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Climate and Aviation – Solution Approaches by Aeronautical Research

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1. Current Situation

1.1. CO2 Emissions

With a CO2 equivalent of 201g per passenger kilometre, air travel is currently one of the modes of transport with a relatively strong impact on the greenhouse effect of the Earth's atmosphere; cf. the fleet averages for 2017.

	Greenhouse gases* in g/pkm	**Load**	**Remarks**
Car	139	1,5 Pers./Car	
Coach	32	60 %	considers buses in occasional services (e.g. for school trips) and long-distance buses
Railroad, Long distance	36	56 %	based on average electricity mix in Germany
Aircraft	201	82 %	considers all climate-impacting effects of air traffic (EWF: Emission Weighting Factor = 2)
Public Bus	75	21 %	
Railroad, Local traffic	60	27 %	
Tram and Subway	64	19 %	

* CO2, CH4 and N2O in CO2 equivalents
g/pkm: Gram per passenger kilometre

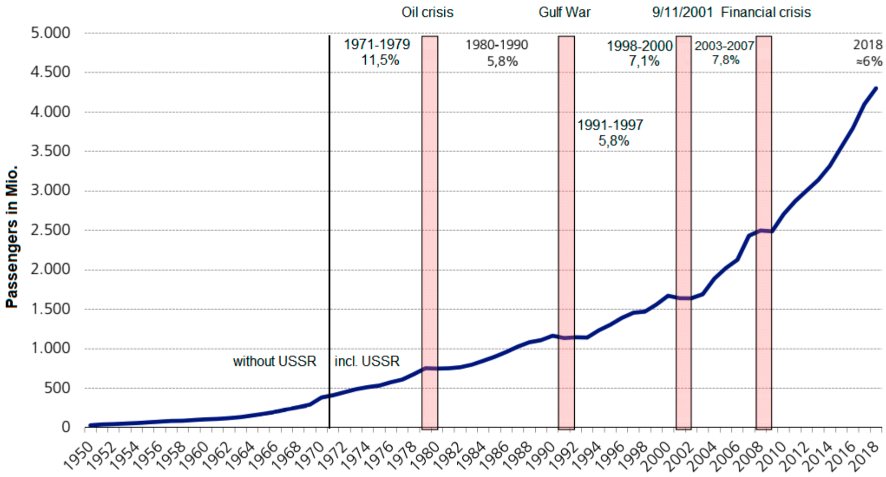
Source: TREMOD 5.82
Federal Environment Agency of Germany 13.11.2018

Fig. 1: Comparison of average emissions from individual means of passenger transport, reference year 2017

The high figure of 201 g/pkm results in particular from the direct emission of greenhouse gases into the stratosphere and the associated greater climate impact compared to emissions near the Earth's surface. Additionally, the fuel consumption for short-range missions is above the fleet average due to the disproportional energy input during take-off. For this reason, a switch to rail transport with 36 g CO2 per passenger kilometre is an environmentally-friendly alternative for travel distances of around 300-1000km. The same applies to local public transport, which at 60 – 64 g/km, is significantly less polluting than a car with 139 g per passenger kilometre driven with an average of 1.5 passengers.

1.2. Worldwide Passenger Development

Even if the growth in passenger numbers in aviation fluctuates to a certain extent, it has been increasing at an average rate of more than 5 % per year since the 1970s (see Fig. 2). There is no firm evidence that major crises such as economic slumps, military conflicts, or pandemics will fundamentally change this situation. While today's air traffic accounts for only about 4 % of climate-equivalent CO2 emissions, this share will increase in the future, as CO2 savings are technically easier to achieve in other industrial sectors.



Source: ICAO, DLR

Fig. 2: Development of global passenger numbers from 1950 until 2018

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[1] In May 2020, ICAO expects a corona-induced slump in global air traffic of at least 39 %
(Source: VDI Nachrichten, May 15, 2020)

2. Effects of Air Traffic on the Earth's Atmosphere

Emissions from aviation have several effects on the atmosphere:

- In general, the CO_2, nitrogen oxides, carbon monoxide, water vapour, and soot emissions lead to a change in the atmospheric composition, which in turn is subject to chemical reactions and conversion processes.

- The greenhouse gas CO_2 leads to an increase in the greenhouse effect, i.e. the absorption of long-wave (terrestrial) radiation and thus to an increase in the temperature of the atmosphere and the Earth's surface.

- Soot in the atmosphere leads to an additional absorption of solar radiation and thus to an increase in the temperature of the atmosphere.

- In addition, the formation of cirrus clouds through water vapour emissions has an impact on the radiation balance. Cirrus clouds reflect solar radiation (cooling effect) and increase the absorption of terrestrial radiation (warming effect).

- Except for the general increase in CO_2 content, all effects are temporally and spatially highly variable. Therefore, a change in flight routes and altitudes (flight trajectories) has an influence on the climate impact of the emissions.

3. New Technologies to Reduce Emissions and Energy Consumption

3.1 Technologies on the Aircraft

In the essential phases of flight, the necessary propulsive power of an aircraft's engines depends largely on the aerodynamic drag to be overcome. A drastic reduction in drag can therefore directly reduce the emissions of the aircraft's propulsion system. Such a reduction leads to a positive „snowball effect" because the reduced amount of energy needed to fly also reduces the fuel mass or mass of energy storage, which in turn can reduce the structural mass (tanks, landing gears, etc.) and ultimately the engines' required power and size. This also reduces costs.

Without describing in detail all complex dependencies in aircraft design, it can be summarised that drag can be reduced by the following main measures.

- Passive and active laminar flow control to reduce the friction losses on large parts of the aircraft's surface. Such measures directly translate into drag reduction. However, the need for research and the complexity of the technical implementation is high. The long-term potential of this technology can be estimated at up to 50 % reduction in fuel consumption.

- The drag of a commercial aircraft also depends largely on the lift. The necessary lift is linearly dependent on the mass of the aircraft. It follows that reducing the mass of the empty aircraft is a good way of reducing the drag to be overcome. Mass reduction can be achieved by new construction methods and functional integration, new materials, as well as the load reduction during flight. This cannot be achieved without new technologies and efforts either. The extent of potential weight savings compared to the current state of the art, e.g. an A350, depends on the aircraft mission and the certification rules. In the long term, however, the savings could amount to up to 40 % of the current primary structure weight of fuselage and wings. Relative to an A320, this could save about 6.8 metric tons of weight, which means about 1200 litres of fuel on a medium duration flight.

- Drag can be further reduced by the transition to new aircraft configurations, such as Blended Wing Body, Clean Wing Aircraft, and others. This has not yet been implemented since the associated development costs and the manufacturers' financial risks are very high.

Besides the reduction of aerodynamic drag, the development of sustainable propulsion technologies offers various possibilities for minimizing or even completely avoiding greenhouse gas emissions:

- As in the automotive sector, a switch to purely electric aircraft is in principle also possible in aviation. However, due to the limited energy density of current batteries and their relatively large weight, this propulsion option is, from today's perspective, only suitable for short-haul flights such as domestic flights.

- For short- and medium-haul flights, there is the possibility of using hybrid propulsion systems, in which highly efficient electric engines provide thrust at aerodynamically favourable locations on the aircraft. These engines are driven by a fuel-based generator. Fuel savings are thus possible, the magnitude of which is currently estimated to be around 10-20 %.

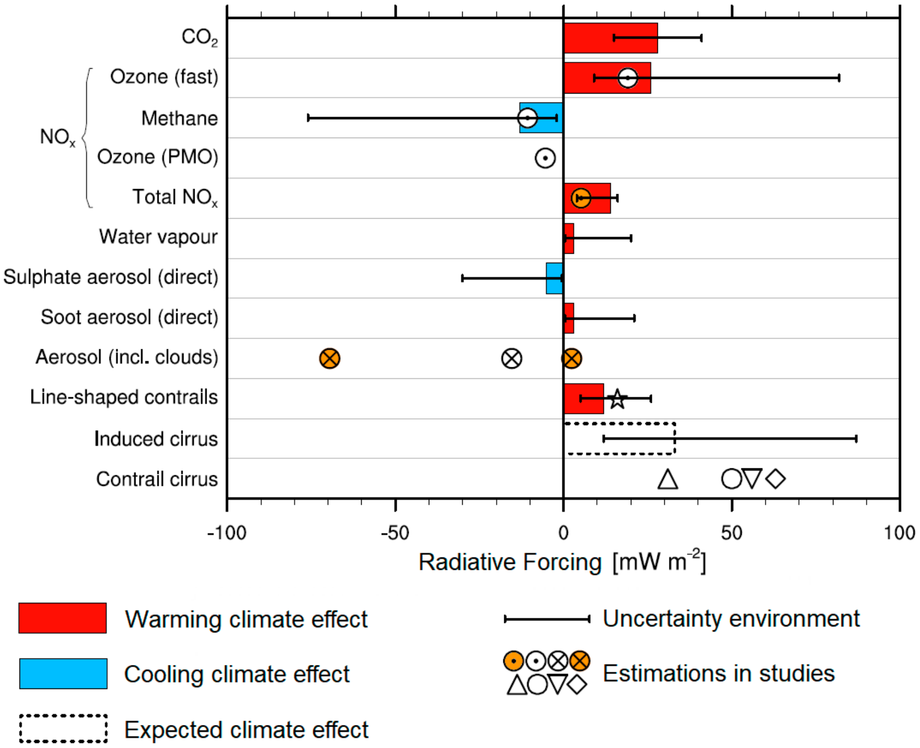
- For long-haul flights, hydrogen-powered fuel cells are conceivable for generating energy for electrically powered aircraft. However, due to the low density of hydrogen and the complexity of integrating fuel cells with the necessary subsystems in high-flying commercial aircraft, these concepts are still in their infancy.

- A conceivable alternative for all distances is offered by fuels from renewable primary products and, in parallel, fully synthesised fuels that are obtained from water and CO2 using renewable energies. Both approaches allow a closed carbon cycle by removing CO2 from the air during the extraction process, which is later released again by combustion in the engine. However, there are currently no sustainable production possibilities for renewable raw primary products to meet the energy needs of aviation. The production of synthetic kerosene is still three to five times more expensive than fossil kerosene and is thus not economically viable. For example, even for future hydrogen-based energy systems, synthetic kerosene will always remain a very expensive fuel due to the necessary steps involved in its production.

- The further development of existing aircraft engines still offers potential for further fuel savings, estimated at 10-20 %, in the upcoming years through the further increase of bypass ratios up to non-encased, open rotors and propellers.

3.2 Measures in Air Traffic Management

The emissions from today's gas turbine aircraft engines and their typical effects are shown in Figure 3. According to current DLR studies, it can be summarised that the adverse climate effects are primarily produced from CO2 and NOx emissions as well as cloud formations induced by the aircraft engines. Cloud formation is strongly dependent on atmospheric boundary conditions. Cirrus clouds, formed at high altitudes, reflect the heat radiated from the Earth and do not allow it to escape into space. The effect of contrails and cirrus clouds generated by exhaust gases on the climate has not yet been properly characterized. Initial estimates and models indicate that they have a comparable or even higher radiative forcing than CO2. The uncertainty in the models is reflected in the prediction uncertainty in Figure 3. Even when considering these elevated uncertainties, it is clear that aircraft emissions' effect on the climate must be seriously considered.



Source: Grewe et al., "Mitigating the Climate Impact from Aviation: Achievements and Results of the DLR WeCare Project", Aerospace 2017, MDPI, 2017.

Fig. 3: Impact of different emissions from air traffic on the radiation balance of the atmosphere

The investigations to date clearly show that the climate impact of cirrus clouds can be reduced by adjusting the flight trajectories. Studies by DLR show that the climate effect of cirrus clouds can be reduced by up to 20 % by accepting an increase in flight costs for climate-friendly detours. Depending on how the cost structure for airlines develops in the future, the additional costs for climate-friendly routes on long-haul flights could also be economically justified.

While airlines are already systematically optimising their operations today in terms of costs, service benefits for customers and improvement of flight safety, new technologies in air traffic management and the introduction of politically-defined climate-protection-oriented framework open up further potential for reducing climate-damaging emissions. In addition to climate-friendly long-haul routes, examples include the development of efficient support systems for pilots and air traffic controllers, further digitalisation and automation, and the seamless integration of air traffic into the overall transport system.

4. Ethics

4.1. Responsibility of the Individual

The prospect of technical solutions for climate-neutral air transportation is not sufficient to solve the current and future problems of climate change. In technology development, scientific methods are used to optimise for a predicted future demand for freight and passenger transport. However, due to the long cycles of product development in aviation, the introduction of new technology takes two or even three decades.

Ultimately, it is the responsibility of the individual to decide whether or not to fly for an intended journey. The alternatives are known to everyone and, as shown above, are usually more environmentally-friendly. Of course, a long-distance travel, e.g. a trip across the Atlantic, is impossible to do in a short period of time without an aircraft. Nevertheless, it is possible to responsibly reduce one own's CO2 footprint. CO2 compensation providers such as Atmosfair, Klima-Kollekte, and Primaklima were rated “very good” by Stiftung Warentest and calculate a voluntary compensation amount depending on the CO2 aircraft emission. This money is then invested in CO2 avoidance projects.

4.2. The educational role of engineers

The work of engineers is basically aimed at developing technologies that are used responsibly by the general public. The VDI position paper on the ethical principles of the engineering profession states: “Engineers are aware of the embedding of technical systems in social, economic and ecological interrelationships and take the corresponding criteria into account when designing technology that also respects the conditions for action of future generations...”

Of course, it is not always possible to foresee all social influences or even late effects in detail. It is therefore all the more important that engineers assume an educational role in which they assess risks and communicate them transparently.

5. Summary and Outlook

With a climate-impacting CO2 equivalent of 201g per passenger kilometre, the aircraft is currently one of the means of transport that places a heavy burden on the environment with its emissions. For this reason, when travelling distances of around 300-1000 km, a switch to rail transport with 36 g CO2 per passenger kilometre is an environmentally friendly alternative.

The emissions caused by air traffic have several effects on the atmosphere. The greenhouse gases CO2 and NOx lead to an increase in the greenhouse effect, while soot in the atmosphere leads to an additional absorption of solar radiation and thus to an increase in the temperature of the atmosphere. According to current knowledge, cloud formation such as cirrus due to contrails and additionally induced cirrus also contribute to a large part of the climate impact of aviation.

From a technical point of view, there is a large number of well-founded approaches to drastically reduce harmful emissions from commercial aircraft and to achieve climate-neutral air traffic in the long term. In Braunschweig, there is outstanding expertise in the required research, which is bundled in the Aeronautics Research Centre Niedersachsen (NFL) and the Cluster of Excellence „Sustainable and Energy Efficient Aviation“ (SE^{2}A) with long-term funding by the German Research Foundation DFG. As an interdisciplinary research association, the SE^{2}A cluster works to drastically reduce energy requirements of future commercial aircraft, to develop new sustainable approaches to energy storage and energy conversion in aircraft, and to holistically evaluate and optimise the ecological efficiency and profitability of the air transport system. This requires basic research and the creative and in-depth pursuit of disruptive solutions that can only be realised in the long term. One cannot imagine that a single research institution alone could cope with these huge tasks. Therefore, the TU Braunschweig, LU Hannover and DLR have joined forces within NFL on a national basis, cooperating closely together. Internationally, TU Braunschweig and TU Delft are connected in a strategic partnership.

New aeronautical technologies for the future will not solve all problems. Part of the responsibility lies with the traveller. It is already possible today to reduce the CO2 footprint on one’s own initiative by carefully choosing the means of transport. Furthermore, CO2 compensation providers open up the possibility of making an individual contribution to offsetting the unavoidable CO2 emissions of long-distance travel. Engineers have a special role to play in shaping the future. They develop technologies and make them available to the general public for responsible use. As such, they have the responsibility of informing society and decision-makers about the cost of a new technology, its consequences and its risks.

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