights can be derived from Figure 3:
- Without corrective measures and with current technologies in aircraft, carbon dioxide emissions from global air traffic are expected to more than quadruple by 2050.
- If every possible technical measure is implemented to reduce aircraft energy requirements, by developing particularly efficient engines and optimising flight routes, the increase in carbon dioxide emissions can be limited to just 50 percent of 2020 levels.
- If energy-efficient technologies are combined with the introduction of sustainably produced kerosene, a reduction in carbon dioxide emissions to just under 30 percent of 2020 levels

can be achieved by 2050.
- If all currently feasible options for reducing carbon dioxide are integrated, the result for the year 2050, based on today´s perspective, will be a marginal threshold of only approximately 17 percent of carbon dioxide emissions compared to 2020.

The DLR strategy presents the four key areas of focus for climate-neutral aviation, their fields of action and the overarching objectives. It is the result of extensive coordination involving all institutes, the Executive Board and external stakeholders. At the heart of the strategy are the timescales pertaining to the key areas of focus, along with their challenges, approaches and the unique features of DLR's work.

The key areas of focus are:
- *Low-emission aircraft engines* – innovative and disruptive technologies, materials and manufacturing methods will enable further improvements in efficiency and the minimisation of emissions for different propulsion concepts, while considering performance and safety requirements.
- *Energy-efficient aircraft* – new and highly efficient aircraft technologies make it possible to significantly reduce energy consumption. The aim is to lower the energy requirements of future aircraft to around half of the current propulsive power.
- *Reduced-emissions air transport system* – minimising the climate impact of air transport by reducing its carbon dioxide and non-carbon-dioxide effects is absolutely essential. This can be sustainably supported by a more effective design of the air transport system.
- *Digitalisation* – as a methodology, the digitalisation of aviation has the potential to develop and evaluate new solution approaches in a more time-efficient and cost-effective manner, in order to accelerate the transformation towards climate neutrality.

5. A joint effort is required

All these areas are required to enable the vision of zero-emission aviation. Each area of focus comes with a table connecting fields of action to the coming three decades with their main actions to be covered in these timescales, such as shown in the following Figure 4.

LOW-EMISSION AIRCRAFT ENGINES

FIELDS OF ACTION

	2020-2030	2030-2040	2040-2050
Turbo-engines	Innovative composite materials, optimised SLM components, active noise reduction and low-emission SAF combustion	Engines with innovative fan and turbine blades and open rotors with 100% hydrogen combustion	UHBR engines and open rotors with low-emission hydrogen combustion available
Electrical components	High-power components developed and electromagnetic compatibility validated on the test stand	Increased power and higher power density validated on the test stand	Validation of improved system architecture, further increases in power, and increased power density on the test stand
Distributed thrust	Optimisation and virtual integration of propulsion using distributed thrust	Proof of propulsion concepts with distributed thrust through experiments	Overall configurations ready for use with distributed thrust
Fuel cells	Aviation-compatible fuel cell stacks with increased power are available and validated in long-term tests	Aviation-optimised fuel cell stacks with a further-developed design and increased power are available and validated in long-term tests	Aviation-optimised fuel cell stacks with a further-developed design and increased power ready for use
Hybrid electric fuel cell propulsion systems	Fuel cell electric propulsion systems developed and tested on the altitude test stand	Highly integrated fuel cell electric propulsion systems developed and tested on the altitude test stand	Highly integrated fuel cell electric propulsion systems ready for use
Revolutionary propulsion systems	Revolutionary propulsion system components developed and tested on the test stand	Integrated revolutionary propulsion system validated on the test stand	Revolutionary propulsion system concept validated on the altitude test stand
Hydrogen technology	Concept for the safe storage and use of hydrogen in aircraft devised and validated	Numerical methods validated, for evaluating the effects of water vapour corrosion and embrittlement	Integrated concept for cryotechnology / superconductivity developed and validated
Digitalisation and virtualisation	Virtual engine can be used for multidisciplinary engine design	AI ready for modelling and predictive digital twins	Simulation-based certification of engines and engine components

Figure 4. The figure highlights the fields of action with their corresponding timescales for a particular key area of focus.

Obviously, these actions cannot be carried out by DLR alone. The transformation of aviation towards global climate-neutral air transport is not merely a national task either; global challenges require global solutions. Close international cooperation and the exchange of knowledge between research institutions, universities, industry, policymakers and regulatory authorities with regard to technology development, standardisation and certification are vital to the development of aircraft that meet the ecological requirements of an international market. This cooperation enables not only the promotion of knowledge transfer between all stakeholders, but also the optimal use of resources and infrastructure, along with targeted technology transfer from research into commercial products.

The cooperation will work best, if all partners concentrate on their respective strengths; joining forces to achieve the common goal:

- Universities – Concentrating on the basic research universities can lay the groundwork for the technologies required in 20 to 30 years.
- Research establishments – With cost-intensive infrastructure and large-scale demonstrations, research establishments are the right partners to ensure the technology transfer into higher TRLs of 6 and more, thus bridging the gap from research to industrial application. With the global and integrated view, those entities can also serve as consultants to regulators.
- Industry and operators – Enterprises will be the ultimate instance to develop and to foster entry into market of climate-neutral technologies and products.
- Regulators – Public regulators can play a key role in setting a framework that will nourish climate-neutral solutions. It will be a specific challenge to keep circular economy in sight as well as the entirety of climate-relevant emissions.

6. Examples from DLR research

The following projects highlight areas in the broad range of research required for zero-emission aviation. All of this research is conducted by DLR together with its national and international partners:

- *EXACT* is the DLR internal flagship project with respect to zero-emission aviation. It bundles the expertise from 20 institutes in order to explore and identify the best technology combinations for different aircraft classes; considering the entire life-cycle. [4]
- *Do228FFC* is one of DLR's flight demonstration projects, showcasing the use of hydrogen fuel cells for a range of commuter to regional aircraft. The demonstrations involve several German industry entities, small-to-medium enterprises and universities.
- *HyTaZer* tackles the strategic challenge of design, manufacturing and certification of innovative hydrogen tank structures. The HyTaZer project works closely with industry and certification bodies to provide feasible solutions to this challenge. [5]
- *ECLIF* is one of the large-scale emission measurement efforts led by DLR. Results from the measurement series are groundbreaking in characterizing the emissions of different sustainable aviation fuel blends, especially with respect to non-CO_2 emissions. [6]
- *CityATM* covers the area of unmanned and urban air mobility, which is usually tightly connected to the development of zero-emission propulsion technologies. The project climaxed in several flight demonstrations of unmanned vehicles in urban airspace. [7]

The width and variety of the topics covered by these projects showcase the complexity of the aviation system and the numerous challenges that aeronautics research faces along the path to climate-neutral aviation. Furthermore, in order to make air transport climate-neutral by 2050, the various stakeholders must work closely together in three key areas – aviation research, energy research and legislative matters. In spite of said complexity, these projects are also proof of the common will to take on the challenge together.

7. Copyright Statement

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