Sustainable and Energy-efficient Aviation: Physically Feasible and Economically Viable Technologies

Bachelorarbeit

zur Erlangung des akademischen Grades „Bachelor of Science (B. Sc.)“ im Studiengang Wirtschaftsingenieur der Fakultät für Elektrotechnik und Informatik, Fakultät für Maschinenbau und der Wirtschaftswissenschaftlichen Fakultät der Leibniz Universität Hannover

vorgelegt von

Name: Dust Vorname: Jannis

[redacted] [redacted]

Prüfer: Prof. Dr. M. H. Breitner

Hannover, den: 4. Juli 2022

Table of Contents

Chapter I: Introduction

Imagine yourself around the year 1927. The farthest you were away from your hometown was a few dozen kilometers you traveled by train. You may have never even heard about aviation, and you may never have seen a real plane. You may have heard stories about planes in WW1 or persons like Howard Hughes or Charles Lindbergh from America. But the chances that you flew a plane were definitely around 0%.
Now, get back to 2022. You can take a trip to other countries in Europe in the blink of an eye. You can fly to other continents in under one day. Often most of your clothing or your technology comes to you by plane. Today's aviation is the backbone of our society. It is by far the fastest transportation opportunity with cruise speeds of 1.000 kilometers per hour and often even the cheapest one. It is the safest mode of mass transportation.[1]

"A mile of road leads nowhere, and a mile of runway leads everywhere!"

states the slogan of the Aircraft Owners and Pilot Association (AOPA). And that seems to be true.[2] Aviation opened doors to possibilities people from the last century barely could imagine. Aviation enables the world we live in.
But aviation also has one clear disadvantage. Its impact on global CO2 emissions. Around 2-5% of emissions are directly attributable to aviation in 2018 alone. That is more than Germany emitted in total over the entire period[3], and the trend is still rising.[4] To get a clear picture of the excessive emission level, imagine the whole aviation sector as an independent country. With its 2-5% of human-induced emissions in total, it would be the eighth-largest polluter of GHG in the world.[5] Without counter-action, the CO_2 emissions could even reach 2700 MT by 2050.[6]

In 2015 airlines already carried around 3.6 billion (bln) passengers.[7] However, not even 80% of the world's population has traveled in an aircraft yet. Especially countries in Asia or Latin-America are going to let the numbers rise. In the upcoming years, the volume of the air population, but also the general importance of aviation, will continue to increase significantly. Transport numbers and online sales will also mean a rapid increase in flights.[8]

[1] van Gent (CleanEra) 2015, 9.
[2] Ibid.
[3] Merlot 2019, 1.
[4] Ibid.
[5] International Renewable Energy Agency 2017, 2.
[6] Ibid.
[7] Ibid.
[8] The Boeing Corporation 2021.

The commercial future looks bright, with revenues, passengers, and miles expected to rise sharply, causing significant climate damage on the other hand. If these problems are not solved, the industry could enter a decline phase due to secondary effects.[9] Fuels are too expensive, the environment is damaged, people's opinion changed against aviation, and there is not even enough room to make aviation possible on the landside.

Not only since the Paris Agreement, which states that the global temperature increase should be limited to 1.5 °C by 2030, has the question been raised how emissions can be reduced despite the projected growth and how sustainable aviation can be established that does not have to be based on finite resources.[10] The aviation industry is working on various models that could reduce CO_2 emissions - e.g. to 75% less CO_2, 90% less NO_x and CO emitted, and overall 65% less noise development compared to 2000 in 2050 set by ACARE (Advisory Council for Research and Innovation in Europe).[11] The problem is to reduce the emissions strong enough to compensate for the industry's growth.

Moreover, considering aviation's growing role in global CO_2 and GHG emissions, it has to work vigorously against further developments due to its key role in reaching 2015's Paris Agreement.[12] However, current standards seem insufficiently designed for this goal. What is missing are technological innovations that provide an alternative energy source in aviation.

A *"Tesla of the skies"*.
Without alternative technologies, hydrogen aircraft, electrified drives and biofuels are considered promising approaches, but global aviation emissions continue to rise hopelessly. According to research from 2019, around 25.900 commercial aircraft were used globally. This number is expected to rise to 49.405 in 2039[13]. An in-depth look shows that these aircraft yielded ~915 million tonnes of CO_2 in 2019.[14] For the next 20 years, Boeing forecasts average annual air traffic growth of 4.3% per year[15].

Without proper adjustments in mitigation strategies, the aviation industry will drastically miss the set targets, making the ACARE goal of -75% CO_2 emissions by 2050 highly unrealistic. The stated goal could be achieved by using various mitigation measures as fast as possible. Thus, this thesis investigates different alternative technologies and energy sources. I will particularly focus on hydrogen propulsion systems, electrification

[9] van Gent (CleanEra) 2015, 15.
[10] Ebitsch et al., n.d.
[11] CleanEra Team 2015, 112.
[12] International Renewable Energy Agency 2017, 2.
[13] Boeing Inc. 2019.
[14] ATAG Association 2020.
[15] Boeing Inc. 2019.

and alternative fuel technologies. Other sustainability factors like society, as well as the landside of aviation, noise emissions, and auxiliary power units, will not be dealt with, even if those can be considered relevant topics as well.

Based on this examination, the research question is whether modern technologies for reducing climate emissions are physically feasible and economically viable. The aim is to be able to assess the technologies mentioned and to work out potentials that could have a positive impact on achieving the goals of the aviation industry. The sources for this thesis will be current textbooks, papers, journals, and the publishing of involved companies. Thus, this thesis is intended to be a theoretical analysis in the form of a literature paper, dealing primarily with the findings of current energy research and the practical implementation of companies working on it.

Methodologically, it focuses on the conditions for functioning concepts and relates them to current concepts. For this, the theoretical approaches and findings from physics have to be evaluated and systematized. Moreover, the economical perspective is considered as well. Structurally, this thesis will start with the fundamentals of aviation and sustainability before combining them to introduce sustainability in aviation. Continuing, current technologies, visions, and factors for working sustainable aircraft are introduced before taking an in-depth analysis of current mitigation strategies. Finally, I will take a look at pathways to sustainability before reaching a conclusion.

Chapter V: Conclusion

Aviation's negative impact on the environment in terms of emissions is rising fast. With passenger numbers and cargo per year forecasted to grow rapidly and harsh goals set by institutions across the world to limit these emissions, the questions occur about how to lead the industry in a carbon-neutral or even carbon-negative stage. Considering that, the research topic of this thesis was sustainable and energy-efficient aviation and which technologies could be physically feasible and economically viable.

It became clear that current standards and technologies are not sufficient enough to reach set goals. Thus, alternative approaches, especially in terms of energy sources and overall efficiency of aircraft have to be developed. The future of aviation in technological consideration seems bright. In the short-term, biofuels can lead the way towards sustainable aviation, reducing emissions substantially if the required feedstock is produced in the right way. In the medium-term, hydrogen could become a promising alternative to Jet-A and towards the end of the century electric aviation and concepts like solar-powered planes could also become reality in commercial aviation. However, all of them bring major hurdles along - from storage, to weight, to safety and space.

Promising technologies could also pave the way towards sustainable aviation. Concepts like BWB, hybrid engines or carbon fiber structures improve the efficiency and actually enable alternative energy sources. Considering the technology, efficiency is the main aspect that should be improved. In aerodynamics, lift-to-weight ratios and air resistance, less drag, and less weight result in fewer emissions and less noise. On the structural side, composite structures could lead to lower overall weight with increased strength. In terms of body design, the BWB concepts are promising technologies to improve efficiency. On the propulsion side, new hybrid concepts can significantly reduce CO_2, NO_x, soot, and other emission substances.

In summary, sustainable and energy-efficient aviation can be realized by a combination of alternative energy sources and promising technologies. Moreover, the set goals for 2050 are realistic if the innovation rate can be improved and the presented technologies are implemented commercially.

However, to do this, a paradigm shift in aviation is needed. Plenty of designs and concepts were drafted in the past decades, but the improvements rarely become reality due to restrictions and certification hurdles. Unfortunately, the innovation rate is not really improving. The current number one goal of the industry is to not make radical changes but to be efficient in financial terms. Innovation and Disruption seems to be not a part of

the equation for success. Actually, it appears that aviation's biggest challenge is to overcome past decades' success. The system must be changed, but the question is why shareholders agree with doing so. Without major improvements, aviation will become the transport sector’s main polluter - an unacceptable situation for society and the industry itself. If aviation cannot make innovation an integral part of its system and increase its flexibility and improvement rate, it might be replaced by another alternative - not in the foreseeable future, but this progress is what happens when industries refuse to innovate.

The mixture of “being afraid of changing a working system while taking (financial) risks” and “only accepting new technologies unless they are perfectly proven and absolutely flawless” derived from the attitude in terms of certification, is dangerous, and majorly affects the needed innovation rate. Right now, the aircraft is statistically considered the safest transport vehicle. But it is questionable how much longer. The discrepancy is apparent. Improvements are so hard to certify and implement that we must rely on outdated technology even if new designs are cheaper. Improvement is too expensive, thus innovation is hindered unintentionally.

The smartphone overtook PCs, emails overtook letters, the car overtook the horse. Innovation can happen everywhere. Aviation is not a blank sheet anymore, therefore it has to innovate or it risks being overtaken by a technology no one can imagine today.
The need to improve the industry for the sake of sustainability fights against the hard restrictions it has to face. Thus, a paradigm shift has to occur to improve the adoption rate. It is clear that aviation has the potential with its technological improvements to reach the set targets until 2050. From biofuels to BWB - efficiency can be improved significantly. The many different approaches and developments could lead to an exciting time ahead of us.